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By

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AN ACOUSTICAL BASIS FOR UNIVERSAL CONSTRAINTS

ON SOUND SEQUENCES

by

Haruko Kawasaki

ABSTRACT

This study investigates acoustic characteristics of some selected sound sequences in an attempt to explain and predict cross-linguistic tendencies in phonotactic constraints. Phonological literature reveals the following universal tendencies. Consonant clusters and vowel clusters in general are disfavored. Initial consonants are preferred to final consonants. Obstruent clusters in the same manner of articulation are rare. Obstruent + liquid clusters are preferred to nasal + liquid clusters. Among obstruent + [l] clusters, dental stop + [l] clusters are rare. Obstruent + [r] clusters, however, are not restricted in any particular way. Among consonant + glide clusters, labial + [w] and dental/alveolar/palatal + [j] are disfavored. Similarly, labialization and palatalization as secondary articulations are disfavored on labial consonants and dental/alveolar/palatal consonants, respectively. Combinations of a labial or velar consonant and a rounded vowel and of a dental/alveolar/palatal or velar consonant and a front vowel are relatively rare. Among vowel clusters, combinations of a low vowel and a

high vowel are preferred to other vowel combinations. Moreover, sound change affects some specific sound sequences. Labiovelars or velar + [w] sequences often change to labials, and palatalized labials or labial + [j] sequences often change to dentals/alveolars/palatals.

Accounts of various kinds have been proposed for universal sequential constraints. Among them are accounts based upon the 'strength/sonority' hierarchy, accounts based upon articulatory features, and accounts based upon differences between successive phonemes in terms of distinctive features. These hypotheses are reviewed and critically discussed in this study.

A new hypothesis is offered that some universally attested sequential constraints are acoustically/auditorily motivated. Two acoustic factors are posited as determinants of favored/disfavored sound sequences: the magnitude of acoustic modulation within a sequence and the degree of acoustic difference between sequences. The lack of acoustic modulation explains the disfavoring of consonant clusters, vowel clusters, and obstruent clusters in the same manner of articulation as well as the disfavoring of nasal + liquid clusters as opposed to obstruent + liquid clusters.

The hypothesis is tested experimentally for its applicability to sequential constraints of more specific nature. Trajectories of the first three formants are obtained by an LPC analysis for selected sequences of stop + liquid + vowel, stop + glide + vowel, stop + vowel, and vowel + stop. Standard Euclidean distance in frequency is computed as a measure that approximates each of the above two acoustic factors.

The results suggest that some universally rare sound sequences are explained on the basis of their lack of spectral modulation and/or

their spectral similarity to other sound sequences. For example, stop + [r] clusters are better differentiated spectrally than stop + [l] clusters. The dental stop + [l] cluster, though spectrally well-modulated, shows similarities to other stop + sonorant clusters, particularly velar stop + [l] and dental stop + [w]. Labial stop + [w] and dental stop + [j] show relatively small spectral modulation. Labial or velar stop + rounded vowel sequences and dental or velar stop + front vowel sequences are not spectrally well-modulated. Further, velar + [w] or [u] sequences and labial + [j] or [i] sequences are shown to be spectrally very similar to labial + [w] or [u] sequences and to dental + [j] or [i] sequences, respectively. The three places of articulation are spectrally better contrasted in CV syllables than in VC syllables. It is concluded that the acoustic/auditory factors play a significant role in determining the phonetic shape of language.

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CHAPTER ONE

INTRODUCTION

In recent years, various hypotheses have been offered as to the factors which determine the phonetic shape of human language. For example, Liljencrants and Lindblom (1972) hypothesized that the configuration of vowel systems was largely determined by the perceptual principle that members of a given system should be maximally different from one another. By using this principle of maximal perceptual contrast, Wright (1980) proposed a possible account for a cross-linguistic tendency that nasal vowels never outnumber oral vowels in a given language. Ohala and Riordan (1979) suggested that the aerodynamic requirements on voicing and the compliance of surface tissue of the oral cavity would explain why back-articulated voiced stops are missing in the voiced stop series in many languages. The quantal theory of speech proposed by Stevens (1972, 1973; also Klatt and Stevens 1969, Halle and Stevens 1971, Stevens and Blumstein 1975) holds that the relations between articulatory gestures and their acoustic consequences are hardly linear in that in some conditions variations in some articulatory parameters may not result in appreciable changes in the acoustic output while in other conditions it takes only a slight change in articulation to produce a significant shift in the acoustic signal. Stevens hypothesized that consonants and vowels that are frequently encountered in the world's languages might meet the condition for which the former type of articulatory-acoustic relation exists.

These studies exemplify attempts to seek explanations and, further, to make predictions for universal aspects of phonological structure. What is common to these studies is an assumption that motivations for universal phonological patterns must lie in such independently motivated physical realities as the vocal tract, the ear, and the brain of human beings. This is a reasonable assumption. Phonological patterns and processes similar across languages which are not related geographically, genealogically, or typologically must have arisen due to 'human-universal' conditions applicable to the speakers of all languages, i.e., what are physically given to them such as the constraints on the phonatory and articulatory apparatuses, the auditory system, and the central nervous system. Although this is a fairly recent approach to traditional phonological questions, the success that it has enjoyed in providing answers to some of these questions seems to foreshadow its significant contribution to the discipline of phonology.[1] Evidently, studies characterized by this approach owe their success to two factors: technological advancement in instrumental phonetics on the one hand, and accumulation of our knowledge of phonological universals on the other.

All of the aforementioned studies deal with paradigmatic aspects of phonology, i.e., common or rare sound segments in phonological inventories and their phonetic bases, phonological contrasts and their phonetic correlates, and so forth. Syntagmatic aspects of phonology have also stimulated interest among scholars. Though studies on combinatory constraints on phonemes are found throughout the long history of phonology, it was not until recently that they were conducted in depth from the point of view of phonological universals. Greenberg's (1978) proposal of forty universals on initial and final consonant clusters represents work of this kind.

A quick glance at the phonotactics of various languages would lead one to an exceptionless universal; a language utilizes only a subset of the logically possible combinations of phonemes (Hockett 1958). English with its 22 consonant phonemes provides a typical example. All consonants except /ŋ, ʒ/ can occur word-initially. Out of 484 ($=22^2$) logically possible clusters of two consonants in the initial position, only 28 actually occur. Out of 10,648 ($=22^3$) logically possible clusters of three consonants in the initial position, only 8 are permissible (Greenberg 1978).

In the light of modern communication theory, such severe restrictions on phoneme arrangements may be considered to serve the purpose of enhancing communicative efficiency. Every signal is susceptible to possible distortions due to noise in transmission. By limiting the number of permissible sound combinations, a certain amount of redundancy will be maintained in the signal, and this redundancy will make it possible to recover the intended signal in spite of the inevitable errors of transmission. Thus, as Miller and Selfridge (1950) stated, by preferring and overworking some sequences of elements while totally ignoring or minimally utilizing others, "language is protected against error."

Languages, however, do not randomly select permissible phoneme combinations. As will be shown in the following chapter, there is considerable cross-linguistic agreement about favored and disfavored sound sequences.[2] A question then arises as to what the determinants of such 'favoritism' would be. The present study proposes a hypothesis that they are, to a large extent, acoustically and auditorily based. One determinant, the magnitude of acoustic modulation in a given sound sequence, assumed to be directly related to its perceptual saliency, should affect the viability of the sequence. Another determinant, the degree of acoustic difference among various sound sequences, should be inversely related to the likelihood of perceptual confusion and hence predict the sequences which are less susceptible to merger than others.

The validity of this hypothesis is examined through a quantitative analysis of spectral characteristics of some selected consonant + vowel, vowel + consonant, and consonant + sonorant + vowel sequences uttered by a speaker of English. It will be shown that some widespread phonotactic patterns are predicted (or post-dicted) on the basis of their acoustic characteristics. This study confirms the importance of the listener's role in determining the phonetic shape of language (Ohala 1981).

An objection may be raised to such an assertion. How could we claim to have solved a matter of universal import by examining only one language? Or even if we examined more than one language, how could we generalize our findings to all the other unexamined languages of the world? In response to this objection, we must stress the fact that, in the obvious absence of a speaker of a 'universal' language, concrete phonetic data have to come from some particular language in *any* study dealing with phonological universals. Though we cannot deny the possibility that the data so gathered supply us with language-specific phonetic information, we can only remedy this shortcoming by comparing them with data from other languages. This limitation, however, does not invalidate our approach. In fact, this appears to be the most viable way to test hypotheses of universal relevance.

CHAPTER TWO

UNIVERSALS ON PHONOTACTIC CONSTRAINTS

This chapter presents details on 'explicanda,' that is, cross-linguistic tendencies in sequential constraints. These universal constraints are categorized into the following types: general constraints on sound sequences, constraints on initial and final consonants, constraints on obstruent clusters, constraints on clusters of a consonant and a liquid, constraints on clusters of a consonant and a glide, constraints on sequences of a consonant and a vowel, and constraints on vowel clusters and diphthongs. In addition to these phonotactic constraints, two phonological processes which affect certain sound sequences and may consequently give rise to phonotactic constraints are also presented. Before the discussion of these universals, a brief description of their sources is given.

2.1. Corpora

All phonological data presented here were taken from the literature including 1) phonetic or phonemic analyses of individual languages, 2) studies of universal tendencies in specific phonological patterns and processes, and 3) compilations of short phonetic and phonemic descriptions of selected languages. Much of the data was directly obtained from the first type of source. To the second type of data source belongs Bhat's (1978) study on palatalization, from which some of the data concerning the constraints on sequences with dental/alveolar/palatal or palatalized consonants were found. To the third type of data source belongs Crothers, Lorentz, Sherman, and Vihman's (1979) Handbook of Phonological Data from a Sample of the World's Languages, which was consulted most extensively. Their summaries of syllable structures, phonological word structures, phonemic inventories, co-occurrence restrictions, and allophonic rules are the sources of data in a number of cases. Furthermore, the 197 languages constituting their sample are the basis for my statistics concerning the length of initial and final consonant clusters and labialization as a secondary articulation. As to the latter phenomenon, statistics obtained by Ohala and Lorentz (1977) using Ruhlen's (1975) sample of some 700 languages are also referred to. Crothers et al.'s and Ruhlen's samples overlap considerably in terms of their selection of languages; the great majority of languages in the former are included in the latter. In evaluating the statistical results, however, more weight should be given to those obtained for Crothers et al.'s sample despite its smaller size for the following reasons. First, their sample represents languages more evenly in geographic and generic terms. Second, their treatment of material is far more detailed, i.e., phenomena at phonemic and phonetic levels are differentiated, and occasional reference is made to remarks in original sources regarding such extraneous factors as borrowing and frequency of occurrence.

Mention is made of many implicational universals which have their grounds in statistical observations in other language samples, though such statistical figures are not directly quoted. They include Greenberg's (1978) universals on initial and final consonant clusters based on his sample of 104 languages, and A. Bell's (1971) universal on syllable types based on his sample of 144 languages.

When cross-referring to the universal tendencies derived from these different samples, we must be assured that all the samples show, first, balanced representation of the world's languages and, second, comparable modes of analyses. It seems that the first point is satisfactorily met. For detailed discussion on the rationale of sampling, see each reference listed above. The second point is not as easily affirmed. Whether a given sound sequence should be treated as a unit or a cluster may be the most difficult problem that confronted the analyses of these samples. However, within each of these samples, attempts seem to have been made to apply as consistently as possible the predetermined criteria for choice of analysis modes. By and large, these criteria are similar across the samples, though slight differences do exist. Therefore, with some reservation we may assume that the resulting statistics and the generalizations based upon them are valid not only for individual samples but also for the world's languages as a whole.

An important assumption is made as to what is implied by the term 'constraint.' It should be understood that the term may refer to a variety of forms of restrictions on sound sequences ranging from absolute prohibition to relative infrequency of occurrence. Bell, A. (1971) among others made explicit the view that sequential universals should be stated in such probablistic terms. Thus, along with non-existent sound sequences, the text includes as equally substantial evidence examples of rare sound sequences and data on the productivity of certain phonological word structures.

As will be seen in the following sections, some universal tendencies are substantiated by more data points than others. However, the soundness of a given universal is not determined by the mere number of languages that exhibit it. To put it more strongly, even if some of the data points exemplifying a universal were to be rejected by further examinations, its validity should not be proportionately reduced. What is significant is not so much the fact the data are drawn from *many* languages, but rather the fact that they are drawn from *unrelated* languages.

Following the convention used in many studies on universals, the references for individual languages cited as examples are not included in the text of Sections 2.2 to 2.8 except for some cases where data may appear controversial. References are provided along with the data in Section 2.9. An index to all the references for the languages cited in the text is found in the Appendix.

Some of the phonetic symbols used in original transcriptions are modified slightly. The sole purpose of this is to make cross-linguistic comparisons easier.

2.2. General Constraints on Sound Sequences[3]

The first phonotactic universal to be considered is the tendency to avoid consonant clusters in general (Bell and Hooper 1978, Greenberg 1978). Languages in the Caucasus and Northwest America, which allow a long stretch of consonants without intervening vowels, belong to the linguistic minority in this aspect. This is illustrated by the following statistics concerning the syllable structures of 197 languages documented in Crothers et al. (1979).[4] Out of 193 languages which allow initial consonants at all, 90 allow only single consonants in the initial position.[5] Seventy-three allow clusters of 2 consonants as well as single consonants in this position. Thirty languages allow initial clusters of more than two consonants. One hundred and seventy-five languages allow consonants in the final position.[6] Eighty-six languages allow only one consonant, 67 allow up to 2 consonants, and 22 allow more than 2 consonants. Thus, in either position, single consonants are preferred to double-consonant clusters. Only 15% of the languages in this sample permit long consonant sequences.

In some languages, consonant clusters occur relatively infrequently though their syllable canons permit them. For example, initial clusters are rare in Kaliai. Initial CC sequences are rare in Maltese and Kashmiri, and are restricted to a few morphemes in Chontal. Final consonant clusters are rare in Mahas Fiyadikka, Kashmiri, and Luiseño. Final clusters of three consonants are rare in Yurak and Bulgarian. Word-medially and finally, three-consonant clusters occur only rarely in Ket. Initial clusters of two consonants occur only before a stressed vowel in Island Carib. Syllable-initial consonant clusters occur only word-medially in Kharia and Seneca. In Sinhalese, most of the words containing clusters are loans. In Komi, word-initial clusters of two or three consonants occur in Russian loan words and in a few other rare cases.

Another phenomenon to evidence the inherently unfavorable nature of consonant clusters is breakup of a consonant sequence with an epenthetic vowel usually characterized as [ə] or [ɨ]. Such a process takes place synchronically in Amharic, Angas, Apinaye, Moroccan Arabic, Atayal, Bengali, Cambodian, Dagbani, Dakota, Georgian, Modern Hebrew, Karok, Khasi, Kota, Kurukh, Paez, Southeastern Pomo, Portuguese, Shilha, and Spanish among others.[7]

Somewhat analogous to the avoidance of consonant clusters but not as often mentioned is the tendency to disfavor vowel clusters (Bell and Hooper 1978). For example, vowel clusters are not allowed in Dakota, Sentani, Telugu, and Tunica. Sundanese maximally allows a sequence of two vowels. There are no syllable-internal vowel clusters or diphthongs in Molinos Mixtec and Oneida. In Ganda, a word-final vowel /e, a/ or /o/ is elided when preceding a word-initial vowel.

Ancillary to this is the tendency to avoid long sonorant clusters. In his sample of 104 languages, Greenberg (1978) found no case of a initial or final cluster consisting of three sonorants. Two seemed to be the maximum number of sonorants that could occur in succession.

2.3. Constraints on Initial and Final Consonants

It is well-known that open syllables are preferred to closed syllables (Jakobson and Halle 1956, Malmberg 1963, 1965, Pulgram 1965, 1970, Greenberg, Osgood and Jenkins 1966, Bondarko 1969, Bell, A. 1971, Bell and Hooper 1978). This universal can be stated in even stronger form. If a language permits a closed syllable, it should also permit an open syllable (Jakobson and Halle 1956, Greenberg, Osgood, and Jenkins 1966, Bell, A. 1971, Bell and Hooper 1978). The predominance of open syllables is also observed in child language acquisition. A child starts producing open syllables earlier than closed syllables (Winitz and Irwin 1958, Jakobson 1968, Ingram 1978). Out of the 197 languages documented in Crothers et al. (1979), 19 allow only open syllables.[8] Preference for open syllables is even manifested in the word productivity of various syllable types in English. According to Trnka (1968), CV and CCV are more productive than VC and VCC in yielding monosyllabic words. In disyllabic words, CVCV is more productive in this way than VCVC. Dewey (1923) found 424 monosyllabic monomorphemes among the 1027 words that occurred more than 10 times in connected utterance of 100,000 words. 66 of these monomorphemic words were of the CV form, and 22 were of the VC form. 15 were of CCV, and 4 were of VCC. In the same material, the frequency of occurrence of CV-type words was greater by far than that of VC-type words. Thus, consonants seem to favor the syllable- or word-initial position. Another fact that supports this generalization is that languages with obligatory initial consonants outnumber languages with obligatory final consonants. In Crothers et al.'s sample, there are 42 languages that require an initial consonant, whereas only one language requires a final consonant.[9]

As regards consonant clusters, there is some evidence that the initial position is preferred to the final position (Guile 1973, Bell and Hooper 1978). There are 135 languages in Crothers et al.'s sample that allow some consonant cluster at all. In 37 out of these languages, the maximal length of consonant clusters is the same at the initial and final positions. 58 languages allow longer clusters initially, and 40 languages allow longer clusters finally. Trnka's findings on word productivity in English reveal a similar pattern. In creating monosyllabic words, CCVC is more productive than CVCC, CCCVC is more productive than CVCCC, CCCVCC is more productive than CCVCCC, etc. It has also been pointed out that, diachronically, word-initial clusters are less prone to change than word-final clusters (Pulgram 1970).

2.4. Constraints on Obstruent Clusters

Greenberg (1978) found that the juxtaposition of obstruents produced in the same manner of articulation tend to be disfavored. If a language has a stop + stop sequence, it is almost always the case that it also has both stop + fricative and fricative + stop sequences. Languages may have fricative + stop and/or stop + fricative sequences without having stop + stop sequences, but no language would have stop + stop sequences while lacking the other two obstruent sequences. This holds for both initial and final clusters. However, Greenberg noted a slight preference for stop + fricative in the initial position, and for fricative + stop in the final position. Similarly, combinations of two fricatives are disfavored. The presence of a fricative + fricative combination implies the presence of either the stop + fricative or fricative + stop combination. This is true of both initial and final clusters. Among fricative + fricative clusters, combinations of two sibilants such as [ʃs], [sʃ], [ʒz] and [zʒ] tend to be avoided.

2.5. Constraints on Clusters of a Consonant and a Liquid

There is a general tendency that a liquid is not juxtaposed with another liquid. Thus, combinations like [rl] and [lr] are very rare (Greenberg 1978). Liquids are frequently found with other consonant types, but here, too, we find some implicational hierarchies. According to Greenberg, a liquid is more frequently combined with an obstruent than with a nasal. For example, in both initial and final positions, the presence of a nasal + liquid cluster implies that of an obstruent + liquid cluster. Moreover, in the final position, the presence of a liquid + nasal cluster presupposes that of a liquid + obstruent cluster.[10]

If we limit our consideration to initial stop + liquid clusters, the following universals present themselves. In clusters of a stop and a lateral, the preferred places of articulation for the stop are bilabial and velar. The sequences of alveolar stop + lateral, i.e., [tl] and [dl], are relatively rare. This is true of many Indo-European languages. Among them are Breton, Danish, Dutch, English, German, Modern Greek and Norwegian. This pattern is observed in languages of other families as well. Examples of permissible initial clusters of a stop and /l/ are given in (1):

(1)	p, k	Pacŏh, Kisi
	p, k^h, k, b	Hayu
	p^h, p, ^{ʔ}b	Lakkia
	p^h, p, k^h, k	Thai
	p^h, p, b, k^h, k, g	Palaung
	p^h, k, b, g	Chamorro
	p, k, b, g, ɓ	Sre
	p^h, k^h, ^{ʔ}b, ^{ŋ}g	Sedang
	k	Oneida
	p, b, k, g	Cua
	k^h, k͡p, b, g, g͡b	Ewe
	p, k, k^w, k͡p, b, g͡b	Wobé
	p, k, k^w, k͡p, b, ɓ, g, g͡b	Guéré

In Tagalog and Chinantec, initial clusters occur only in Spanish loans. In such words, Tagalog allows /p, k, b, g, f/ + /l/, but not /t, d/ +

/l/. Chinantec allows /k, g, f/ + /l/ but not /p, b, t, d/ + /l/. Katu does not have /t, d, tʃ/ + /l/ sequences, but there are complementary dialectal variations between alveolar stops + /l/ and velar stops + /l/. For instance, /tl, dl/ in Phûhòa dialect correspond to /kl, gl/ in Anˀdiˀêm dialect. The former has no /kl, gl/, and the latter has no /tl, dl/. See (2) for examples of such correspondences.

(2)	Anˀdiˀêm	Phûhòa	
	klâm	tlâm	'urinate'
	gluh	dluh	'go out'

Bell, A. (1971) contended that all liquids in general showed a tendency to combine with initial grave consonants. A detailed survey, however, reveals a different pattern for clusters of a stop and an /r/-like sound. All places of articulation are equally represented in initial stops in Adzera, Apinaye, Chamorro, Garo, Sre, Tagalog, Thai, and many Indo-European languages. In skewed series of stop + /r/ clusters, a gap may be at the velar place, e.g., in Amuesha with /pr, tr/ and in Burushaski with /pr, br, tr, dr/, or at the alveolar/palatal place, e.g., in Palaung with /p^hr, pr, br, k^hr, kr, gr/ and in Urhobo with /pr, br, kr, gr, k͡pr, g͡br/.[11] However, contrary to Bell's contention, a slight preference seems to exist for non-grave stops to combine with /r/, as evidenced in the following languages. /tr/ is the only initial stop + /r/ cluster in Maranungku. /tr, dr ˀdr/ are the only initial stop + /r/ clusters in Cua and Logbara. In Sedang, all voiceless stops /p^h, t^h, k^h/ may occur before /r/, but among the voiced stops, only /ˀd/ may do so. /c, ɟ/ and /t, d, c, ɟ/ are the only stops that may form initial clusters with /r/ in Wobê and Guéré, respectively.

2.6. Constraints on Clusters of a Consonant and a Glide

There are two major types of constraints on clusters of a consonant and a glide, namely, the rarity of clusters of a labial consonant and /w/, and the rarity of clusters of a dental/alveolar/palatal consonant + /j/.

2.6.1. Rarity of clusters of a labial consonant and /w/

The labiovelar glide /w/ tends not to follow labial consonants. In English, /pw/ and /bw/ occur only in loan words, e.g., pueblo, bwana, etc. Other languages with such a restriction are Korean, Ronga, Tarascan, Urhobo, Vietnamese and Zulu.

Similarly, labialization as a secondary articulation tends not to accompany labial consonants. Abkhaz has labialized dental and velar series but lacks labialized labials. Gã and Mambila also show this pattern. Bura and Margi, sister languages of the Chadic family, have cognates differing in terms of labialization. Corresponding to labialized labials in Bura, Margi often shows plain labials.

However, there is a lot of counterevidence. After surveying phonological inventories of about 700 languages compiled by Ruhlen (1975), Ohala and Lorentz (1977) suggested that secondarily-articulated labialization accompanied grave consonants more often than non-grave consonants. The numbers of languages with labialization at various places of articulation according to their tabulation are: 48 on labials, 26 on dentals, 16 on alveolars, 43 on palatals, 318 on velars, 107 on uvulars, and 26 on pharyngeals/glottals. If the figures for dentals and alveolars were added together since these consonants are not differentiated in many languages, the total number would come close to that of languages with labialized labials. While it is true that an overwhelming number of languages favor labialization of velars, it is not clear whether labialization of labials is also popular. Crothers et al.'s (1979) sample of 197 languages revealed the following pattern. Out of 40 languages with phonemic labialization of obstruents, only 3 have labialized labials.[12] Two have labialized alveolars and palatals. The rest have only labialized velars and uvulars. Out of some 20 languages with allophonic labialization, five allow it on practically all consonants before back vowels. Two languages allow it only on labials, one allows it only on alveolars and palatals, and the rest have it only on velars. Thus, the universal should be restated as follows; labialization as a secondary articulation occurs predominantly on velars.

It is not certain, however, whether we should expect the labialization of consonants and the consonant + /w/ clusters to behave in the same manner. Among the languages with labialized labials are a number of cases where the labialization seems to have originated as assimilatory allophonic labialization of the vowel onglide because of the 'inherently labialized' nature of labial consonants, and later seems to have been reinterpreted as being independent of the conditioning consonant and 'institutionalized' as phonemic labialization. Such 'parasitic' labialization would not develop around dentals and palatals. Thus, secondarily-articulated labialization may have a skewed origin. This is in contrast with the case of consonant clusters, where, theoretically, all consonants have an equal chance to be combined with /w/.

Unfortunately, we have no easy and reliable way of separating these two phenomena except in those few cases where the history of languages is known. We can even find in the phonological literature cases in which the decision for a unit analysis as opposed to a cluster analysis seems rather arbitrary. The proposed universal about the disfavoring of labial + /w/ sequences cannot be substantiated by many examples for this reason.

2.6.2. Rarity of clusters of a dental/alveolar/palatal consonant and /j/

The palatal glide /j/ tends not to occur after dental, alveolar, and palatal consonants. The post-consonantal /j/ in words like *Tuesday*, *due*, and *news* is retained in the Southern dialects and some Eastern New England dialects of American English, i.e., [t^hjuzdi], [dju], and [njuz], but the majority of dialects, including those in the Northeastern and Mid-Atlantic states, the Mid-West and the Western states, have lost it, i.e., [t^huzdi], [du], and [nuz]. In the following languages, some dental, alveolar, and palatal consonants are not found in initial clusters with /j/. /j/ is permitted only after /p^h, p, b, m, m̥, n, n̥/ in Burmese, only after /p^h, p, p̰, k^h, k, k̰, h, m, n, l/ in Korean, only after labials and /ʔ, h/ in Lisu, only after labials, labiodentals, and alveolars in Urhobo, and only after /p, b, m/ in Yay. /j/ does not follow /ts, dz/ in Wukari Jukun, palatoalveolars in Fox, alveolars and palatoalveolars in Paez, and palatals in Sre. In Armenian, /je/ loses its onglide when it follows a palatoalveolar. Likewise, the glide in /jɛ/ is lost after palatals in Dagbani.

Palatalization as a secondary articulation is disfavored on dentals, alveolars and palatals in some languages. Only labials are palatalized in Akha. In Dagbani, Even, Gilyak, and Wapishana, initial consonants are palatalized by the adjacent front vowels, but alveolars and palatals are not subject to this palatalization.[13] However, just as it was the case with secondarily-articulated labialization, there are many counterexamples. In some languages, dental, alveolar, and palatal consonants are accompanied by a non-distinctive palatal off-glide, while other consonants are not. In other languages, this palatal off-glide has been phonologized as secondarily-articulated palatalization, giving rise to a palatalized series skewed toward the alveolar-palatal region. Thus, we have diametrically opposite tendencies both of which seem quite wide-spread.

2.7. Constraints on Sequences of a Consonant and a Vowel

There are two major types of constraints on sequences of a consonant and a vowel. One is the rarity of sequences of a labial or labialized consonant and a rounded vowel, and the other is the rarity of sequences of a dental/alveolar/palatal or palatalized consonant and a front vowel.

2.7.1. Rarity of sequences of a labial or labialized consonant and a rounded vowel

Labial consonants, including labialized consonants and the labio-velar glide /w/, tend not to be followed by a rounded vowel. There is an abundance of evidence for this universal. Examples of forbidden sequences are listed in (3). It should be assumed that the rounded vowels may be freely combined with other consonants in these languages, though no specific examples of such sequences are given.

(3)	*pu, bu, mu	Izumo Japanese
	*βo, βõ	Mazateco
	*foo, fon	Vietnamese
	*vu	Guahibo
	*/w/ + /u, o, o:, ɔ/	Loma
	*/p, b, k^W, g^W, m, v/ + /u, ũ, o/	Ayutla Mixtec
	*fu, fũ, mu	Tenango Otomi
	*/w/ + /u, ũ, o, ɔ/	Tenango Otomi
	*wu	Ainu, Huichol, Ignaciano Moxo, Old Japanese, Kalinga, Totonaco, Yaqui, Yucuna
	*wo	Capanahua, Chacobo, Orizaba Nahuatl, Cavineña, Tarascan
	*wu, wo	Belangao, Trique
	*wo, wɒ	Luo
	*wu, wo, wə	Korean
	*ʋU, ʋo	Sinhalese
	*ŏu, ŏo, ŏɔ	Suto-Chuana
	*C^Wu	Akɔ́ɔ̄sē

*Cwu, Cwɔ	Yao, Zulu
*Cwu, Cwo	Wukari Jukun
*C^{w}u#, C^{w}ɔ#	Mambila
*/t, k, g/ + /w/ + /u/	English[14]
*p^{w}u, k^{w}u	Yaqui
*k^{w}u	Molinos Mixtec
*k^{w}o	Cavineña
*k^{w}o, k^{w}ʉ, k^{w}ũ	Silacayoapan Mixtec
*k^{w}u, ŋ^{w}u, k^{w}o, ŋ^{w}o	Parintintin
*k^{w}u, x^{w}u	Yuma
*k^{w}u, k^{w}ʌ	Huichol
*/kw, gw/ + back vowels	Toura
*/k^{w}, k$^{w'}$, g^{w}, h^{w}/ + /u, o/	Amharic
*q^{w}u, q$^{w'}$u, χ^{w}u	Bella Coola

A case parallel to this is neutralization of contrast between plain and labialized consonants before back rounded vowels. For instance, /k, k', q, q', χ/ and k^{w}, k$^{w'}$, q^{w}, q$^{w'}$, χ^{w}/ do not contrast before /o/ and /u/ in Chehalis.

The following are sequences of rare occurrence.

(4)	C^{w}U	Salish
	mu (only in loans)	Molinos Mixtec
	wo, mo	Kalinga
	wu, wo	Swahili

In some languages, labial or labialized consonants occur only or predominantly before front vowels, before low vowels, or before both front and low vowels. See (5) for examples.

(5)	/β/ only before /i, ɛ/	Ignaciano Moxo
	/k^{hw}/ only before /ɪ, ɛ/	Navaho
	/x^{w}/ only before /ɛ/	Navaho
	/w/ only before /ɛ, a, ã/	Navaho
	/$tʃ^{w}$, $dʒ^{w}$/ only before front vowels	Gã
	C^{w} only before /i, e, a/	Yareba
	/k^{w}, $ŋ^{w}$/ only before /e, a, ə/	Guajajara
	/h^{w}/ only before /$a^{<}$/	Tewa
	/w/ only before /a/	Nepali, Modern Japanese
	/w/ only before /ã, ɔ̃/ among nasalized vowels	Gbeya
	/k^{w}, g^{w}/ only before /a/	14-16C Japanese, some modern Japanese dialects
	/C^{w}/ mainly before /e, ɛ, a/	Akɔ́ɔ̃sē
	/w/ commonest before front vowels, /ə, a/ (word-initially); before or after front vowels, between /a/'s, and between /ə/ and /a/ (word-medially)	Punjabi
	/ŋ/ and /$ŋ^{w}$/ contrast only before /a/	Kpelle
	/Cw/ and /C/ contrast only before /a/	Gwari, Nupe
	Plain and labialized velars and uvulars contrast only before /a, e, i/	Awiya

Labialization and the glide /w/ are sometimes lost before a rounded vowel. For example, /w/ is lost before /u/ in Luvale, and before /u, o/

in Wolof. The loss of /w/ also occurred in the history of English, e.g., in <u>sword</u> [sɔ:d] and <u>ooze</u> [u:z] (< Old English <u>wōs</u>) (Dobson 1957). Labialization is lost in /C^{w}u/ in Bella Coola. A rounded vowel may be lost after a labial consonant. In Ganda, a word-final /u/ following /f, v/ is deleted when preceding a word-initial vowel.

The glide and labialization are sometimes reported to be weak or barely audible in the environment of rounded vowels. /w/ is very lax adjacent to /u, u:/ in Breton. /w/ is weak before /o/ in Luvale. The labial off-glide of labialized consonants is not audible before /u/ in Squamish. /wo, wu/ are realized as [o:, u:] respectively in New Caledonese.

The propensity for disfavoring sequences of a labial or labialized consonant and a rounded vowel occasionally leads to dissimilatory changes where the vowel loses some of its rounded or close quality. Examples are given in (6).

(6)	u ⟶ ʊ˂ / C^w _ o ⟶ ɔ	Angas
	U ⟶ o / adjacent to labials	Egyptian Arabic
	o ⟶ ɔ / k^w_	Molinos Mixtec
	u ⟶ ɯ̆ / p, p^h, b, m _	Lahu
	u ⟶ o / k^w, w _	Wichita
	o ⟶ ə / w _, _ w	Yao

Similarly, final VC sequences show the tendency to avoid juxtaposing a rounded vowel and a labial or labialized consonant. Examples of missing final sequences are given in (7).

(7)	*ɔp, up, yp, ɔm, ym, œm, um	Guangzhou Chinese
	*ɔp, up, ɔm, um	Meixian Chinese
	*up, um	Xiamen Chinese
	*back vowels + $w^{ʔ}$	Katu
	*rounded vowels + w	Thai
	*uw	Ainu, Maidu, Washo
	*ow	Chacobo, Guajajara
	*uw, ow	Kalinga
	*up^{w}, uk^{w}, uw	Yaqui

Moreover, /w/ follows only /a/ in Sa'ban, /ə, a/ in Nepali, and low and front vowels in Yay. /u/ is optionally deleted before /w/ in Tagalog.

2.7.2. Rarity of sequences of a dental/alveolar/palatal or palatalized consonant and a front vowel

Dental, alveolar, and palatal consonants, including the palatal glide /j/, and palatalized consonants tend not to occur before front vowels. Examples are given in (8). No remarkable co-occurrence restrictions exist for other consonant + front vowel sequences in these languages.

(8)	*$tʃ^{h}i$, $t^{h}ɛ$	Tarascan
	*ti	Guajajara
	*tse, tʃe, ʃe	Orizaba Nahuatl
	*ti, si	Goajiro
	*palatal stops + front vowels	Acoma
	*ni, nĩ, ʂɛ, ʂɛ̃	Mazateco
	*nɪ, ne:	Digueño

*ɲi	Western Popoloca, Yucuna
*ji	Ainu, Capanahua, Guahibo, Cavineña, Huichol, Korean, Ignaciano Moxo, Totonaco
*ji, jĩ	Tenango Otomi
*jɪ	Sinhalese
*ji, je	Modern Japanese, Trique
*ji, jɛ	Bulgarian
*C^ji, C^jɛ	Bulgarian
*C^ji, C^jĩ	Ayutla Mixtec, Dan
*C^ji, C^je, tsi, ʃe	Cavineña
*Cji, Cjĩ, Cje, Cjẽ	Silacayoapan Mixtec
*Cji, Cje	Modern Japanese
*Cji, Cjæ	Yao

Moreover, the sequences /ji/ and /je/ are rare in Kalinga and Cavineña, respectively. Neutralization of plain/sharp contrast in some consonants occurs before /i, e, æ/ in North Estonian, and before front vowels in Karakatšan. Standard Czech words with /ji/ or /ij/ sequence are replaced by other lexical items lacking such sequences in common colloquial Czech. The /ji-/:/i-/ distinction in words like yeast and east is maintained in the Northeastern dialects of American English, but in the Mid-Atlantic and Southern dialects, these words are rendered homophonous. Both yeast and east are pronounced as /ist/ (Kurath and McDavid 1961).[15]

Dental, alveolar, palatal, or palatalized consonants are most frequently found in the environment of back vowels and low vowels. See (9) for examples.

(9)	/tʃ/ only before /u, a/	Parintintin
	/j/ only before /a, o/	Nepali
	/j/ only before back vowels	Selepet
	/j/ only before back vowels, ə, a	Punjabi
	/ě/ largely before /ɛ, a/, rarely before /i, u/	Suto-Chuana
	C^j only before /e, ɛ, ə, a, ɔ, o/	Akɔ̃ɔ̄sē
	/C^j/ and /C/ contrast only before /a/	Gwari, Nupe
	/C^j/ and /C/ contrast only before back and central vowels	Lithuanian
	/k^j/ and /k/ contrast only before /a<, o, u/	Russian

The palatalized off-glide and the glide /j/ are occasionally deleted before front vowels. E.g., /j/ is lost before /e/ in Wolof. /Φ^j/ loses its palatalization before /i/ in Paez.[16] A high front vowel may be deleted after a dental, alveolar, or palatal consonant. E.g., /ɪ/ in /ɪw/ is lost especially after /s, j/ in Diegueño. A word-final /i/ following /s, z, j, ɲ/ is elided before a word-initial vowel in Ganda.

The glide /j/ may be weak before front vowels. E.g., /j/ is very lax before and after /i, i:/ in Breton. /j/ is reported to be hard to hear before /i/ in Logbara. /j/ is normally not heard before /i/ in Swahili.

Sequences of a front vowel and a dental, alveolar, and palatal consonant are similarly disfavored. See (10) for examples.

(10)	*ij, ej, æj	Thai
	*ij	Ainu, Belangao, Kalinga, Maidu, Washo, Guajajara
	*it	Capanahua
	*front vowels + /tʃ, ˀdj, s, n, j/	Katu

/j/ is extra short after /i/ in Finnish. /j/ follows only /a/ in Sa'ban, /ə, a/ in Nepali, and low and back vowels in Yay. /i/ is optionally deleted before /j/ in Tagalog.

In sequences with a velar consonant, two patterns are evident. Some languages forbid combinations of a velar and a rounded vowel. See (11) for examples.

(11)	*ku, uk, uŋ	Belangao
	*xon	Vietnamese
	*gu, xu	Tenango Otomi
	*/ɣ, ŋ/ + /u, o, ɔ/	Loma
	*yk, yŋ	Guangzhou Chinese
	*uk, uŋ	Xiamen Chinese

The other pattern is to avoid combinations of a velar consonant and a palatal glide or a front vowel. Examples are given in (12).[17]

(12)	*/k, g, ŋ/ + front vowels, /j/	Dagbani
	*ki, ik, iŋ	Belangao
	*ik, ɛk, iŋ	Meixian Chinese
	*/k, g, x, ɣ/ + /i, e/	Karakatšan

From this we may assume that velar consonants are commonest around low vowels.

2.8. Constraints on Vowel Clusters and Diphthongs

Vowels are combined relatively freely with each other. However, when languages impose restrictions on their inventories of vowel clusters or diphthongs, the following statement generally seems to hold. Combinations of a low vowel and a high vowel are favored over other combinations of vowels. Combinations of a low vowel and a mid vowel, and of a mid vowel and a high vowel are often found missing or rare. Some examples of vowel cluster or diphthong inventories exhibiting this pattern are shown in (13).[18]

(13)	/ɪ, ɨ, U/ + /a/	Thai
	/ɪ, ɯ̌, U/ + /ʌ/, /æ˃, ʌ/ + /w/	Vietnamese
	/a/ + /ɪ, U/, /ɔ/ + /ɪ/	German
	/ɒi, ɒo/ in native words, /oi, iɒ, eɒ, oe, iu/ in loans	Chamorro
	/a:w/ is the only V:G sequence	Somali
	/iɑ/	Tiwa
	/a̹/ + /i, u/	Ticuna
	/i, ɨ, u/ + /a/	Katu
	/i, ɯ, u/ + /ə/, /a/ + /ɯ/	Yay
	/aɪ, ɛɪ, ɔɪ/ more frequent than /aɔ/	Navaho
	all vowel clusters except /ae/; /ao/ is rare	Campa
	/aɛ/ is very rare	Ignaciano Moxo
	all vowel clusters except /iɨ/	Chacobo

There is a wide-spread synchronic process that affects vowel clusters. It is insertion of a glide to break up a vowel sequence, and it invariably occurs between vowels of different qualities. Between a front (especially high front) vowel and a non-front vowel, /j/ is inserted. Between a rounded (especially high back) vowel and an unrounded vowel, /w/ is inserted.[19] See (14) for examples.

(14)	/j/ inserted /i _ V	Swahili
	/w/ inserted / back rnd V _ unrnd V	Swahili
	/w/ inserted /u _ i	Inuit
	/u _ a	
	/j/ inserted /i _ u	Inuit
	/i _ a	
	/w/ inserted /o _ a	Campa
	/j/ inserted /i _ u	Tarascan
	/ɛa/ ⟶ /eja/	Tarascan

Moreover, in Dakota, which does not allow vowel clusters, potential vowel clusters are broken up by inserting a glide or /ʔ/ or by contraction.

2.9. Unstable Sequences

There are sound sequences which often undergo phonological change, and therefore may be considered as unstable sequences. Ordinarily, such sequences are not discussed within the scope of phonotactics. However, in the preceding sections, we assumed that disfavoring of certain sound sequences might take the form of relative rarity as well as absolute avoidance of such sequences. The vulnerability of certain sound sequences to change may also be regarded as one factor leading to sequential restrictions. The change of labialized consonants or clusters of a consonant and /w/ to labials, and the change of palatalized labials or clusters of a labial and /j/ to alveolars or alveo-palatals are among the commonest. Most of the examples given below are diachronic processes, but synchronic variations of these kinds also take place.[20]

2.9.1. Change of labiovelars to labials

The change of labialized velars, velar + /w/ sequences, or velar + rounded vowel sequences to labials is attested in many unrelated languages. Examples are given in the lists (15) through (25).

(15) Proto-Indo-European labiovelars > labials in Greek (Pokorny 1959)[21]

PIE	Greek			
*k^{w}o-	ποῦ	'where'	πότερος	'which'
*sek^{w}o-	ἕπομαι	'follow'		
*g^{w}m̥-^{j}ṓ	βαίνω	'go'		
*reg^{w}os	ἔρεβος	'darkness'		
*g^{w}hóno-s	φόνος	'murder'		

(16) Proto-Indo-European labiovelars > labials in Latin (Pokorny 1959)

PIE	Latin	
*wl̥k^{w}os	lupus	'wolf'
*g^{w}m̥-^{j}ṓ	veniō	'come'
*g^{w}hormo-	formus	'warm'

(17) Proto-Indo-European labiovelars > labials in Germanic (Prokosch 1938, Pokorny 1959)

PIE	Germanic	
*wl̩k^{w}os	Gothic *wulfs*	'wolf'
	Old Norse *ulfr*	'wolf'
	Old English *wulf*	'wolf'
	Old High German *wolf*	'wolf'
*k^{w}etwores-	Gothic *fidwōr*	'four'
*uk^{w}nos	Old Norse *ofn*	'fire, stove'
	Old English *ofen*	'fire, stove'
	Old High German *ofan*	'fire, stove'

(18) Proto-Indo-European plain velar + /w/ > labials in Greek (Pokorny 1959)

PIE	Greek	
*kwr̩snos	*πρῖνος*	'oak'

(19) Proto-Indo-European plain velar + /w/ > labials in Latin (Pokorny 1959, Watkins 1969)

PIE	Latin	
*gwot-olo-	*botulus*	'sausage'

(20) Proto-Indo-European palatal + /w/ > labials in Greek (Pokorny 1959)

PIE	Greek	
*ek̑wo-s	*ἵππος*	'horse'
*ĝhwoig^{w}-	*φοῖβος*	'bright'

(21) Proto-Indo-European palatal + /w/ > labials in Latin (Pokorny 1959)

PIE	Latin	
*ĝhwero-s	ferus	'wild'
*ĝhwōk^{w}-	fax	'torch'

(22) Japanese (Hirayama and Oshima 1975, Oishi and Uemura 1975, Shibata 1976)

	Dialects with /k^{w}/	Tsushima, Amakusa, Kagoshima Makurazaki[22]	Standard Japanese
'fire'	k^{w}adʒi	padʒi	kadʒi
'Bodhisattva'	k^{w}annoN	pannoN	kannoN
'cake'	k^{w}aʃi	paʃi	kaʃi
'do not eat'	kuwanu, k^{w}anu	paN	kuwanu
'Eat!'	kue, k^{w}e	pe:	kue

(23) Labrador Inuttut (Smith 1975)

Older generation	Younger generation	
inikvik	inipvik, iniffik	'drying place'

(24) Vietnamese (Haupers 1969)

Standard Vietnamese	Southern dialects	
xoan	foan	'want'
xoa	foa	'lock'
xoai	foai	'potato'

(25) Bantu (Meinhof 1929)

Sotho	Other dialects	
maχura	mafuta	'fat
-χwa[I]	-fwa, -fa	'die'

The change of /k^w/ to /p/ occurred also in Proto-Otomanguean. Ohala and Lorentz (1977) cites similar cases in Proto-Yuman and Sonkhla.

The changes of dental + /w/ sequences to labials occurred, for example, in Latin and Gujerati. See (26) and (27). This change, however, seems to be less frequent than the change of labiovelars and velar + /w/.

(26) Proto-Indo-European dentals + /w/ > labials in Latin (Pokorny 1959)

PIE	Latin[23]	
*dwis	bis	'twice'

(27) Gujerati (Turner 1921, Mehta and Mehta 1925)

Middle Indian	Gujerati	
*dʋara	bār	'door'
*dʋē	bɛ̄	'two'
*dʋitīya-	bīj	'second day'
*ūrdhʋa-	ūbhū̃	'erect'

2.9.2. Change of palatalized labials to dentals/alveolars/palatals

The change of palatalized labials, clusters of a labial + /j/, and sequences of a labial and a front vowel to dentals, alveopalatals or palatals is found in a great many languages including the following.[24]

(28) French (Grandgent 1907, Elcock 1960)

Latin	French	
cavea	cage	'cage'
leviarium	léger	'light'
appropiare	approcher	'bring, approach'
tibia	tige	'stem'
rabia	rage	'madness, rage'
serviente	sergent	'sergeant'

(29) Czech (Andersen 1973)

Standard Czech	Litomyšl dialects (Northeastern Bohemia)	
$p^j ekn^j e$	$tekn^j e$	'nicely'
b^jeʒeti	deʒet	'run'
m^jesto	nesto	'town'
koupiti	koutit	'buy'
míti	ni:t	'have'

(30) Chinese (Chang and Chang 1972)

Archaic Chinese		Sino Annamese
*pjin	賓	tân
*bjin	頻	tần
*mjin	民	dân

(31) Tai (Gedney 1973)

Ning Ming	Siamese	
bjaaŋ	daaŋ	'white spotted'
bjook	dɔɔk	'flower'

(32) Tibetan (original transcription)(Thomas 1948, Benedict 1972)

Tibetan		Tangut	Lolo	Mili, Loutse	Moso
mig, myig (> mnyig)	'eye'	nik	nie-sö	nie	nya-lü

		E. Colonial	Lhasa	Ahi
bya	'bird'	śia, śiü, sǖ, z̀ü	ca	do
byi-ba	'rat'	śiua, tsüi, śio, jeh	ci-wa	

		Thōchū	Go-lok	Pa-U-Rong
mi, myi	'man'	nāḥ	néé	nyi

(33) Ryukyuan (Nakamoto 1976)

Northern Okinawa	Iejima	Tokunoshima	Yonakuni	Standard Japanese	
pˀi:	ti:	ʃi:	tʃˀi:	hi	'sun'
p'iɾu	tiɾuma	sɨɾu	tsˀu:ma	hiɾuma	'afternoon'

(34) Labrador Inuttut (Smith 1975)

Older generation	Younger generation	
igupjaivuk	igutjaivuk, igutʒaivuk	'he picks it to pieces'

(35) Kwa (original transcription)(Hyman and Magaji 1970)

Gawun (Gwari)	Nupe	Ganagana	
byè	dzò	dywè	'sow'
byī	dzū	dywī	'bury'
ēpyá	ētswā	ēpshā	'moon'

(36) Bantu (Tucker 1929, Meinhof 1932, Guthrie 1967-70)

Ur-Bantu	Herero	SePedi	SeSuto	SeChuana	Zulu	
*pjata		ts^{wh}ara	ts^{wh}ara			'grasp'
	-pja				ʃa	'burn'
*libue		leʋ^{ɥ}ɛ	leʒ^{w}ɛ	lentʃ^{w}ɛ	ilitʃ'e	'stone'
		ʋ^{ɥ}aŋ	ʒ^{w}aŋ			'grass'
		lif^{ɥ}a	leʃ^{w}a	leʃ^{w}a		'be paid'
		tseʋ^{ɥ}a	tseʒ^{w}a	tseʒ^{w}a		'be known'
		t^{h}up^{ɥ}a	t^{h}otʃ^{w}a	t^{h}otʃ^{w}a		'be captured'
		kx^{h}ap^{ɥh}a	kx^{h}atʃ^{wh}a	kx^{h}atʃ^{wh}a		'be scooped'

Modern Romance languages such as Genoese Italian, Portuguese, and Spanish have palatoalveolars which originated from labial + /l/ clusters in Latin (Meyer-Lübke 1890, Malkiel 1963-64). Ohala (1978) cites some such cases.[25]

CHAPTER THREE

PREVIOUS ACCOUNTS FOR UNIVERSAL SEQUENTIAL CONSTRAINTS

This chapter reviews and critically discusses several earlier attempts to account for universal sequential constraints. They are of three types. The first type of hypothesis is based upon the ranking of segments and syllable positions in the 'strength/sonority' hierarchy. The second is based upon articulatory features or physiological constraints. The third type is based upon featural contrasts between successive phonemes.

3.1. Hypotheses Based on the 'Strength/Sonority' Hierarchy

Explanations for universal phonotactic constraints on the basis of the 'strength/sonority' hierarchy are threefold (Hooper 1976). First, segments are rank-ordered in terms of their 'strength/sonority.' Second, positions within the syllable are also characterized by the hierarchy. Then it is shown that the patterns of segmental 'strength' and of syllabic 'strength,' which are motivated on independent phonological grounds, are correlated. These hypotheses are discussed below in the following order. First, a general description of the hierarchy is given. Second, bases for the proposed ranking of segments and syllable positions are reviewed. Third, accounts offered by the hypotheses for some phonotactic universals are outlined. Finally, general and specific problems of the hypotheses are pointed out.

3.1.1. Hierarchy

Many scholars have suggested that there exist hierarchical relationships among segments. Various names have been used for such a hierarchy, e.g., 'sonority hierarchy' (Hankamer and Aissen 1974), 'strength hierarchy' (Foley 1970, 1977, Vennemann 1972, Hooper 1976), 'vowel adherence' (Sigurd 1955), and 'vowel affinity' (Fujimura 1975, Fujimura and Lovins 1977), but the rank-ordering of segments is basically the same in all cases. Hooper (1976) proposed the following ranking for a supposedly universal 'strength hierarchy.'

	glides	liquids	nasals	voiced continuants	voiceless continuants voiced stops	voiceless stops
strength ⟶	1	2	3	4	5	6

According to this hierarchy, obstruents are characterized as the 'strongest' segments as opposed to vowels which are the 'weakest.' Among the obstruents, voiceless stops are 'stronger' than fricatives and voiced stops. Ordinarily, voiceless obstruents are 'stronger' than voiced ones. Nasals are generally 'stronger' than liquids which are in turn 'stronger' than glides.

The 'sonority hierarchy' proposed by Hankamer and Aissen is just a mirror-image of the 'strength hierarchy,' with vowels, the most 'sonorous' segments, placed at the higher end of the scale, and stops, the least 'sonorous,' at the other end. According to Heffner (1960), segments are ranked on 'sonority' as follows.

	voiceless obstruents	voiced obstruents	nasals laterals	"r"s	close vowels	mid vowels	open vowels
Sonority	⟶						

Hooper (1976) points out the striking similarity between the 'sonority' and 'strength' hierarchies except for the inverse relationship. The notion of 'sonority' has a long history in phonological literature. It was mentioned in conjunction with syllable structure by Sievers (1893), Jespersen (1904) and Saussure (1916), and more recently by Hâla (1961) and Krâmský (1971) among others. They noted that the syllable nucleus was occupied by the most 'sonorous' sound, normally a vowel. Farther away from the nucleus is a less 'sonorous' sound, and on both syllable margins are found the least 'sonorous' ones. Various impressionistic parameters such as acoustic energy, audibility, tonality, and relative degree of aperture have been suggested without stringent experimental verification as a basis for the ranking in 'sonority.' (The problem of defining these hierarchies in physical terms and the different views on whether or not to pursue such physical correlates are discussed in detail in Section 3.1.5.)

3.1.2. Bases for the hierarchical ranking of segments

The hierarchical relationship of segments was determined in part by the very fact that some segments were more frequently observed and thus more suitable for syllable-initial and syllable-final positions than others. In discussing syllable-initial and final consonant clusters in Spanish, Hooper (1972) noted that, for instance, obstruents were more suitable for syllable margins, and liquids and glides occurred closer to the vowel nucleus. Hence, obstruents are ranked higher than sonorants on the scale. Similarly, Sigurd (1955) proposed a rank-order of Swedish consonants on the basis of their tendency to adjoin a vowel in the syllable. For instance, the existing initial clusters /kl-/ and /kr-/ and final clusters /-lk/ and /-rk/ indicate a greater degree of 'vowel adherence' for /l/ and /r/ than for /k/. The final cluster /-rl/ further suggests that /r/ is more adherent to a vowel than /l/. Thus, an order is established among the three consonants: k-l-r. Through examining such distributional patterns, he attempts to determine hierarchical relationships among all the consonants involved in initial and final clusters. It is clear that either the 'strength' or 'vowel adherence' hierarchy established by this criterion is merely a restatement of suitability or unsuitability of consonants for syllable margins.

It has been claimed, however, that these hierarchies can be established completely independently of observations on syllable structure. Foley (1970, 1977), Vennemann (1972), Zwicky (1972), Hankamer and Aissen (1974), and Hooper (1976) emphasized that bases for the hierarchies should be sought in diachronic and synchronic phonological processes. The applicability of phonological rules most often depends on the inherent properties of segments, which, in their argument, would be best described in terms of 'sonority' or 'strength.' The following are some of the phonological processes in Modern Icelandic which Vennemann (1972) regarded as indicative of relative 'strength' of consonants in this language.

1) Voiceless stops /p, t, k/ are the only consonants that are aspirated.

2) All fricatives except for /s/ are voiced in voiced environments.

3) Only /p, t, k/ and /s/ devoice the preceding fricatives and sonorants.

4) /r/ is always devoiced by the following voiceless stops, while nasals /m, n/ and lateral /l/ only sometimes.

5) /r/ is always devoiced by /s/, while the other sonorants never are.

6) /j/ palatalizes and /v/ labializes adjacent segments just as the high vowels do.

The first three observations separate the voiceless stops and /s/ from other consonants as being 'strong.' The fourth and fifth observations suggest that nasals are relatively 'stronger' than /r/, and the last observation attests to the vowel-like and hence the 'weak' nature of /j/ and /v/.

Hankamer and Aissen (1974) reaffirmed the hierarchy of consonantal dominance in Pali consonant assimilations found in earlier studies of the language. Sometimes when two non-identical consonants are butted together at a morphemic boundary, one of the consonants completely assimilates to the other, e.g., /r/ assimilates to /y/, /s/, and stops, /y/ to /s/ and stops, and /s/ to stops.

Zwicky (1972) noted a hierarchical manner of application of what he called the Slur in English. This rule deletes /ə/ between a consonant and a sonorant in fast or casual speech. He pointed out that /r/ was a preferred sonorant for the rule to apply. It applies less frequently before /l/, and exceptions are even more numerous if the sonorant is a nasal.

More or less the same ranking of segments is obtained from these different sources of phonological evidence. Most of the above scholars agree that the ranking is language-specific, because it differs from language to language especially with regard to liquids and glides. However, Hankamer and Aissen (1974) and Bell and Hooper (1978) conjectured that the variability in ranking of these segments might reflect actual cross-linguistic variations in the way they were articulated. "r" is a notorious case in this sense. Likewise, sounds described as glides range from a vowel-like variant to a fricated variant. Hankamer and Aissen (1974) further hypothesized that the ordering of obstruents and nasals should be similar across languages because of their relatively invariant pronunciations. These assumptions imply that the hierarchy is universal, with minor deviations being determined by phonetic factors pertinent to individual languages (Hooper 1976).

3.1.3. Bases for the hierarchical ranking of syllable positions

A claim has been made that there exist hierarchical relationships among positions within the syllable (Vennemann 1972, Hooper 1976). That is, the syllable has intrinsically 'weak' and 'strong' positions. Evidence is drawn from phonological observations as follows.

1) The nucleus of the syllable is occupied by the most vowel-like sound.
2) CV is the predominant type of syllable structure in the world's languages.
3) 'Strengthening' processes such as glide-obstruentization always take place syllable-initially.
4) More consonants contrast syllable-initially than syllable-finally. Some contrasts are neutralized syllable-finally.

5) Syllable-initial allophones are 'stronger' than syllable-final allophones, e.g., initial [t^h] vs. final [t˺].

6) Diachronically and synchronically, assimilation and loss of consonants occur more readily in the syllable-final position.

These observations have led Vennemann (1972) and Hooper (1976) to the following hypothesis. Both syllable margins are inherently 'stronger' than the syllable nucleus, and as for the syllable margins, the initial position is 'stronger' than the final position.

3.1.4. Accounts for some universal phonotactic constraints

Hooper (1976) attempted to explain some universal phonotactic constraints by correlating the 'strength' of segments with the 'strength' of syllable positions. She hypothesized that 'strong' consonants tended to occur at 'strong' positions and 'weak' consonants at 'weak' positions in the syllable. Universal preference for obstruent + liquid clusters over nasal + liquid clusters in the syllable-initial position was explained as follows. 'Strong' consonants such as obstruents are more apt to appear in the 'strong' syllable-initial position than nasals. Moreover, some languages require that there be a minimum difference in 'strength' between the first and second consonants in a cluster. Referring to the universal in the earlier version of Greenberg's paper (1978) that the presence of initial obstruent + nasal clusters presupposes that of initial obstruent + liquid clusters, Hooper (1976) offered an explanation that nasals universally ranked higher in 'strength' than liquids, and if the second position of a syllable allowed a consonant with a 'strength' value as high as that of nasals, then it should also allow liquids.

She argued further that VC syllables and syllable-final consonant clusters were rarer than CV syllables and syllable-initial consonant clusters because of the condition that the maximum 'strength' value for consonants in the final position be lower than that for consonants in the initial position.

3.1.5. Criticisms

There are many problems with the kind of explanations offered by Hooper (1976), if they can be called explanations at all. A serious flaw in her and others' approach lies in the fact that they never made explicit what 'strength' was. The phonological evidence on which the 'strength' hierarchy is based is indeed of various sorts, but in some cases there seems to be no a priori reason why the observed pattern or process should be considered to be associated with any kind of 'strength.' Why, for instance, should voiceless stops be considered 'strong' because they are aspirated? Why should devoicing or voicelessness imply 'strength' rather than 'weakness'? It seems that *any* phonological phenomena could be brought together under the cover term of 'strength,' unless there were some empirically determinable property that defines the notion of 'strength.' What is particularly damaging to their claims is that there seems to be no clear physical parameter in terms of which one can characterize the hierarchy. In fact, attempts to find physical correlates for 'strength' and 'sonority' have not been very fruitful, if not totally unsuccessful (Sigurd 1955, Krámský 1971, Hankamer and Aissen 1974, Hooper 1976, Fujimura and Lovins 1977). However, most advocates of the hierarchies were not particularly discouraged by this, for they believed that the significance of their hierarchies lay in their functional value in a linguistic theory or in psychologically real constructs which motivate the native speaker's linguistic behavior. Such a view is evident in the following quotes.

> "I am viewing the syllable, and for that matter the cover feature strength, as theoretical constructs, not entirely divorced from physical reality, but abstract in that their importance is seen only in their function in a linguistic system (Hooper 1976; p. 198)."

> "[T]he part of the brain which is responsible for processing speech sounds constructs 'psychological' parameters which bear no simple or direct relation to observable phonetic parameters (Hankamer and Aissen 1974; p. 137)."

> "If we want to solve the problem of the syllable from the functional point of view, we must begin by clearly separating that which in the phenomenon of the syllable is of phonetic character from that which is phonological, functional (Krámský 1971; p. 46)."

This is not to say, however, that they denied the necessity or possibility of substantiating their claims by empirical evidence.

> "[W]hich is not to say that they bear no relation to such observables -- only that the relation is complex (Hankamer and Aissen, continued from above)."

> "However, this does not mean that we are giving up the help of phonetics. It is necessary to reach agreement on the phonetic explanation of the syllable and to decide which of the phonetic explanations is the most adequate for the functional appreciation of the syllable (Krámský, continued from above)."

> "[A]nd to be completely satisfying, the tenets of such a theory should have some external justification, for example, in terms of phonetics (Zwicky 1972; p. 277)."

> "We would like to speculate that this problem [=phonetic universals on clusters] is best formulated in terms of very concrete phonetics....The 'phoneme sequence' restrictions would simply be a result of the phonetic factors (Fujimura and Lovins 1977; p. 40)."

On the other hand, a strong condemnation against reference to physical entities in a phonological theory was expressed by Foley (1970). He charged that the distinctive features used by transformational phonologists could not satisfactorily describe certain sound changes.[26] Blaming the inadequacy of distinctive features on their acoustic bases, he states:

> "Phonology is not concerned with the physical structure of sounds, but with the relationships that exist between entities that manifest themselves as sounds. To attempt the establishment of a system of phonology on acoustical data is a contravention of this principle.
>
> "The distinctive features of a phonological system must be based on phonological, not phonetic, data if that system is to be viable. Acoustics has only peripheral relevance to phonology;
>
> "Phonology is primarily a system of relationships. The eventual manifestation of the entities of this system in the world of physical sounds is of little concern to the phonologist. A theory based on phonetic incidentals is sterile, inherently incapable of yielding insight into the essential nature of language.
>
> "The assumption of phonetic (physical) relevance in a phonological (non-physical) system is a commission of the reductionist fallacy (pp. 88-89)."

Ironically, some of the phonological data which Foley presented to illustrate his point would be better explained in terms of simple aerodynamic facts. That is, in North German, the intervocalic voiced velar stop became a continuant, whereas the voiced labial and dental stops remained unchanged. In Sanskrit, /g^h/ changed to /h/ but /b^h, d^h/ remained unchanged. In Standard Danish, intervocalic /g/ and /d/ became continuants while /b/ did not. Latin /g/ and /d/ but not /b/ were lost intervocalically in Spanish. As mentioned in Chapter One, a hypothesis has been proposed that this is due to differences in compliance of the surface tissue of the cavity involved in the production of these stops (see Ohala and Riordan (1979) and the references therein for phonetic facts surrounding this issue; Gamkrelidze (1975) and Sherman (1975) for asymmetries in stop inventories presumably arising from the same cause; Kawasaki (1981) for similar diachronic and synchronic data in Japanese). Foley's account was that /b/ was phonologically 'stronger' than /d/ which was in turn 'stronger' than /g/. This is a restatement of the facts, not an explanation.

In addition, his hierarchy makes the wrong predictions on certain universal phonological phenomena: frication of aspirated stops and disfavoring of /p/. The hierarchy ranks voicelessness and stoppedness high among manners of articulation. Thus, voiceless aspirated stops are 'stronger' than voiced stops and voiced or voiceless fricatives. Then why do these 'strong' segments often change to (or become weakened to) fricatives while supposedly 'weaker' voiced stops remain unchanged? Phonetics would provide a straightforward explanation for this process; the burst of aspirated stops is interpreted by the listener as the noise of fricatives.

Among places of articulation, the hierarchy ranks forward places higher than back places. This makes the voiceless aspirated bilabial stop the 'strongest' among the consonants that he considered. However, /p^h/ and /p/ are not very stable segments phonologically. They are frequently lost in diachronic changes, and synchronically, they are missing in the voiceless stop series of a number of languages. These patterns are also accountable in reference to the phonetic properties of these segments (Stevens 1980, Ohala in press). These sounds are produced with a constriction at the lips with no resonating cavity in front of it. As a result, their bursts lack sharp spectral peaks and are low in amplitude (Zue 1980). In other words, $/p^h/$ and /p/ lack very salient auditory cues, and hence the above phonological tendencies are observed. Foley's (1977) answer to this problem was what he called 'modular depotentiation of strengthened elements;' the strongest element cannot appear as a stronger element, therefore, when further strengthened, it will appear as the weakest element (i.e., loss of /p/). It is obvious which of these two solutions have greater explanatory value, and which is a close analogue within linguistics of the epicycle within Ptolemaic cosmology.

Some experimental studies have been conducted in an attempt to find phonetic bases for the hierarchy of segments. For example, Lindblom (1979, in press) recently presented data on the degree of jaw opening during the articulation of Swedish apical consonants flanked by low vowels. He showed that the degree of jaw opening during consonants increased in obstruents, /n/, /l/, and /r/ in that order, which roughly correlates with the 'sonority' hierarchy. He suggested that the hierarchical nature of phonotactic constraints might be ascribable to the consonants' propensity to coarticulate with vowels. Fujimura and Lovins (1977) likewise speculated that a possible explanation for sequential constraints might be found in physiological properties of the speech production mechanism. This certainly is an area which awaits further investigation.

With regard to the other hierarchical structure that Vennemann (1972) and Hooper (1976) proposed, namely the relative 'strength' of positions within the syllable, more severe criticism is warranted. What they considered as the bases for such a hierarchy are themselves the linguistic facts which are supposed to be explained, rather than to be treated as primitives to explain other phenomena. The naturalness of CV syllables was one of the grounds cited for putting forward the hypothesis that the syllable-initial position is inherently 'strong,' and yet the same hypothesis is supposed to account for why no languages prohibit CV syllables. This is circular. How could a hypothesis explain a given fact if that fact was used to build the hypothesis in the first place?

Finally, the 'hierarchy' hypotheses fail to explain some of the common phonotactic skewings that were discussed in Chapter Two, for example, the rarity of /pw/ and /tj/. Hooper's (1976) hierarchy does not differentiate places of articulation, so all voiceless stops are ranked equally. Likewise, /w/ and /j/ have the same 'strength' value. Thus, based on her hierarchy, no prediction would be made as to constraints on stop + glide sequences. In Hankamer and Aissen's (1974) hierarchy for Pali consonants, all stops belong to the same category, but "v" (assumed by them to be [w]) ranks higher than /j/. Vennemann (1972) placed /j/ and /v/ in the same category, but ranked /t/ higher than /p/ and /k/. Even if either of these hierarchies turned out to be universal, it would not predict any particular constraint except for, perhaps, the favoring of stop + /j/ clusters over stop + /w/ clusters in the case of Hankamer and Aissen's hierarchy, and the favoring of /t/ + glide clusters over other stop + glide clusters in the case of Vennemann's. Both of these predictions are too general, because in fact more specific clusters are favored. Foley's (1970) hierarchy ranks forward places of articulation higher than back places of articulation. In this case, the universal should be contrary to what is actually observed, i.e., /pw/ should be *favored* over /tw/ and /kw/, because the supposedly 'strongest' /p/ would be the most suitable for the 'strongest' initial position of the syllable.

Further, these hypotheses would not explain why the sequences of /w/ + rounded vowel and of /j/ + front vowel are disfavored. Some scholars have proposed tentative rankings of vowels in terms of 'strength/sonority,' but they show very little agreement. However, the fact is that no matter how the glides and the vowels were ordered, the above gaps would present a difficulty to the hypotheses, because the favored and disfavored vowels after /w/ are exactly the opposite of what are favored and disfavored after /j/.

The rarity of /tl, dl/ is another universal that is not accounted for by the hypotheses. Hooper (1976) acknowledged this problem, but tried to solve it at least for Spanish by positing that dental consonants were 'weaker' than bilabial and velar consonants. She claimed that dentals and /l/ were not combined because they were not different enough in terms of their 'strength.' However, she conceded that this account would not apply to other languages lacking /tl, dl/, and suggested that a real account for this particular restriction might not have anything to do with the 'strength' of the consonants.

3.2. Articulatory Hypotheses

Diver (1975) attempted to explain certain universal sequential constraints in articulatory terms. He proposed articulatory features [mobile] and [stable] to characterize consonants. Among obstruents, plosives were 'mobile,' while fricatives were 'stable.' Among liquids, /r/ was 'mobile,' while /l/ was 'stable.' By using these features, he accounted for the following phonotactic skewings. On the one hand, combinations of a plosive and /r/ are more frequent than combinations of a plosive and /l/, and on the other hand, combinations of a fricative (/s/ or /f/) and /l/ are more frequent than combinations of a fricative and /r/. He hypothesized that the succession of two different features was disfavored compared to the repetition of the same feature on the ground that the control of musculature would be easier in the latter case. In other words, /pl, tl, kl/ are [mobile] + [stable] sequences, and /sr, fr/ are [stable] + [mobile] sequences, so they are all disfavored. /pr, tr, kr, fl, sl/ are either [mobile] + [mobile] or [stable] + [stable], so they are favored.[27] In /tl, dl/ and /sr/, the flanking consonants are both lingual sounds. The tongue musculature must adjust itself to the shift from [mobile] to [stable] or vice versa. /pl, kl, fr/ also have incompatible feature sequences, but here the musculature that has to be brought under control is different in the first and second consonants. Diver conjectured that it would be more difficult to learn to control the former type of articulatory gestures, hence strong avoidance of /tl/ and /dl/.

However, he explained the rarity of /pw, bw, fw/ on a different ground. The juxtaposition of consonants in the same place of articulation is disfavored. He ascribed this to a human trait to avoid the repetition of the same gesture. This argument seems to be inconsistent with his earlier argument concerning the clusters of an obstruent and a liquid. If it is a human nature to avoid the repetition of the same gesture, then why is the repetition of [mobile] or [stable] feature preferred to the combinations of these two features? The 'mobility' and 'stability' of the articulators are rather opaque concepts. They need physiological corroboration before being assigned explanatory value.

Malmberg (1965) offered an articulatory explanation for the preference for open syllables over closed syllables. He claimed that "the difficulty of realizing too complex structures" in the syllable-final position was due to "the successive weakening of the speech muscles involved" (p. 405). Again, too little is known about such physiological constraints to evaluate this hypothesis.

3.3. Hypotheses Based on Featural Contrasts

The third type of explanation for universal sequential constraints utilizes the notion of phonemic difference between constituents of sound sequences. A hypothesis was proposed by Saporta (1955) that Zipf's (1949) principle of 'least effort' would manifest itself in languages' selection of consonant clusters. Clusters that entail 'least effort' on the part of the speaker would be those in which successive phonemes are minimally different. This, however, would necessitate maximal effort on the part of the listener, for he would be burdened with fine perceptual discriminations. From the listener's point of view, 'least effort' would mean that successive sounds are maximally different, but this would in turn require maximal effort on the side of the speaker. It would be advantageous to both the speaker and the listener if clusters consist of neither extremely dissimilar nor extremely similar sounds. In order to test this hypothesis, Saporta proposed a method of quantifying the degree of phonemic difference between any two consonants.[28] Having described English consonants by means of Jakobson, Fant and Halle's (1952) distinctive features, he defined the phonemic difference between each pair of consonants as the number of features by which the two consonants differed. If this hypothesis is correct, the most frequent consonant clusters should exhibit intermediate degrees of phonemic difference. The result showed that this was indeed the case. To take a few examples, ʒ-ʃ, s-z, d-ð, b-v, θ-f and s-θ were among the combinations with low values of phonemic difference. Among those with high values of phonemic difference were ʃ-d, k-z, ʒ-t, ŋ-θ and k-m. Somewhere between these two extremes were s-t, g-b, n-θ, ŋ-k, s-p, and m-p.[29]

Cutting (1975) adopted Saporta's principle of phonemic difference and his method of quantifying it in predicting the frequency of occurrence for clusters with liquids /l/ and /r/ and with glides /j/ and /w/, which were not included in Saporta's material.[30] On the whole the values of phonemic difference are not very large for these clusters. Because of this, Cutting suggested that some modifications be made in Saporta's hypothesis. He hypothesized that frequently occurring consonant clusters should have *maximal* rather than intermediate values of phonemic difference. Further, he objected to associating the measure of phonemic difference with the principle of 'least effort.' He compared the obtained values of phonemic difference with the actual frequencies of occurrence for the clusters /p, t, k, b, d, g/ + /r, l, w, j/ in English, and found that the two were correlated at least for American English corpora. He correctly predicted higher frequencies for /tw, dw, kw/ than for /pw, bw/, for /pl, bl, kl, gl/ than for /tl, dl/, and for /pj, bj, kj, gj/ than for /tj, dj/.

This is a lucid explanation which is derived from well-defined primitives. Its possible shortcoming is that an analysis in terms of distinctive features may not be ideal for examining contrasts between *successive* segments (Bondarko 1969). Distinctive features are defined in terms of presence or absence of certain acoustic attributes, and a phoneme is characterized by a certain set of distinctive features. What is unfortunate for a featural analysis of sound sequences is the fact that a phoneme interacts with surrounding phonemes so extensively that one cannot expect its phonetic realization to be always accompanied by the same acoustic attributes, e.g., /bub/ and /dud/ have highly different /u/'s due to the adjacent labial and dental stops. For some phonemes, allophonic variations are small enough to be represented by the same set of features. Other phonemes, however, allow greater contextual perturbations, great enough, in fact, to alter their feature specifications (Bush 1964, Hultzén 1965a). Such contextual perturbations may possibly 'smear' the featurally-predicted contrast between adjacent phonemes. A good example is the case of /g/'s in the /gj/ and /gw/ clusters. Saporta and Cutting used the same set of features to represent the velar stops in determining their degrees of phonemic difference from /j/ and /w/, and yet it is hardly true that these two /g/'s are physically realized as the same sound. This indicates that their actual acoustic contrast with the following semivowels is not as great as their featural representations suggest.[31] The 'featural-contrast' hypothesis thus ignores the context-dependent variability of phonemes. It assumes that the acoustic attributes associated with distinctive features are 'locked into' individual phonemes in succession, which in physical reality never holds. It seems appropriate, then, to take Cutting's hypothesis of maximal contrast one step further and test it at the level of concrete phonetic realization of phonemes.

CHAPTER FOUR

HYPOTHESIS BASED ON ACOUSTIC/AUDITORY CONTRASTS

In this chapter, a hypothesis is proposed that many phonotactic skewings are best explained with reference to acoustic/auditory factors. Accounts based on this hypothesis are offered for some of the universals presented in Chapter Two and some other common phonological patterns. The validity of the hypothesis is tested specifically for some selected sound sequences. The material and the procedure of the test are explained, and the results are presented. Finally, the implications of the results for phonotactic universals are discussed in further detail.

4.1. Acoustic/Auditory Accounts for Some of the Universal Sequential Constraints

Two acoustic factors are hypothesized to play a role in determining universally favored or disfavored sound sequences. One is the magnitude of acoustic modulation (Ohala 1980). Human sensory systems are more sensitive to well-modulated signals than to steady-state signals. The magnitude of acoustic modulation in a given sound sequence should be directly related to its perceptual saliency. Acoustically well-modulated phoneme sequences should be, therefore, more viable in languages. This in principle agrees with Cutting's hypothesis in upholding the principle of maximal contrast within a sound sequence.

The current hypothesis, however, assumes phonetic contrast instead of gross phonemic differences. The principle of maximal contrast has already been found to affect the configuration of the phonemic vowel space in languages (Liljencrants and Lindblom 1972). Lindblom (1980) speculated that this principle might hold not only paradigmatically but also sequentially, suggesting the possibility of its determining the languages' inventories of diphthongs.

The second factor is the degree of acoustic difference among sound sequences. Regardless of the magnitude of acoustic modulation, if a given sound sequence possesses acoustic characteristics which are very close to those of another sound sequence, then these two sequences should be mutually confusable and susceptible to merger. Acoustic similarities as a cause of sound change have been discussed by many researchers (Passy 1890, Sweet 1892, Durand 1956, Jonasson 1971, Ohala 1974, 1975, 1978, 1979b, 1980, Javkin 1977, Ohala and Lorentz 1977, Ohala, Riordan, and Kawasaki 1978, Wright 1980, Ohala and Amador 1981). Therefore, phonetic contrast both *within* a sequence and *among* different sequences should determine what sound sequences would prevail in languages.

Some of the universal sequential constraints discussed in Chapter Two are predicted solely by the importance of acoustic modulation. Consonants and vowels form the two most fundamental classes of speech sounds. The distinction between these two classes is the first sound opposition to be learned by the child and the last to be lost in aphasic speech (Jakobson 1968). It is hardly a coincidence that these two classes, when strung together, create maximal acoustic modulation. Stevens (1971, 1975, 1979, 1980) pointed out that an acoustic representation of connected speech consisted of time intervals with abrupt changes in multiple acoustic parameters and other intervals lacking such characteristics, and that the former marked the presence of consonants and further differentiated the types of consonants. Rapid acoustic change may take the form of an abrupt rise in sound intensity in all frequency regions. This property is observed at the release of segments classified as [-continuant]. The rise in amplitude occurs within just a few milliseconds. Acoustic change may also be manifested as a rapid (10 to 30 msec.) variation in the spectrum. This property characterizes sounds labelled as [+consonantal]. These two attributes do not necessarily accompany each other. The release of fricatives, for example, shows a rapid spectral change, but not an abrupt change in amplitude. Both abrupt amplitude rise and rapid spectral change are observed at the release of stops, affricates, and nasals. Such attributes are most apparent when these consonants occur immediately before a stressed vowel. On the basis of psychoacoustic studies, Stevens hypothesized that the auditory system focused on these rapid acoustic changes. He further hypothesized that the response of the auditory system to rapid spectral changes was qualitatively different from its response to signals with an abrupt onset but no spectral change or with slowly-changing spectra.[32] He inferred that perception gave priority to sounds with rapid spectral changes, and expected this to be reflected in languages' selection of consonant inventories and child language acquisition.

Languages indeed exploit this acoustic/auditory factor to the fullest. Consonant clusters and vowel clusters are avoided, for acoustic modulation within such sequences is minimal. Sequences of consonants in the same manner of articulation, e.g., stop + stop, fricative + fricative, sibilant clusters, liquid clusters, etc., are disfavored for the same reason. The tendency of languages to maximize the acoustic modulation in the speech signal is evident from the observation that simple alternation between a consonant and a vowel is often the most productive word structure in the sense of 'productive' given above. Stevens' prediction of languages' preference for consonants with rapid spectral changes is borne out by the patterns of consonant proliferation (Ohala in press). To be more precise, an abrupt onset as well as a rapid spectral change seems to characterize the favored consonants. The more consonants a language has, the greater is the ratio of obstruents to non-obstruents (Hockett 1955). Within the class of obstruents, a language generally has more stops than fricatives, affricates, or fricatives and affricates combined (Gimpel 1980). It was mentioned in Section 2.5 that clusters of a nasal and a liquid are not as favored as clusters of an obstruent and a liquid. This is explained in a parallel fashion. Obstruent + liquid clusters would yield greater acoustic modulation than nasal + liquid clusters if for no other reason, because the amplitude modulation would be greater. Furthermore, Stevens' finding that the invariant acoustic cues to different places of articulation contained in the transient interval of about 30 msec. are most distinct in consonant + stressed vowel sequences (Stevens 1971, 1975, 1979, 1980, Stevens and Blumstein 1978, Blumstein and Stevens 1979, 1980) may partly account for the universal preference for CV syllables and initial clusters as opposed to VC syllables and final clusters.

There is yet another phonotactic pattern which is likely to be acoustically and auditorily motivated. It is the universal scarcity of syllable-initial [ŋ]. Front-articulated nasals such as [m] and [n] readily occur both syllable-initially and syllable-finally, but back-articulated nasals such as [ɳ], [ɲ], and [ŋ] are severely restricted in their occurrence. Examples of impermissible initial nasals are given in (37). Note that these nasals do occur in other environments in these languages.

(37)	* ɲ	Basque
	* ɳ	Maung
	* ŋ	Bengali, Burushaski, Carib, English, Garo, German, Iraqw, Kharia, Ostyak
	* ŋ̊	Iai
	* ɲ, ŋ	Breton
	* ɳ, ɲ, ŋ	Punjabi

/ŋ/ is rare initially in Gbeya. /n/ and /ŋ/ are rare initially in Ket. Nasals as a class are characterized as having an abrupt onset of spectral energy and a rapid spectral change at the release. Within the class, however, different nasals are known to show different spectral characteristics during the closure intervals. The frequency of the antiresonance is inversely related to the length of the side cavity, i.e., low in /m/ and high in /ŋ/ (House 1957, Fujimura 1962). The antiresonance in /ŋ/ falls in the greatly attenuated high frequency regions of the spectrum, and it is suspected to be perceptually less evident. The lack of an apparent antiresonance makes /ŋ/ less like a nasal and more like a nasalized vowel (Ohala 1975). It follows that the sequence of /ŋ/ and a vowel is not as acoustically well-modulated as other consonant + vowel sequences.[33]

I have shown that some of the universal sequential constraints discussed earlier are predicted on the basis of acoustic properties of sound sequences, particularly their extent of acoustic modulation. The aim of the current study is to determine whether this factor together with the factor of inter-sequence acoustic difference can predict the other sequential restrictions presented in Chapter Two.

4.2. Scope of the Study

By positing the two acoustic/auditory determinants, 1) the magnitude of acoustic modulation within a given sequence and 2) the degree of acoustic difference between any two sequences, the present study attempts to explore possible motivations for universal constraints on the following sound sequences in particular.

Sequences of a stop and a liquid

In Section 2.5, we have seen that the lateral /l/ is disfavored after a dental stop. Is this because of the lack of acoustic modulation (Ohala 1980)? Or is the other factor involved also? Why does the same constraint not apply to sequences of a stop and "r"? What explains the absence of strong constraints on stop + "r" clusters?

Sequences of a stop and a glide

Do the acoustic/auditory factors correctly predict the favoring of /dw, gw, bj/ and the disfavoring of /bw, dj/ (Section 2.6)? Moreover, do they successfully explain common changes of /dw, gw/ to /b/ and of /bj/ to /d/ (Section 2.9)?

Sequences of a consonant and a vowel

Does the hypothesis account for the observed disfavoring of sequences of a labial or velar stop and a rounded vowel and of a dental or velar stop and a front vowel (Section 2.7)? Does it also account for the observation that the glides /w/ and /j/, and labialization and palatalization as secondary articulations are restricted to or are commonest in the vicinity of low vowels in some languages (Section 2.7)? If it does, we may even be able to ask which acoustic parameter is the most effective in producing the acoustic modulation which the human ear is sensitive to.

CV and VC sequences

Is there any acoustic attribute other than the rapid spectral change at the consonantal release which predicts the preference for CV as opposed to VC syllables (Section 2.3)?

4.3. Material and Analysis Method

The material analyzed consisted of monosyllables of the CSV, CV, or VC structure where C(=consonant), S(=sonorant), and V(=vowel) were selected from the following segments.

C = b, d, g

S = l, r, w, j

V = i, ɛ, a, u

The CSV and CV monosyllables were embedded in a frame 'Say ______ twice' and the VC monosyllables were embedded in a frame 'Repeat ______ after.'[34] These sentences pronounced six to nine times by an adult male speaker of American English were recorded onto a magnetic tape by a high-quality tape recorder in a sound-treated room. Those parts of the recorded sentences that contained the monosyllables under investigation were then digitized at a 10 KHz sampling rate and stored on a computer disk. With the aid of a waveform editing program, the monosyllables were marked at the following segment boundaries: in the case of CSV and CV syllables, at 130 msec. before the release of the stop, at the release of the stop, and at the end of the vowel, and in the case of VC syllables, at the beginning of the vowel and at the implosion and the release of the stop.[35]

There are many acoustic parameters which one could use to measure the magnitude of acoustic modulation within a sequence and the degree of acoustic difference between sequences. They would include formant frequency, relative formant amplitude, over-all spectral energy, and periodicity. In the present study, the frequencies of the first three formants were chosen for analysis, since they were presumed to be the most influential parameters. The formant trajectories were obtained for the entire syllables including the stop closures by linear prediction using the autocorrelation method (Markel 1971). The number of poles was 14. The analysis was done with a Hamming window of 25 msec. in 10 msec. steps. The resulting formant trajectories were then manually smoothed on the screen of a computer terminal. When any frequency value on a formant trajectory appeared unreasonably deviant, the trajectory was smoothed by linearly interpolating the adjacent values. The formant trajectories sometimes had to be extrapolated at the consonantal release. Then an average of the various parameters was obtained for each syllable type after time-warping was performed on some tokens of CSV syllables (since the durations of their postconsonantal sonorants varied). Table 1 lists the number of tokens averaged for each syllable type.

The standard Euclidean distance was used to measure the magnitude of formant frequency change within a given syllable and the difference between two different syllables (Lindblom 1975). The magnitude of formant frequency change, henceforth referred to as 'salience,' was computed by the formula:

$$\text{Salience}=\sum_i \sqrt{[F_1(t_{i+1})-F_1(t_i)]^2+[F_2(t_{i+1})-F_2(t_i)]^2+[F_3(t_{i+1})-F_3(t_i)]^2}$$

where t_i represents each temporal point where formant frequencies were measured. $F_1(t_i)$, $F_2(t_i)$, and $F_3(t_i)$ represent frequencies of F_1, F_2, and F_3 at the i-th temporal point, respectively. Thus, the salience in a given syllable was approximated by the sum of the distance in frequency between all pairs of successive temporal points.

The degree of difference, henceforth referred to as 'dissimilarity,' between two syllables was given by the formula:

$$\text{Dissimilarity}=\sum_i \sqrt{[F_{1a}(t_i)-F_{1b}(t_i)]^2+[F_{2a}(t_i)-F_{2b}(t_i)]^2+[F_{3a}(t_i)-F_{3b}(t_i)]^2}$$

Here, the subscripts a and b represent two different syllables. The dissimilarity between two syllables was thus approximated by the sum of the distance between them in frequency at each corresponding temporal point.

In both formulas, distances were summed over the duration of 250 msec. from the stop release in the case of CSV syllables, over the

Table 1

Number of Tokens Averaged for
Each Monosyllable

ClV		CrV		CwV		CjV		CV		VC	
bli	6	bri	8	bwi	6	bji	7	bi	6	ib	6
blɛ	6	brɛ	6	bwɛ	7	bjɛ	6	bɛ	6	ɛb	6
bla	6	bra	6	bwa	6	bja	6	ba	6	ab	6
blu	6	bru	6	bwu	7	bju	6	bu	6	ub	6
dli	6	dri	6	dwi	8	dji	6	di	6	id	6
dlɛ	6	drɛ	6	dwɛ	6	djɛ	6	dɛ	6	ɛd	6
dla	6	dra	6	dwa	6	dja	6	da	6	ad	6
dlu	6	dru	5	dwu	9	dju	6	du	6	ud	6
gli	8	gri	6	gwi	8	gji	6	gi	6	ig	6
glɛ	6	grɛ	6	gwɛ	6	gjɛ	6	gɛ	6	ɛg	6
gla	6	gra	8	gwa	6	gja	6	ga	6	ag	6
glu	6	gru	6	gwu	7	gju	5	gu	6	ug	6

duration of 130 msec. from the stop release in the case of CV syllables, and over the duration of 130 msec. before the stop implosion in the case of VC syllables. These durations included 75% or more of the vowels' total durations.

In computation using the above formulas, frequency variations in higher formants, especially in the third formant, are weighted more heavily than frequency variations in a low formant. The resulting values of salience and dissimilarity will then be largely determined by the higher formants. We know, however, that the perception of frequency is hardly linear, and it would be desirable if the computed values of salience and dissimilarity reflected this psychoacoustic reality. For this reason, formant frequencies were converted to corresponding Mel values using the following formula (Fant 1973):

$$y = \frac{1000}{\log 2} \log \left(1 + \frac{f}{1000}\right)$$

where y is the Mel value for f, a frequency in Hz. The obtained Mel values were then used to compute the 'salience' and 'dissimilarity' as just described.

4.4. Results

This section presents the computed 'salience,' i.e., a value representing the magnitude of spectral change within a syllable, and the computed 'dissimilarity,' i.e., a value representing the degree of spectral difference between a pair of syllables. As there is a great deal of data, I will intermix presentation of the results and a preliminary discussion of them. A general discussion is given in Section 4.5.

4.4.1. Clusters of a stop and a liquid

The average formant trajectories in the syllables with stop + [l] clusters are shown in Figures 1, 2, and 3. The average formant trajectories in the syllables with stop + [r] clusters are shown in Figures 4, 5, and 6. In these and other computer-drawn figures of average formant trajectories, all phonetic symbols appear capitalized except for /E/ which stands for the IPA [ε]. The frequency scale is linear. Zero msec. on the abscissa corresponds to the release of the initial stop.

Stop + liquid: 'salience'

Table 2 shows the 'salience' computed with linear frequency values for the syllables with stop + [l] clusters.[36] Columns correspond to the vocalic contexts, while rows correspond to the initial clusters. The data are graphically represented in Figure 7.

The results indicate that stop + [l] clusters create spectrally better-modulated sound sequences when combined with front vowels. Differences in 'salience' values between the vocalic contexts [i] and [u] are ≈ 600 Hz for [bl], 570 Hz for [dl], and 830 Hz for [gl].[37] Among [bl], [dl], and [gl] clusters, [bl] seems to yield the least spectral change. The values for the syllables with [bl] are smaller by ≈ 220 to ≈ 390 Hz than those for the syllables with [dl], and by 180 to ≈ 400 Hz than those for the syllables with [gl]. Figure 8 shows the 'salience' computed with Mel values for the same syllables. Similar tendencies are evident.

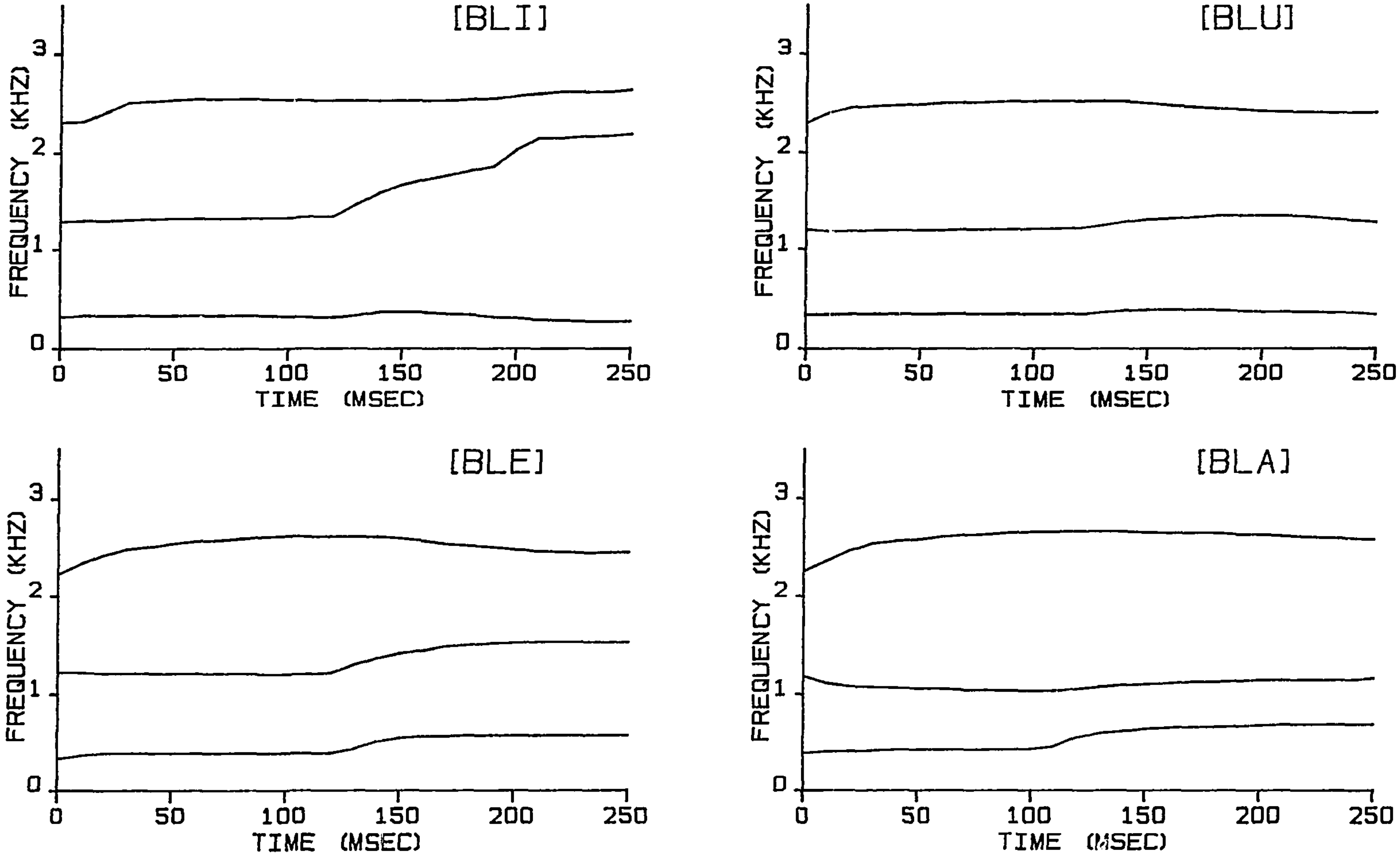

Figure 1: Average Formant Trajectories in [bl] + Vowel Sequences.
Time is measured from stop release.

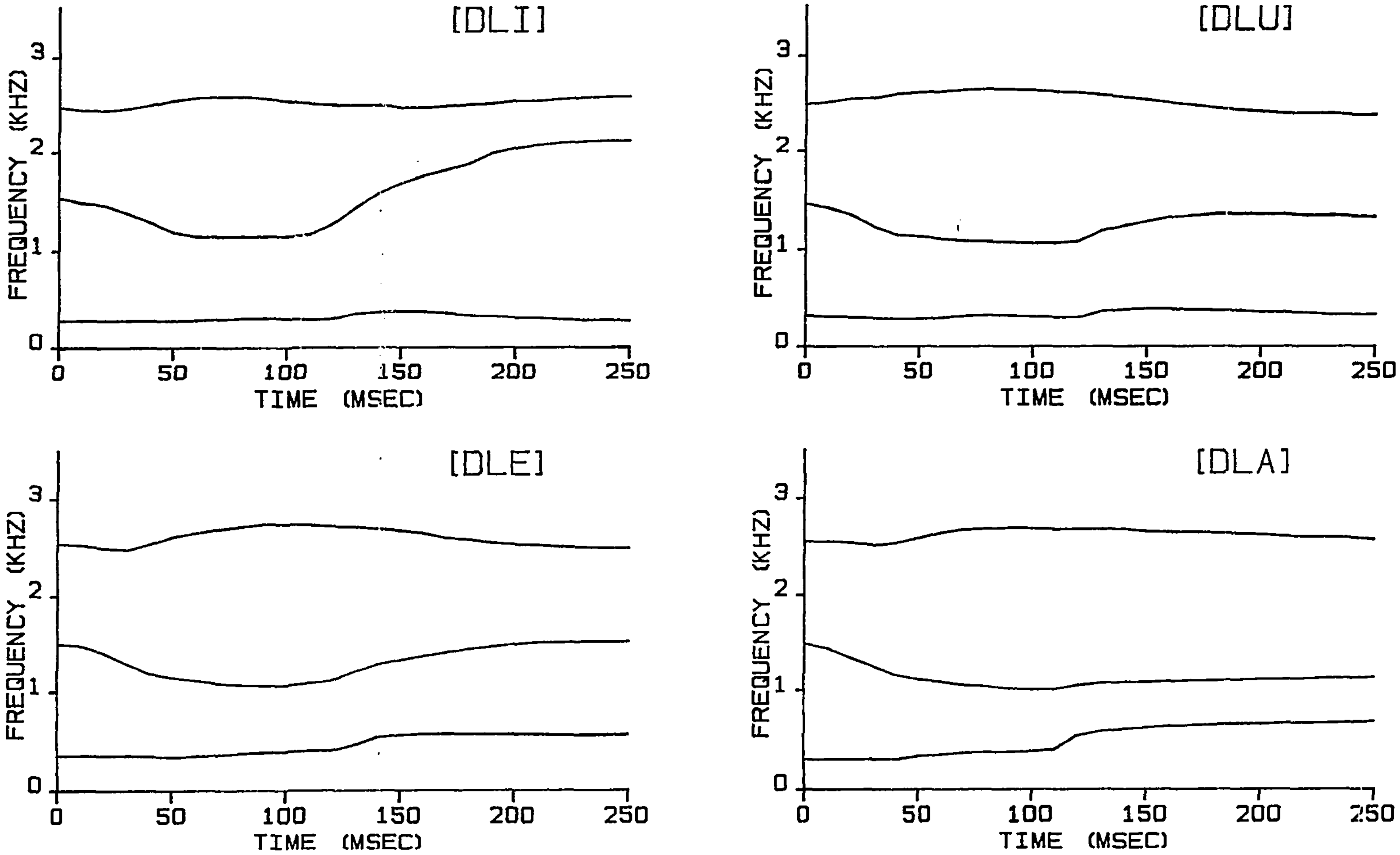

Figure 2: Average Formant Trajectories in [dl] + Vowel Sequences.
Time is measured from stop release.

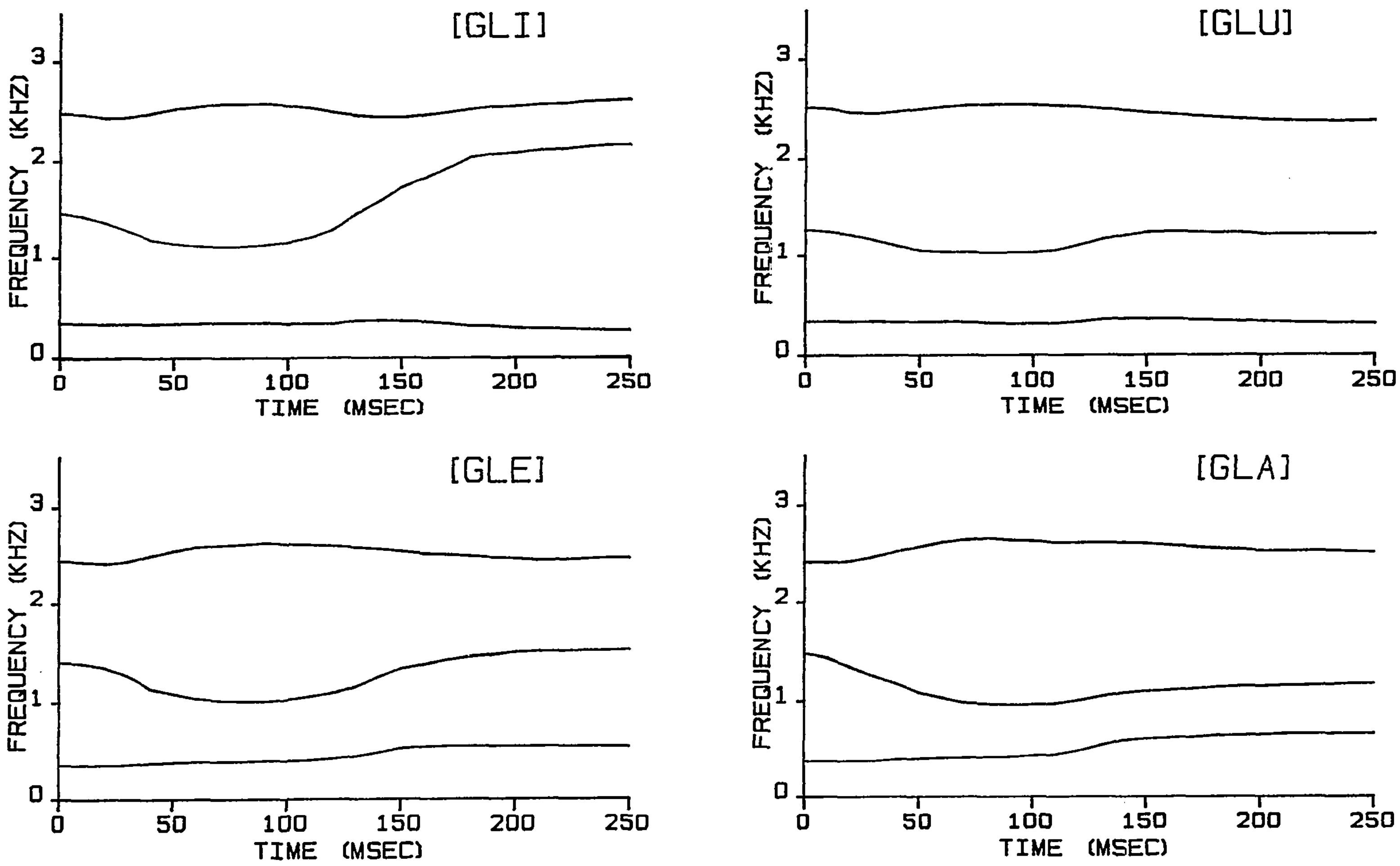

Figure 3: Average Formant Trajectories in [gl] + Vowel Sequences. Time is measured from stop release.

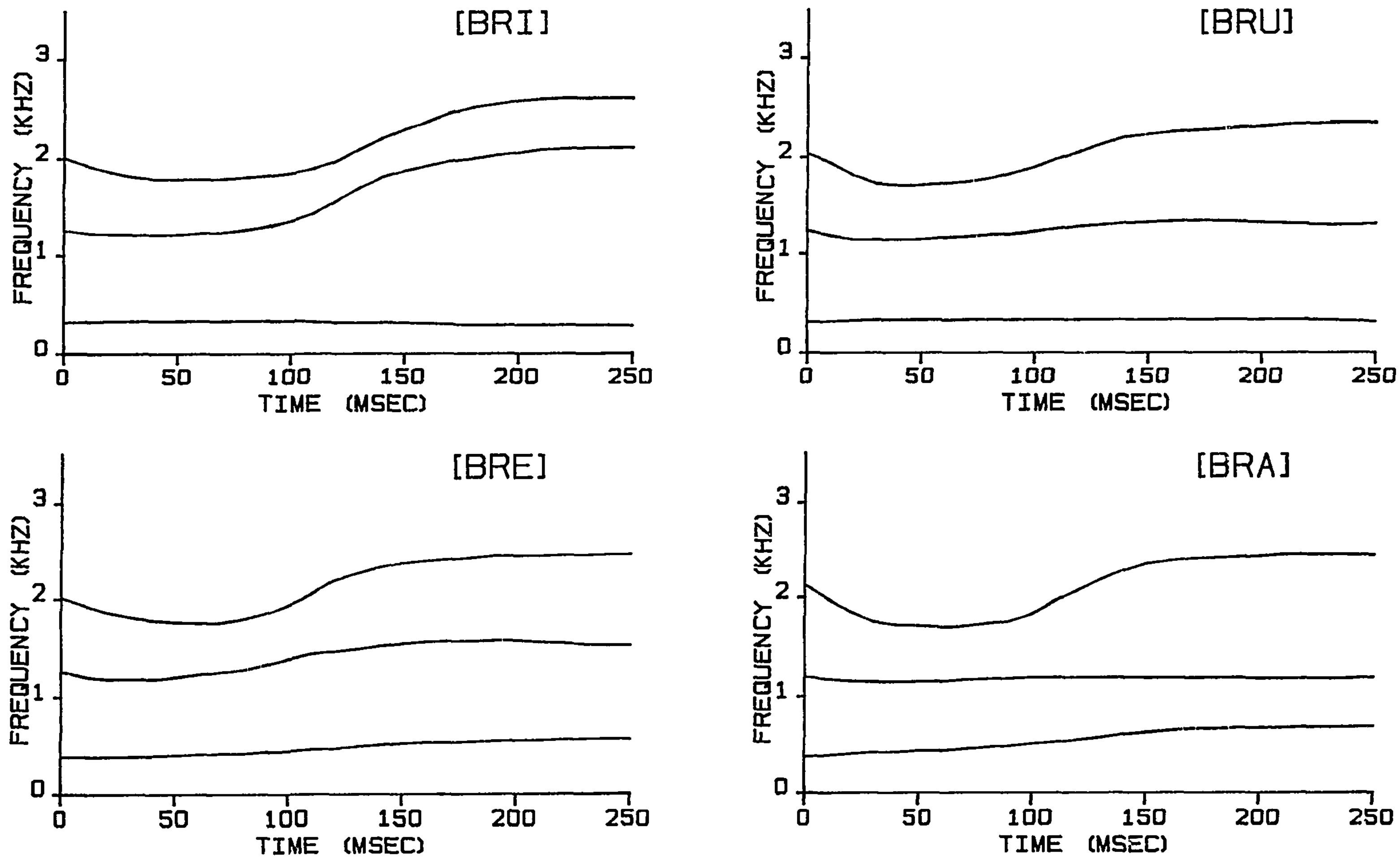

Figure 4: Average Formant Trajectories in [br] + Vowel Sequences.
Time is measured from stop release.

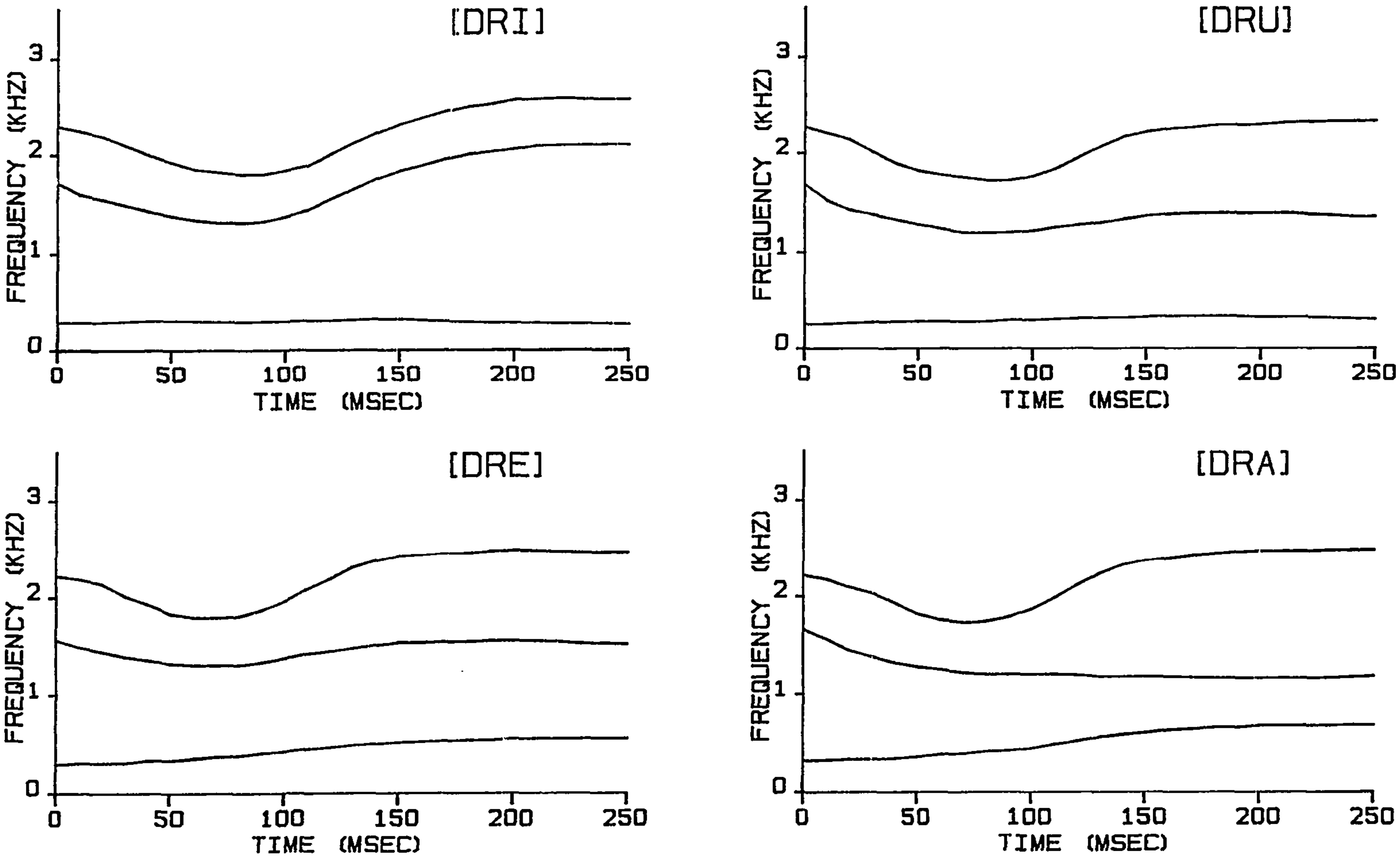

Figure 5: Average Formant Trajectories in [dr] + Vowel Sequences.
Time is measured from stop release.

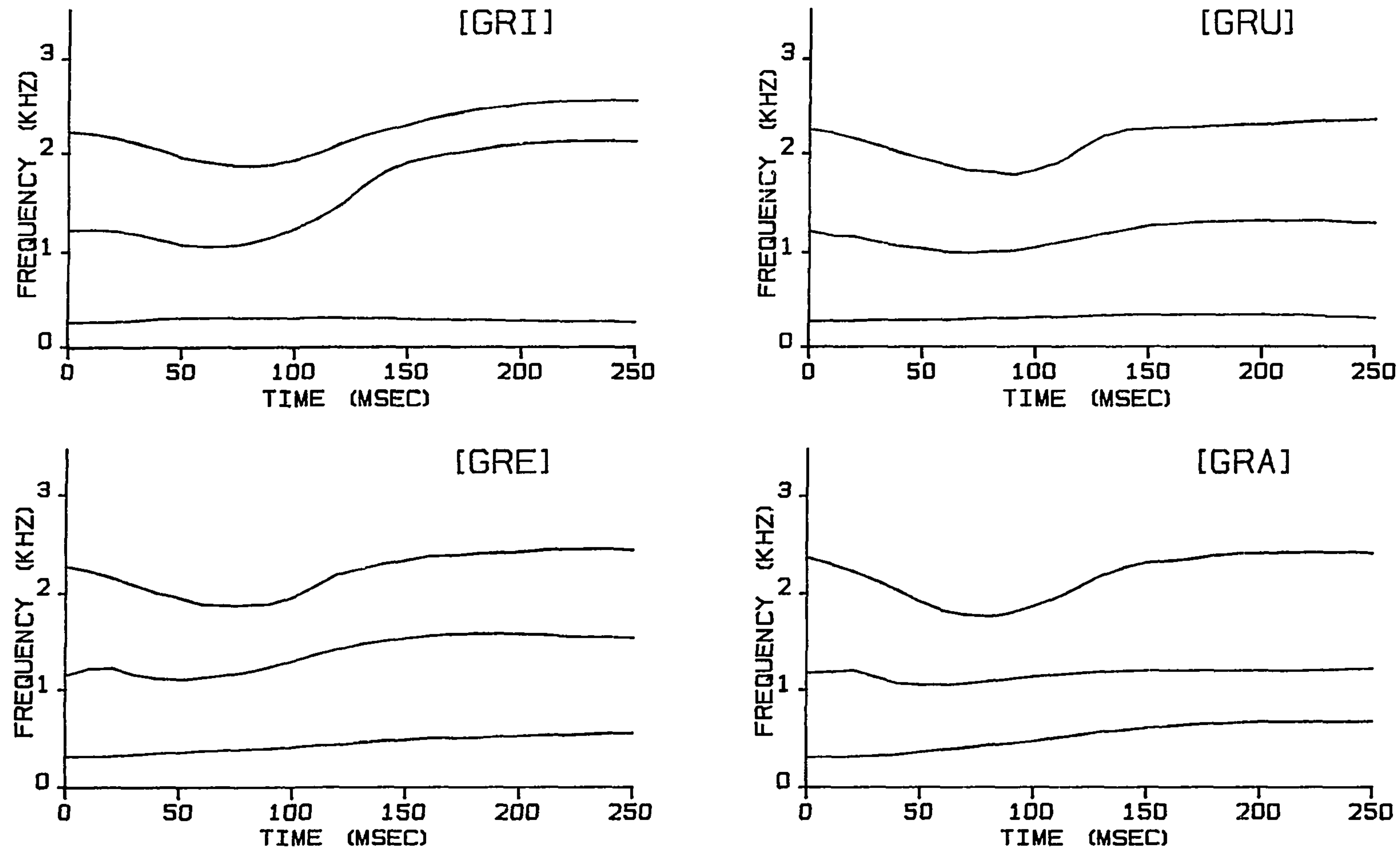

Figure 6: Average Formant Trajectories in [gr] + Vowel Sequences.
Time is measured from stop release.

Table 2

'Salience' in Hz for Stop + [l] Clusters
in Four Vocalic Contexts

Initial Cluster	Vocalic Contexts [i]	[ɛ]	[a]	[u]
[bl]	1155	879	776	552
[dl]	1518	1227	998	948
[gl]	1562	1097	977	732

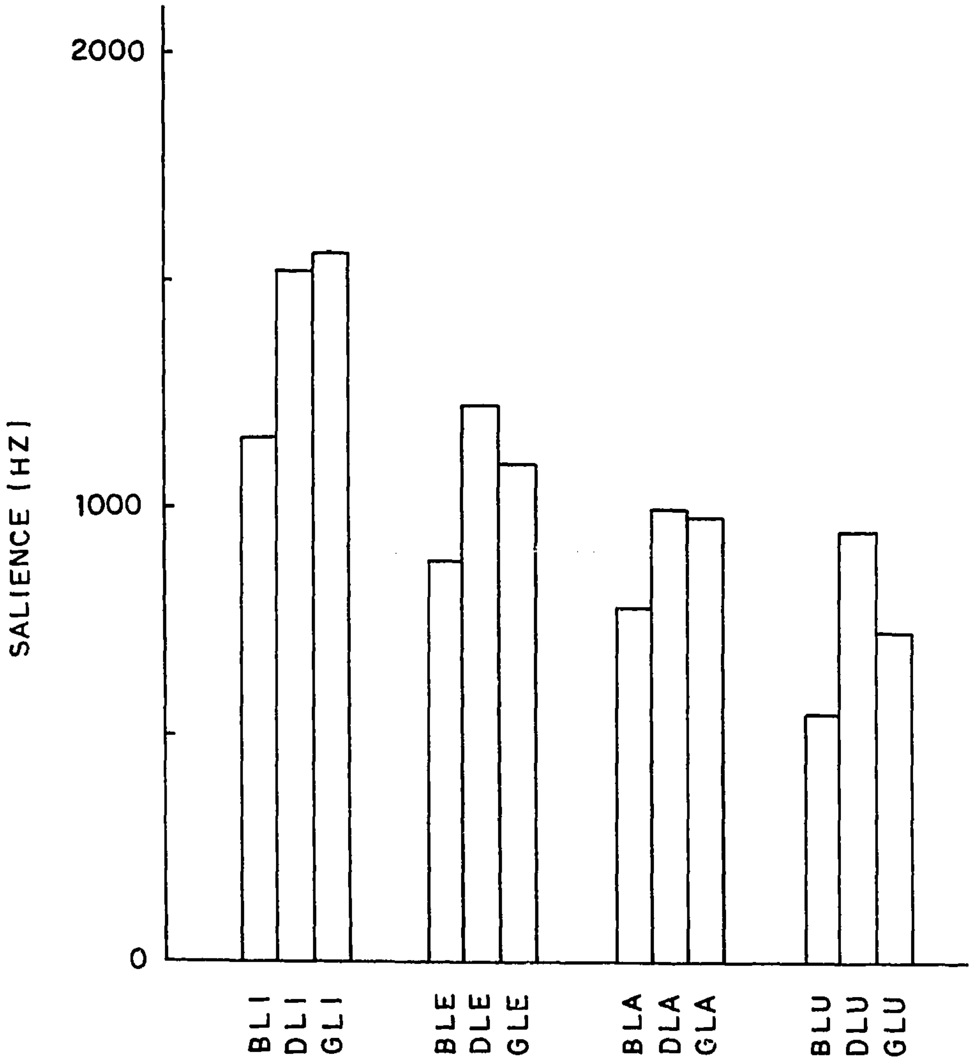

Figure 7: 'Salience' in Hz for Stop + [l] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

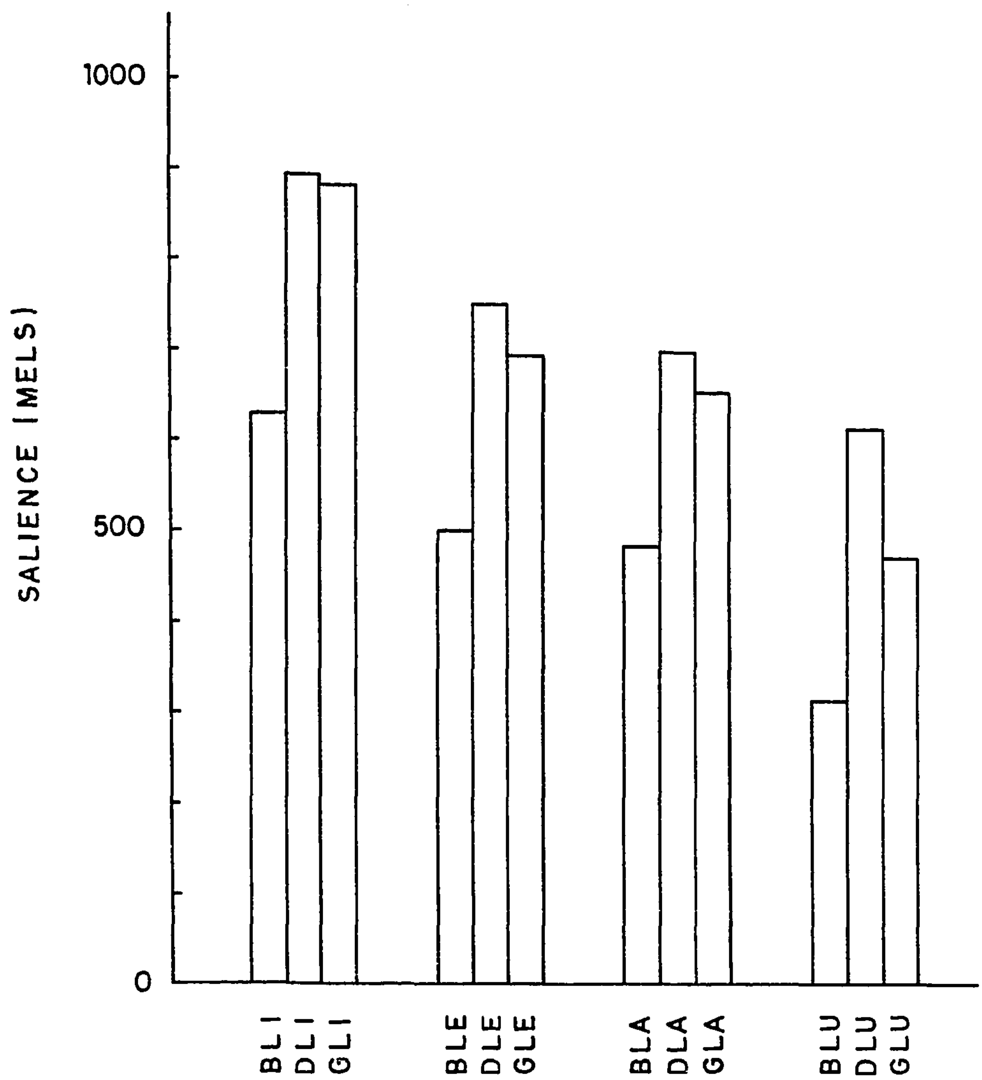

Figure 8: 'Salience' in Mels for Stop + [l] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

Table 3 shows the 'salience' in Hz for the syllables with stop + [r] clusters. The data are also plotted in Figure 9.

The stop + [r] clusters show the greatest spectral change when followed by the front vowel [i]. They uniformly yield greater spectral change when followed by the low vowel [a] than when followed by the mid vowel [ɛ]. The least spectral change is observed when the clusters are followed by [u]. Differences in 'salience' between the vocalic contexts [i] and [u] are ≈ 440 Hz for [br], ≈ 320 Hz for [dr], and ≈ 430 Hz for [gr]. In all vocalic contexts, the [dr] cluster shows the greatest spectral change, and the [br] cluster the least. Differences in 'salience' values between these two clusters range from 144 Hz to 420 Hz. The 'salience' in Mels is shown in Figure 10. Similar patterns seem to hold except that the differences in 'salience' between [dr] syllables and [gr] syllables are not very great.

A comparison between the data in Tables 2 and 3 (and between the data in Figures 8 and 10) reveals that the magnitude of spectral change is generally greater in the syllables with stop + [r] clusters than in the syllables with stop + [l] clusters, by about 230 Hz when followed by a front vowel. In the context of a low or back vowel, the difference in the amount of formant frequency change between Cr and Cl clusters is of the order of 550 Hz.

<u>Stop + liquid: 'dissimilarity'</u>

Table 4 shows the values of 'dissimilarity' in Hz for pairs of stop + [l] clusters. Columns correspond to the vocalic contexts, while rows correspond to the pairs of clusters. Only the syllables with the same vowel were compared. The data are also given in Figure 11. The

Table 3

'Salience' in Hz for Stop + [r] Clusters
in Four Vocalic Contexts

Initial Cluster	Vocalic Contexts			
	[i]	[ε]	[a]	[u]
[br]	1500	1202	1299	1063
[dr]	1805	1346	1518	1483
[gr]	1678	1328	1420	1244

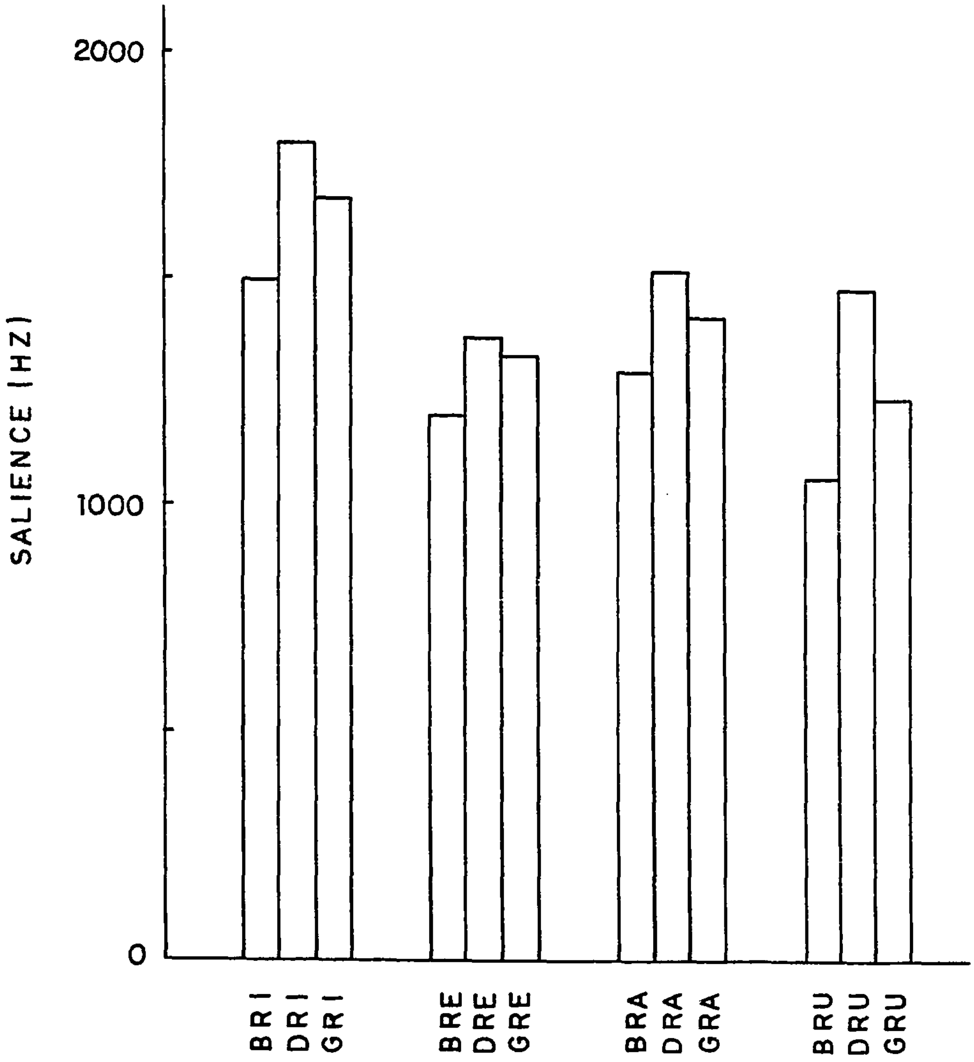

Figure 9: 'Salience' in Hz for Stop + [r] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

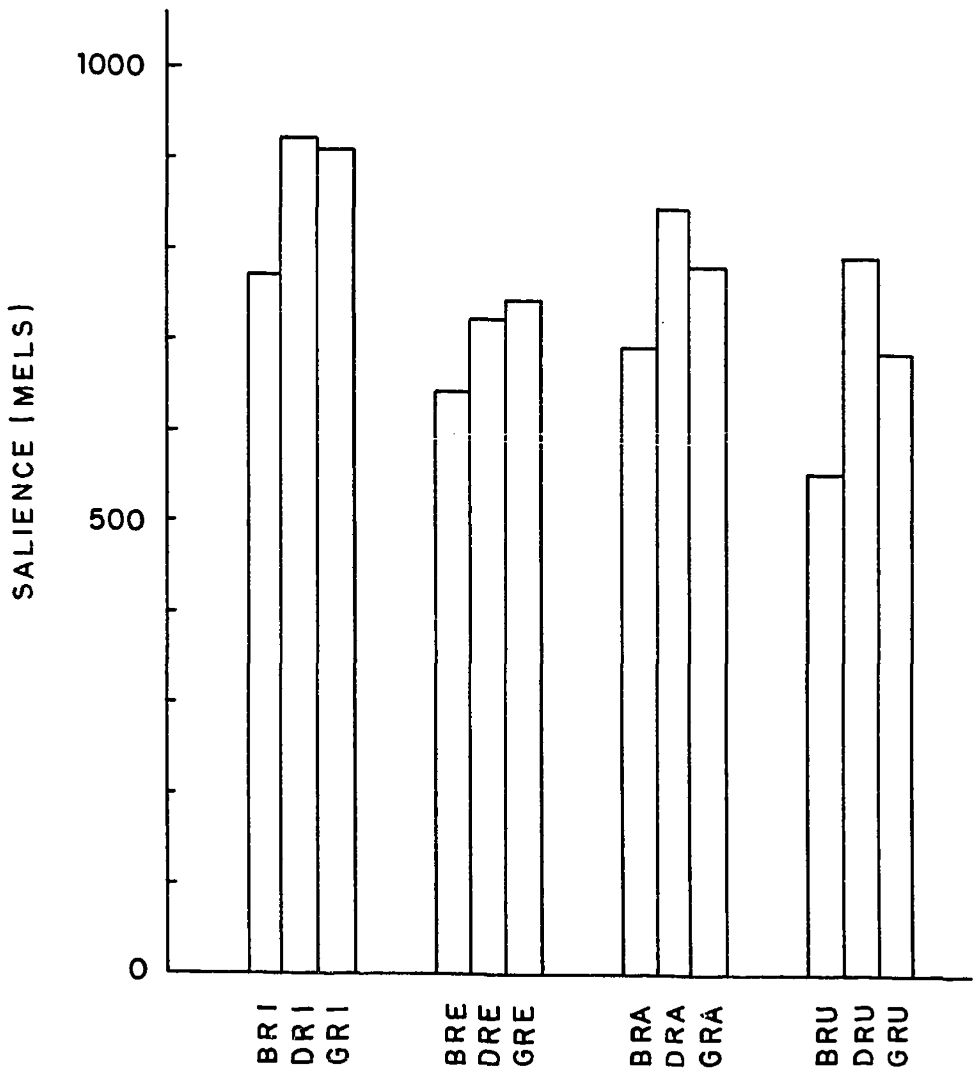

Figure 10: 'Salience' in Mels for Stop + [r] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

Table 4

'Dissimilarity' in Hz between Stop + [l] Clusters in Four Vocalic Contexts

Pair of Initial Clusters Compared	Vocalic Contexts			
	[i]	[ε]	[a]	[u]
[bl]-[dl]	3038	3222	2491	2997
[dl]-[gl]	1826	2049	2094	3169
[bl]-[gl]	3323	2780	2750	3163

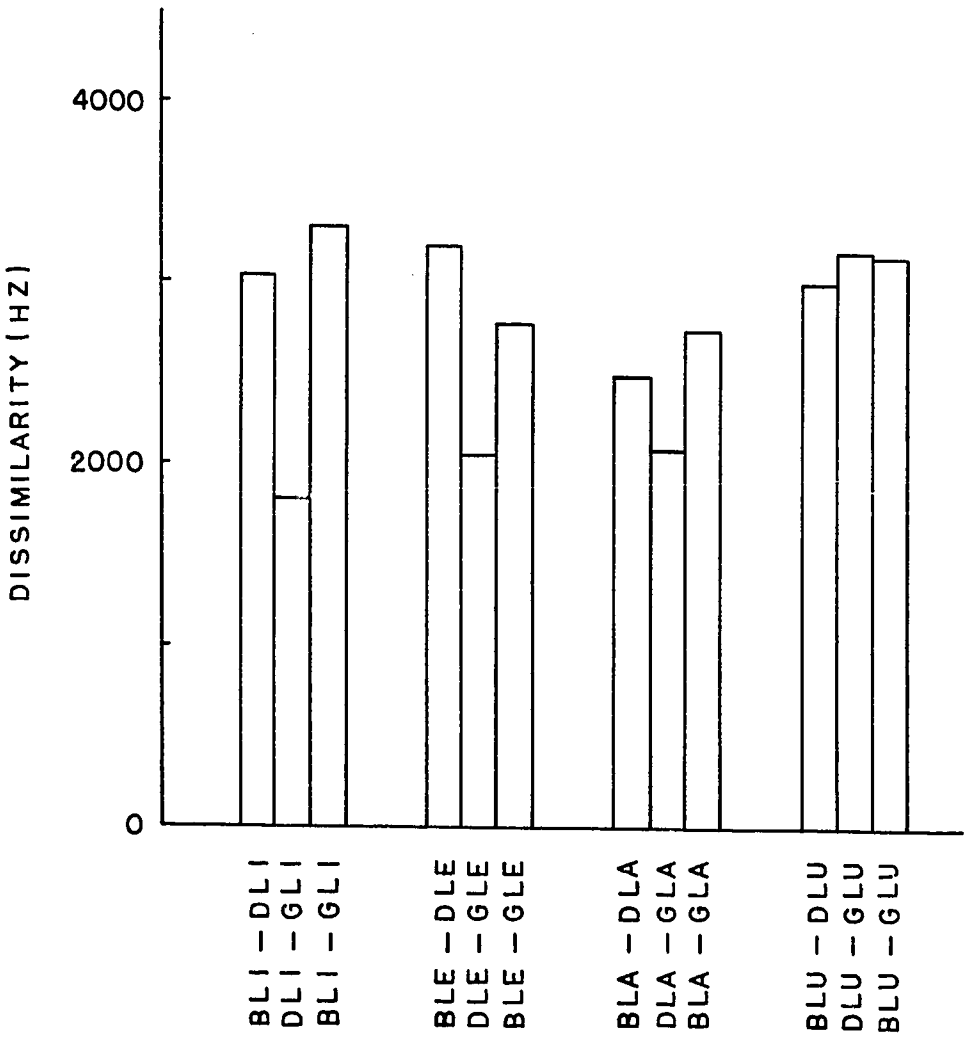

Figure 11: 'Dissimilarity' in Hz between Stop + [l] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

'dissimilarity' in Mels is given in Figure 12. Both figures show that [dl] and [gl] are closer to each other than either of them is to [bl], at least in the context of [i], [ɛ], and [a].

Table 5 shows the values of 'dissimilarity' in Hz for pairs of stop + [r] clusters. The same data are plotted in Figure 13. The 'dissimilarity' in Mels is given in Figure 14. A pattern observed here is opposite to the one for stop + [l] clusters. [dr] and [gr] are spectrally more different than either of them is to [br] in all the vocalic contexts. Moreover, Figures 11 and 13 reveal that the degrees of spectral difference are in general greater among stop + [r] clusters than among stop + [l] clusters.

In order to examine in more detail the effect of stops upon initial formant frequencies, average formant trajectories were obtained for each stop + liquid cluster. All vowel contexts were pooled. The trajectories in the initial 30 msec. of stop + [l] clusters and of stop + [r] clusters are shown in Figures 15 and 16, respectively. Table 6 shows the values of 'dissimilarity' for pairs of stop + [l] clusters and for pairs of stop + [r] clusters during this 30 msec. interval. The values in parenthesis are in Mels.

Spectral differences among the stop + [r] clusters are over 1200 Hz, while spectral differences among the stop + [l] clusters are much less. The difference between [dl] and [gl] seems especially small, i.e., 400 Hz. This result suggests that stops are not well-differentiated in the context of [l]. The three places of articulation of the initial stops are better contrasted in the clusters with [r].

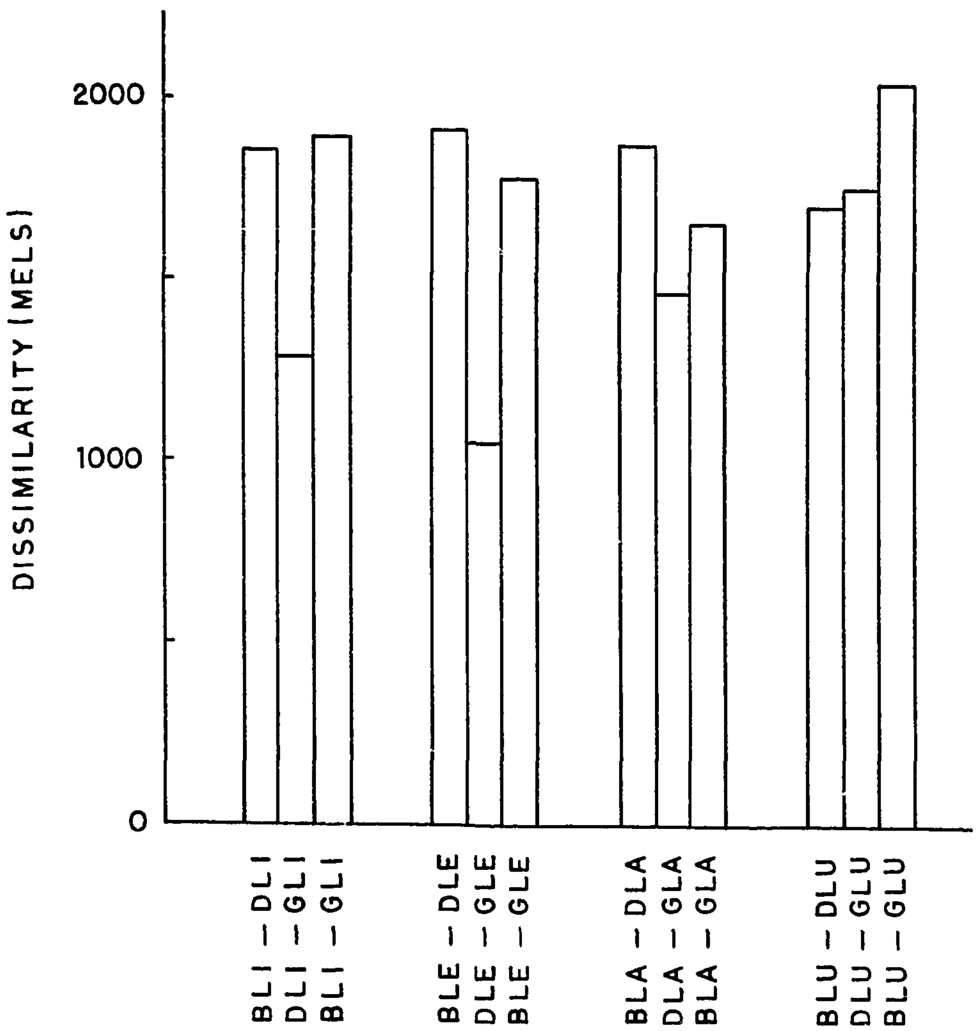

Figure 12: 'Dissimilarity' in Mels between Stop + [l] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

Table 5

'Dissimilarity' in Hz between Stop + [r] Clusters
in Four Vocalic Contexts

Pair of Initial Clusters Compared	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
[br]-[dr]	3162	2616	3082	3723
[dr]-[gr]	4194	3286	3620	4302
[br]-[gr]	3484	3014	3402	3566

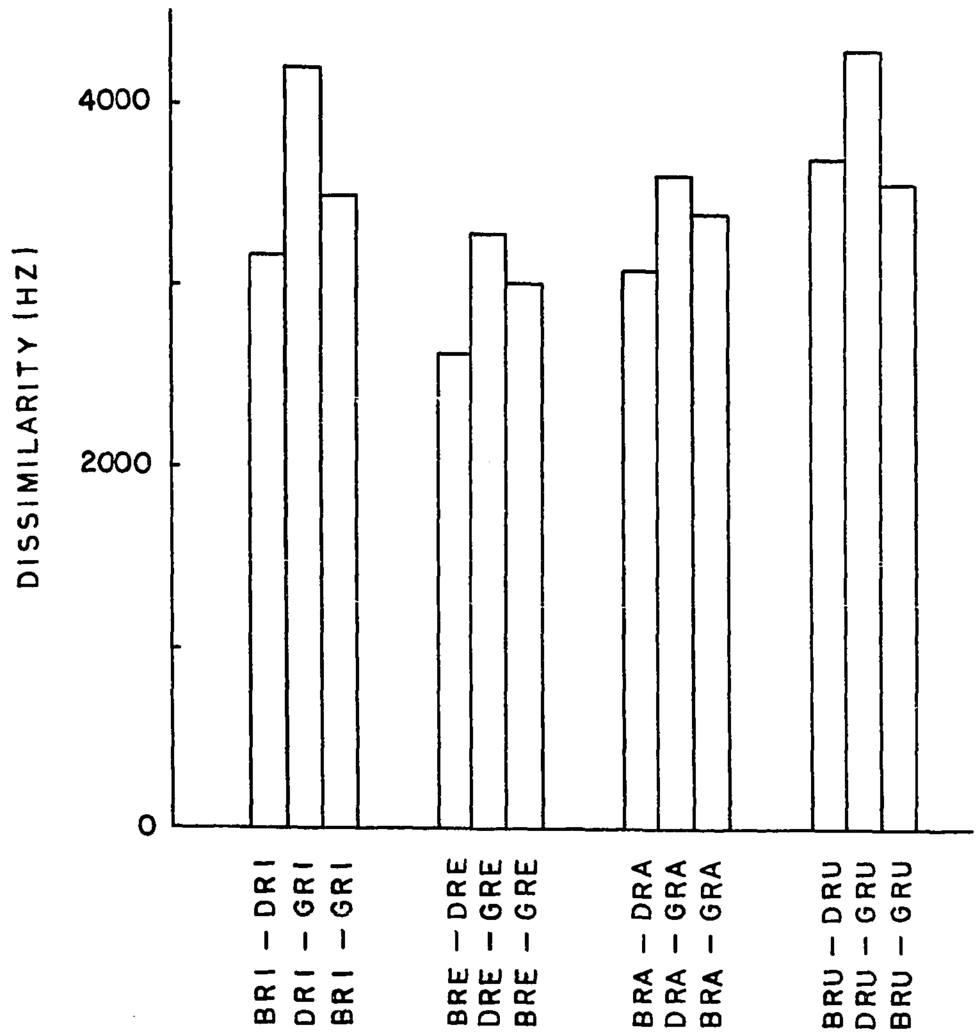

Figure 13: 'Dissimilarity' in Hz between Stop + [r] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

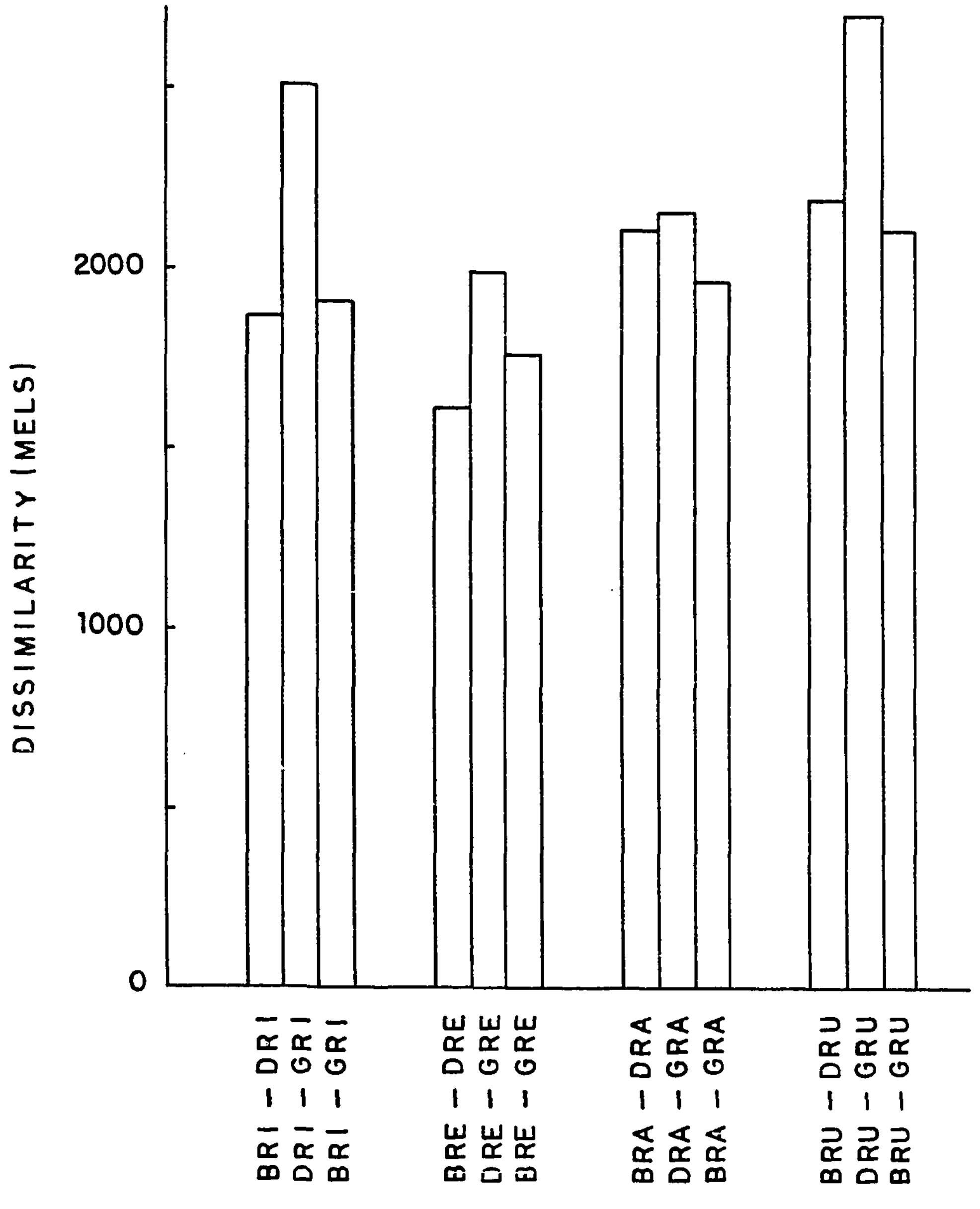

Figure 14: 'Dissimilarity' in Mels between Stop + [r] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

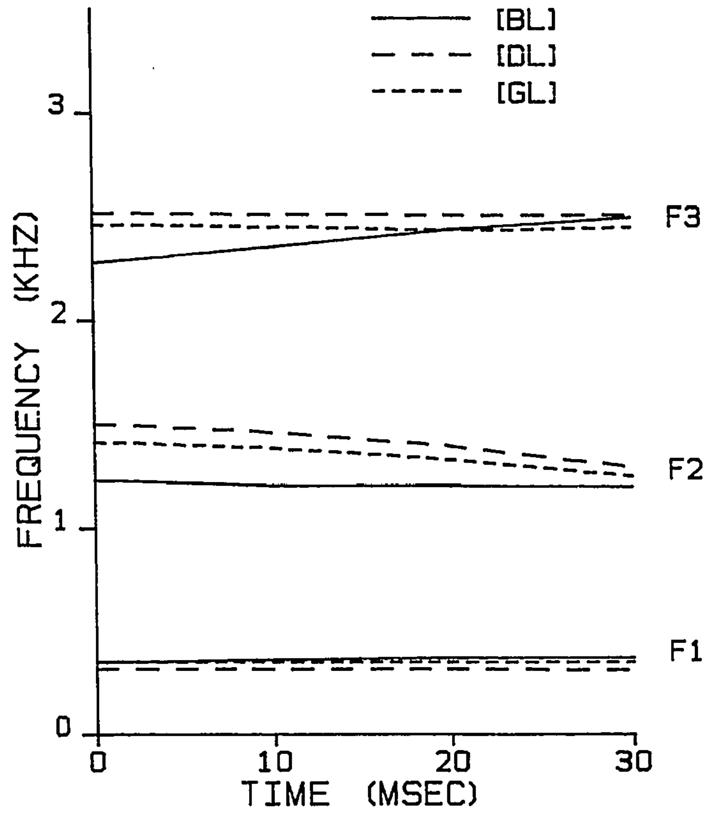

Figure 15: Average Formant Trajectories in Stop + [l] Clusters. Initial 30 msec. after stop release are shown. All vowels are pooled.

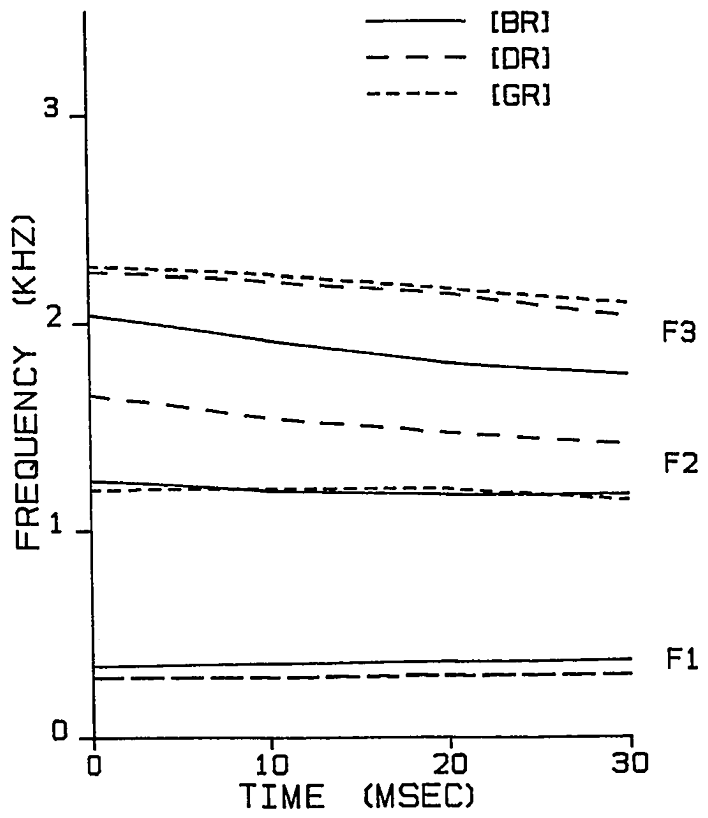

Figure 16: Average Formant Trajectories in Stop + [r] Clusters. Initial 30 msec. after stop release are shown. All vowels are pooled.

Table 6

'Dissimilarity' in Hz and in Mels between Stop + [l] Clusters and between Stop + [r] Clusters in Initial 30 Msec.

Pair of Clusters Compared	Hz	(Mels)
[bl]-[dl]	985	(605)
[dl]-[gl]	400	(259)
[bl]-[gl]	661	(385)
[br]-[dr]	1756	(1010)
[dr]-[gr]	1342	(819)
[br]-[gr]	1290	(670)

4.4.2. Clusters of a stop and a glide

Stop + /w/: 'salience'

The average formant trajectories in the syllables with stop + [w] clusters are shown in a linear scale in Figures 17, 18, and 19. Table 7 shows the values of 'salience' in Hz for stop + [w] clusters in the four vocalic contexts. The same data are shown graphically in Figure 20. All stop + [w] clusters yield more spectral change when combined with more front vowels. The difference in the magnitude of spectral change between Cwi and Cwu is as much as 1000 Hz. Among [bw], [dw], and [gw] clusters, [dw] shows the greatest formant frequency change in all vocalic contexts. The values for the syllables with [dw] are greater by 160 to ≈ 330 Hz than those for the syllables with [bw], and by ≈ 140 to ≈ 360 Hz than those for the syllables with [gw]. Figure 21 shows the values of 'salience' in Mels, which exhibit the same patterns.

Stop + /w/: 'dissimilarity'

Table 8 and Figure 22 show the 'dissimilarity' in Hz between each pair of stop + [w] clusters in an identical vowel context. They reveal that [bw] and [gw] are closer to each other than either is to [dw]. This pattern is also apparent in Figure 23, which shows the 'dissimilarity' in Mels. As before, average formant trajectories were obtained for each stop + [w] cluster to see the effect of the initial stop more clearly. The first 30 msec. of these clusters are shown in Figure 24. Values of 'dissimilarity' were computed in Hz and in Mels for this interval and are shown in Table 9. They suggest that [dw] is spectrally well-differentiated from both [bw] and [gw], but that [bw] and [gw] are spectrally very similar.

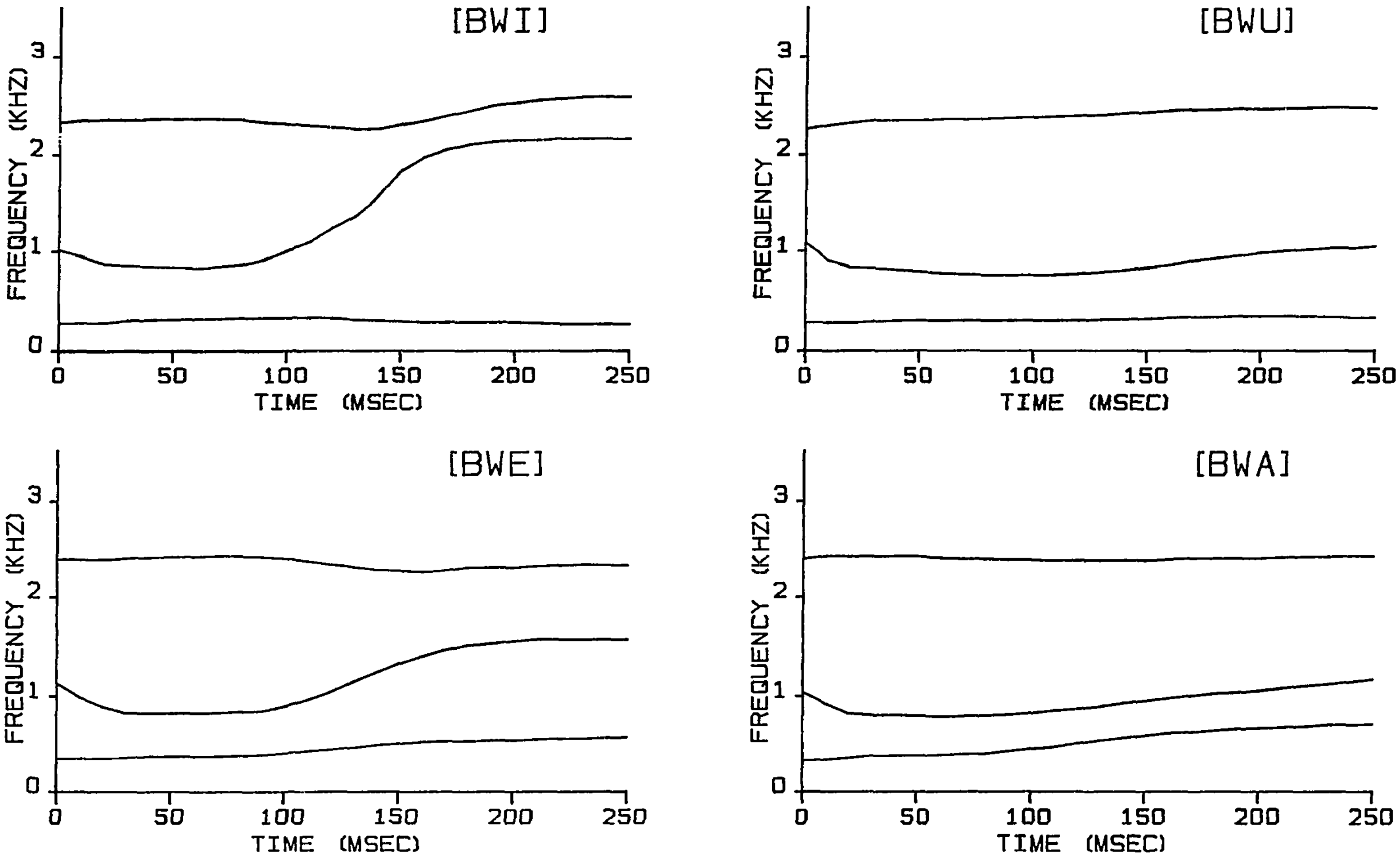

Figure 17: Average Formant Trajectories in [bw] + Vowel Sequences.
Time is measured from stop release.

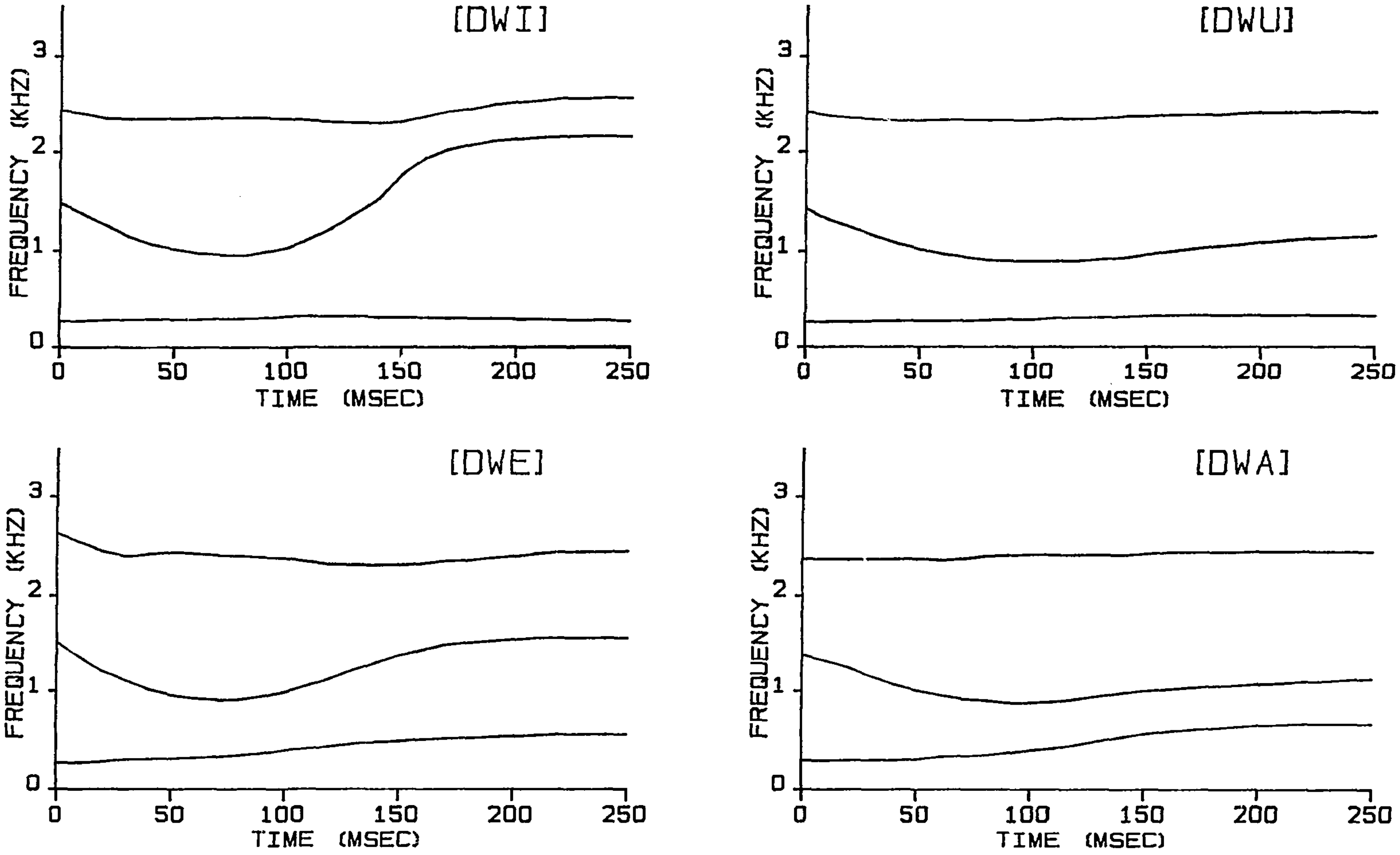

Figure 18: Average Formant Trajectories in [dw] + Vowel Sequences. Time is measured from stop release.

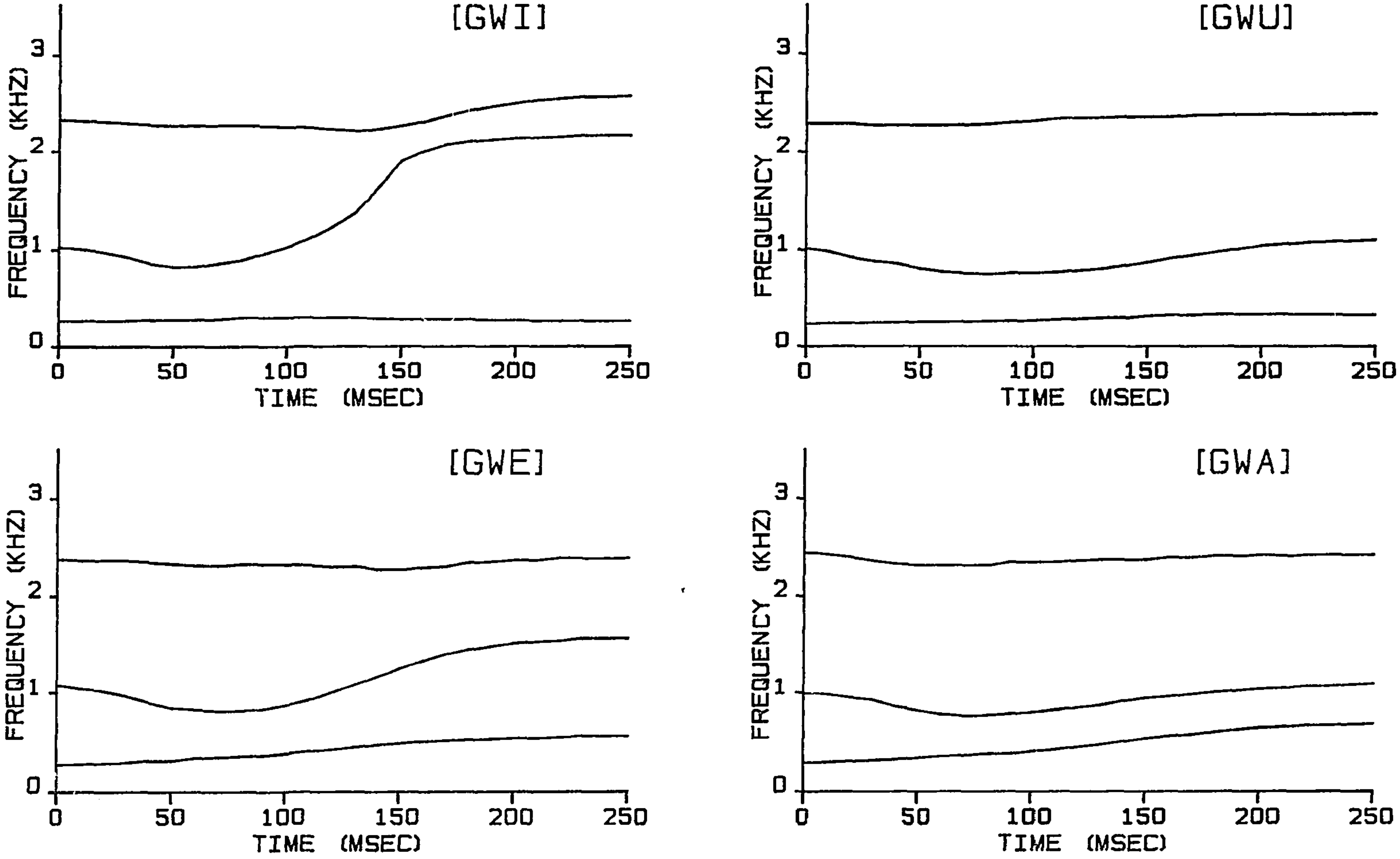

Figure 19: Average Formant Trajectories in [gw] + Vowel Sequences.
Time is measured from stop release.

Table 7

'Salience' in Hz for Stop + [w] Clusters in Four Vocalic Contexts

Initial Cluster	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
[bw]	1702	1187	809	718
[dw]	1884	1509	979	878
[gw]	1743	1150	818	682

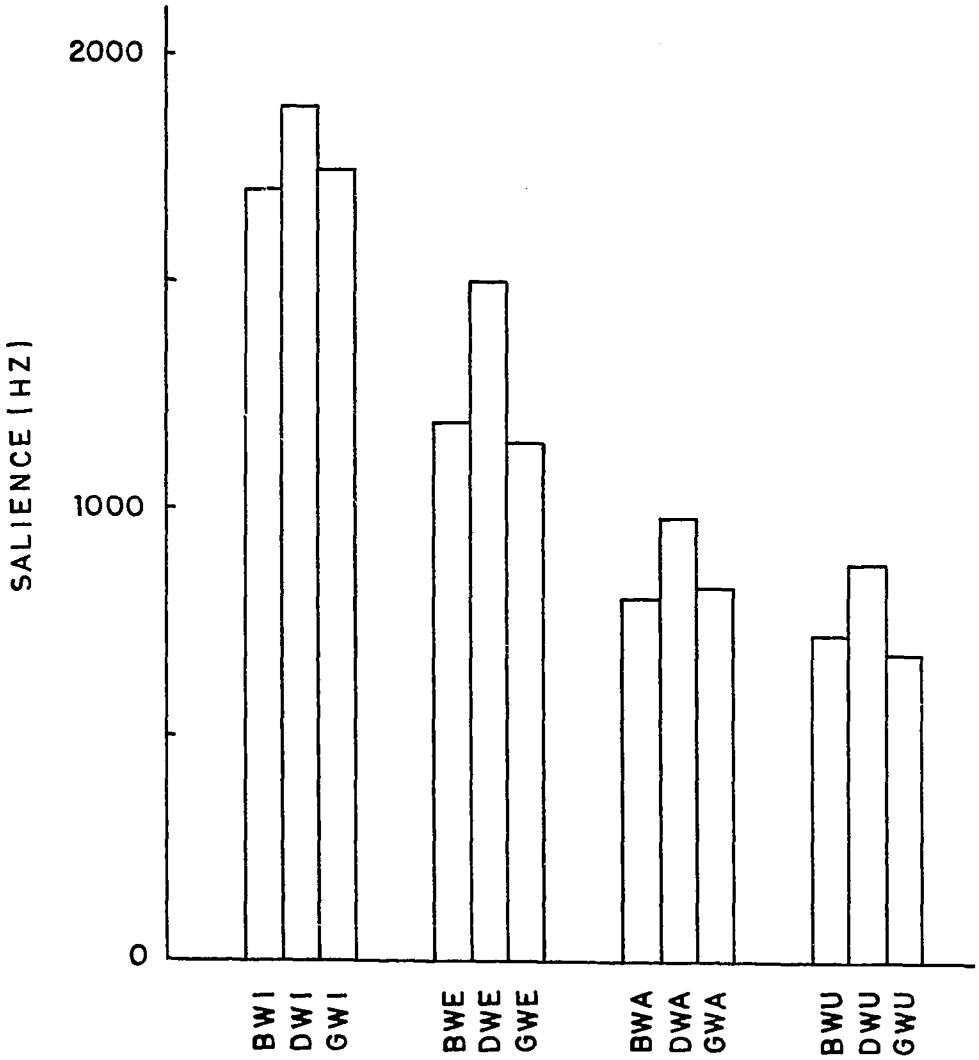

Figure 20: 'Salience' in Hz for Stop + [w] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

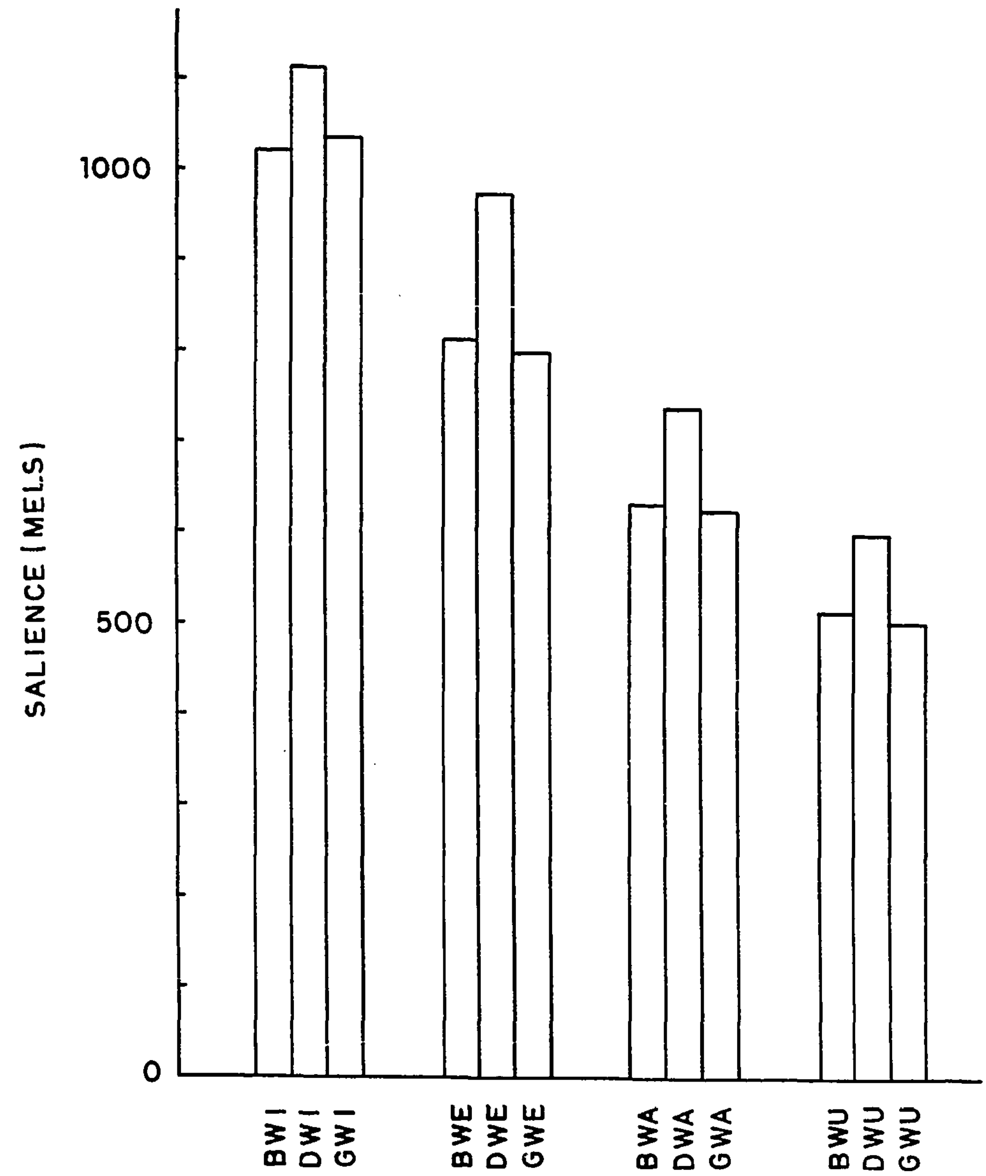

Figure 21: 'Salience' in Mels for Stop + [w] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

Table 8

'Dissimilarity' in Hz between Stop + [w] Clusters in Four Vocalic Contexts

Pair of Initial Clusters Compared	Vocalic Contexts			
	[i]	[ε]	[a]	[u]
[bw]-[dw]	2965	3590	3556	4663
[dw]-[gw]	3126	3630	3399	3943
[bw]-[gw]	1212	2268	2288	2138

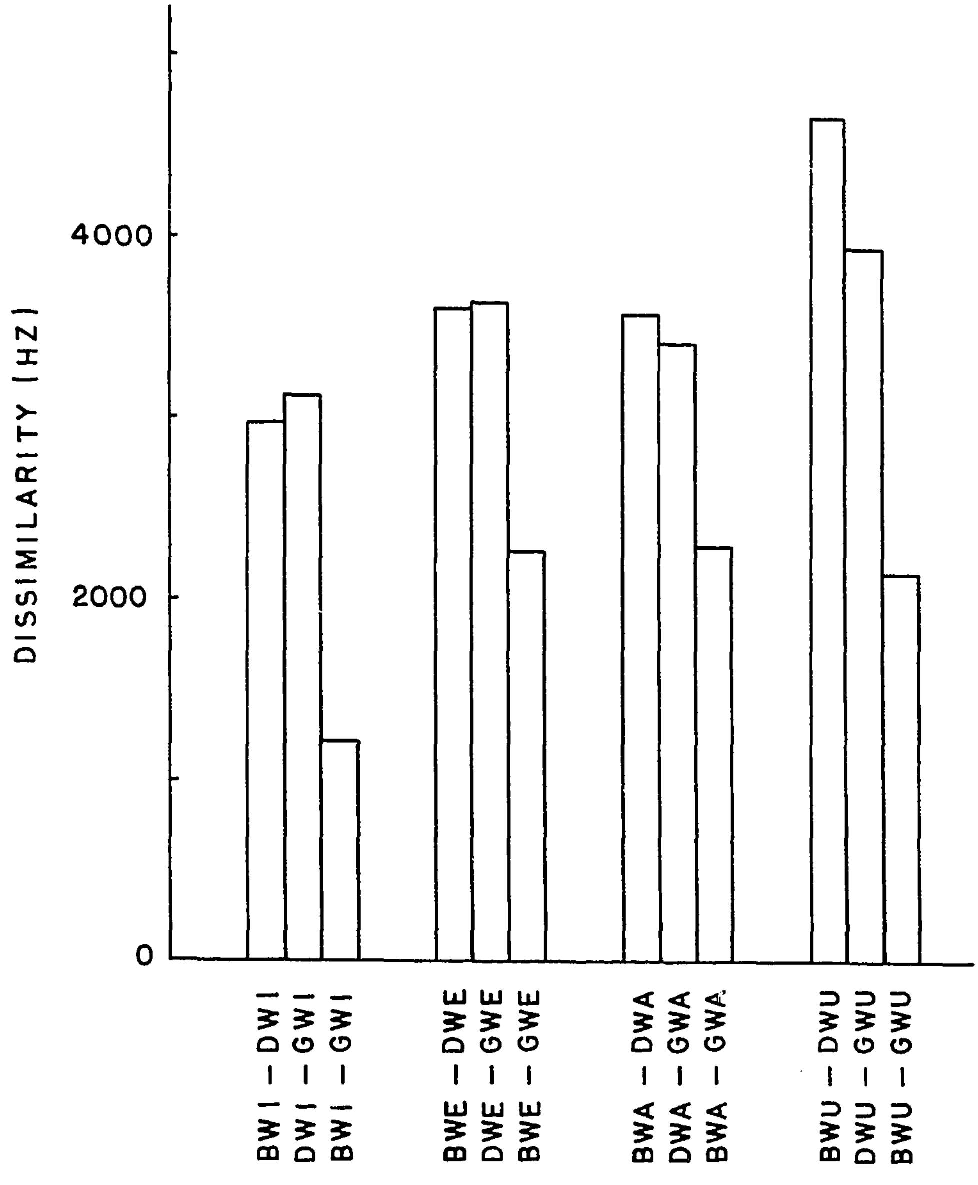

Figure 22: 'Dissimilarity' in Hz between Stop + [w] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

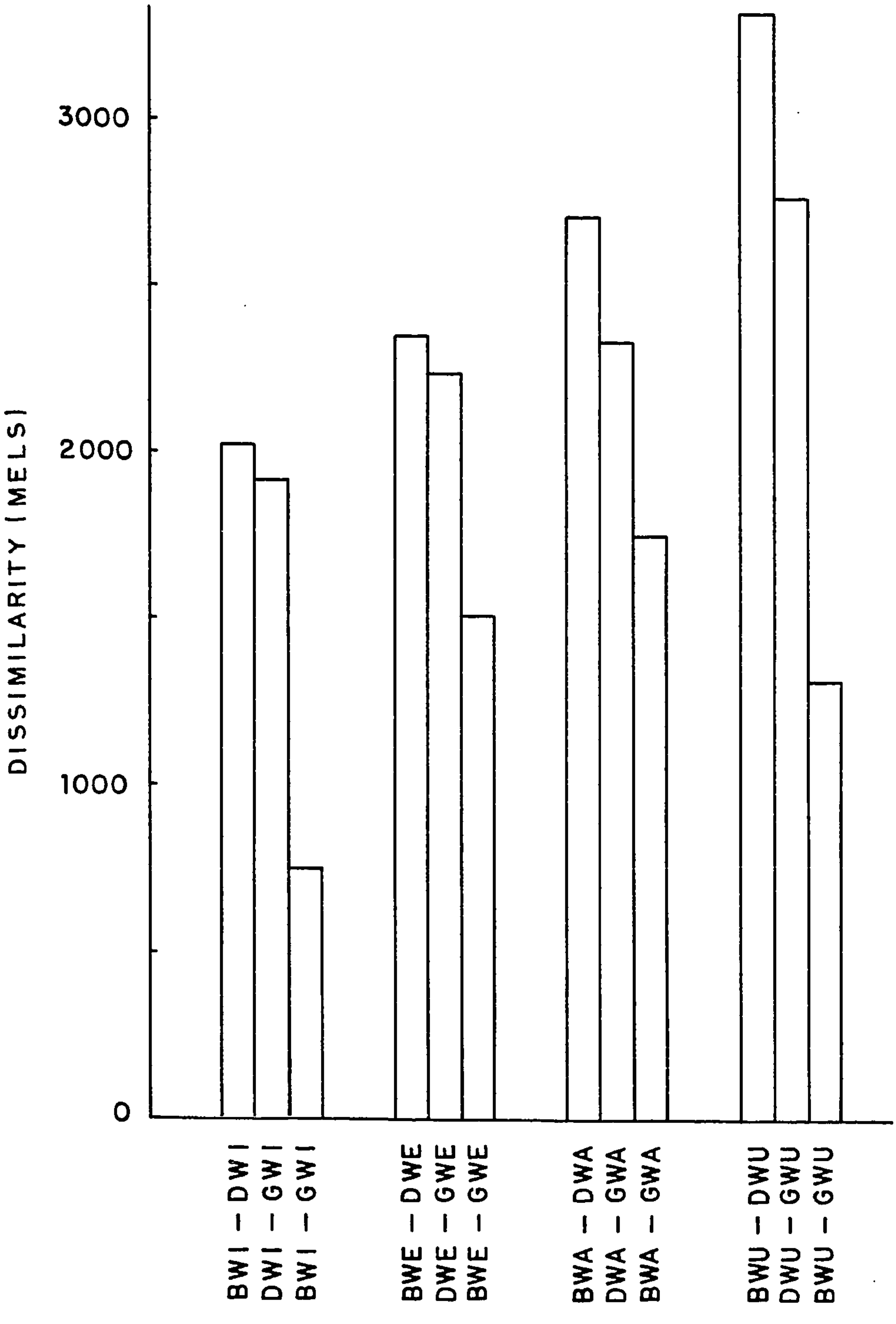

Figure 23: 'Dissimilarity' in Mels between Stop + [w] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

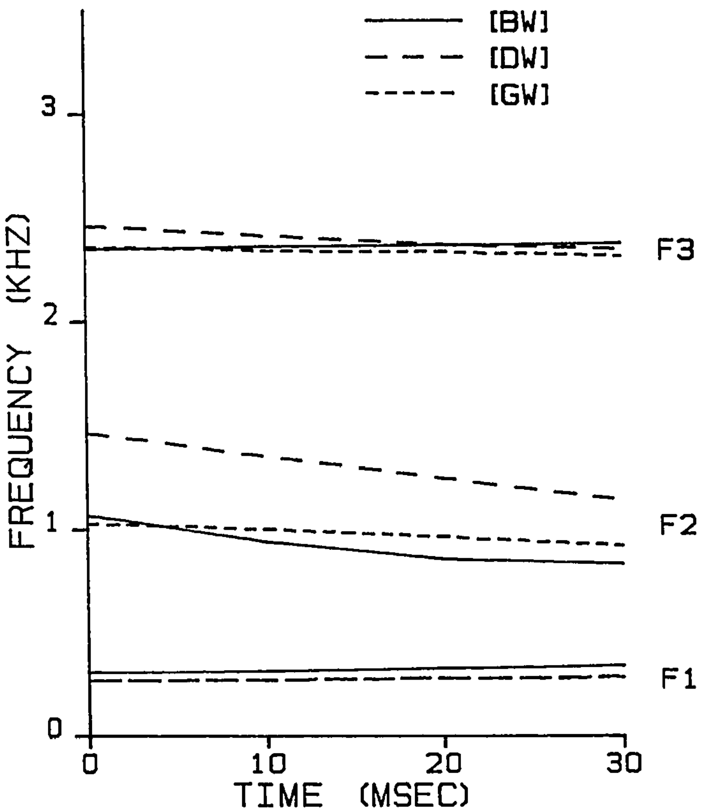

Figure 24: Average Formant Trajectories in Stop + [w] Clusters. Initial 30 msec. after stop release are shown All vowels are pooled.

Table 9

'Dissimilarity' in Hz and in Mels between Stop + [w] Clusters in Initial 30 Msec.

Pair of Clusters Compared	Hz	(Mels)
[bw]-[dw]	1533	(1055)
[dw]-[gw]	1311	(871)
[bw]-[gw]	378	(312)

Stop + /j/: 'salience'

The average formant trajectories in the syllables with stop + [j] clusters are shown in a linear scale in Figures 25, 26, and 27. Table 10 shows the values of 'salience' computed in Hz for stop + [j] clusters in the four vocalic contexts. The same data are plotted in Figure 28. Formant frequencies change more when the stop + [j] clusters are followed by low or back vowels. The differences in 'salience' between Cji sequences and sequences of Cj and a low or back vowel range from ≈ 370 Hz to ≈ 750 Hz, which are not as great as the differences between Cwi and Cwu (≈ 1000 Hz). Figure 29 shows the 'salience' in Mels for stop + [j] clusters in the four vocalic contexts. Here, it holds for all initial stops that Cja sequences have greater 'salience' than Cju sequences. When the data in Tables 7 and 10 are compared, we find that the magnitude of spectral change is greater in Cwi sequences than in Cju sequences. We also find a greater spectral change in Cja than in Cwa.

It generally holds that, among [bj], [dj], and [gj] clusters, [bj] shows the greatest spectral change, and [dj] the least in all vocalic environments. The differences in 'salience' between these two types of clusters may be as much as ≈ 530 Hz.

Stop + /j/: 'dissimilarity'

Table 11 and Figure 30 show the 'dissimilarity' in Hz between each pair of stop + [j] clusters in an identical vocalic context. These values suggest that [bj] and [dj] are spectrally closer to each other than either of them is to [gj] in at least three vocalic environments. This pattern is preserved when plotted in Mels as in Figure 31. Figure 32 shows the formant trajectories in the first 30 msec. of the

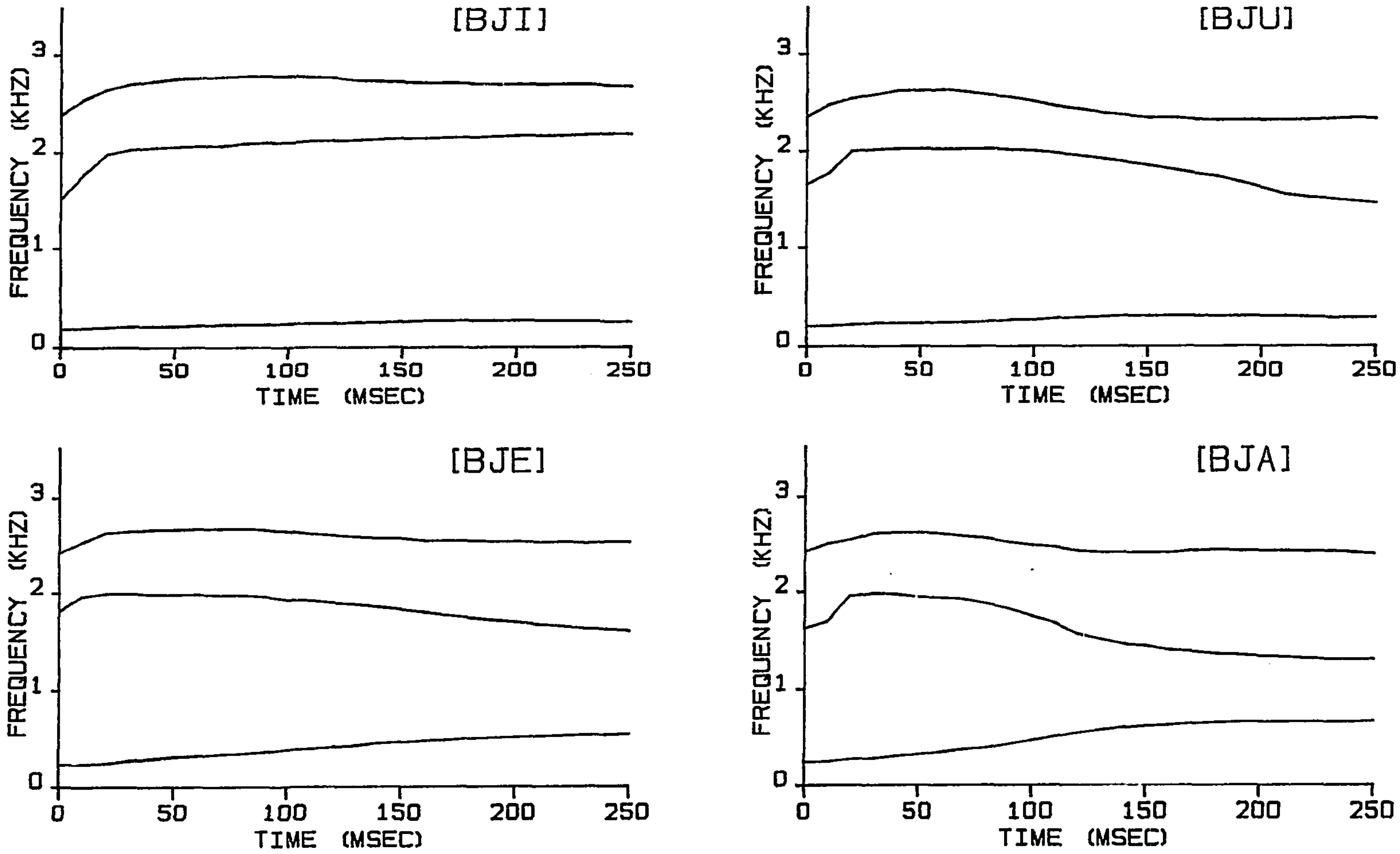

Figure 25: Average Formant Trajectories in [bj] + Vowel Sequences.
Time is measured from stop release.

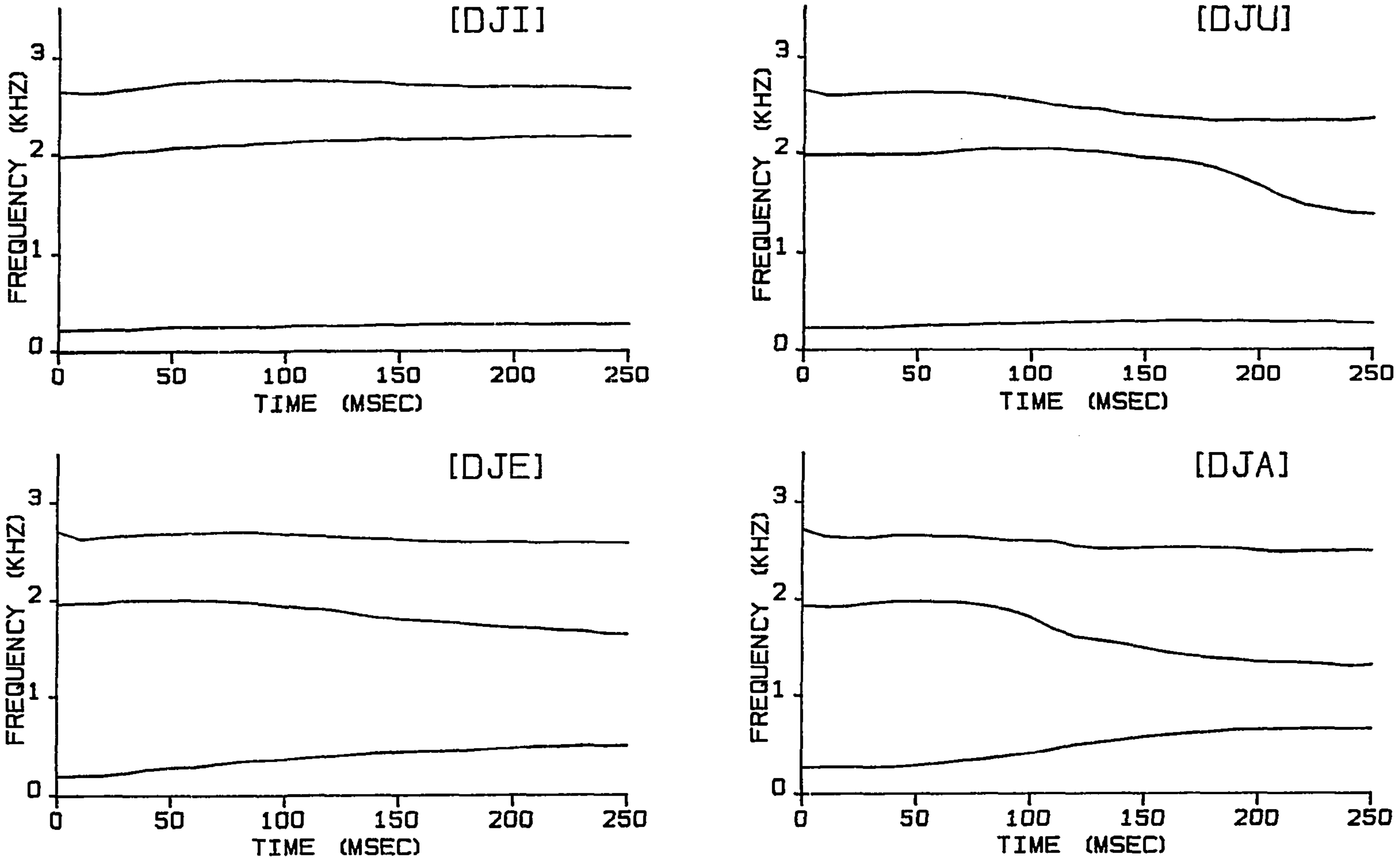

Figure 26: Average Formant Trajectories in [dj] + Vowel Sequences. Time is measured from stop release.

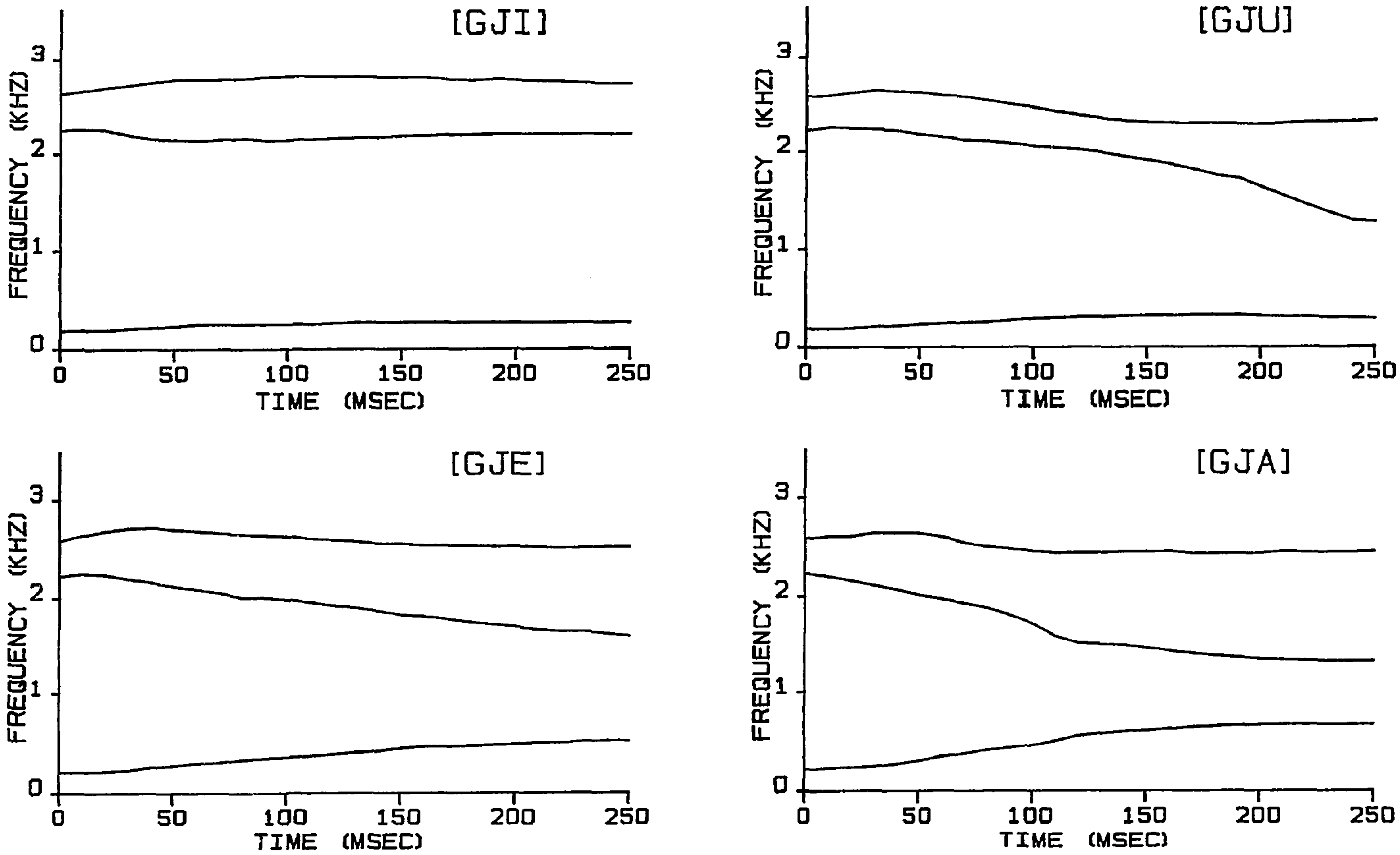

Figure 27: Average Formant Trajectories in [gj] + Vowel Sequences. Time is measured from stop release.

Table 10

'Salience' in Hz for Stop + [j] Clusters in Four Vocalic Contexts

Initial Cluster	Vocalic Contexts [i]	[ɛ]	[a]	[u]
[bj]	899	890	1343	1272
[dj]	372	669	1029	1033
[gj]	482	896	1159	1228

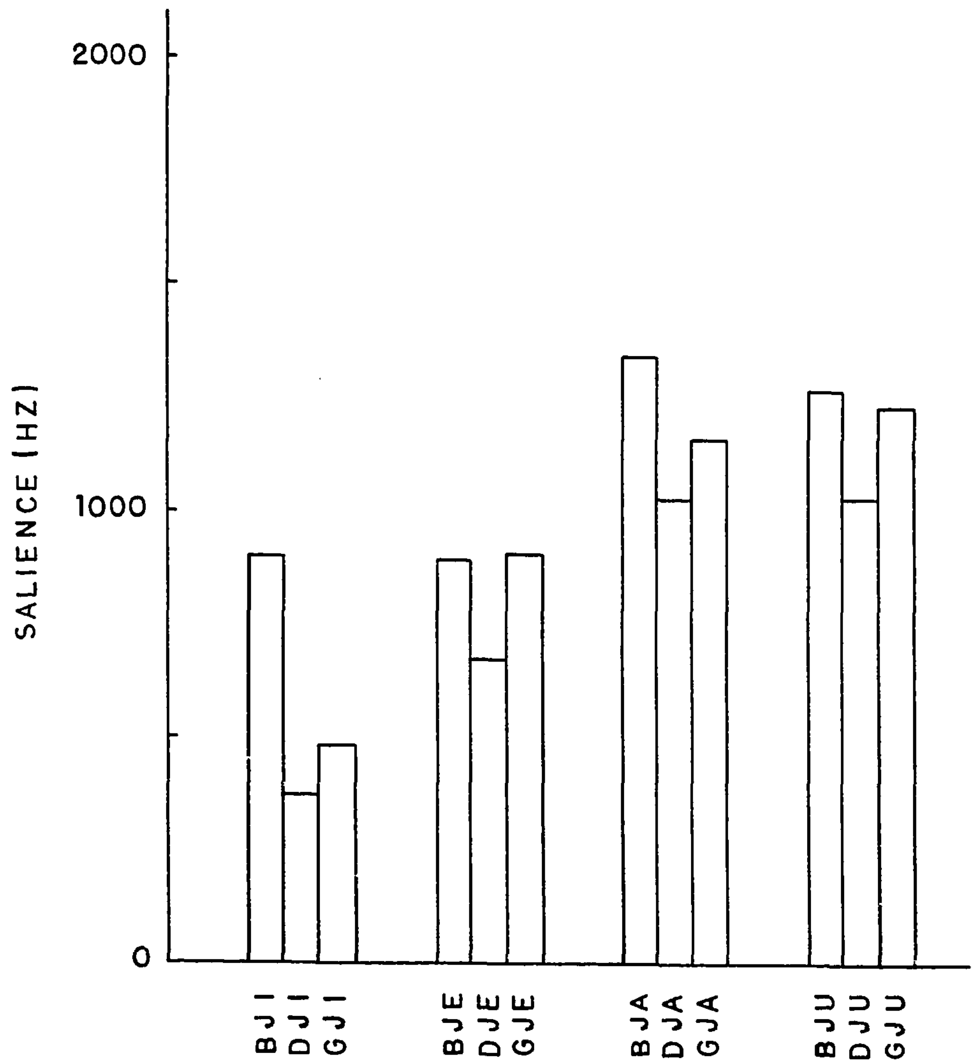

Figure 28: 'Salience' in Hz for Stop + [j] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

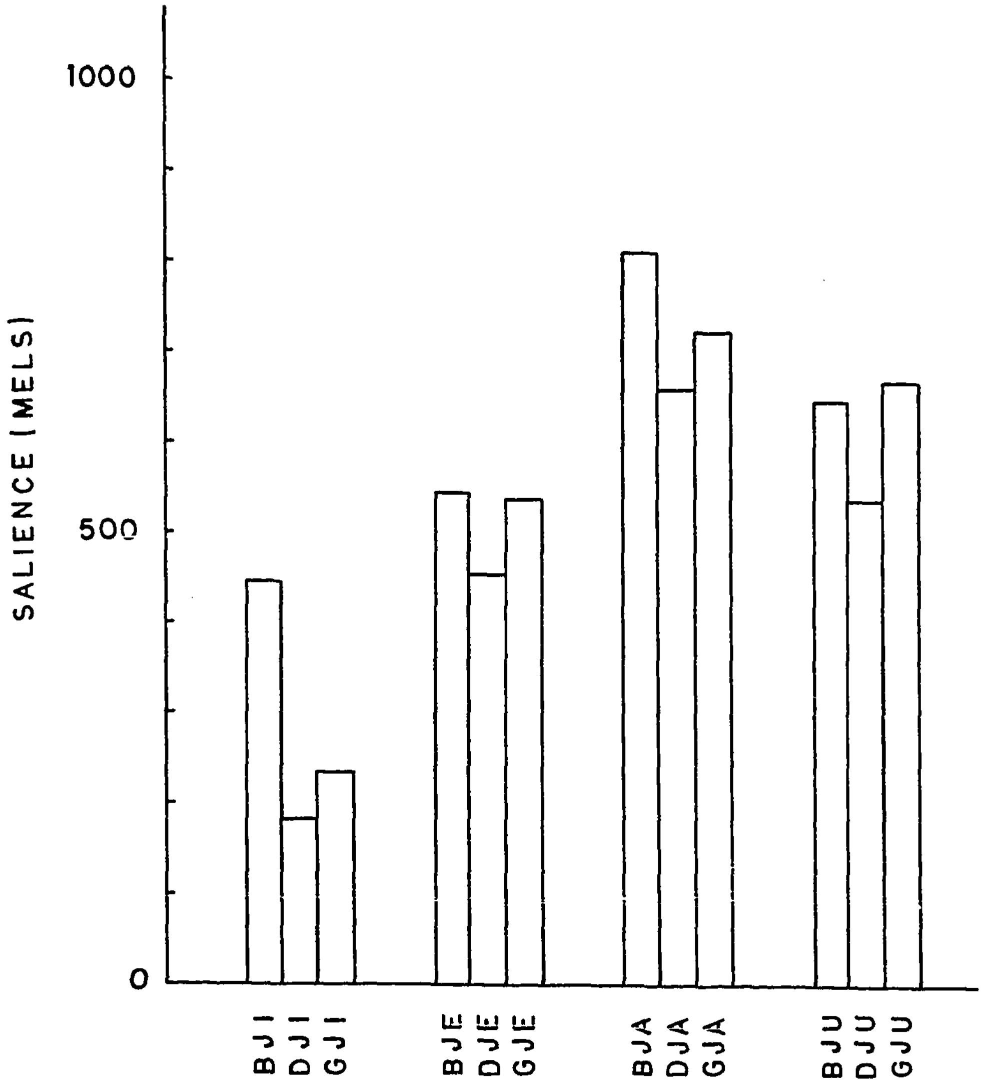

Figure 29: 'Salience' in Mels for Stop + [j] Clusters in Four Vocalic Contexts. Three initial clusters in the same vocalic context are shown together on the abscissa.

Table 11

'Dissimilarity' in Hz between Stop + [j] Clusters in Four Vocalic Contexts

Pair of Initial Clusters Compared	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
[bj]-[dj]	1309	1502	2569	2397
[dj]-[gj]	2083	2593	2835	3296
[bj]-[gj]	3163	2303	2407	3585

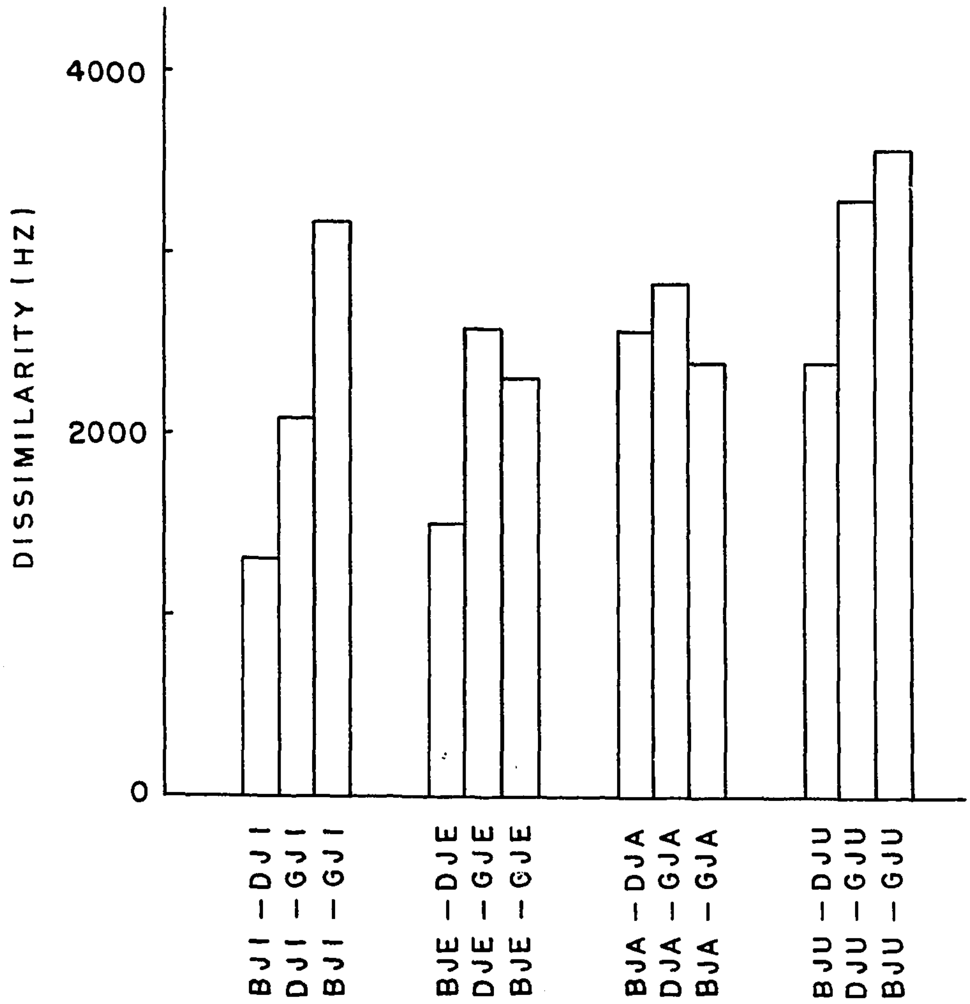

Figure 30: 'Dissimilarity' in Hz between Stop + [j] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

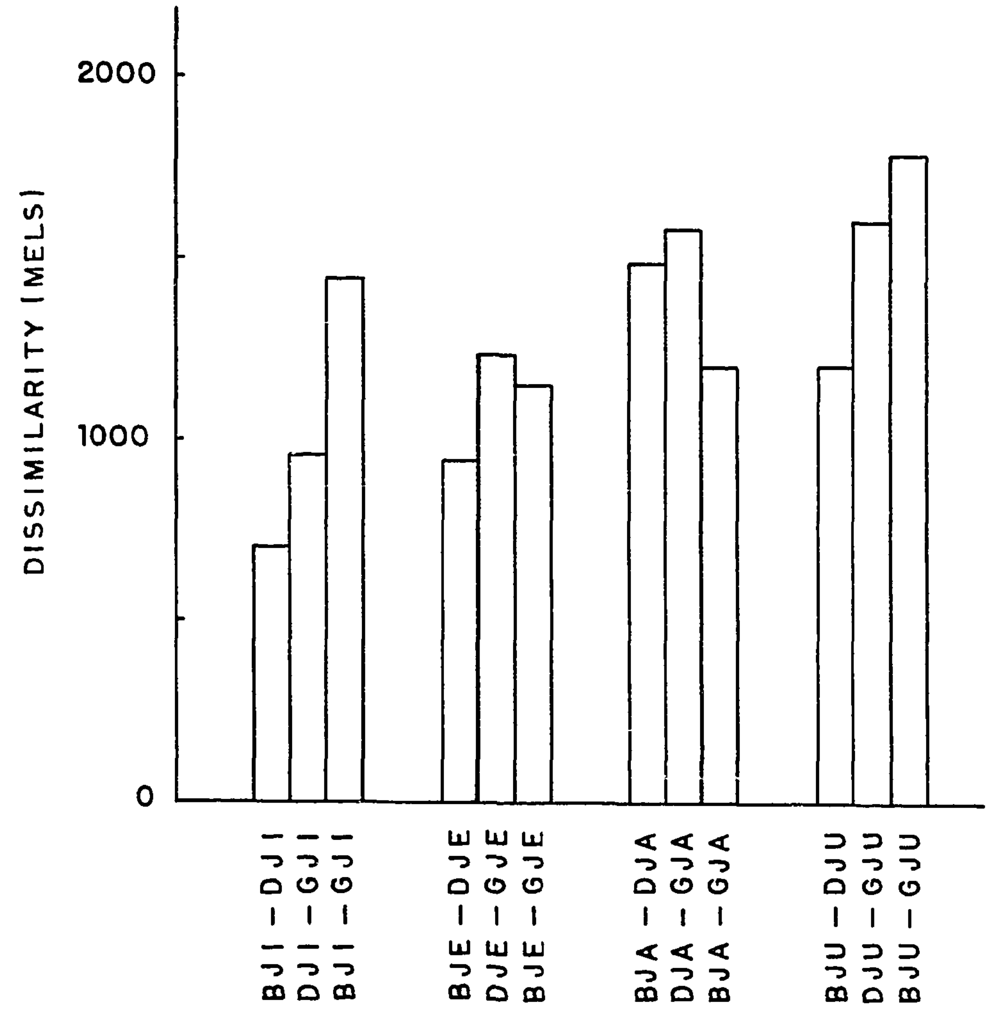

Figure 31: 'Dissimilarity' in Mels between Stop + [j] Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

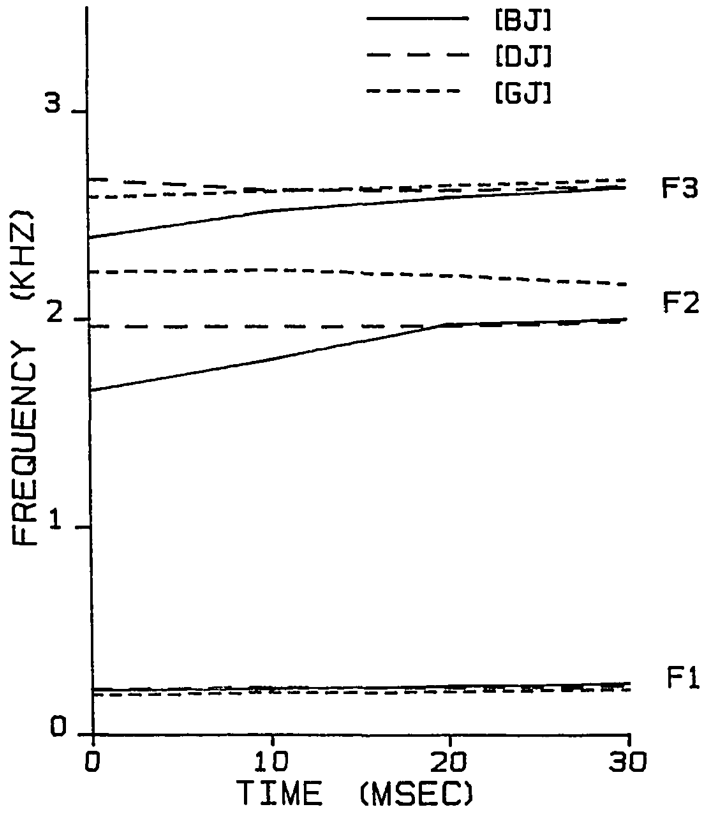

Figure 32: Average Formant Trajectories in Stop + [j] Clusters. Initial 30 msec. after stop release are shown. All vowels are pooled.

stop + [j] clusters where all the vocalic contexts are pooled. Values of 'dissimilarity' were computed for this interval and are given in Table 12. The values suggest that [bj] and [dj] are the closest pair, and that [gj] is closer to [dj] than to [bj].

Figure 33 graphically represents the data given in Tables 6, 9, and 12. Only the Hz values are plotted. The relative degree of spectral similarity is greatest between [bw] and [gw]. [dl]-[gl], [bj]-[dj], and [bl]-[gl] are also spectrally very similar, [dj]-[gj] and [bl]-[dl] are somewhat less so, and all the pairs of Cr clusters, [bw]-[dw], [dw]-[gw], and [bj]-[gj] seem to be spectrally well-differentiated.

4.4.3. CV and VC syllables

The average formant trajectories in CV syllables are shown in Figures 34, 35, and 36. Zero msec. on the abscissa corresponds to the consonantal release. The average formant trajectories in VC syllables are shown in Figures 37, 38, and 39. Zero msec. in these figures corresponds to the consonantal implosion. The frequency scale is linear in these figures.

CV and VC: 'salience'

Table 13 shows the values of 'salience' in Hz for all CV and VC syllables. The same data are graphically represented in Figures 40, 41, and 42. The corresponding values of 'salience' in Mels are plotted in Figures 43, 44, and 45. The shaded bars represent the CV syllables, and the unshaded bars represent the VC syllables in these six figures.

Similar tendencies are noted in both the linear and Mel values of 'salience.' As for the CV syllables, greater spectral change is found

Table 12

'Dissimilarity' in Hz and in Mels between Stop + [j] Clusters in Initial 30 Msec.

Pair of Clusters Compared	Hz	(Mels)
[bj]-[dj]	673	(326)
[dj]-[gj]	981	(464)
[bj]-[gj]	1467	(709)

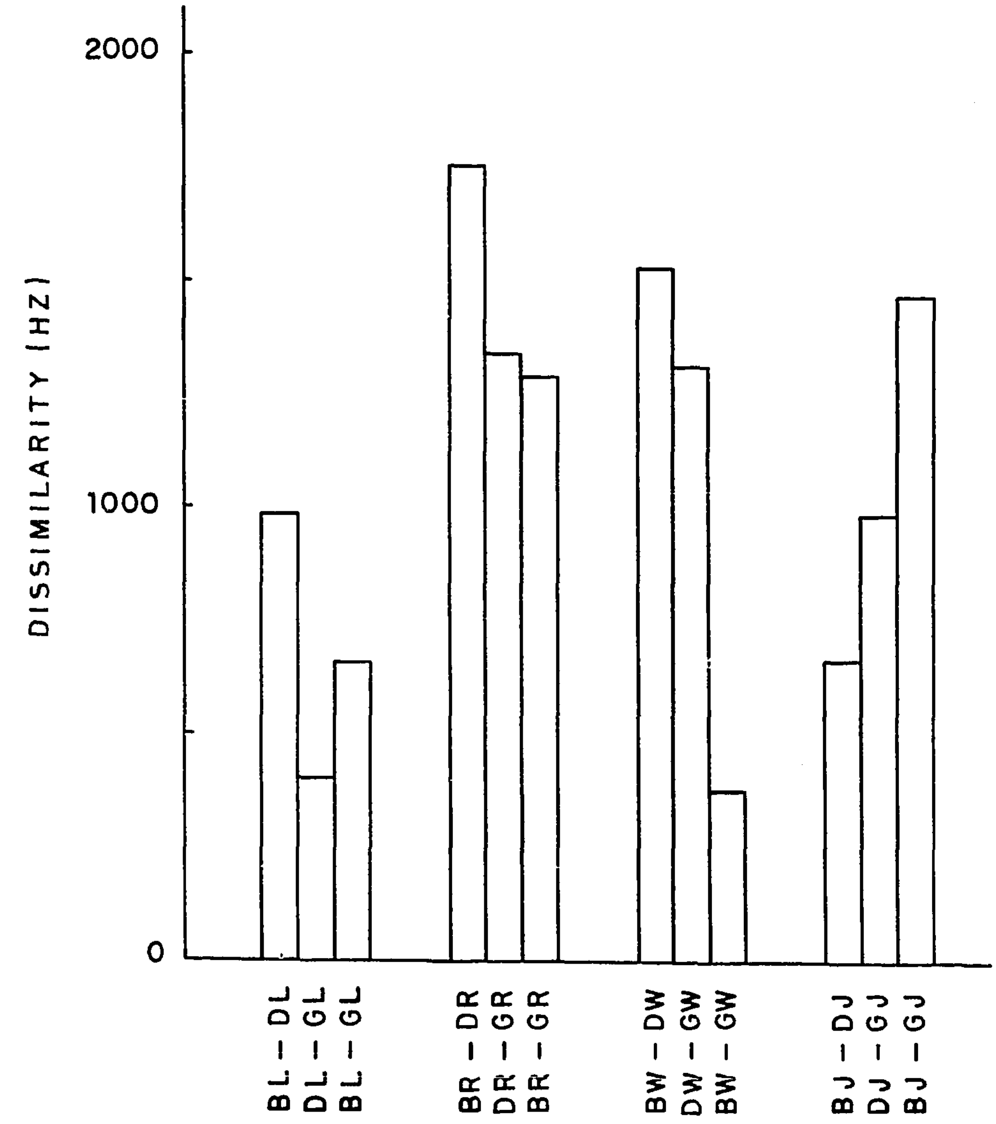

Figure 33: 'Dissimilarity' in Hz between Stop + Sonorant Clusters. Initial 30 msec. are compared.

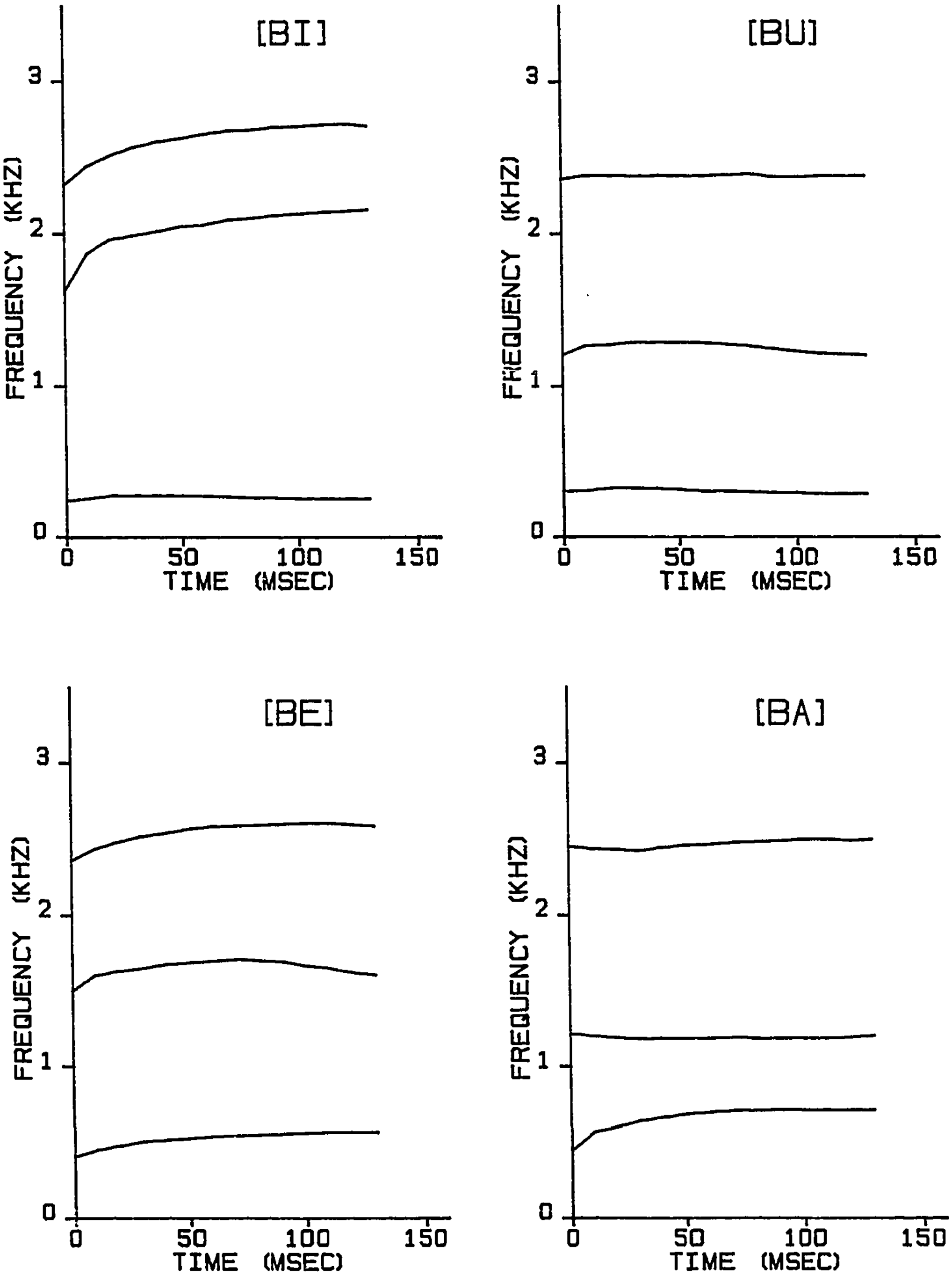

Figure 34: Average Formant Trajectories in [b] + Vowel Sequences. Time is measured from stop release.

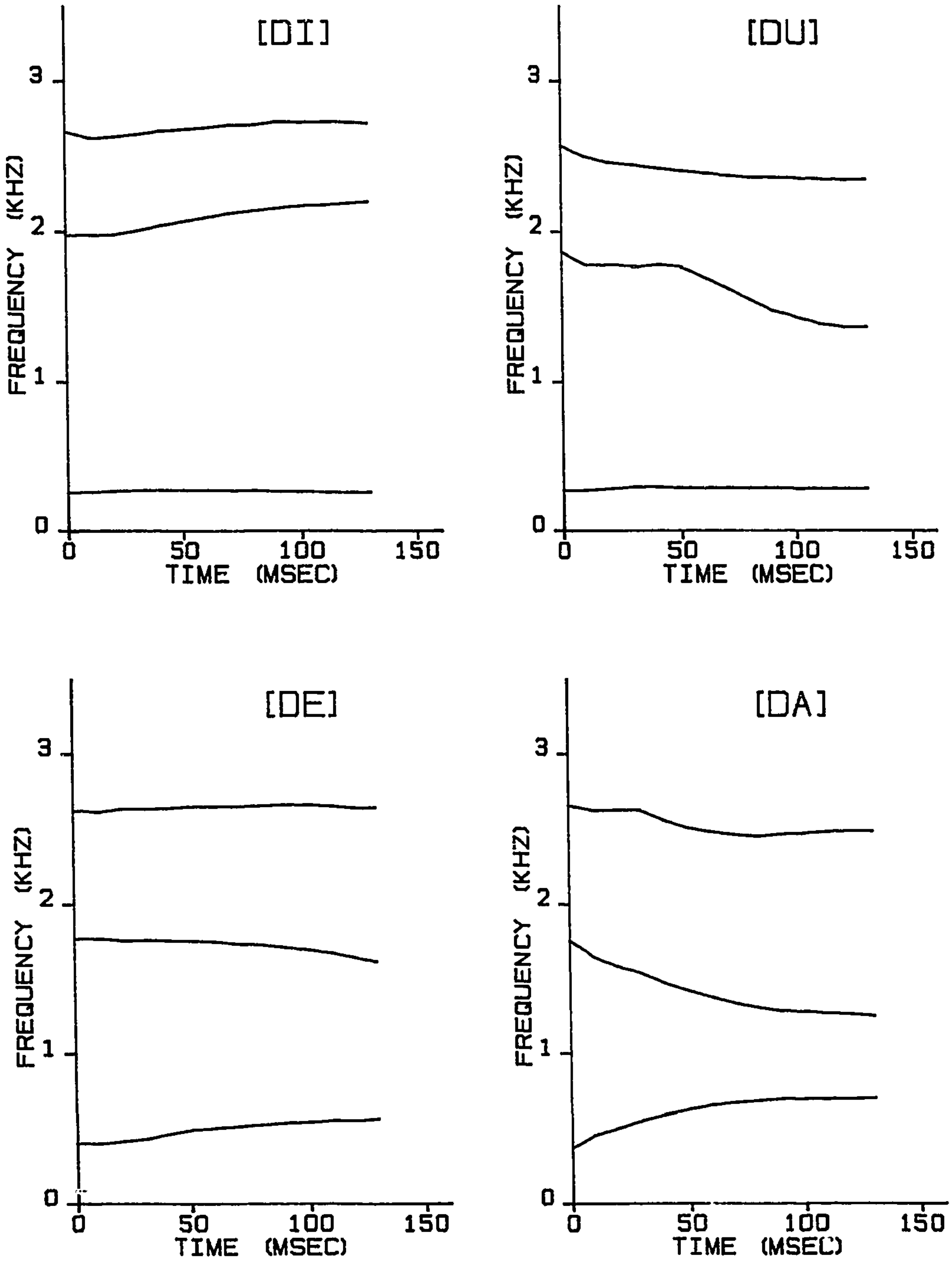

Figure 35: Average Formant Trajectories in [d] + Vowel Sequences. Time is measured from stop release.

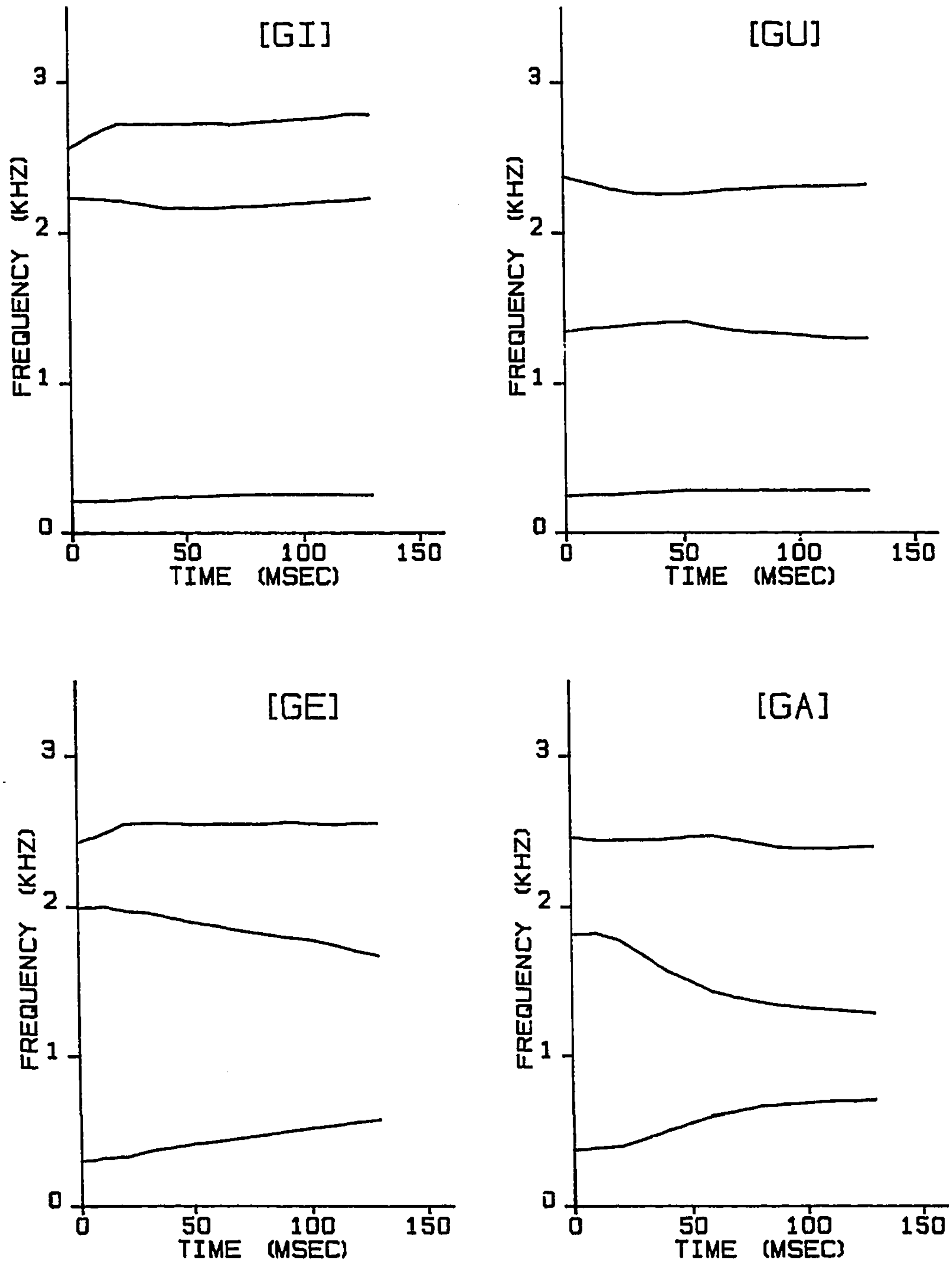

Figure 36: Average Formant Trajectories in [g] + Vowel Sequences. Time is measured from stop release.

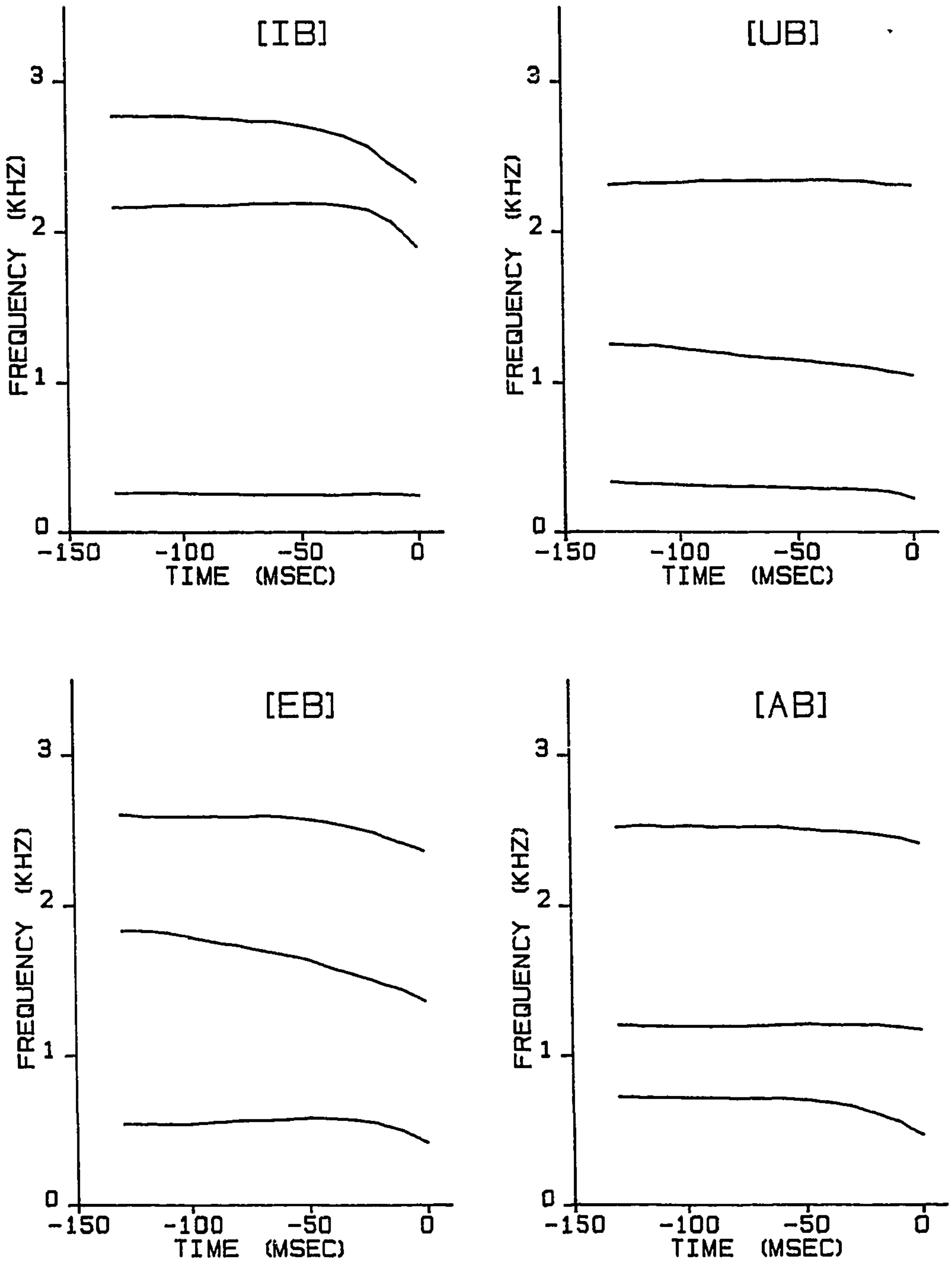

Figure 37: Average Formant Trajectories in Vowel + [b] Sequences. Time is measured from stop implosion.

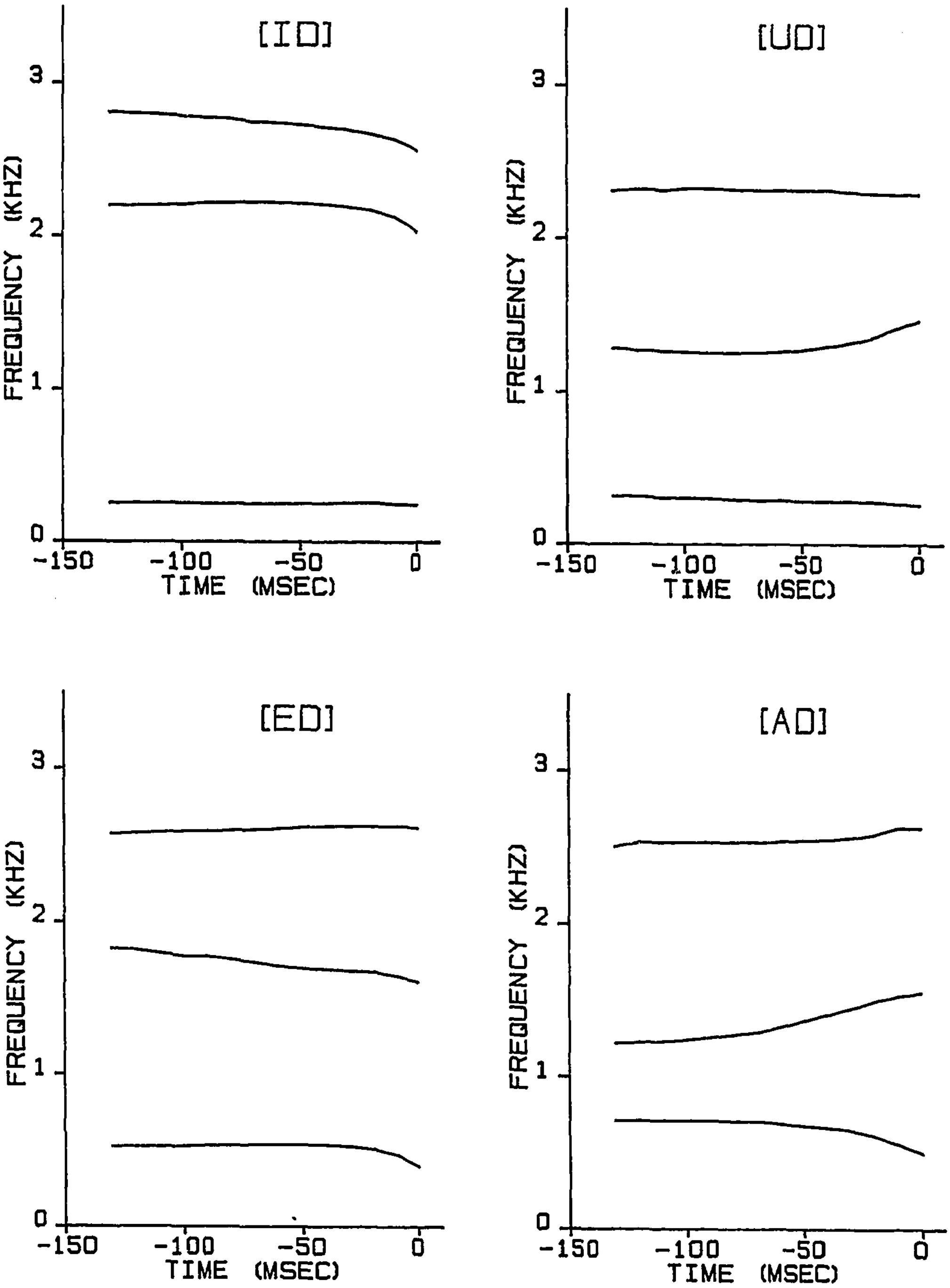

Figure 38: Average Formant Trajectories in Vowel + [d] Sequences. Time is measured from stop implosion.

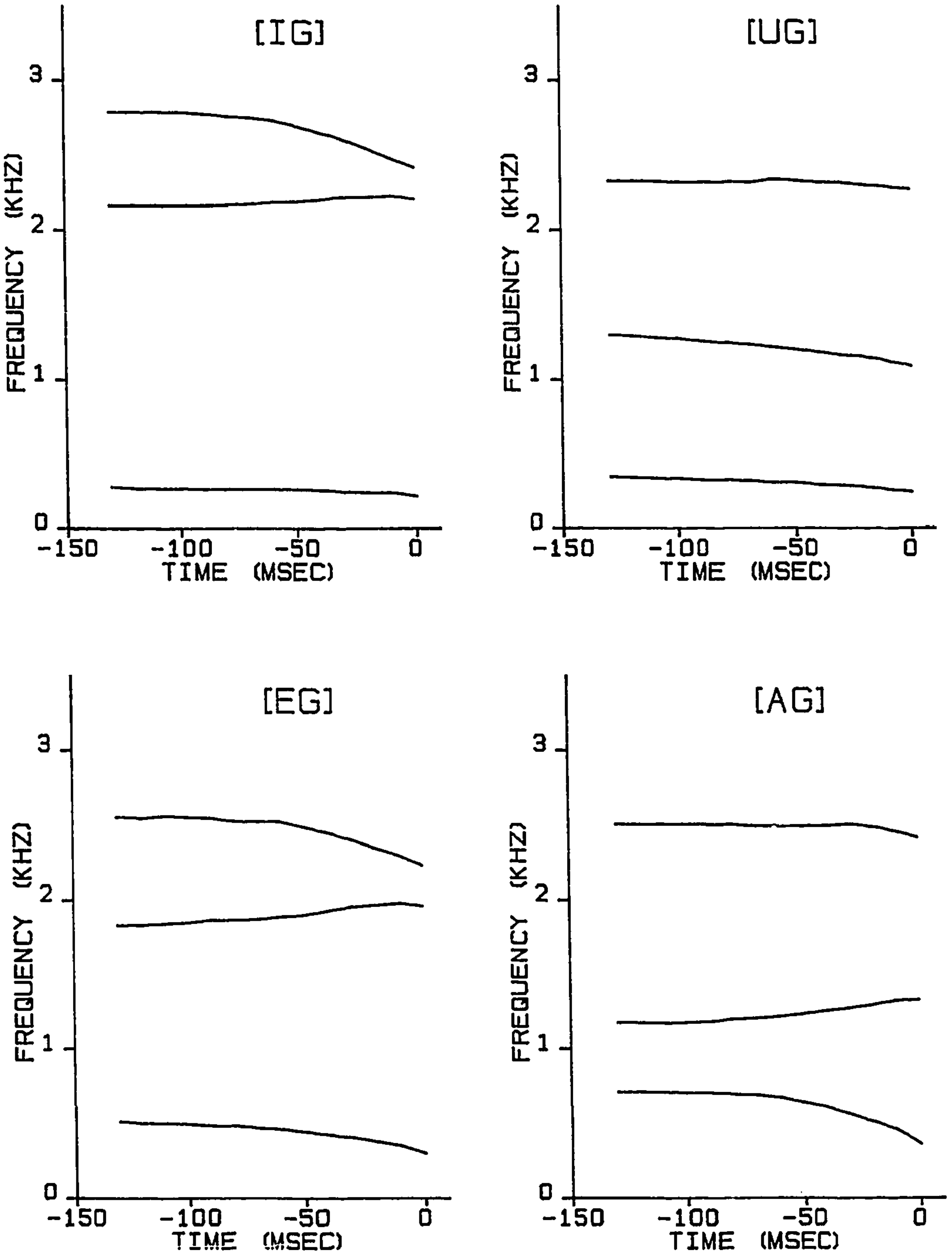

Figure 39: Average Formant Trajectories in Vowel + [g] Sequences. Time is measured from stop implosion.

Table 13

'Salience' in Hz for CV and VC Syllables

	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
Initial Stop				
[b]	700	471	343	224
[d]	326	284	687	635
[g]	352	544	695	285
Final Stop				
[b]	595	623	324	262
[d]	348	324	476	297
[g]	406	471	439	623

Note: 'Salience' for CV syllables is shown in the upper half.
'Salience' for VC syllables is shown in the lower half.

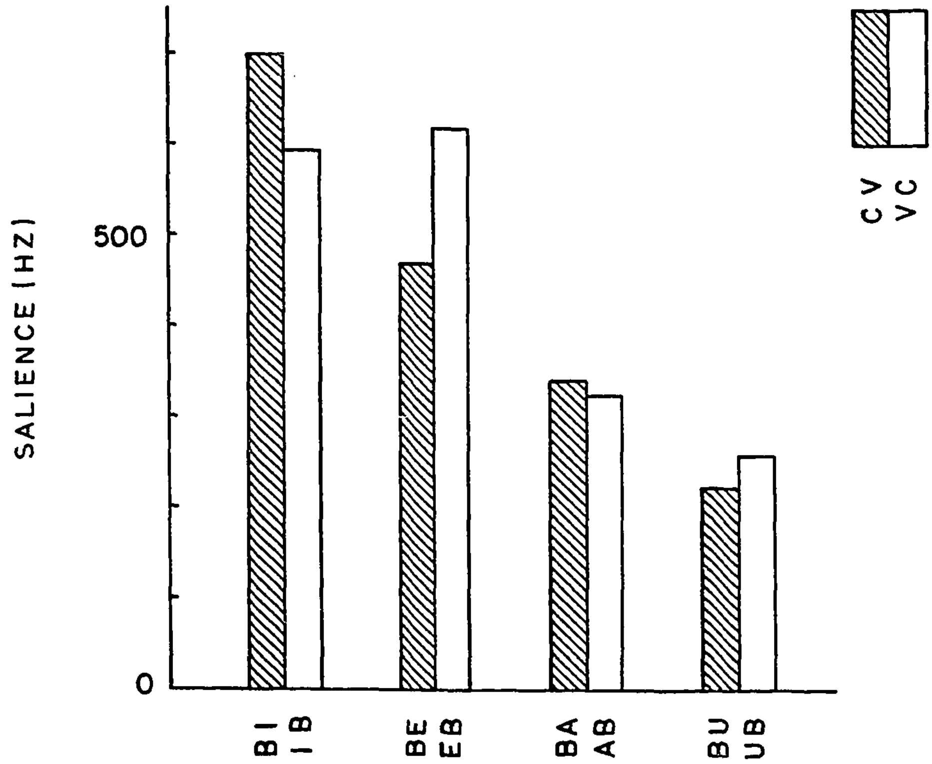

Figure 40: 'Salience' in Hz for [b] + Vowel and Vowel + [b] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

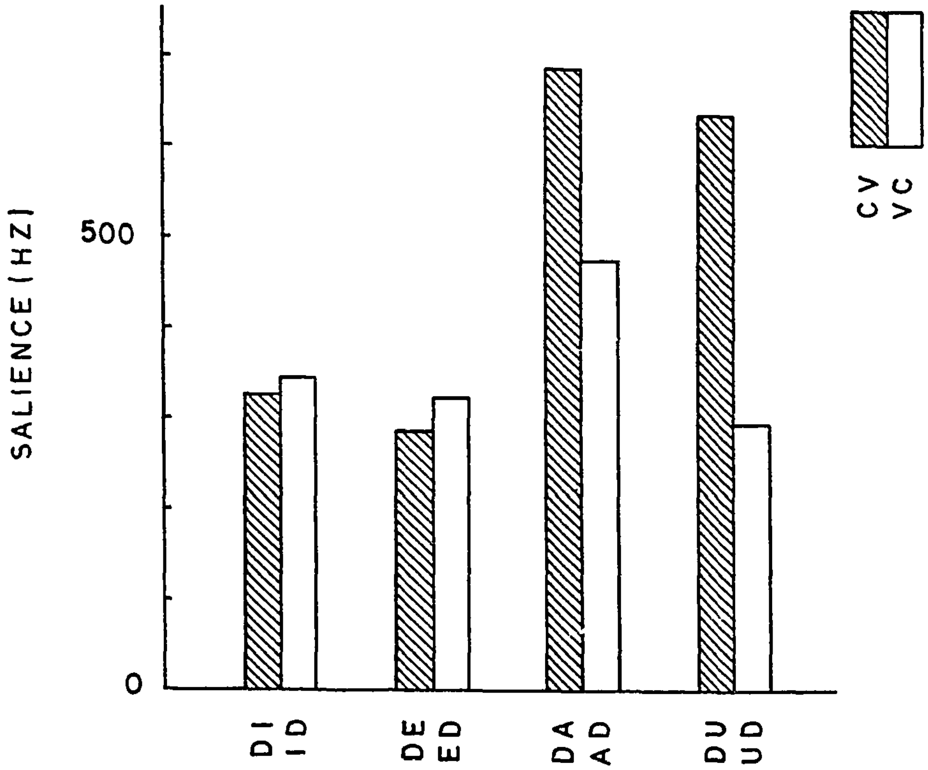

Figure 41: 'Salience' in Hz for [d] + Vowel and Vowel + [d] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

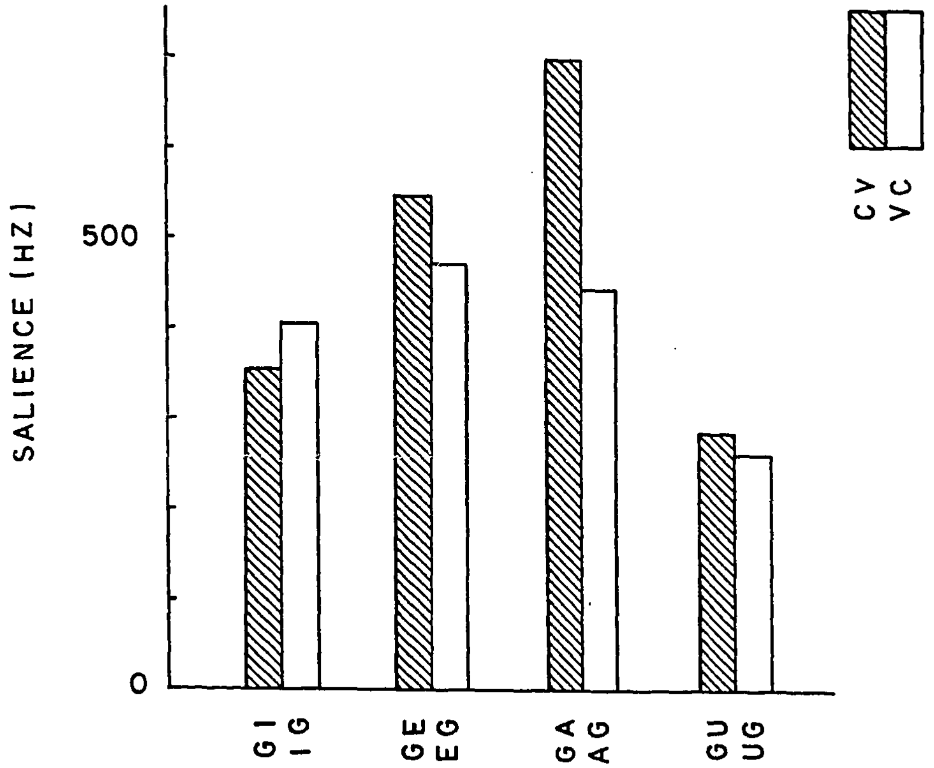

Figure 42: 'Salience' in Hz for [g] + Vowel and Vowel + [g] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

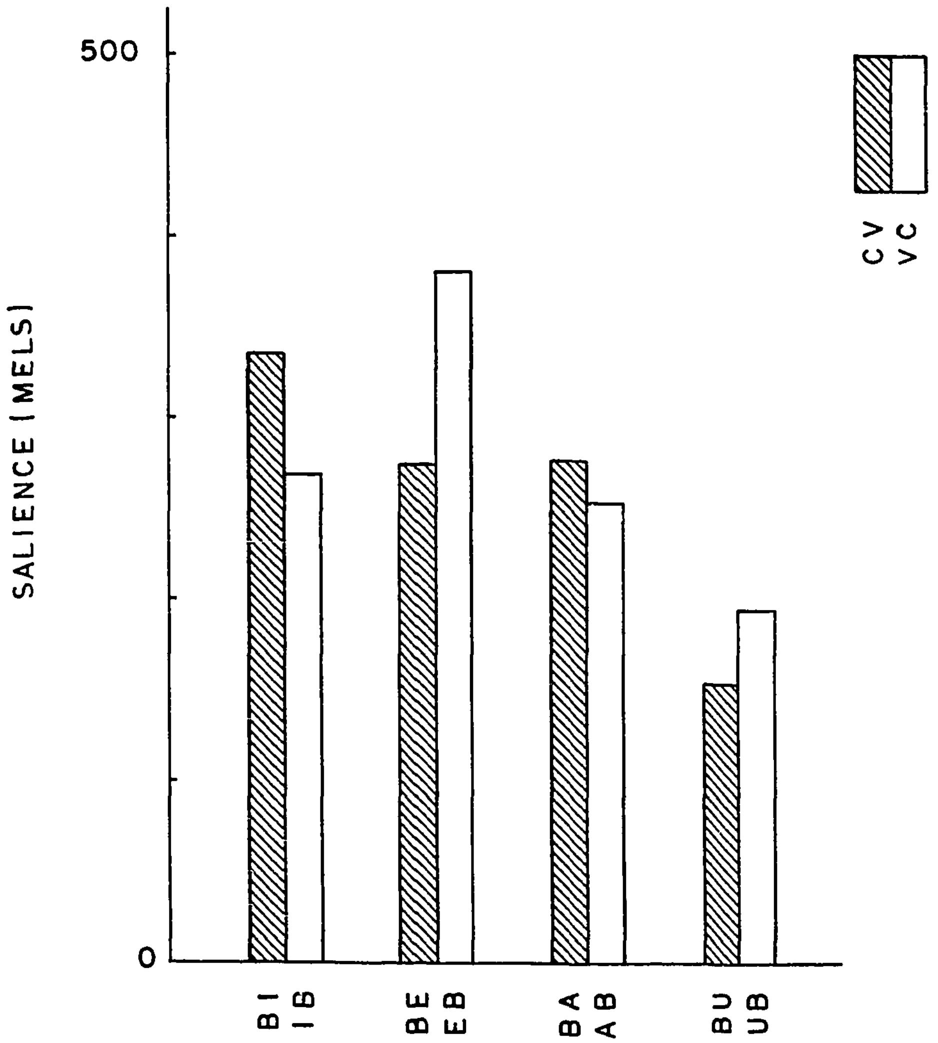

Figure 43: 'Salience' in Mels for [b] + Vowel and Vowel + [b] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

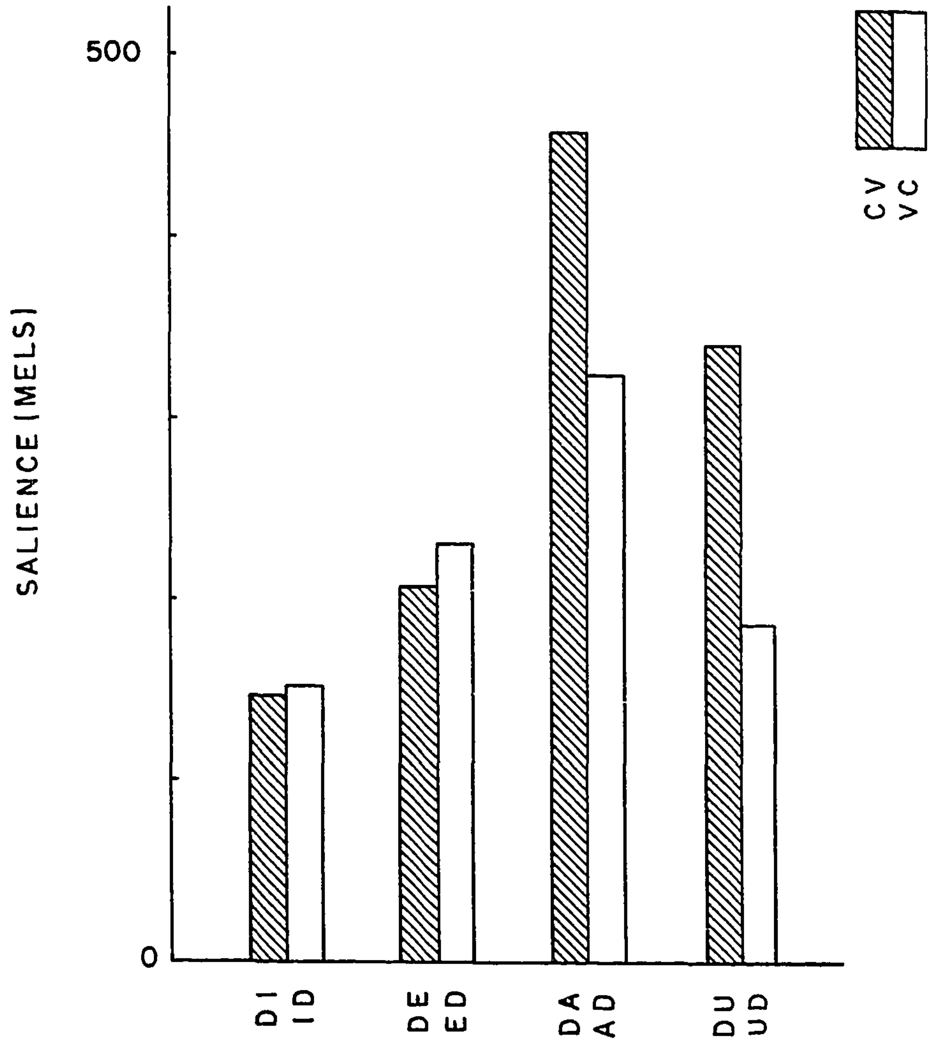

Figure 44: 'Salience' in Mels for [d] + Vowel and Vowel + [d] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

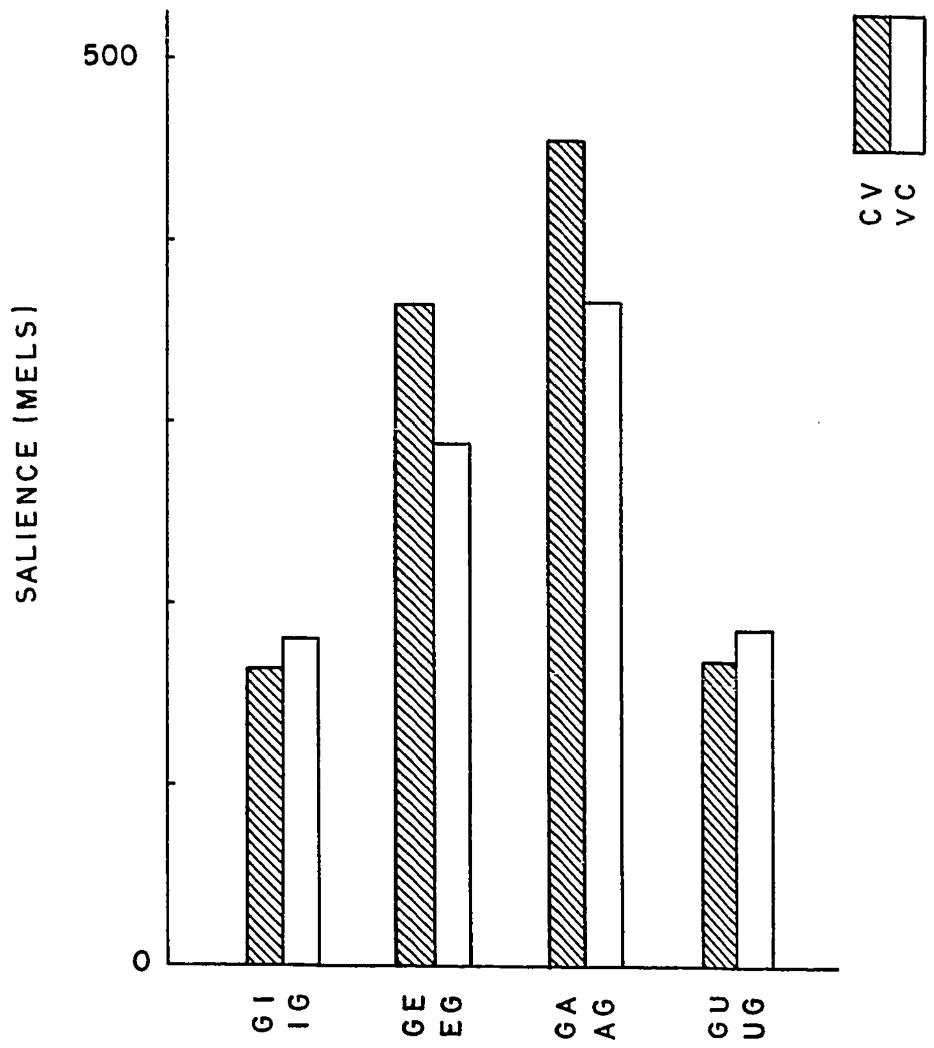

Figure 45: 'Salience' in Mels for [g] + Vowel and Vowel + [g] Sequences. CV and VC in the same vocalic context are shown together on the abscissa.

in sequences of [b] and a non-back vowel, sequences of [d] and a non-front vowel, and sequences of [g] and a non-high vowel. Especially small amounts of formant frequency change are observed in [bu], [di], [gi], and [gu]. Formant frequency change in [du] is greater by ≈ 400 Hz than that in [bu], and by ≈ 350 Hz than that in [gu]. It is also seen that [da] and [ga] show more spectral change (by ≈ 350 Hz) than [ba].

As to the VC syllables, the figures indicate that spectral change is relatively small in [ub], [id], [ud], [ig], and [ug]. Thus, combinations of [b] and [u], of [d] and [i], of [g] and [i], and of [g] and [u] do not create extensive spectral change whether the consonants appear syllable-initially or finally. This does not hold for combinations of [d] and [u]. [du] is a spectrally well-modulated sound sequence, while [ud] is not.

We do not find a consistent pattern as to whether formant frequencies change more in CV syllables or in VC syllables. The results suggest that it is dependent both on the stop and on the vocalic context. On the one hand, CV syllables show better-modulated formants than VC syllables if they are combinations of [d] and [u], of [d] and [a], of [g] and [a], and of [b] and [i]. On the other hand, [εb] shows greater spectral change than [bε]. In all the other combinations, however, differences in the magnitude of spectral change between CV and VC syllables seem to be very small.

CV and VC: 'dissimilarity'

Table 14 shows the degrees of 'dissimilarity' computed for pairs of CV syllables and of VC syllables. The data are graphically shown in Figure 46 where the CV syllables appear on the left side and the VC

Table 14

'Dissimilarity' in Hz between CV Syllables
and between VC Syllables

	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
Pair of Initial Stops Compared				
[b]-[d]	1370	1789	3362	5143
[d]-[g]	1712	2536	2004	3934
[b]-[g]	2767	3195	4595	1931
Pair of Final Stops Compared				
[b]-[d]	1013	1544	2292	2013
[d]-[g]	1145	3299	2060	1524
[b]-[g]	829	3952	1085	792

Note: 'Dissimilarity' between CV syllables is shown in the upper half. 'Dissimilarity' between VC syllables is shown in the lower half.

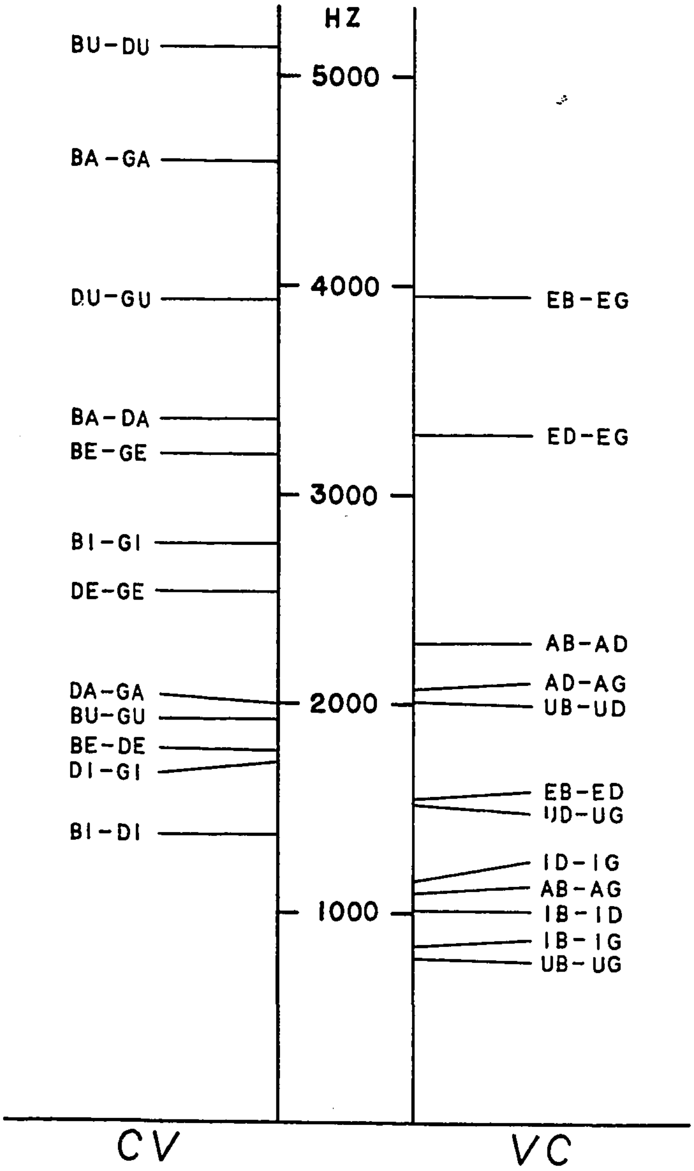

Figure 46: 'Dissimilarity' in Hz between CV Syllables and between VC Syllables. Pairs of CV syllables are shown on the left. Pairs of VC syllables are shown on the right.

syllables on the right side. The pairs of syllables are ranked according to their values of 'dissimilarity' on the frequency scale in Hz in the middle. Figure 47 shows the corresponding 'dissimilarity' values in Mels. Among the pairs of CV syllables, [bi]-[di], [di]-[gi], [bɛ]-[dɛ], [bu]-[gu], and [da]-[ga] are especially similar, while such pairs as [bu]-[du], [ba]-[ga], [du]-[gu], and [ba]-[da] are spectrally dissimilar. Among the pairs of VC syllables, [ib]-[ig], [ib]-[id], [ub]-[ug], and [id]-[ig] are spectrally similar, while [ɛb]-[ɛg] and [ɛd]-[ɛg] are spectrally dissimilar.

We further note that the degrees of spectral difference among the CV syllables are on the whole greater than those among the VC syllables. This is apparent in the scatter of values for the VC pairs toward the lower end of the scale in Figures 46 and 47. This result seems to indicate that the stops are spectrally better contrasted in the syllable-initial position than in the syllable-final position.

4.4.4. Comparison between stop + glide clusters and CV syllables

The initial 30 msec. of the Cw and Cj clusters were compared with the initial 30 msec. of various CV syllables. The resulting values of 'dissimilarity' in Hz are given in Tables 15 and 16. The corresponding values of 'dissimilarity' in Mels are given in Tables 17 and 18. The two smallest values in each row of Tables 15, 16, 17, and 18 are plotted in Figures 48, 49, 50, and 51, respectively. In these figures, the pairs are ranked according to their values of 'dissimilarity' on the frequency scale in Hz on the left. The pairs of [b] + glide and a CV syllable are listed in the left column, the pairs of [d] + glide and a CV syllable in the middle column, and the pairs of [g] + glide and a

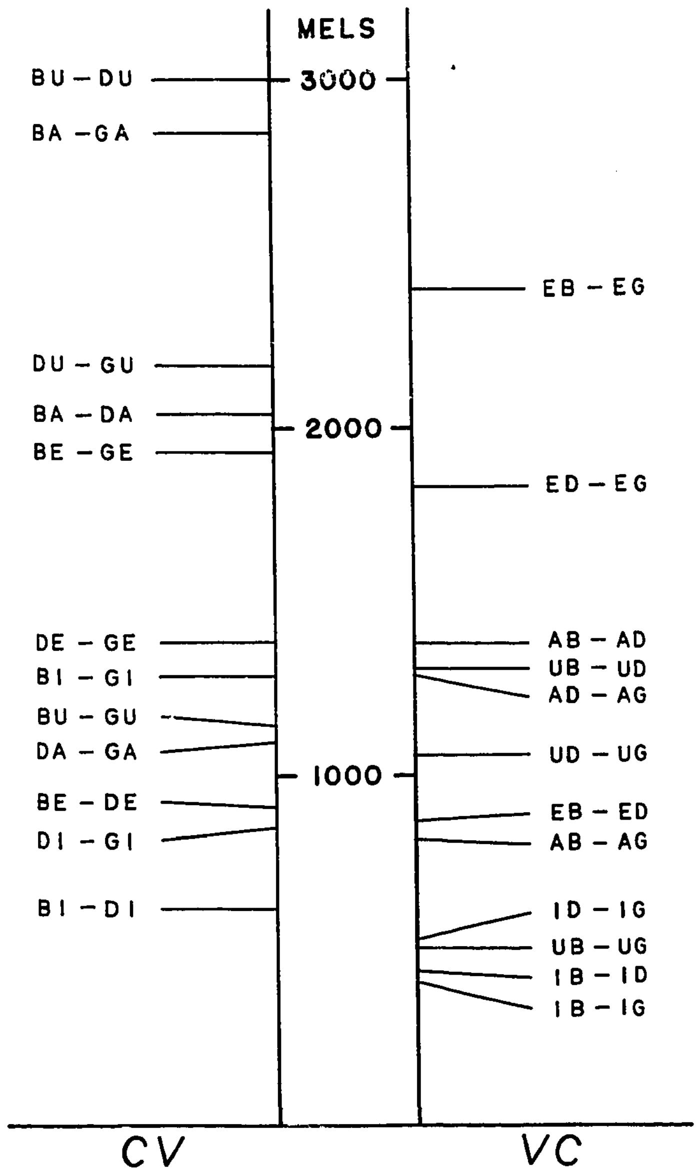

Figure 47: 'Dissimilarity' in Mels between CV Syllables and between VC Syllables. Pairs of CV syllables are shown on the left. Pairs of VC syllables are shown on the right.

Table 15

'Dissimilarity' in Hz between Cw Cluster and CV Syllable in Initial 30 Msec.

Pair of Cw and CV Compared	Vocalic Contexts in CV Syllables			
	[i]	[ε]	[a]	[u]
Pair of [bw] & CV				
[bw]-[bV]	3791	2752	1492	1330
[bw]-[dV]	4397	3545	3073	3529
[bw]-[gV]	5336	4259	3413	1817
Pair of [dw] & CV				
[dw]-[bV]	2345	1499	1338	583
[dw]-[dV]	2911	2148	1789	2013
[dw]-[gV]	3849	2781	1961	649
Pair of [gw] & CV				
[gw]-[bV]	3592	2614	1502	1139
[gw]-[dV]	4210	3401	2968	3324
[gw]-[gV]	5148	4075	3237	1571

Note: 'Dissimilarity' between [bw] and CV is shown at the top, 'dissimilarity' between [dw] and CV is shown in the middle, and 'dissimilarity' between [gw] and CV is shown at the bottom. Columns indicate vowels in CV syllables.

Table 16

'Dissimilarity' in Hz between Cj Cluster
and CV Syllable in Initial 30 Msec.

Pair of Cj and CV Compared	Vocalic Contexts in CV Syllables			
	[i]	[ɛ]	[a]	[u]
Pair of [bj] & CV				
[bj]-[bV]	355	1480	3039	2539
[bj]-[dV]	707	1127	1671	907
[bj]-[gV]	1529	850	1182	2190
Pair of [dj] & CV				
[dj]-[bV]	899	1980	3512	3079
[dj]-[dV]	168	1133	1702	969
[dj]-[gV]	1036	758	1367	2758
Pair of [gj] & CV				
[gj]-[bV]	1582	2799	4407	3991
[gj]-[dV]	961	1983	2586	1825
[gj]-[gV]	207	1201	2097	3633

Note: 'Dissimilarity' between [bj] and CV is shown at the top, 'dissimilarity' between [dj] and CV is shown in the middle, and 'dissimilarity' between [gj] and CV is shown at the bottom. Columns indicate vowels in CV syllables.

Table 17

'Dissimilarity' in Mels between Cw Cluster and CV Syllable in Initial 30 Msec.

Pair of Cw and CV Compared	Vocalic Contexts in CV Syllables			
	[i]	[ε]	[a]	[u]
Pair of [bw] & CV				
[bw]-[bV]	2320	1826	1246	926
[bw]-[dV]	2598	2184	1964	2180
[bw]-[gV]	3056	2544	2143	1247
Pair of [dw] & CV				
[dw]-[bV]	1300	1095	1247	400
[dw]-[dV]	1567	1292	1194	1143
[dw]-[gV]	2019	1541	1218	377
Pair of [gw] & CV				
[gw]-[bV]	2146	1759	1335	786
[gw]-[dV]	2432	2085	1912	2013
[gw]-[gV]	2879	2401	2032	1047

Note: For details, see the Note in Table 15.

Table 18

'Dissimilarity' in Mels between Cj Cluster and CV Syllable in Initial 30 Msec.

Pair of Cj and CV Compared	Vocalic Contexts in CV Syllables			
	[i]	[ɛ]	[a]	[u]
Pair of [bj] & CV				
[bj]-[bV]	207	1157	2075	1452
[bj]-[dV]	381	911	1239	499
[bj]-[gV]	724	613	902	1167
Pair of [dj] & CV				
[dj]-[bV]	449	1335	2278	1704
[dj]-[dV]	185	929	1269	510
[dj]-[gV]	477	554	948	1432
Pair of [gj] & CV				
[gj]-[bV]	787	1698	2691	2147
[gj]-[dV]	515	1269	1636	923
[gj]-[gV]	102	760	1270	1862

Note: For details, see the Note in Table 16.

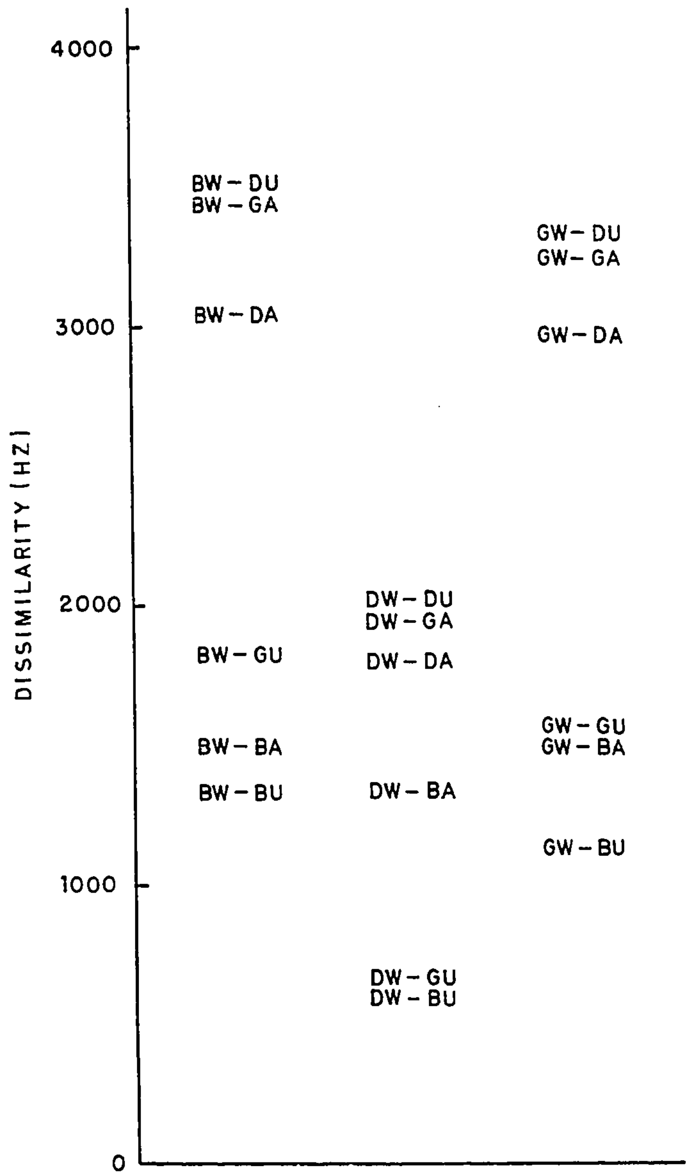

Figure 48: 'Dissimilarity' in Hz between Cw Cluster and CV Syllable. Two smallest values in each row of Table 15 are plotted. [bw]-CV pairs are shown on the left. [dw]-CV pairs are shown in the middle. [gw]-CV pairs are shown on the right.

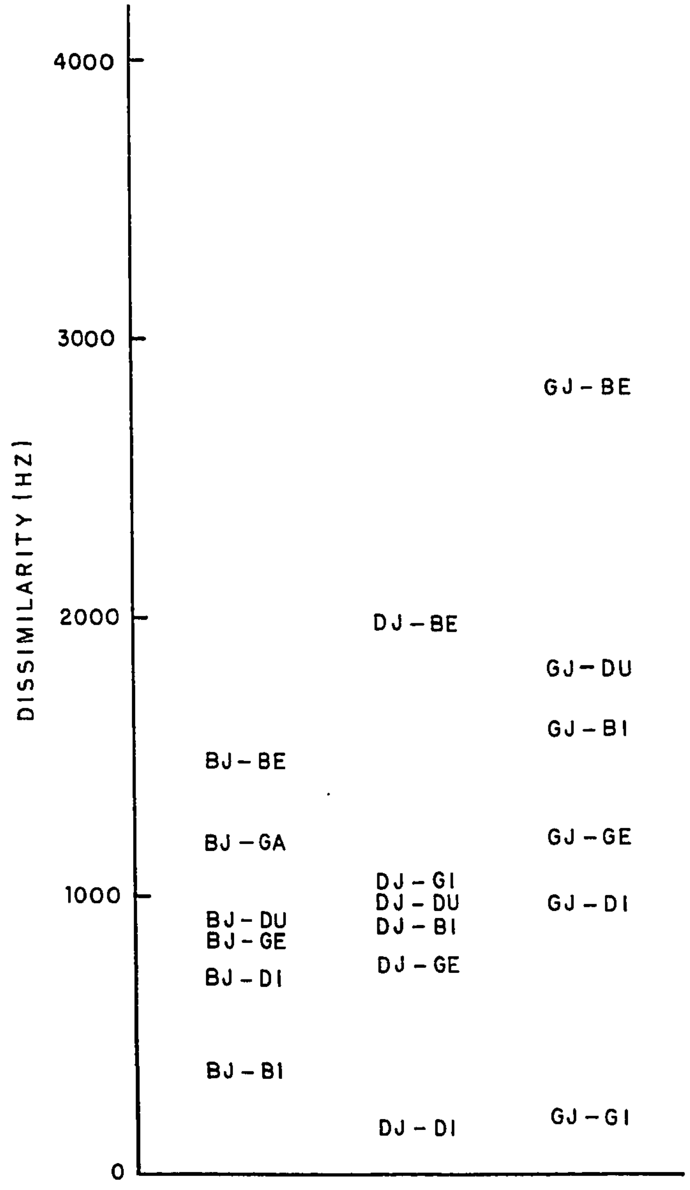

Figure 49: 'Dissimilarity' in Hz between Cj Cluster and CV Syllable. Two smallest values in each row of Table 16 are plotted. [bj]-CV pairs are shown on the left. [dj]-CV pairs are shown in the middle. [gj]-CV pairs are shown on the right.

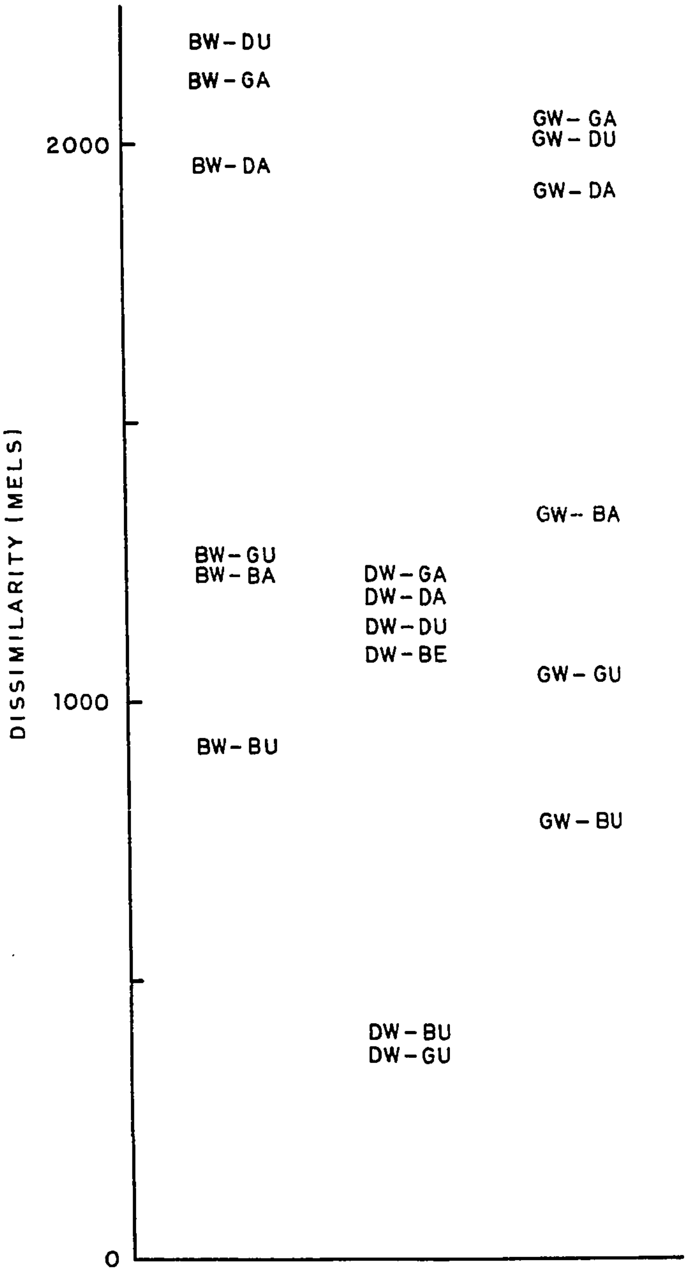

Figure 50: 'Dissimilarity' in Mels between Cw Cluster and CV Syllable. Two smallest values in each row of Table 17 are plotted. [bw]-CV pairs are shown on the left. [dw]-CV pairs are shown in the middle. [gw]-CV pairs are shown on the right.

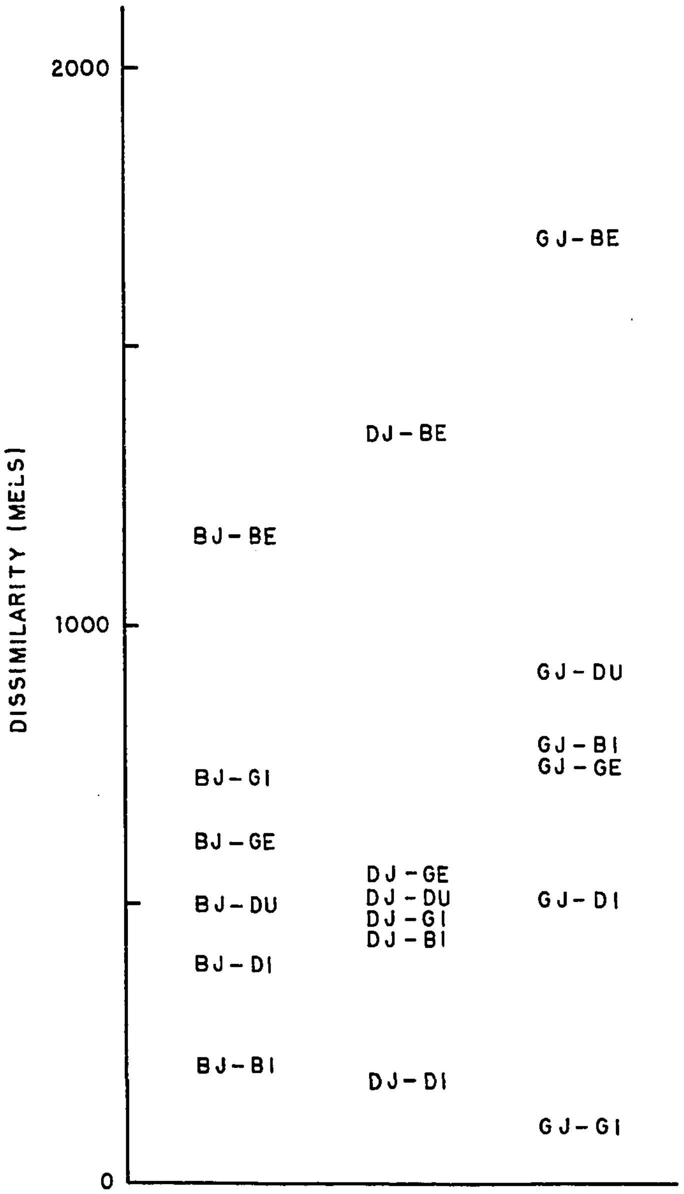

Figure 51: 'Dissimilarity' in Mels between Cj Cluster and CV Syllable. Two smallest values in each row of Table 18 are plotted. [bj]-CV pairs are shown on the left. [dj]-CV pairs are shown in the middle. [gj]-CV pairs are shown on the right.

CV syllable in the right column. Among the pairs of stop + [w] and stop + vowel, [dw]-[bu], [dw]-[gu], and [gw]-[bu] are spectrally very similar. If we disregard such pairs as [dj]-[di], [gj]-[gi], and [bj]-[bi] where the initial stops are identical, [bj]-[di], [bj]-[du], [dj]-[bi], [dj]-[du], [dj]-[gi], [dj]-[ge], and [gj]-[di] are especially similar among the pairs of stop + [j] and stop + vowel.

4.4.5. Comparison among stop + sonorant + vowel sequences

Figures 1, 2, 3, 4, 5, 6, 17, 18, and 19 reveal a certain spectral characteristic shared by the clusters of a stop + [l], of a stop + [r], and of a stop + [w], i.e., a relatively low F_2 vis-à-vis the F_2 of adjacent vowels. Therefore, comparisons were made among the syllables with these three types of clusters.

Table 19 shows the values of 'dissimilarity' in Hz between each pair of Cl and Cr clusters in an identical consonantal and vocalic context. The data are graphically represented in Figure 52. The 'dissimilarity' in Mels for the same pairs is given in Figure 53.

Table 20 shows the values of 'dissimilarity' in Hz between each pair of Cl and Cw clusters in an identical consonantal and vocalic context. The data are graphically represented in Figure 54. The 'dissimilarity' in Mels for the same pairs is given in Figure 55.

Table 21 shows the values of 'dissimilarity' in Hz between each pair of Cr and Cw clusters in an identical consonantal and vocalic context. The data are graphically represented in Figure 56. The 'dissimilarity' in Mels for the same pairs is given in Figure 57.

The results show that, among Cl, Cr, and Cw clusters, Cl and Cw are the spectrally most similar. Furthermore, Cl and Cw clusters are

Table 19

'Dissimilarity' in Hz between Cl and Cr Clusters in Four Vocalic Contexts

Pair of Cl and Cr Clusters Compared	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
[bl]-[br]	10726	10241	12529	10464
[dl]-[dr]	9260	10866	11637	11872
[gl]-[gr]	8406	9474	10624	8905

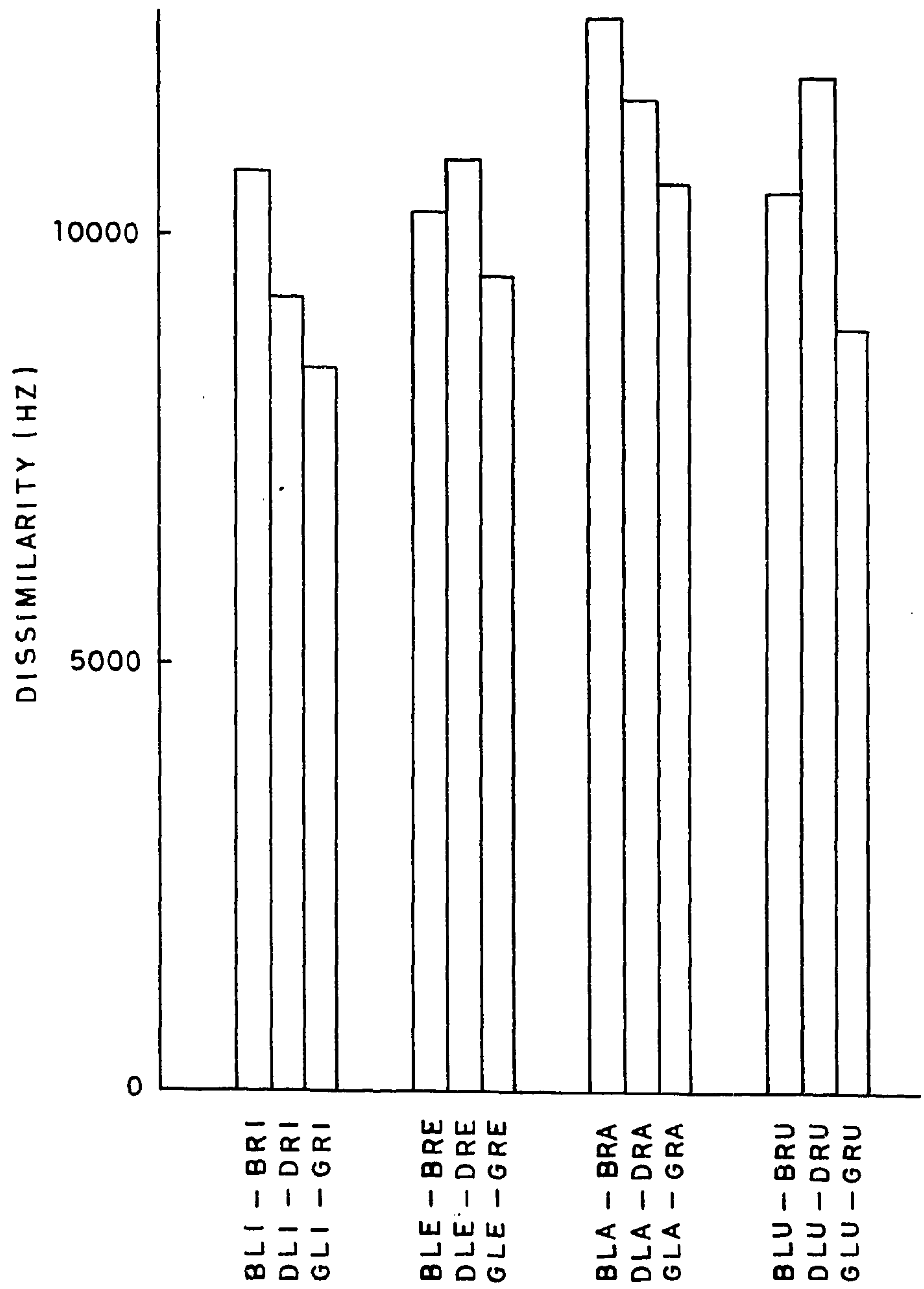

Figure 52: 'Dissimilarity' in Hz between Cl and Cr Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

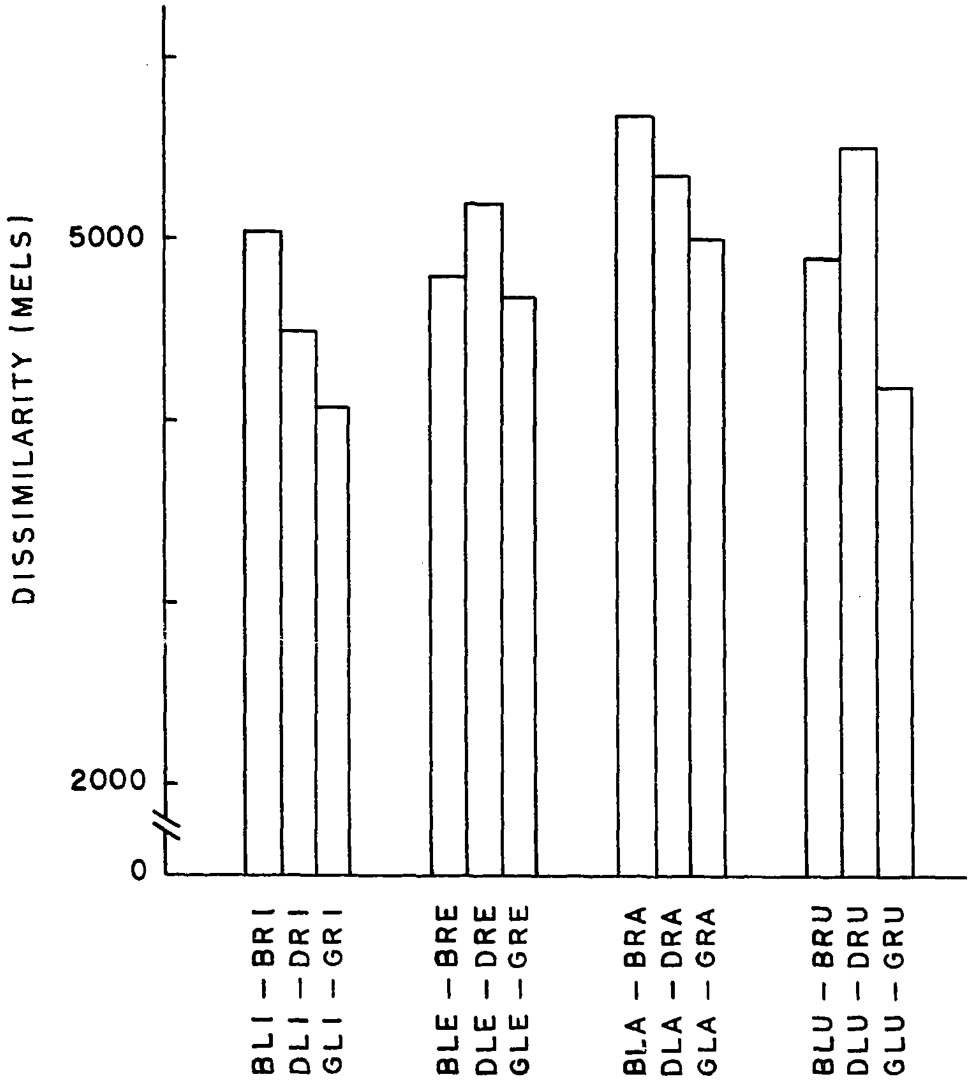

Figure 53: 'Dissimilarity' in Mels between Cl and Cr Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

Table 20

'Dissimilarity' in Hz between Cl and Cw Clusters in Four Vocalic Contexts

Pair of Cl and Cw Clusters Compared	Vocalic Contexts			
	[i]	[ε]	[a]	[u]
[bl]-[bw]	8042	7366	6977	10453
[dl]-[dw]	4929	6362	5927	7410
[gl]-[gw]	6564	7036	7688	7966

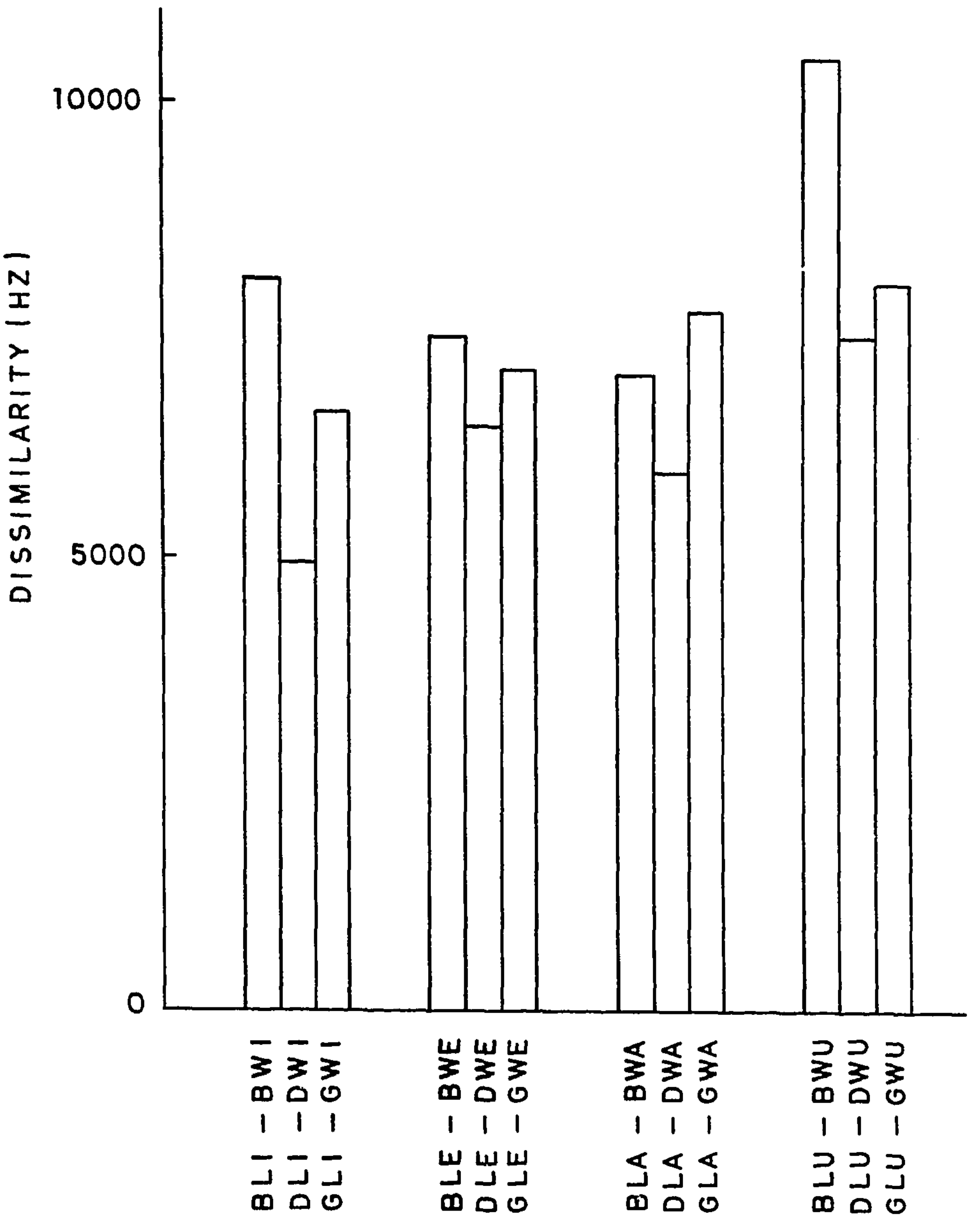

Figure 54: 'Dissimilarity' in Hz between Cl and Cw Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

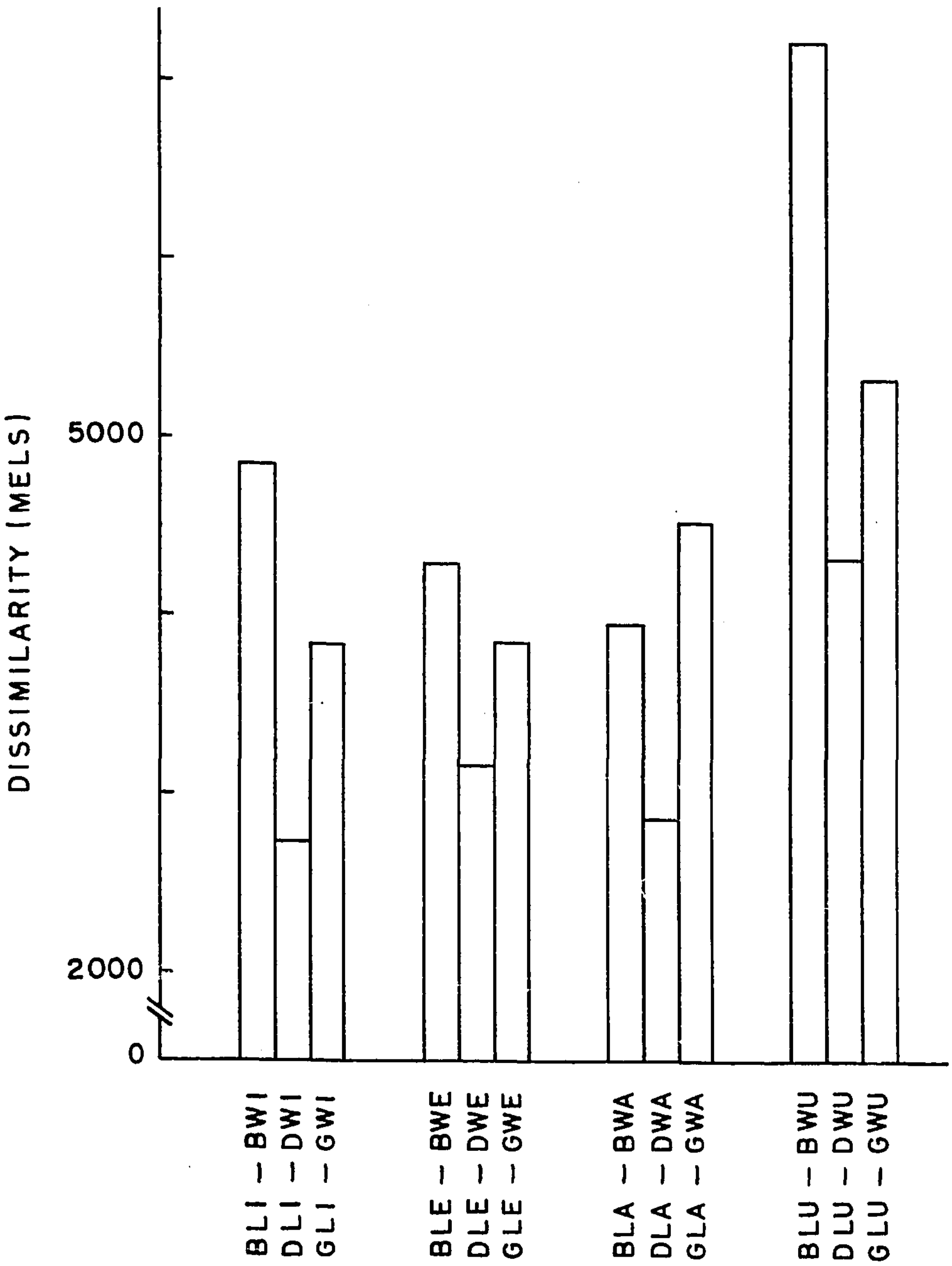

Figure 55: 'Dissimilarity' in Mels between Cl and Cw Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

Table 21

'Dissimilarity' in Hz between Cr and Cw Clusters in Four Vocalic Contexts

Pair of Cr and Cw Clusters Compared	Vocalic Contexts			
	[i]	[ɛ]	[a]	[u]
[br]-[bw]	9067	10995	10753	13483
[dr]-[dw]	7712	8667	8534	11190
[gr]-[gw]	5867	7776	8419	9647

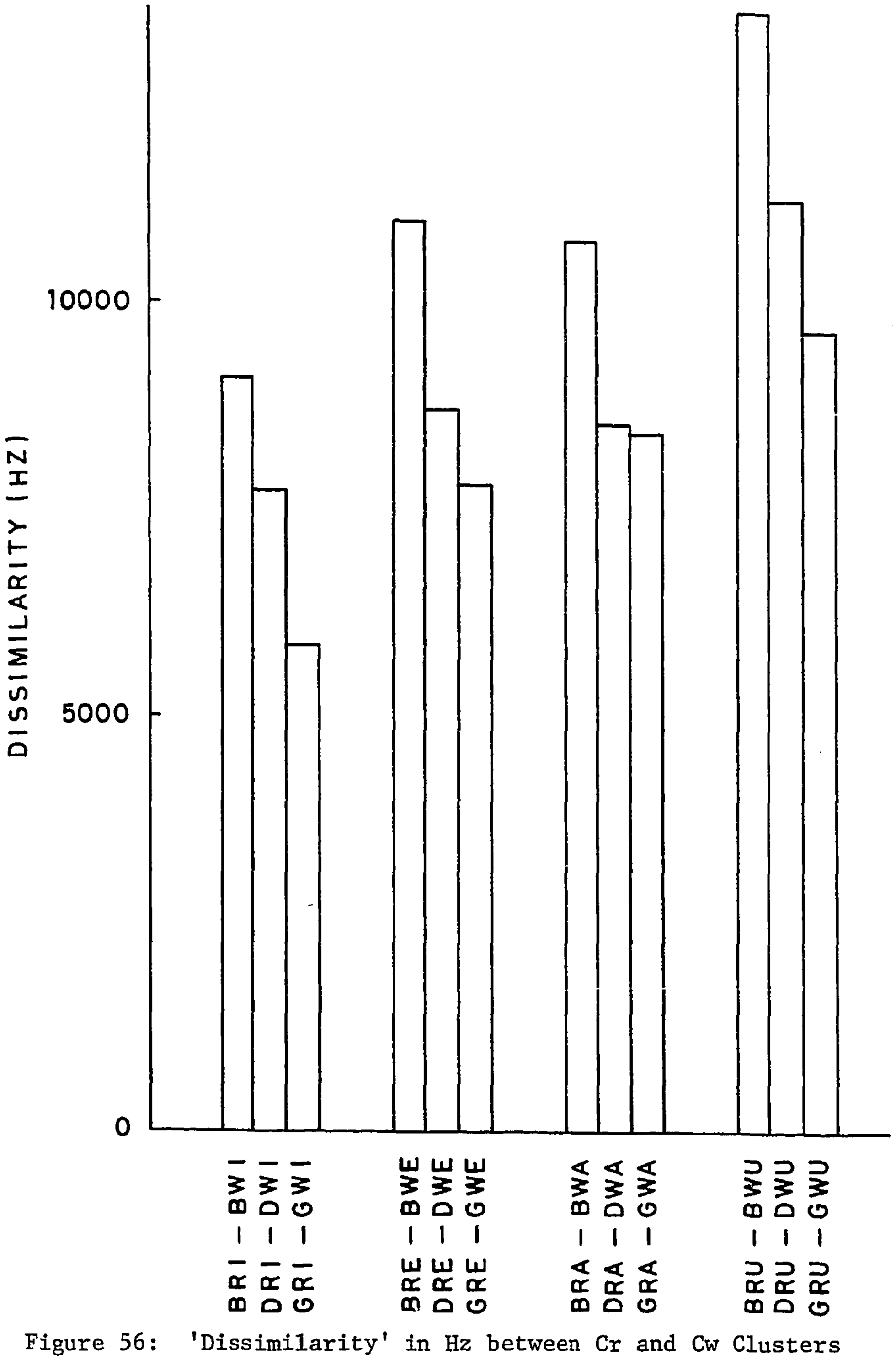

Figure 56: 'Dissimilarity' in Hz between Cr and Cw Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

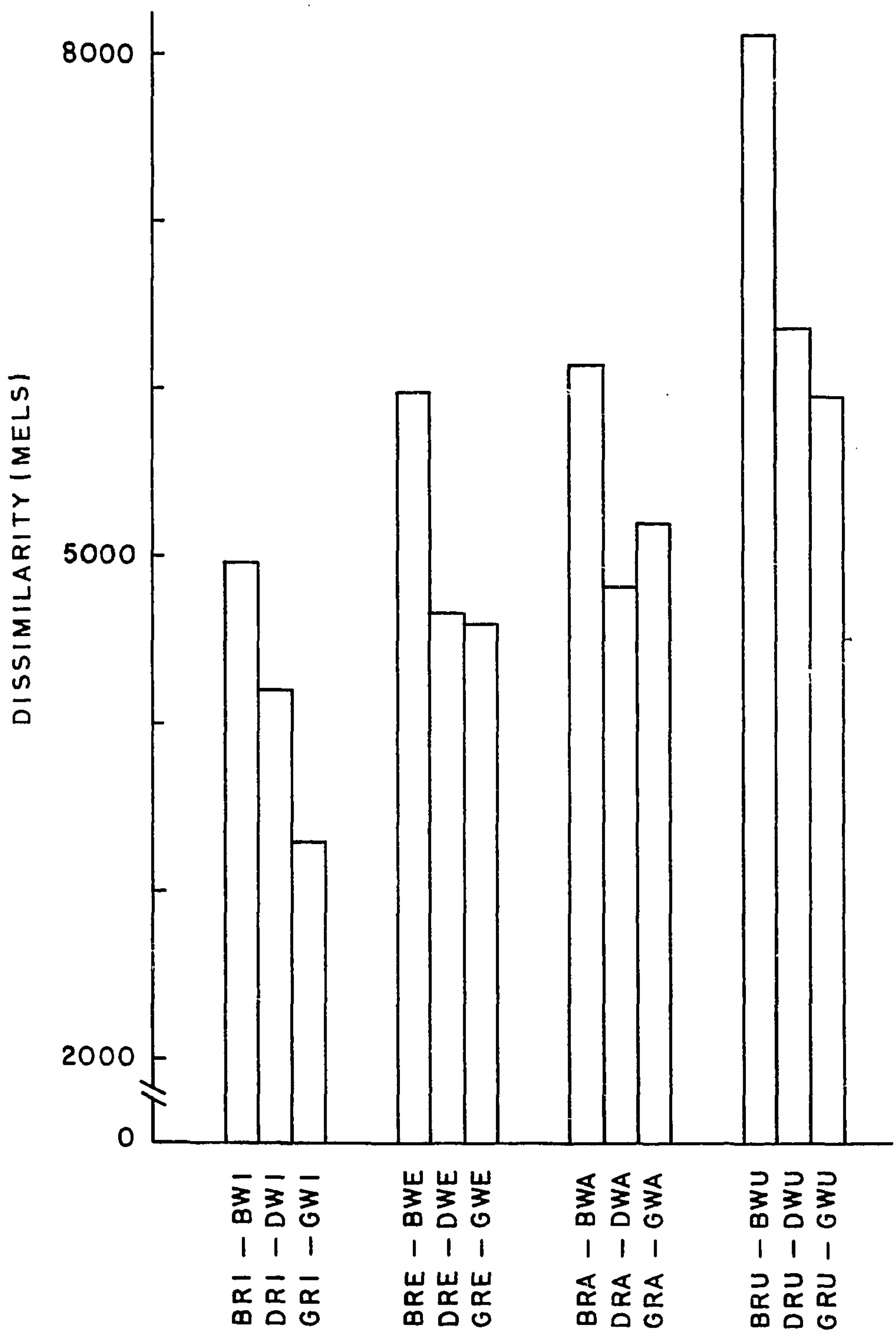

Figure 57: 'Dissimilarity' in Mels between Cr and Cw Clusters in Four Vocalic Contexts. Pairs of initial clusters in the same vocalic context are shown together on the abscissa.

more similar to each other when the initial stop is [d] than when it is [b] or [g]. This holds for all the vocalic contexts. It is also found that Cw and Cr clusters are more different when the initial stop is [b] than when it is [d] or [g].

Table 22 shows the 'dissimilarity' computed for various pairs of stop + sonorant clusters for the duration of the initial 30 msec. The values in parenthesis are in Mels. The 'dissimilarity' values in Hz in this table are also graphically represented in Figure 58. Here again, the pair of [dl] and [dw] clusters seems to be acoustically more similar than any other pair of stop + sonorant cluster. When the data in Figures 33 and 58 are compared, we find that the degree of acoustic similarity between [dl] and [dw] is greater than those between [bw] and [gw] and between [dl] and [gl], but smaller than those between [bl] and [gl] and between [bj] and [dj]. Figure 58 also shows that the spectral differences between Cl and Cr clusters and between Cr and Cw clusters are greater when the initial stops are at forward places of articulation.

4.5. Discussion

This section discusses the results in conjunction with some of the phonological universals presented in Chapter Two with occasional reference to the findings of other phonetic studies.

4.5.1. Clusters of a stop and a liquid

Clusters of a stop and a liquid show smallest overall formant frequency change when followed by the high back vowel [u] (see Figures 7, 8, 9, and 10). This tendency holds whether the initial stop is

Table 22

'Dissimilarity' in Hz and in Mels between Various Pairs of Stop + Sonorant Clusters in Initial 30 Msec.

Pair of Clusters Compared	Hz	(Mels)
Pair of Cl and Cr		
[bl]-[br]	2006	(957)
[dl]-[dr]	1495	(679)
[gl]-[gr]	1253	(664)
Pair of Cl and Cw		
[bl]-[bw]	1187	(834)
[dl]-[dw]	643	(380)
[gl]-[gw]	1550	(1049)
Pair of Cr and Cw		
[br]-[bw]	2239	(1199)
[dr]-[dw]	1322	(692)
[gr]-[gw]	1034	(645)

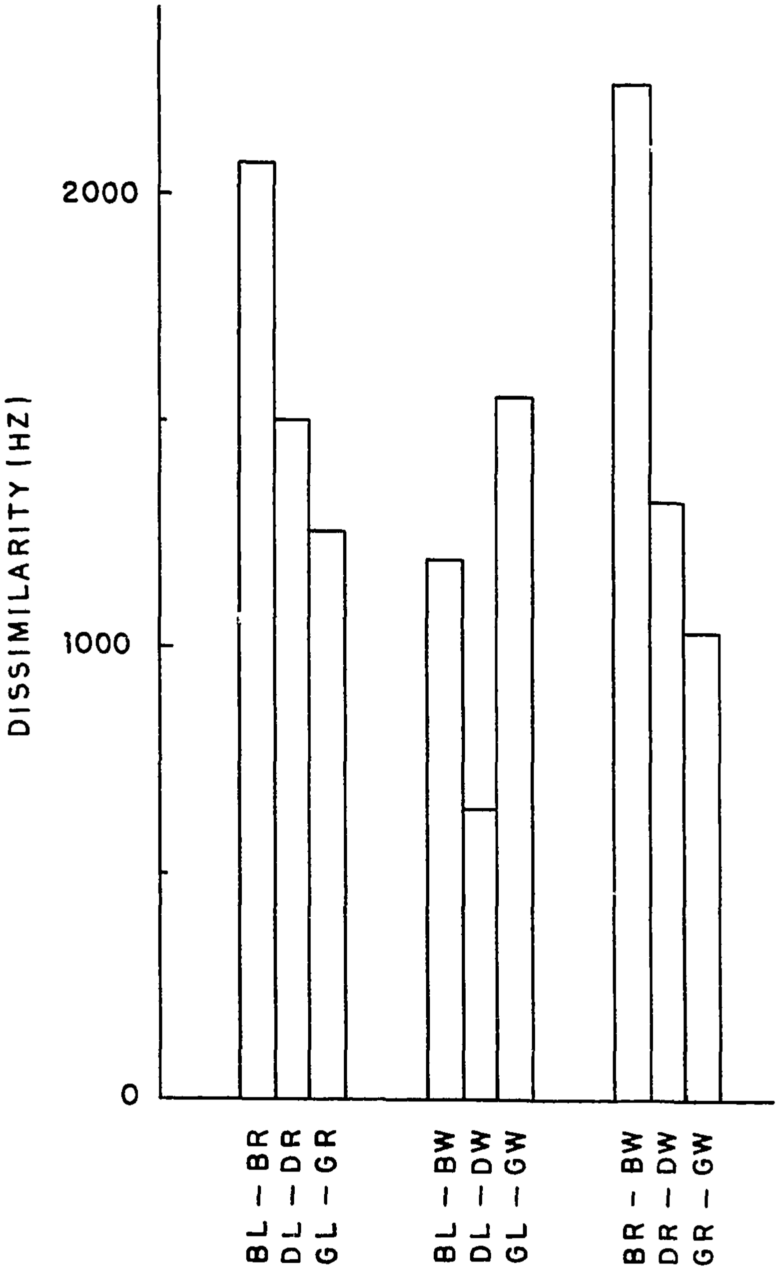

Figure 58: 'Dissimilarity' in Hz between Various Pairs of Stop + Sonorant Clusters. Initial 30 msec. are compared.

bilabial, alveolar, or velar, and whether the liquid is [l] or [r]. In the main, this is due to the fact that these liquids and the vowel [u] have similar F_1 and F_2. The difference in F_2 between [l] or [r] and the following vowel is actually smallest for the vowel [a]. However, there is an appreciable upward shift in F_1 in the sequences [la] and [ra], since the F_1 of [l] and [r] is fairly low and that of [a] is very high. The change in F_1 is very small in the sequence [lu], and is almost non-existent in the sequence [ru].[38] Among all the combinations of [r] and a vowel, [ru] shows the least F_3 change.

The hypothesis thus predicts the sequences [lu] and [ru], which are acoustically not well modulated, should be among the universally disfavored. However, liquids seem to be relatively freely combined with vowels. We find no obvious phonotactic skewings restricting sequences of a liquid and [u] while allowing sequences of a liquid and a front vowel. Whether or not such a skewing would manifest itself in the relative frequency of occurrence of liquid + vowel sequences is an open question.

The clusters of a stop and a liquid show the least spectral change when the initial stop is bilabial. In the case of [bl], this is because of the relatively unvarying F_2 throughout the interval of [l]. The F_2 onset after [b] is around 1200 Hz, which is closer to the target F_2 frequency in [l] than the F_2 onsets after [d] and [g] are. Moreover, except for the sequence [bla], the F_2 frequency in the middle of [l] is 130 to 200 Hz higher and therefore closer to the F_2 of the following vowel after [b] than after [d] or [g].[39] This may indicate a greater extent of coarticulation between [l] and the following vowel after the initial stop [b]. This is reasonable since the lip articulation would not interact with or constrain the lingual articulation.

In the case of [br], both F_2 and F_3 onsets are as low as 1240 Hz and 2050 Hz, respectively, which are closer than the F_2 and F_3 onsets after [d] or [g] to the F_2 and F_3 frequencies in [r], and hence this cluster yields the least spectral change among all the Cr clusters. Although the F_2 frequencies are compatible between [br] and [gr] at the consonantal release, they are somewhat different in the middle of [r]. The F_2 in [r] following [g] is lower than that following [b] by 100 to 180 Hz. Thus, the magnitude of F_2 change is greater in [gr] than in [br].

In general, formant frequencies change to the greatest extent in [d] + liquid clusters. This is primarily due to the high F_2 onset at the consonantal release. The spectral change in [g] + liquid clusters is sometimes as much as that in [d] + liquid clusters.

The results discussed so far are not totally compatible with the phonological universals that were presented earlier. They would suggest that clusters of a bilabial stop and a liquid should be among the infrequent clusters and clusters of an alveolar stop and a liquid among the most frequent ones. This is not true except for the relative commonness of alveolar stop + [r] clusters. In particular, they fail to predict the strong tendency in the world's languages to disfavor alveolar stop + [l] clusters. Therefore, the attested universal patterns are not explained solely by the magnitude of spectral change, i.e., the degree of phonetic contrast, within sound sequences, as measured here. However, it should be noted here that the magnitudes of spectral change are smaller for the clusters of a stop and [l] than for the clusters of a stop and [r], which implies that the Cl clusters as a class may not be as favorable sequences as the Cr clusters are.

The other factor hypothesized to be a determinant of sequential constraints, namely the degree of spectral difference among sequences, seems to at least partly explain the universals concerning stop + liquid clusters. The data reveal that the clusters with [r] are better differentiated among themselves than the clusters with [l], as can be seen in Figure 33. This is due to the following formant patterns. In terms of F_2, [gr] and [br] are similar and they are both distinctly different from [dr], while in terms of F_3 and F_1, [dr] and [gr] are closer and [br] is different from either of them (see Figure 16). Specifically, the difference in the F_2 onset between [br] and [gr] on the one hand and [dr] on the other is about 435 Hz, and the difference in the F_3 onset between [dr] and [gr] on the one hand and [br] on the other is about 220 Hz. Thus the three initial stops present a clear contrast to one another. This may explain why there is no apparent gap in the series of Cr clusters in many languages, and why in the case of skewed series the gap is not found at any particular place of articulation. The differences among the clusters with [l] are smaller. [dl] and [gl] are especially similar to each other in terms of the F_2 and F_3 frequencies during [l] as well as at the consonantal release (see Figures 15 and 33). The spectral similarity between [dl] and [gl] may be responsible for the dialectal variation between the two in Katu (discussed in Section 2.5). We can find more examples of alternations between these two clusters. Abercrombie (1937) found a case of the English word cloaks being transcribed as [tlôx] by a spelling reformist circa 1700. In late Latin, an unstressed penultimate vowel was dropped in such words as vetulus and vitulus. The medial cluster [tl] was then replaced by [kl], yielding veclus and viclus (Pole 1934). The data further reveal a spectral similarity between [dl] and [dw] (see Figures 54, 55, and 58). The absence or relative infrequency of alveolar stop + [l] clusters may therefore be ascribed to spectral similarities of these clusters to other stop + sonorant clusters.

The finding that the clusters with [w] are spectrally closer to the clusters with [l] than to the clusters with [r] (Figures 54, 55, 56, and 57) is contrary to what we might expect on the basis of a well-attested pattern of sound substitution in child phonology. In the acquisition of word-initial clusters, Cr is often replaced by or alternates with Cw (Compton and Streeter 1977). Acoustically, Cw is distinct from both Cl and Cr because of its lower F_2.[40] However, the differences among Cl, Cr, and Cw clusters are principally determined by their F_3 trajectories, which are closer between Cl and Cw than between Cr and Cw. It appears that the child's substitution of [w] for [r] has an articulatory rather than acoustic/auditory motivation.

4.5.2. Clusters of a stop and a glide

There is a greater spectral change in sequences of Cw and a front vowel than sequences of Cw and a back vowel (see Figures 20 and 21). The difference is primarily due to a greater amount of F_2 movement in the former. The F_2 changes by as much as 1200 to 1350 Hz in Cwi sequences. The Cj sequences, on the other hand, show a greater spectral change when followed by [a] or [u] than when followed by a front vowel (see Figures 28 and 29). The F_2 changes by 550 to 980 Hz in such sequences. As noted earlier, this is considerably less than the F_2

change in sequences of Cw and a front vowel. The results also show that the overall formant frequency change is slightly greater in Cja sequences than in Cju sequences. This is ascribable to the fact that the F_1 change in Cja is about 300 Hz greater than that in Cju whereas the F_2 change is not much greater in Cju than in Cja.

The acoustic hypothesis thus correctly predicts the universal preference for the sequences of a labiovelar glide or a labialized consonant and a front vowel on the one hand, and for the sequences of a palatal glide or a palatalized consonant and a back vowel (discussed in Section 2.7). Languages seem to fully utilize acoustically well-modulated sound sequences.

The hypothesis has more implications than can be verified by the linguistic data at hand. The acoustic data show that formant frequencies change to a greater extent in [wi] than in [ju], which may suggest that the former sequence should be more favored than the latter sequence. The prediction is not supported by the phonotactics of Modern Japanese which has [ju] but not [wi]. The data also indicate that [ja] is a better modulated sequence than [wa]. Whether or not preferences for [wi] over [ju] and for [ja] over [wa] are universally prevailing patterns is a question yet to be investigated in the phonological literature. It was pointed out in Section 2.7 that some languages allowed [w], labialized consonants, [j], or palatalized consonants only before low vowels. Additional phonological evidence for the preference for [ja] over [ju] is found in some Kanto dialects of Japanese, where /ju/ changed to [i] while /ja/ remained unchanged, and in a number of dialects throughout Japan which have postconsonantal /ja/ but lack postconsonantal /ju/ (Oishi and Uemura 1975). English, on the other hand, presents a pattern contrary to this; the postconsonantal /j/ is followed only by /u/ (Hofmann 1967, Jones 1967). Acoustically, [ju] and [ja] seem almost equally well-modulated in terms of their linearly measured magnitudes of formant frequency change. The formant frequency change measured in Mels suggests that [ja] may be psychoacoustically better modulated than [ju].

Ainu provides additional evidence for the preference for [wa] over [wi]. While the syllable /wa/ may appear in native Ainu words, the syllable /wi/ is described by Kindaichi (1960) as appearing only in onomatopoeia, and is described by Chiri (1956) as non-existent. Old Japanese had the syllables /wi, we, wa, wo/. Among these, /wi/ was the first to disappear. /we/ and /wo/ disappeared later, and only /wa/ is allowed in Modern Standard Japanese (Okumura 1972, 1977). Similarly, among the syllables /kwi, kwe, kwa, kwo/ that existed in Middle Japanese, /kwi/ disappeared fairly early. /kwa/ remained longest, and is still found in a number of Japanese dialects (Okumura 1972, 1977). The vowel cluster /ui/ often undergoes sound change in Japanese. It is realized as [i:] in the Hokuriku, Nagano, Kyushu, and southern Tohoku dialects, and as [u:] in the Aichi and Gifu dialects (Oishi and Uemura 1975). Acoustic data, however, do not predict such patterns. [wi] is a considerably better modulated sequence than [wa].

It is not certain how general this tendency to avoid sequences of a glide and a high vowel is. Also hard to determine is whether combinations of low and high vowels are more frequent than combinations of high front and high back vowels. Such seems to be an indication of the data presented in Section 2.8, but a more extensive and systematic search is needed to clarify the picture. There may be other possible reasons why the vowel /a/ is preferred to be combined with glides, labialized or palatalized consonants, and high vowels. One of them may be the maximal amount of F_1 frequency change in such sequences. Multidimensional analyses of the listener's dissimilarity judgments on vowel qualities have shown that F_1, which is directly proportional to vowel height, is the most perceptually salient dimension of vowels (Terbeek and Harshman 1971, Wright 1980). Whether this factor plays any role in determining preferred sound sequences is not clear.

Clusters of a stop and [w] exhibit the greatest formant frequency change when the initial stop is [d] (see Figures 20 and 21). This is mainly due to the high F_2 onset after [d] compared to that after [b] or [g]. The F_2 at the release of [d] is around 1460 Hz, which is 520 to 620 Hz higher than the F_2 in the following [w]. In the sequences of [bw] and [gw], the F_2 during [w] is lower than in [dw] by 50 to 160 Hz. However, the overall F_2 frequency change is much smaller than in [dw], since their F_2 onsets are low, i.e., 1000 to 1120 Hz.

The rarity of [bw] is predicted by its small magnitude of spectral change. [gw] is likewise predicted to be a disfavored sequence on the same ground, and [dw] is predicted to be a favored sequence because of its greater magnitude of spectral change. English exhibits patterns in line with these predictions. The stop + /w/ clusters that appear in native words are /tw/, /dw/, and /kw/. The other clusters such as /pw/, /bw/, and /gw/ appear only in loans (Hultzén 1965b, Trnka 1968). As discussed in Section 2.6.1, many languages lack clusters of a labial consonant and [w] or labialization of labial consonants. These constraints are explained by the acoustic hypothesis. However, the hypothesis does not explain why labialization as a secondary articulation is most common in velar consonants. It is possible that some other factors not considered in the current hypothesis, such as burst amplitudes, determine the favoring of [g^w] as opposed to the disfavoring of [b^w].

Clusters of a stop and [j] show the least spectral change when the initial stop is [d] (see Figures 28 and 29). This is due to the proximity between the onset F_2 frequency and the target F_2 frequency of [j]. The F_2 starts and stays almost steady around 2000 Hz in [dj]. The F_2 invariably rises in [bj] and falls in [gj] after the consonantal release, and hence greater amounts of spectral change in these sequences. Thus, the acoustic hypothesis correctly predicts the absence or rarity of alveolar consonant + [j] clusters and of palatalization of alveolar consonants.

Among the stop + [w] clusters, [gw] and [bw] are by far the closest pair (see Figure 33). This is because they have very similar F_2 trajectories. Among the stop + [j] clusters, [bj] and [dj] are the closest pair (see Figure 33). This is again due to the similarity in F_2. The comparisons between stop + glide clusters and CV syllables (in Section 4.4.4) show the following pairs to be among the closest: [dw]-[bu], [gw]-[bu], [bj]-[di], [bj]-[du], and [dj]-[bi] (see Figures 48, 49, 50, and 51). The auditory similarity in some of these pairs has been documented in the phonetic literature. For instance, Saito (1961) and Iida (1973) reported that [pj] and [bj] were frequently confused with [tʃ], [dʒ], and [ɾj] under noisy or filtered conditions. Spectral similarities and hence auditory similarities in these pairs explain the common change of labialized alveolars and velars to labials and of palatalized labials to alveolars (discussed in Section 2.9).

A question may be raised as to why the changes in initial stops are accompanied by the loss of glide elements. That is, [b] but not [b^w], and [d] but not [d^j] result from the original [g^w] and [b^j], respectively. A possible answer to this is as follows. It has already been pointed out that such sequences as [bw] and [dj] show but a minimal spectral change which may not be perceptually salient. Moreover, these labial and palatal glide elements may be taken by the listener as allophonic perturbatory effects of the initial stops on the following vowels and consequently factored out perceptually, yielding the simple stops [b] and [d]. Detailed discussion on this perceptual process is found in Ohala, Riordan, and Kawasaki (1978), Kawasaki (1978), and Ohala (1981). Especially relevant in this connection is an assumption of this perceptual process in an account for those sound changes traditionally known as 'dissimilation'. See Ohala (1979a, 1981) for examples of dissimilatory processes and the phonetic explanations for them.

The results also suggest the spectral similarities in such pairs as [dj]-[gi], [dj]-[ge], and [gj]-[di]. So-called 'Velar Softening', a change characterized by fronting and (af)frication of palatalized velars, is generally thought of as an articulatorily caused sound change. And yet the above results indicate that the sounds involved in this change are also auditorily very similar and therefore likely to have one substituted for the other.

4.5.3. CV and VC syllables

The observed formant characteristics of the CV and VC syllables are very much in line with the spectrographic observations made by

Halle, Hughes, and Radley (1957). The CV syllables are characterized as follows. The F_2 and F_3 shift upward in [b] + front vowel sequences. They are either steady or falling in the syllables with [d]. [g] + front vowel sequences show a falling F_2, which is not observed in other stop + front vowel sequences. [gu], unlike the other gV syllables, is characterized by the widely separated F_2 and F_3 onsets. The VC syllables show the following characteristics. The F_2 and F_3 are falling in front vowels followed by [b]. The vowels before [d] show F_2 transitions that move toward a locus-like frequency region around 1750 Hz. Front vowels before [g] are characterized by converging F_2 and F_3. The F_2 rises in [u] only when followed by [d].

The magnitudes of spectral change in CV syllables are largely determined by their F_2 transitions. The syllables with relatively great spectral change are [bi], [da], [du], [ge], and [ga] (see Figures 40, 41, 42, 43, 44, and 45). The F_2 and F_3 rise sharply, by about 360 and 250 Hz respectively, in the initial 30 msec. of [bi]. In the four other syllables, the F_2 frequencies fall by 450 to 540 Hz. [bu], [di], [gi], and [gu], on the other hand, show very little spectral change. All three formants stay relatively steady throughout these syllables. Bondarko (1969) found for Russian that the difference between the onset and steady F_2 frequencies in a vowel is 900 Hz in bilabial + [ɨ], 500 Hz in alveolar + [u], and 0 Hz in bilabial or velar + [u]. Öhman (1966) measured the same for Swedish data and obtained the values 620 ~ 690 Hz for [du], 5 ~ 25 Hz for [bu], and 15 ~ 50 Hz for [gu].

The magnitudes of spectral change in VC syllables show similar tendencies. For example, [ub], [id], [ig], and [ug] have very little spectral change. However, there are some differences. [ud] is among the least spectrally modulated, though [du] is among the most so. [ɛb] shows the greatest spectral change among the Vb syllables, though [bɛ] is not as well modulated as [bi]. Such differences arise from the fact that the formant trajectories of CV and VC syllables are not necessarily mirror images of each other. The asymmetry between CV and VC formant transitions has been noted by Lindblom (1963), Öhman (1966), Stevens, House, and Paul (1966), and Broad and Fertig (1970) among others. Whether the formant excursion is greater in CV or VC seems to depend on both the stop and the vowel involved. Stevens et al. found that the final F_2 values are closer to the target F_2 values of the vowels than the initial F_2 values in the syllables CiC and CuC. This was only partially borne out by the present data, namely, in the pairs [bi]-[ib] and [du]-[ud]. Lindblom and Öhman also found for Swedish that the postconsonantal F_2 excursion was markedly greater than the preconsonantal F_2 excursion in [d] + back vowel + [d] and back vowel + [d] + back vowel sequences. In the sequences of [b] or [g] and a back vowel, however, the tendency was not as clear or even the opposite. Stevens et al. found that the deviation from the target F_2 is greater for the F_2 offset than the F_2 onset in such syllables as [bɛb] and [dɛd]. This is confirmed by the present data. As to the vowel [a], the initial transition is greater than the final transition especially for [d] and [g]. The Swedish data, however, showed this consistently only for [d].

These results have the following implications for universal phonotactic constraints. Evidence was presented in Section 2.7 that the sequences of a bilabial consonant and a rounded vowel, of a dental consonant and a front vowel, and of a velar consonant and a high vowel are disfavored regardless of the order of the consonant and the vowel. As the hypothesis predicted, these sequences are not spectrally well modulated. There is further evidence from the perceptual tests by Bondarko (1969) and Halle et al. (1957) that transitionless sound sequences such as these are susceptible to incorrect identification. The universal preference in syllable structure for CV over VC, on the other hand, cannot be explained simply in terms of their magnitudes of spectral modulation.

The results show that the following pairs are spectrally very similar: [bi]-[di], [ib]-[id], [bɛ]-[dɛ], [di]-[gi], [id]-[ig], [da]-[ga], [bu]-[gu], [ub]-[ug], and [ib]-[ig] (see Figures 46 and 47). Spectral similarities between [bi] and [di] and between [ub] and [ug] were pointed out by Halle et al. (1957). Perceptual studies have suggested that these acoustically similar syllables are very often confused with each other. In particular, misperception of bilabials for dentals in the context of [i] and of velars for bilabials in the context of [u] and [o] has been observed in a number of confusion studies (Halle et al. 1957, Winitz, Scheib, and Reeds 1972, Iida 1973). Thus, the cause of the common change of labials to dentals/alveolars/palatals before front vowels and of velars to labials before rounded vowels lies in their auditory similarities. As mentioned in the preceding section, the acoustic similarities between [d] and [g] in the context of [i] suggest that the change of Velar Softening is also auditorily motivated.

The results further indicated that, with a few exceptions, VC syllables are spectrally closer among themselves than CV syllables. This is in accordance with Öhman's (1966) finding in his spectrographic analysis of CV and VC transitions. He obtained the range of F_2 offset frequencies in øbV, ødV, øgV, and the range of F_2 onset frequencies in

Vbø, Vdø, and Vgø, where the vocalic context V was varied. He found that the range of F_2 offsets for [d] fell within that for [g] and that there was even a frequency region around 1450 Hz where the ranges of F_2 offsets for all three stops overlapped. Such an overlap was reduced somewhat when the terminal F_3 frequencies were also taken into consideration. Nevertheless, the ranges of F_2 and F_3 offsets for [b] and [g] still overlapped. The ranges of F_2 and F_3 *onsets*, on the other hand, were relatively well-defined for the three stops. The present results along with Öhman's indicate that the stops are better contrasted with each other when occurring in CV syllables than in VC syllables. This acoustic property may be partly responsible for the predominance of CV syllable structure in the world's languages.

There are certainly other properties, acoustic or otherwise, that may make CV syllables more favorable than VC syllables. Both transition and burst serve as perceptual cues to the identities of stops. In the final position, the burst cue is easily lost (Halle et al. 1957). Another possible factor is the difference in masking effects of vowels preceding or following a noise burst. Resnick, Weiss, and Heinz (1979) found that the forward masking effect (where a vowel precedes a burst) was greater than the backward masking effect (where a burst precedes a vowel). However, theirs and Slis and van Nierop's (1970) study concluded that masking would play only a minor role in the misperception of stops in VC syllables. Yet another possible determinant for the universal preference for CV was suggested by Malmberg (1965). He hypothesized that the stability of a phoneme is inversely proportional to its predictability. According to his argument, final phonemes are redundantly cued by preceding phonemes and therefore more predictable than initial stops. Hence, final phonemes are less resistant to loss. There may also be physiological/articulatory factors. Fromkin (1966), for example, found differences in neuromuscular activities between initial and final stops. However, it seems reasonable to assume that the observed spectral differences between CV and VC are a major factor that motivates the preference for the former syllable type.

CHAPTER FIVE

CONCLUSION

Phonological studies have revealed a number of cross-linguistic tendencies in permissible and impermissible sequences of phonemes. The present study was conducted with the aim of finding possible explanations for these universal phonotactic constraints. In examining such universals, I gave special attention to clusters of a stop and a liquid, clusters of a stop and a glide, sequences of a consonant and a vowel, vowel clusters, and sequences of a vowel and a consonant.

I reviewed in some detail several earlier attempts to account for the universal phonotactic patterns. Among them are Hooper's (1976) account based upon the 'sonority/strength' hierarchies, Diver's (1975) account based upon the sequential constraints on articulatory gestures, and Saporta's (1955) and Cutting's (1975) accounts based upon the degree of featural contrast between successive phonemes. It was argued that some of these attempts were unsuccessful in explaining the observed universals. Their limitations resided in the fact that their arguments often rested on ill-defined concepts.

I agreed with Cutting in hypothesizing that favored or frequently-occurring sequences should be those whose constituent sounds are maximally different, but tested the validity of this hypothesis not in terms of distinctive features as he did, but in terms of selected acoustic parameters. An assumption underlying the hypothesis is as follows. The listener, or the decoder of signals, must prefer acoustically well-modulated signals, for they are perceptually more salient than signals with small changes. Therefore, universally favored sound sequences should be those which exhibit great acoustic changes. A further assumption was made: if two or more sound sequences share certain acoustic characteristics, they should be perceptually similar. Regardless of the amounts of acoustic change in such sequences, they would be mutually confusable and, in consequence, susceptible to a merger. Thus, favored sound sequences should not only exhibit maximal acoustic contrast among their constituent sounds, but also be sufficiently different from other sound sequences.

The acoustic hypothesis explains the universal tendency to avoid long consonant clusters and long vowel clusters on the ground that the amount of acoustic modulation is relatively small in these sequences. The same explanation is offered for the universal avoidance of sequences of consonants produced in the same manner of articulation, the rarity of nasal + liquid clusters compared to obstruent + liquid clusters, and the rarity of word-initial back-articulated nasals.

The hypothesis was tested further for its applicability to other universal sequential constraints, such as the rarity of alveolar stop + [l] clusters, labial consonant + [w] clusters, dental/alveolar/palatal stop + [j] clusters, labial consonant + round vowel sequences, and dental/alveolar/palatal consonant + front vowel sequences, and the preference for CV syllables over VC syllables. The test was carried out by acoustically analyzing a variety of stop + liquid + vowel, stop + glide + vowel, stop + vowel, and vowel + stop sequences (where stop =[b, d, g], liquid=[l, r], glide=[w, j], and vowel=[i, ɛ, a, u]), and comparing the numerically represented magnitudes of acoustic modulation within themselves and degrees of acoustic differences among them. The frequencies of the first three formants were chosen as the acoustic parameter along which the above two factors were measured, and were obtained by an LPC analysis. Standard Euclidean distance was used as approximations to the magnitude of spectral change within a sequence and the degree of spectral dissimilarity between sequences.

The findings were as follows. The clusters of a stop and a liquid show the least spectral change when the stop is [b], and the greatest spectral change when it is [d]. They show greater spectral change when followed by a front vowel than when followed by a back vowel. The stop + [l] clusters are in general less spectrally modulated and mutually closer than the stop + [r] clusters. Among the stop + [l] clusters, [dl] and [gl] are especially similar. [dl] is also found to be spectrally closer to [dw].

The clusters of a stop and [w] show the least spectral change when the stop is [b], and the greatest spectral change when it is [d]. Formants move more when they are followed by a front vowel than when they are followed by a back vowel. Among these clusters, [bw] and [gw] are particularly similar. [dw] and [gw] further show a spectral resemblance to [bu] during a short interval after the consonantal release.

The clusters of a stop and [j] are least spectrally modulated when the stop is [d]. They show the greatest formant frequency change when followed by the low vowel [a], almost as great spectral change when followed by the high back vowel [u], and the least spectral change when followed by the high front vowel [i]. Among the stop + [j] clusters,

[bj] and [dj] are spectrally very similar. [bj] is also close to [di] and [du], and [dj] is close to [bi] at the formant onset.

Because of the asymmetry in their formant trajectories, CV and VC syllables with identical stops and vowels may show different amounts of spectral change, but the following combinations yield minimum spectral change regardless of the order between the stop and the vowel: [b]-[u], [d]-[i], [g]-[i], and [g]-[u]. The following pairs of syllables are spectrally similar: [bi]-[di], [ib]-[id], [bɛ]-[dɛ], [di]-[gi], [id]-[ig], [da]-[ga], [bu]-[gu], [ub]-[ug], and [ib]-[ig]. Spectral differences are in general smaller among VC syllables than among CV syllables.

These acoustical results suggest that stop + [r] clusters are phonotactically less severely constrained than stop + [l] clusters because the former are better-modulated and better-contrasted among themselves than the latter. A slight preference for alveolar stop + [r] clusters may be due to their great amounts of formant frequency change. The avoidance of alveolar stop + [l] clusters, however, cannot be explained with reference to the same factor. It seems that this particular constraint is ascribable to the spectral similarities of these clusters to other stop + sonorant clusters, especially velar + [l] clusters and alveolar stop + [w] clusters. The results further predict the rarity of liquid + back vowel sequences, but this is not immediately confirmed by phonological data.

The disfavoring of labial consonant + [w] clusters and dental/alveolar/palatal consonant + [j] clusters is explained on the basis of their lack of spectral change. The spectral similarities among [bw], [dw], [gw], and [bu] and among [bj], [dj], [bi], and [di] suggest that the common changes of labialized alveolars and velars to labials and of palatalized labials to alveolars are caused by their strong likelihood of perceptual confusion. The obtained acoustic results, however, do not explain the frequent occurrence of labialized velars.

The factor of spectral modulation also accounts for the disfavoring of [w] + back vowel sequences and [j] + front vowel sequences. In some languages, only low vowels are combined with glides or high vowels. This is predicted in the case of [j] + vowel sequences. [ja] shows greater formant frequency change than any other [j] + vowel sequences. However, [wa] does not show greater spectral change than [wi] or [wɛ], leaving a discrepancy between the acoustic and phonological data. It was suggested that the change in F_1 frequency is important in the perception of vowels and glides, which factor was not properly weighted in the current hypothesis.

The rarity of combinations of a labial consonant and a rounded vowel, of a dental/alveolar/palatal consonant and a front vowel, and of a velar consonant and a high vowel are explained by their lack of spectral modulation. The changes of labials to alveolars before front vowels and of velars to labials before rounded vowels are ascribable to their spectral and hence auditory similarities. The greater spectral contrast among CV syllables than among VC syllables may be one of the factors motivating the universal preference for the former syllable structure.

The present study has thus shown that a number of cross-linguistic phonotactic constraints have predominantly acoustic/auditory bases. It provides further corroboration for the view that the listener plays a significant role in determining the phonological structure and the course of phonological change (Liljencrants and Lindblom 1972, Ohala 1981). However, this conclusion does not preclude the possibility that some phonotactic universals are articulatorily motivated. In fact, though not discussed in Chapter Two, there are a good many universal phonotactic constraints whose bases are more likely to be physiological and/or aerodynamic. Such constraints most typically regard the state of the glottis. For example, Greenberg (1978) found the following universals.

1) Initial and final obstruent clusters tend to be homogeneous in regard to voicing.
2) Initially and finally, the existence of sequences of two voiced obstruents implies that of sequences of two voiceless obstruents.
3) Except for sequences of a voiced nasal followed by a homorganic voiceless obstruent, an initial voiceless consonant or an initial sequence of voiceless consonants immediately preceding a vowel is not itself preceded by a voiced consonant.
4) Except for sequences of a voiceless obstruent followed by a voiced nasal, a final voiceless consonant or a final sequence of voiceless consonants following a vowel is not followed by a voiced consonant.
5) Initially, the presence of voiced obstruent + nasal sequences implies that of voiceless obstruent + nasal sequences, and the presence of voiced obstruent + glide sequences implies that of voiceless obstruent + glide sequences.
6) Finally, the presence of sonorant + voiced obstruent sequences implies that of sonorant + voiceless obstruent sequences.

7) Combinations of otherwise identical voiceless and glottalized consonants are extremely rare.

8) There are no initial or final combinations of a voiced obstruent and a glottalized obstruent.

The incompatibility between voicing and oral constriction for obstruents and between voicing and pre- and post-boundary positions which is evident in the above universals is explained in reference to aerodynamic facts. The restriction on co-occurrence of the pulmonic and glottalic air stream mechanisms presumably has other physiological reasons as well.

Another strong universal concerns the homorganicity of successive nasal and obstruent. According to Greenberg (1978), the existence of heterorganic final nasal + obstruent clusters implies that of homorganic ones. This tendency and the tendency for liquids to appear in contiguity with vowels may have articulatory reasons, such as the propensity for coarticulation suggested by Lindblom (1979, in press).

Although the present study only considered the frequencies of the first three formants in examining the hypothesis, other acoustic parameters should also play some part in giving rise to phonotactic universals. For instance, favored stops in consonant sequences might be better predicted if such parameters as burst frequencies and amplitudes were taken into consideration (Zue 1980).

The current acoustic hypothesis has one serious limitation. It does not explain the asymmetry of some sound changes. The changes of kw ⟶ p, gw ⟶ b, pj ⟶ t, bj ⟶ d, kj ⟶ tʃ, gj ⟶ dʒ, p ⟶ h, for example, almost invariably occur in the directions indicated. The changes in the reverse directions are extremely rare. The hypothesis, however, only predicts the mutual confusability between these sounds. Additional assumptions must be incorporated in order to explain these changes. Ohala (1982) hypothesized that asymmetrical changes proceed from sounds with more acoustic details to sounds with less acoustic details. He speculated that the sharp spectral peak in the noise burst in [kw] as opposed to the diffuse burst spectra after [p], and the rapid rise in F_2 after the stop release in [pj] as opposed to the lack of such a transition after [t] might explain why the direction of change is from [kw] to [p] and from [pj] to [t] and not the reverse. The formant frequency data in the present study uphold his hypothesis. Both [bj] and [bi] show a rapid upward shift in F_2 and F_3 frequencies at the stop release. In [dj] and [di], on the other hand, there are no formant transitions to speak of except for a slight downward shift in F_3. As already discussed, the formant frequencies alone do not sufficiently differentiate [gw] from [bw] or [gu] from [bu]. The 'extra' acoustic feature that characterizes [gw] but not [b] should be found elsewhere.

Perhaps the most important implication of the present study is with regard to the potential role of phonetic research in constructing phonological theories. Traditionally, phonetics has been assigned only a marginal role in phonology toward its goal of finding explanations for phonological structure and phonological change. As Liljencrants and Lindblom (1972) would describe it, it has been viewed primarily as a science of 'realizations,' i.e., the task of phoneticians is to 'interpret' in terms of phonetic realities the underlying units and structures posited by linguists. However, the implication of the recent phonetic studies including this one is that this process can be completely reversed. That is to say, we treat the physical constraints on man's neurological, motor, and sensory mechanisms along with the psychological constraints on his communicative capacity as inputs from which to derive linguistic units, structures, and processes. In search of the answers to phonological questions of a universal nature, such an approach seems warranted, for the physical and psychological constraints are likely to be the strongest, if not the only, candidates for the universally applicable conditions under which the similar phonological patterns and processes must have arisen. The physically-based phonological theories depart from other phonological theories in that their concepts and principles are clearly based on facts and principles that are distinct from the phenomena which the theories are designed to account for. This is necessary in order for any theory to be explanatory. Future phonetic research will undoubtedly expand our knowledge of the physical and psychological constraints on speech, which is at present far from complete. However, its role should extend beyond this. It is capable of providing answers to the questions that phonologists have been asking for centuries, i.e., what causes languages to pattern and change the way they do. The present study is offered as a modest contribution towards the realization of this goal.

NOTES

1. The approach is 'recent' in the sense that it was not rigorously pursued before except by such predecessors as Passy (1890) and Grammont (1933).
2. Note that the terms 'favor,' 'disfavor,' 'prefer,' and 'avoid' that appear frequently in the following text are not used in an anthropomorphic sense.
3. The terms 'cluster' and 'sequence' are used by some scholars, e.g., Pulgram (1965, 1970), to denote two different things: the former for a homosyllabic consonant string, and the latter for a heterosyllabic one. In the text to follow, I will not make such a distinction. The two terms, therefore, may be regarded as interchangeable.
4. The fact that these statistics are based on syllable structures rather than morpheme or word structures implies that morpheme- or word-*internal* clusters may consist of a greater number of consonants. However, morpheme- or word-initial or final consonant clusters are in most cases the same as syllable-initial or final consonant clusters. Thus, it should be understood that the data given here only concern absolute word initial and final clusters.
5. Among the four languages that were excluded from this count, one language, Kunjen, is reported to have no initial consonants. Crothers et al. questioned the validity of this analysis of syllable structure given in the original source, and offered an

alternative syllable canon which allowed initial consonants. Nevertheless, the original analysis was followed here. The three other languages excluded are Tunica, Salish, and Aymara. No information is given on the syllable structure in Crothers, et al.'s summary of Tunica. As to Salish and Aymara, a vowel is treated as optional in their syllable canons, and without a vowel it is impossible to determine whether a consonant is initial or final.

6. Tunica, Salish, and Aymara were again excluded from this count, along with the languages which only have open syllables.

7. Simplification of consonant clusters through vowel insertion is a well-known diachronic process, e.g., *pōclom > pōcolom, pōculum in Latin (Buck 1933; p. 37, 98). Clusters may be simplified by other processes such as consonant loss, e.g., *διδάκσκω > διδάσκω in Greek, *torctos > tortus in Latin, castle > [kʰæsl̩] in English (Buck 1933), and vowel prothesis with subsequent consonant loss, e.g., Latin schola > Vulgar Latin ischola > Old French escole > Modern French école (Grandgent 1907, Pope 1934). This is not to say that changes always occur in the direction of simplification. Consonant clusters are often formed by vowel loss or consonant epenthesis, e.g., *déxiteros > dexter in Latin, capitain > captain in English, ἀ-μροτος > ἄμβροτος in Greek (Buck 1933). For detailed discussion of relative likelihood of cluster formation and simplification processes, see Bell, A. (1971). (Forms that are not phonetically transcribed are underlined above and in the following text. They are mostly orthographic. The use of an asterisk (*) is explained in Footnote 20.)

8. There is one language that only has closed syllables: Kunjen. As already mentioned, according to Crothers et al., its syllable structure might be quite different if reanalyzed. It is possible that this language will not constitute counterevidence for the universal after all. According to Bell and Hooper (1978), languages without closed syllables constitute about 10-25% of the world's languages. Crothers et al.'s sample yields a percentage close to the lower end of this estimate.

9. Again, this exception is Kunjen. In A. Bell's (1971) sample of 144 languages, 28 lacked syllables without consonantal onsets. Thus, in both his and Crothers et al.'s samples, approximately 20% of the languages have obligatory initial consonants. This is close to the lower end of the estimate given by Bell and Hooper, i.e., 20-40%.

10. It should be mentioned in conjunction with this that universal preferences also exist with regard to the ordering of these consonants. Greenberg showed that liquids generally *followed* obstruents in initial clusters, but *preceded* obstruents in final clusters. When a liquid and a nasal are combined, the ordering tends to be such that the liquid is closer to the vowel, i.e., nasal + liquid initially, and liquid + nasal finally. Incidentally, though both liquids and nasals are frequently combined with obstruents, obstruent + liquid sequences are preferred to obstruent + nasal sequences at least in the initial position. These patterns will be discussed further in Sections 3.1 and 4.1.

11. Bell listed Kaingáng as another language which lacked alveolar stop + /r/ clusters. The source for this information is Wiesemann

(1964). This language apparently has only one liquid. Though Wiesemann described it as /r/, Henry (1935), another source used by Bell, described it as lateral /l/. If it is a lateral, its failure to combine with alveolars is certainly expected, as we have just seen.

12. Actually, labialized labials exist in two more languages, but their occurrence in these languages is reported to be limited.

13. Another way to interpret this synchronic palatalization is to assume that consonants in all places of articulation are palatalized but that the palatality is subsequently deleted or 'absorbed,' so to speak, in the environment of alveolars and palatals. Such a process finds a diachronic parallel in the history of Vulgar Latin among many other languages. According to Grandgent (1907), the velar stop /k/ was fronted when preceding a front vowel to such an extent that a short palatal off-glide was formed between the consonant and the vowel. This stage was followed by the change of /k/ to a prepalatal stop and then to an affricate. Upon completion of this process, however, the glide element disappeared. Bhat (1978) provides more examples of such cases.

14. An obvious exception to this is such a sequence as [t^hwu] <u>true</u> in child language.

15. Whence the old joke: (Q) Why does the sun rise in the East? (A) [ist] makes everything rise.

16. Bhat (1978) cites a few more cases of this sort. A similar process occurred diachronically in, e.g., Vulgar Latin (Grandgent 1907). Before front vowels, /g/ was fronted and changed into the palatal glide /j/. This glide, when intervocalic, disappeared by fusing

with the following stressed vowel, e.g., magǐster > *mayįster (hypothetical) > maęster.

17. Velar + front vowel (or /j/) sequences may have been originally missing in these languages, but it is also possible that Velar Softening robbed at least some of these languages of such sequences. A thorough diachronic analysis would be necessary to determine for each case whether the pattern represents an original phonotactic constraint or a mere consequence of sound change. In the absence of such an analysis, this particular universal tendency remains tentative.

18. It might be more proper to include here some cases of sequences of a vowel and /j/ or /w/ discussed in Section 2.7.

19. This may appear contradictory to the universal proposed in Section 2.7. That is, sequences like /wu, uw, ji, ij/ are rare. The insertion of glides would create such disfavored sequences. However, the contexts in which these two phenomena are observed are not exactly the same. The glide insertion is limited to the middle of a vowel string.

    This process also occurs sporadically in words with a vowel sequence in Japanese, e.g., [baai] ⟶ [bawai], [bajai] 'situation,' [guai] ⟶ [guwai] 'condition,' [juami] ⟶ [juwami] 'take a bath,' [ariake] ⟶ [arijake] 'dawn,' [miai] ⟶ [mijai] 'interview with a prospective bride(groom),' [omiotsuke] ⟶ [omijotsuke] 'miso soup,' and [ikioi] ⟶ [ikijoi] 'force' (Kindaichi 1963).

20. In the examples below (and in Footnotes 7 and 16), forms marked with an asterisk (*) are only hypothetical in that they were never

attested historically but are reconstructed on the basis of observed sound correspondences among the dialects or languages involved. See the references cited for the bases for reconstruction.

21. The PIE labiovelars did not invariably change to labials. Before front vowels, they generally changed to dentals (Buck 1933, Meillet 1964). E.g., $*k^{w}$is > τίς, $*g^{w}$er-wā > δέρη, and $*g^{w}$hermo- > θερμός (Pokorny 1959). However, there are some labiovelars that changed to labials despite this environment. These exceptions have been explained as cases of analogical leveling. For example, /p/ in λείπω and ἕπομαι were generalized to λείπει and ἕπεται, respectively (Buck 1933).

22. The change of [kw] to [p] in the Hakata region was noted by Rodriguez in his Arte da Lingoa de Iapam written in 1604-8, e.g., [keŋkwa] > [kempa] 'quarrel'. Also cited by him was a case of change in the reverse direction, e.g., [padere] > [kwatere] 'padre' (Oishi and Uemura 1975, Shibata 1976, Yoshimachi 1976). This latter change is intriguing, for the change [kw] > [p] is usually considered uni-directional.

23. According to Wood (1926), this process was blocked by a following labial (p, b, m, ʋ), e.g.,

    *dwēmo- > dēmum 'at length'.

    For an explanation for the loss of /w/ in the labial environment, see Ohala (1979a, 1981).

24. Original non-IPA transcriptions are kept in some of these examples. They are marked as such.

25. Ohala assumes a process /pl/ > /pj/ as an intermediate step in the change of Latin /pl/ to /tʃ/ in the just-mentioned Modern Romance languages. Javkin (1977) pointed out the acoustic similarity between the post-occlusive /l/ and /j/ in Italian, suggesting that the change Cl ⟶ Cj is perceptually caused.

26. The other advocates of the hierarchies also criticized severely the inadequacy of the distinctive feature system in describing consonant assimilations, syllabification, and processes conditioned by the segments' positions in the syllable. Transformational phonologists, on the other hand, have attempted to incorporate the 'sonority' hierarchy into their theoretical framework to account for syllable-related phonological phenomena. See, for example, Gray (1979), Kiparsky (1979), Lekach (1979), and Mohanan (1979).

27. The absence of /θl, ʃl/ ([stable] + [stable]) in spite of the presence of /θr, ʃr/ ([stable] + [mobile]) in English contradicts this generalization. Diver argued that the absence of favored /θl/ and /ʃl/ was accountable by the historical fact that they would have had to arise from Old English /tl/ and /skl/, respectively, which themselves were disfavored sequences.

28. There are a few other attempts to use quantified phonemic differences in linguistic descriptions. Grimes and Agard (1959), for example, tried to determine relative 'closeness' among the Romance languages through numerically representing phonetic differences in their phonological correspondences.

29. The order of the constituent consonants was not considered in his study.

30. Cutting used six features, [vocalic], [consonantal], [grave], [diffuse], [voiced], and [continuant] from the distinctive feature system proposed by Halle (1964).

31. According to Cutting, the values of phonemic difference for /kj/ and /gj/ were 5 and 4 respectively. They were greater than the values for clusters of a labial or dental stop and /j/; /pj/=4, /tj/=3, /bj/=3, and /dj/=2.

32. According to Stevens (1971, 1975), rapid spectral changes provide context-*independent* cues as to the manner and place of articulation and hence require no 'precategorical store.' Such a memory is necessary in the case of signals with other acoustic characteristics where the cues are context-dependent. See the above references for a detailed discussion on this subject.

33. Possibly related to this is a substitution of an [ŋ] + vowel sequence for an initial vowel in some languages. In Mandarin, [ŋ] may be inserted before a syllable-initial low vowel. Historically in Yurak, [ɲ] or [ŋ] was inserted before word-initial vowels. This process also testifies to the vowel-like character of the velar nasal.

34. These particular frame sentences were chosen in order to avoid such coarticulation as devoicing, flapping and glottalization as well as to facilitate segmentation.

35. The beginning of the vowel in the VC syllables was always marked at some multiple of 10 msec. from the implosion of the stop rather than at the absolute beginning. As described below, a short-term spectrum was obtained at every 10 msec. The particular marking

allowed the stop implosion to coincide with one of such analysis points.

36. All values in the tables are rounded off to the nearest integer.

37. Henceforth, comparisons among values of 'salience' or values of 'dissimilarity' will be frequently made in this manner. However, remember that since 'salience' and 'dissimilarity' have special meanings defined above, a value of 'salience' is not directly comparable to a value of 'dissimilarity.'

38. There is a sudden upward shift in F_1 at the onset of a vowel following [l] (O'Connor, Gerstman, Liberman, Delattre, and Cooper 1957, Lehiste 1964). This is observable even when the F_1 change is minimum as in the case of [lu] and [li]. This acoustic observation is compatible with Fant's (1960) finding that the abrupt shift in F_1 is a primary cue in the perception of [l]. O'Connor et al. reported that the quality of synthetic /l/ improved when the duration of its F_1 transition was reduced to 10 msec. in order to achieve the effect of the abrupt F_1 change observed in naturally spoken /l/. The sudden F_1 shift is not observed in the sequences of [r] and a vowel.

39. The F_2 frequency of [l] is lower in [bla] than in any other [bl] + vowel sequence. Though by a very small amount, the F_2 frequency of [l] in [dl] and [gl] is also lower before [a] than before any other vowel. This is in line with Lehiste's (1964) finding that the F_2 of word-initial [l] is lower when followed by [a] than when followed by [i], [ɛ], and [u] among others.

40. This is consistent with O'Connor et al.'s (1957) finding in their perceptual study using the Pattern Playback that the F_2 transition is a sufficient cue to distinguish word-initial /w/ from /r/ and /l/; the F_2 should originate at a lower frequency for the perception of /w/.

APPENDIX

Language names are marked with an asterisk (*) if the data cited are also summarized in Crothers et al.'s *Handbook of Phonological Data from a Sample of the World's Languages*. Numbers refer to the pages where languages are cited.

Abkhaz	Catford 1977	16
Acoma	Miller 1965	24
Adzera*	Holzknecht 1973	15
Ahi	(See Tibetan)	
Ainu	Chiri 1956	24, 25, 27, 160
	Kindaichi 1960	20, 160
Akha	Katsura 1973	19
Akɔ́ɔ̄sē	Hedinger and Hedinger 1977	20, 22, 26
Amakusa	(See Japanese)	
Amharic*	Leslau 1968	10, 21
Amuesha*	Fast 1953	15
Anʔdiʔêm	(See Katu)	
Angas*	Burquest 1971	10, 23
Apinaye*	Burgess and Ham 1968	10, 15
Archaic Chinese	(See Chinese)	
Armenian*	Allen 1950	18
Atayal*	Egerod 1966	10

Awiya*	Hetzron 1969	22
Aymara*	Hardman 1966	179
Ayutla Mixtec	Pancratz and Pike 1967	20, 25
Bantu	Guthrie 1967-70	36
	Meinhof 1929	33
	Meinhof 1932	36
	Tucker 1929	36
Basque*	N'diaye 1970	59
Belangao	Shetler 1976	20, 27
Bella Coola	Newman 1947	21, 23
Bengali*	Ferguson and Chowdhury 1960	10, 59
Breton*	Ternes 1970	14, 23, 26, 59
Bulgarian*	Aronson 1968	10
	Klagstad 1958	25
Bura	(See Margi)	
Burmese	Cornyn 1944	18
Burushaski*	Morgenstierne 1945	15, 59
Cambodian*	Huffman 1970	10
Campa*	Dirks 1953	28, 29
Capanahua	Loos 1969	20, 25, 27
Carib*	Peasgood 1972	59
Cavineña	Key 1968	20, 21, 25
Chacobo*	Prost 1967	20, 24, 28
Chamorro*	Topping 1973	14, 15, 28
Chehalis	Kinkade 1963	21
Chinantec	Skinner 1962	14

Chinese		
Guangzhou	Beijing Daxue Zhongguo Yuyan Wenxuexi 1962	24, 27
Meixian	Beijing Daxue Zhongguo Yuyan Wenxuexi 1962	24, 27
Xiamen	Beijing Daxue Zhongguo Yuyan Wenxuexi 1962	24, 27
Archaic	Chang and Chang 1972	34
Mandarin*	Dow 1972	185
Chontal*	Keller 1959	10
Cua	Maier 1969	14, 15
Czech	Andersen 1973	34
	Vachek 1966	25
Dagbani*	Wilson and Bendor-Samuel 1969	10, 18, 19, 27
Dakota*	Boas and Deloria 1939	10, 11, 29
Dan	Bearth and Zemp 1967	25
Danish	Vestergaard 1967	14
Digueño*	Langdon 1970	24, 26
Dutch	Cohen, Ebeling, Eringa, Fokkema, and Van Holk 1959	14
E. Colonial	(See Tibetan)	
Egyptian Arabic*	Kennedy 1960	23
English	Abercrombie 1937	157
	Buck 1933	179
	Dobson 1957	23
	Greenberg 1978	3, 59
	Hofmann 1967	14, 160
	Hultzén 1965b	14, 16, 161

	Jones 1967	14, 160
	Kurath and McDavid 1961	18, 25
	Malécot 1974	14
	Thomas 1947	18
	Trnka 1968	16, 21, 59, 161
Even*	Novikova 1960	19
Ewe*	Stahlke 1971	14
Finnish*	Lehtinen 1964	27
Fox	Hockett 1956	18
French	Elcock 1960	34
	Grandgent 1907	34
	Pope 1934	179
Gã*	Berry n.d.	22
	Kropp 1968	16
Ganagana	(See Kwa)	
Ganda	Cole 1967	11, 23, 26
Garo*	Burling 1961	15, 59
Gawun	(See Kwa)	
Gbeya*	Samarin 1966	22, 59
Genoese Italian	Meyer-Lübke 1890	36
Georgian*	Robins and Waterson 1952	10
German*	Malécot 1974	14
	Philipp 1974	14, 28, 59
Germanic	Pokorny 1959	31
	Prokosch 1938	31
Gilyak*	Panfilov 1962	19
Goajiro*	Holmer 1949	24

	Kindaichi 1963	182
Izumo	Kokugogakkai 1962	20
Old	Nakata 1972	20
Modern dialects	Oishi and Uemura 1975	22, 32, 159, 160, 183
Old and Middle	Okumura 1972	160
	Okumura 1977	160
	Shibata 1976	32, 183
14C - 16C	Toyama 1972	22
	Yoshimachi 1976	183
	(Also see Ryukyuan)	
Kagoshima Makurazaki	(See Japanese)	
Kaingáng	Henry 1935	180, 181
	Wiesemann 1964	180, 181
Kaliai*	Counts 1969	10
Kalinga	Gieser 1972	20, 21, 24, 25, 27
Karakatšan	Bidwell 1964	25, 27
Karok*	Bright 1957	11
Kashmiri*	Kelkar and Trisal 1964	10
Katu	Wallace 1969	15, 24, 27, 28, 157
Ket*	Dul'zon 1968	59
	Krejnovich 1968	10
Kharia*	Biligiri 1965	10, 59
Khasi*	Rabel 1961	11
Kisi	Samarin 1950	14
Komi*	Bubrich 1949	10
Korean*	Cho 1967	16

	Martin 1951	18, 20, 25
Kota*	Emeneau 1944	11
Kpelle*	Welmers 1962	22
Kunjen*	Sommer 1969	178, 180
Kurukh*	Pinnow 1964	11
Kwa	Hyman and Magaji 1970	35
Labrador Inuttut	Smith 1975	32, 35
Lahu*	Matisoff 1973	23
Lakkia*	Haudricourt 1967	14
Latin	Buck 1933	179
	Grandgent 1907	34, 179, 181, 182
	Pokorny 1959	30, 31, 32, 33
	Pope 1934	157
	Watkins 1969	31
	Wood 1926	183
Lhasa	(See Tibetan)	
Lisu	Hope 1971	18
Lithuanian*	Senn 1966	26
Litomyšl Czech	Andersen 1973	34
Logbara*	Crazzolara 1960	15, 26
Lolo	(See Tibetan)	
Loma	Sadler 1951	20, 27
Loutse	(See Tibetan)	
Luiseño*	Bright 1965	10
Luo*	Gregersen 1961	20
Luvale*	Horton 1949	22, 23
Mahas Fiyadikka*	Bell, H. 1971	10

Maidu*	Shipley 1964	24, 27
Maltese*	Borg 1973	10
Mambila	Bendor-Samuel and Perrin 1971	16, 21
Mandarin	(See Chinese)	
Maranungku*	Tryon 1970	15
Margi	Hoffmann 1963	16
Maung*	Capell and Hinch 1970	59
Mazateco*	Pike and Pike 1947	20, 24
Mili	(See Tibetan)	
Mixtec	(See Ayutla, Molinos, and Silacayoapan)	
Modern Greek*	Householder, Kazazis, and Koutsoudas 1964	14
Modern Hebrew*	Chayen 1973	11
Molinos Mixtec*	Hunter and Pike 1969	11, 21, 23
Moroccan Arabic*	Abdel-Massih 1973	10
Moso	(See Tibetan)	
Navaho*	Sapir and Hoijer 1967	22, 28
Nepali	Bandhu, Dahal, Holzhausen, and Hale 1971	22, 24, 26, 27
New Caledonese	Rivierre 1973	23
Ning Ming	Gedney 1973	34
North Estonian	Zeps 1962	25
Northern Okinawa	(See Ryukyuan)	
Norwegian*	Vanvik 1972	14
Nupe	Hyman and Magaji 1970	35
	Smith 1969	22, 26
Old English	Dobson 1957	23

	Pokorny 1959	31
	Prokosch 1938	31
Old High German	(See Germanic)	
Old Norse	(See Germanic)	
Oneida*	Lounsbury 1953	11, 14
Orizaba Nahuatl	Goller, Goller, and Waterhouse 1974	20, 24
Ostyak*	Gulya 1966	59
Pacoh	Watson 1964	14
Paez*	Gerdel 1973	11, 18, 26
Palaung	Shorto 1960	14, 15
Parintintin	Pease and Betts 1971	21, 26
Pa-U-Rong	(See Tibetan)	
Phúhòa	(See Katu)	
Portuguese*	Head 1964	11
	Malkiel 1963-64	36
Proto-Indo-European	Pokorny 1959	30, 31, 32, 33
	Watkins 1969	31
Proto-Otomanguean	Rensch 1977	33
Punjabi*	Gill and Gleason 1963	22, 26, 59
Ronga	Junod 1896	16
Russian*	Jones and Ward 1969	26
Ryukyuan	Nakamoto 1976	35
Sa'ban*	Clayre 1973	24, 27
Salish*	Snyder 1968	21, 179
SeChuana	(See Bantu)	
Sedang*	Smith 1968	14, 15

Selepet*	McElhanon 1970	26
Seneca*	Chafe 1967	10
Sentani*	Cowan 1965	11
SePedi	(See Bantu)	
SeSuto	(See Bantu)	
Shilha*	Applegate 1958	11
Siamese	Gedney 1973	34
Silacayoapan Mixtec	North and Shields 1977	21, 25
Sinhalese*	Coates and de Silva 1960	10, 20, 25
Sino-Annamese	Chang and Chang 1972	34
Somali*	Armstrong 1964	28
Sotho	Meinhof 1929	33
Southeastern Pomo*	Moshinsky 1974	11
Spanish*	Malkiel 1963-64	36
	Navarro Tomás 1961	11
Squamish*	Kuipers 1967	23
Sre	Manley 1972	14, 15, 18
Sundanese*	Van Syoc 1959	11
Suto-Chuana	Tucker 1929	20, 26, 36
Swahili*	Polome 1967	29
	Tucker and Ashton 1942	21, 26
Tagalog*	Schachter and Otanes 1972	14, 15, 24, 27
Tangut	(See Tibetan)	
Tarascan*	Foster 1969	16, 20, 24, 29
Telugu*	Lisker 1963	11
Tenango Otomi	Blight and Pike 1976	20, 25, 27

Tewa*	Hoijer and Dozier 1949	22
Thai*	Abramson 1962	14, 15, 24, 27, 28
Thōchū	(See Tibetan)	
Tibetan		
All languages except Ahi	Thomas 1948	35
Ahi	Benedict 1972	35
Ticuna*	Anderson 1962	28
Tiwa*	Trager 1971	28
Tokunoshima	(See Ryukyuan)	
Totonaco*	Aschmann 1946	20, 25
Toura	Bearth 1971	21
Trique	Hollenbach 1977	20, 25
Tsushima	(See Japanese)	
Tunica*	Haas 1940	11, 179
Ur-Bantu	(See Bantu)	
Urhobo	Kelly 1969	15, 16, 18
Vietnamese*	Haupers 1969	16, 20, 27, 32
	Thompson 1965	28
Wapishana*	Tracy 1972	19
Washo	Jacobsen 1964	24, 27
Western Popoloca	Williams and Pike 1968	25
Wichita*	Garvin 1950	23
Wobé	Link 1975	14, 16
Wolof	Rambaud 1903	23, 26
Wukari Jukun	Welmers 1968	18, 21
Yao*	Purnell 1965	21, 23, 25

Yaqui	Fraenkel 1959	20, 21, 24
Yareba	Weimer and Weimer 1972	22
Yay*	Gedney 1965	18, 24, 27, 28
Yonakuni	(See Ryukyuan)	
Yucuna	Schauer and Schauer 1967	20, 25
Yuma	Halpern 1946	21
Yurak*	Decsy 1966	10, 185
Zulu*	Doke 1969	16, 21
	(Also see Bantu)	

REFERENCES

LIST OF ABBREVIATIONS

BSOAS	Bulletin of the School of Oriental and African Studies, London.
IJAL	International Journal of American Linguistics.
JASA	Journal of the Acoustical Society of America.
RLE-QPR	Research Laboratory of Electronics, Quarterly Progress Report.
SIL	Summer Institute of Linguistics.
SIL-PLRF	Summer Institute of Linguistics, Publications in Linguistics and Related Fields.
STL	Speech Transmission Laboratory (KTH, Stockholm).
UCPL	University of California Publications in Linguistics.

Abdel-Massih, E. 1973. An introduction to Moroccan Arabic. Ann Arbor: Center for Near Eastern and North African Studies, University of Michigan.

Abercrombie, D. 1937. tu: ə:li "transkripʃnz." Le Maître Phonétique. 59.34-36.

Abramson, A. 1962. The vowels and tones of Standard Thai: acoustical measurements and experiments. IJAL 28.2, Part II. Indiana University Publications in Anthropology, Folklore, and Linguistics, No. 20. Bloomington: Indiana University.

Allen, W. 1950. Notes on the phonetics of an Eastern Armenian speaker. Transactions of the Philological Society. 180-206. Oxford: Blackwell.

Andersen, H. 1973. Abductive and deductive change. Language 49. 765-93.

Anderson, D. 1962. Conversational Ticuna. Peru: Yarinacocha Press.

Applegate, J. 1958. An outline of the structure of Shilha. Program in Oriental Languages, No. 11. New York: American Council of Learned Societies.

Armstrong, L. 1964. The phonetic structure of Somali. Ridgewood, N.J.: Gregg Press.

Aronson, H. 1968. Bulgarian inflectional morphophonology. Slavistic Printings and Reprintings, No. 70. The Hague: Mouton.

Aschmann, H. 1946. Totonaco phonemes. IJAL 12.34-43.

Bandhu, C., Dahal, B., Holzhausen, A., and Hale, A. 1971. Nepali segmental phonology. Kirtipur: SIL and Tribhuvan University.

Bearth, T. 1971. L'énoncé toura (Côte d'Ivoire). SIL-PLRF 30. Norman: SIL.

Bearth, T. and Zemp, H. 1967. The phonology of Dan (Santa). Journal of African Languages 6.9-29.

Beijing Daxue Zhongguo Yuyan Wenxuexi. 1962. Hanyu Fangyin Zihui. Beijing: Wenzi Gaige Chubanshe.

Bell, A. 1971. Some patterns of occurrence and formation of syllable structures. Working Papers on Language Universals 6.23-137. Stanford University.

Bell, A. and Hooper, J. 1978. Issues and evidence in syllabic phonology. In: A. Bell and J. Hooper (eds.), Syllables and segments. 3-22. Amsterdam: North-Holland Publishing Co.

Bell, H. 1971. The phonology of Nobiin Nubian. African Language Review 9.115-39.

Bendor-Samuel, D. 1972. Hierarchical structures in Guajajara. SIL-PLRF 37. Norman: SIL.

Bendor-Sameul, D. and Perrin, M. 1971. A note on labialization in Mambila. Actes du 8e Congress Internationale de Linguistique Africaine. Abidjan.

Benedict, P. 1972. Sino-Tibetan: a conspectus. In: J. Matisoff (ed.), Princeton-Cambridge studies in Chinese linguistics II. Cambridge: Cambridge University Press.

Berry, J. n.d. The pronunciation of Ga. Cambridge: Heffer.

Bhat, D. 1978. A general study of palatalization. In: J. Greenberg (ed.), Universals of human language, Vol. 2: phonology. 47-92. Stanford: Stanford University Press.

Bidwell, C. 1964. On Karakatšaṇ phonology. Word, Special Publication, No. 5 (Issued as a supplement to Word, Vol. 20, No. 3). 7-27.

Biligiri, H. 1965. Kharia. Poona: Deccan College.

Blight, R. and Pike, E. 1976. The phonology of Tenango Otomi. IJAL 42.51-57.

Blumstein, S. and Stevens, K. 1979. Acoustic invariance in speech production: evidence from measurements of the spectral characteristics of stop consonants. JASA 66.1001-17.

Blumstein, S. and Stevens, K. 1980. Perceptual invariance and onset spectra for stop consonants in different vowel environments. JASA 67.648-62.

Boas, F. and Deloria, E. 1939. Dakota grammar. Memoirs of the National Academy of Sciences, Vol. 23, Second Memoir.

Bondarko, L. 1969. The syllable structure of speech and distinctive features of phonemes. Phonetica 20.1-40.

Borg, A. 1973. The segmental phonemes of Maltese. Linguistics 109.5-11.

Bright, W. 1957. The Karok language. UCPL 13. Berkeley and Los Angeles: University of California Press.

Bright, W. 1965. Luiseño phonemics. IJAL 31.342-45.

Broad, D. and Fertig, R. 1970. Formant-frequency trajectories in selected CVC-syllable nuclei. JASA 47.1572-82.

Bubrich, D. 1949. Grammar of the Komi literary language. Leningrad: Leningrad State University.

Buck, C. 1933. Comparative grammar of Greek and Latin. Chicago: University of Chicago Press.

Burgess, E. and Ham, P. 1968. Multilevel conditioning of phoneme variants in Apinayé. Linguistics 41.5-18.

Burling, R. 1961. A Garo grammar. Deccan College Monograph Series, No. 25. Poona: Deccan College.

Burquest, D. 1971. A preliminary study of Angas phonology. Studies in Nigerian Languages, No. 1. Zaria: Institute of Linguistics.

Bush, C. 1964. Phonetic variation and acoustic distinctive features. The Hague: Mouton.

Capell, A. and Hinch, H. 1970. Maung grammar. The Hague: Mouton.

Catford, J. 1977. Mountain of tongues: the languages of the Caucasus. Annual Review of Anthropology 6.283-314.

Chafe, W. 1967. Seneca morphology and dictionary. Smithsonian Contributions to Anthropology, Vol. 4. Washington, D.C.: Smithsonian Press.

Chang, K. and Chang, B. 1972. The Proto-Chinese final system and the Ch'ieh-Yün. Institute of History and Philology Monographs, Series A, No. 26. Taipei: Academia Sinica.

Chayen, M. 1973. The phonetics of Modern Hebrew. The Hague: Mouton.

Chiri, M. 1956. Ainugo nyumon. Tokyo: Nire Shobo.

Clayre, I. 1973. The phonemes of Sa'ban: a language of Highland Borneo. Linguistics 100.26-46.

Coates, W. and de Silva, M. 1960. The segmental phonemes of Sinhalese. University of Ceylon Review 18.163-75.

Cohen, A., Ebeling, C., Eringa, P., Fokkema, K., and Van Holk, A. 1959. Fonologie van het Nederlands en het fries. The Hague: Martinus Nijhoff.

Cole, D. 1967. Some features of Ganda linguistic structure. Johannesburg: Witwatersrand University Press.

Compton, A. and Streeter, M. 1977. Studies of early child phonology: data collection and preliminary analysis. Papers and Reports on Child Language Development 13.99-109. Stanford University.

Cornyn, W. 1944. Outline of Burmese grammar. Linguistic Society of America, Language Dissertation, No. 38.

Counts, D. 1969. A grammar of Kaliai-Kove. Oceanic Linguistics Special Publication, No. 6. Honolulu: University of Hawaii Press.

Cowan, H. 1965. Grammar of the Sentani language. Verhandelingen van het Koninklijk Instituut voor Taal-, Land- en Volkenkunde, No. 47. The Hague: Martinus Nijhoff.

Crazzolara, J. 1960. A study of the Logbara (Ma'di) language. London: Oxford University Press.

Crothers, J., Lorentz, J., Sherman, D., and Vihman, M. 1979. Handbook of phonological data from a sample of the world's languages: a report of the Stanford Phonology Archive. Stanford University.

Cutting, J. 1975. Predicting initial cluster frequencies by phonemic difference. Haskins Laboratories, Status Report on Speech Research. SR-42/43.233-39.

Decsy, G. 1966. Yurak chrestomathy. Uralic and Altaic Series, No. 50. Bloomington: Indiana University.

Dewey, G. 1923. Relativ (sic) frequency of English speech sounds. Cambridge: Harvard University Press.

Dirks, S. 1953. Campa (Arawak) phonemes. IJAL 19.302-4.

Diver, W. 1975. Phonology as human behavior. Columbia University Working Papers in Linguistics 2.27-57.

Dobson, E. 1957. English pronunciation 1500-1700, Vol. II: phonology. Oxford: Clarendon Press.

Doke, C. 1969. The phonetics of the Zulu language. Nendeln, Liechtenstein: Kraus Reprint.

Dul'zon, A. 1968. Ketskij jazyk. Tomsk: Tomsk University.

Durand, M. 1956. Du rôle de l'auditeur dans la formation des sons du langage. Journal de Psychologie Normale et Pathologique 52.347-55.

Egerod, S. 1966. A statement on Atayal phonology. Artibus Asiae, Supplement 23. 120-30.

Elcock, W. 1960. The Romance languages. London: Faber and Faber.

Emeneau, M. 1944. Kota texts, part one. UCPL 2. Berkeley and Los Angeles: University of California Press.

Fant, G. 1960. Acoustic theory of speech production. The Hague: Mouton.

Fant, G. 1973. Speech sounds and features. Cambridge: MIT Press.

Fast, P. 1953. Amuesha (Arawak) phonemes. IJAL 19.191-94.

Ferguson, C. and Chowdhury, M. 1960. The phonemes of Bengali. Language 36.22-59.

Fisher, A. 1976. Phonologie guéré. Annales de l'Université d'Abidjan, Serie H, Linguistique 9.85-114.

Foley, J. 1970. Phonological distinctive features. Folia Linguistica 4.87-92.

Foley, J. 1977. Foundations of theoretical phonology. Cambridge: Cambridge University Press.

Foster, M. 1969. The Tarascan language. UCPL 56. Berkeley and Los Angeles: University of California Press.

Fraenkel, G. 1959. Yaqui phonemics. Anthropological Linguistics 1.5.7-18.

Fromkin, V. 1966. Neuromuscular specification of linguistic units. Language and Speech 9.170-99.

Fujimura, O. 1962. Analysis of nasal consonants. JASA 34.1865-75.

Fujimura, O. 1975. Syllable as a unit of speech recognition. IEEE Transactions on Acoustics, Speech, and Signal Processing, ASSP-23.1.82-87.

Fujimura, O. and Lovins, J. 1977. Syllables as concatenative phonetic units. Paper presented at the Symposium on Segment Organization and the Syllable, University of Colorado, Boulder, Colorado, 1977. Shorter version in A. Bell and J. Hooper (eds.), 1978, Segments and syllables. 107-20. Amsterdam: North-Holland Publishing Co.

Gamkrelidze, T. 1975. On the correlation of stops and fricatives in a phonological system. Lingua 35.231-61.

Garvin, P. 1950. Wichita I: phonemics. IJAL 16.179-84.

Gedney, W. 1965. Yay, a northern Tai language in North Vietnam. Lingua 14.180-93.

Gedney, W. 1973. Notes on the Tai dialects of Ning Ming: part one. Paper presented at the 6th International Congress on Sino-Tibetan Languages, University of California, San Diego, California, 1973.

Gerdel, F. 1973. Paez phonemics. Linguistics 104.28-48.

Gieser, C. 1972. Phonemic and morphemic efficiency in Kalinga. Phonetica 25.216-46.

Gill, H. and Gleason, H. 1963. A reference grammar of Panjabi. Hartford Studies in Linguistics, No. 3. Hartford: Hartford Seminary Foundation.

Gimpel, M. 1980. Universal phonological tendencies: segment inventories: proliferation of consonants (with special reference to obstruents). Unpublished paper, University of California, Berkeley.

Goller, T., Goller, P., and Waterhouse, V. 1974. The phonemes of Orizaba Nahuatl. IJAL 40.126-31.

Grammont, M. 1933. Traité de phonétique. Paris: Librairie Delagrave.

Grandgent, C. 1907. An introduction to Vulgar Latin. Boston: Heath and Co.

Gray, W. 1979. A note on resyllabification *in re* Kiparsky. In: K. Safir (ed.), MIT Working Papers in Linguistics, Vol. 1: papers on syllable structure, metrical structure and harmony processes. 178-81.

Greenberg, J. 1978. Some generalizations concerning initial and final consonant clusters. In: J. Greenberg (ed.), Universals of human language, Vol. 2: phonology. 243-79. Stanford: Stanford University Press.

Greenberg, J., Osgood, C., and Jenkins, J. 1966. Memorandum concerning language universals. In: J. Greenberg (ed.), Universals of language, 2nd edition. xv-xxvii. Cambridge: MIT Press.

Gregersen, E. 1961. Luo: a grammar. Ph.D. Dissertation, Yale University.

Grimes, J. and Agard, F. 1959. Linguistic divergence in Romance. Language 35.598-604.

Guile, T. 1973. Glide-obstruentization and the syllable coda hierarchy. Papers from the Regional Meeting 9.139-56. Chicago: Chicago Linguistic Society.

Gulya, J. 1966. Eastern Ostyak chrestomathy. Uralic and Altaic Series, No. 51. Bloomington: Indiana University.

Guthrie, M. 1967-70. Comparative Bantu. Farnborough: Gregg International.

Haas, M. 1940. Tunica. Handbook of American Indian languages, Vol. IV. 12-34. New York: J. J. Augustin.

Hâla, B. 1961. La syllable, sa nature, son origine et ses transformations. Orbis 10.69-143.

Halle, M. 1964. On the basis of phonology. In: J. Fodor and J. Katz (eds.), The structure of language. 324-33. Englewood Cliffs, N.J.: Prentice-Hall.

Halle, M. and Stevens, K. 1971. A note on laryngeal features. RLE-QPR 101.198-213. MIT.

Halle, M., Hughes, G., and Radley, J.-P. 1957. Acoustic properties of stop consonants. JASA 29.107-16.

Halpern, A. 1946. Yuma. In: C. Osgood (ed.), Linguistic structures of native America. Viking Fund Publications in Anthropology 6. 249-88.

Hankamer, J. and Aissen, J. 1974. The sonority hierarchy. In: A. Bruck, R. Fox, and M. La Galy (eds.), Papers from natural phonology parasession. 131-45. Chicago: Chicago Linguistic Society.

Hardman, M. 1966. Jaqaru: outline of phonological and morphological structure. The Hague: Mouton.

Haudricourt, A. 1967. La langue lakkia. Bulletin de la Société de Linguistique de Paris 62.165-82.

Haupers, R. 1969. A note on Vietnamese k^h and p^h. Mon-Khmer Studies III, Publication No. 4. 76. Saigon: Linguistic Circle of Saigon.

Head, B. 1964. A comparison of the segmental phonology of Lisbon and Rio de Janeiro. Ph.D. Dissertation, University of Texas, Austin.

Hedinger, R. and Hedinger, S. 1977. Phonology of Akɔ́ɔ̄sē (Bakossi). Yaoundé: SIL.

Heffner, R.-M. 1960. General phonetics. Madison: University of Wisconsin Press.

Henry, J. 1935. A Kaingáng text. IJAL 8.172-218.

Hetzron, R. 1969. The verbal system of Southern Agaw. University of California Publications, Near Eastern Studies, Vol. 12. Berkeley and Los Angeles: University of California Press.

Hirayama, T. and Oshima, I. (eds.) 1975. Shin nihongo koza 3: gendai nihongo no onsei to hogen. Tokyo: Sekibunsha.

Hockett, C. 1955. A manual of phonology. Baltimore: Waverly Press.

Hockett, C. 1956. Central Algonquian t and c. IJAL 22.202-7.

Hockett, C. 1958. A course in modern linguistics. New York: Macmillan.

Hoffmann, C. 1963. A grammar of the Margi language. London: Oxford University Press.

Hofmann, T. 1967. Initial clusters in English. RLE-QPR 84.263-74. MIT.

Hoijer, H. and Dozier, E. 1949. The phonemes of Tewa, Santa Clara dialect. IJAL 12.139-44.

Hollenbach, B. 1977. Phonetic vs. phonemic correspondence in two Trique dialects. In: W. Merrifield (ed.), Studies in Otomanguean phonology. 35-67. Arlington: SIL and University of Texas.

Holmer, N. 1949. Goajiro (Arawak) I: phonology. IJAL 15.45-56.

Holzknecht, K. 1973. The phonemes of the Adzera language. Pacific Linguistics, Series A, No. 38. 1-11. Canberra: Australian National University.

Hooper, J. 1972. The syllable in phonological theory. Language 48.525-40.

Hooper, J. 1976. An introduction to natural generative phonology. New York: Academic Press.

Hope, E. 1971. Problems of phone assignment in the description of Thailand Lisu phonology. Papers in South East Asian Linguistics 2.53-77.

Horton, A. 1949. A grammar of Luvale. Johannesburg: Witwatersrand University Press.

House, A. 1957. Analog studies of nasal consonants. Journal of Speech and Hearing Disorders 22.190-204.

Householder, F., Kazazis, K., and Koutsoudas, A. 1964. Reference grammar of literary Dhimotiki. IJAL 30.2, Part II. Indiana University Publications in Anthropology, Folklore, and Linguistics, No. 31. Bloomington: Indiana University.

Huffman, F. 1970. Cambodian system of writing and beginning reader. New Haven: Yale University Press.

Hultzén, L. 1965a. Degrees of difference of English consonants. Proceedings of the 5th Congress of Phonetic Sciences. 367-70. New York: S. Karger.

Hultzén, L. 1965b. Consonant clusters in English. American Speech 40.5-19.

Hunter, G. and Pike, E. 1969. The phonology and tone sandhi of Molinos Mixtec. Linguistics 47.24-40.

Hyman, L. and Magaji, D. 1970. Essentials of Gwari grammar. Institute of African Studies, Occasional Publication, No. 27. Ibadan, Nigeria: University of Ibadan.

Iida, S. 1973. Meiryodo tesuto ni okeru icho no keiko. Journal of the Acoustical Society of Japan 29.527-34.

Ingram, D. 1978. The role of the syllable in phonological development. In: A. Bell and J. Hooper (eds.), Segments and syllables. 143-55. Amsterdam: North-Holland Publishing Co.

Jacobsen, W. 1964. A grammar of the Washo language. Ph.D. Dissertation, University of California, Berkeley.

Jakobson, R. 1968. Child language, aphasia, and phonological universals. The Hague: Mouton.

Jakobson, R. and Halle, M. 1956. Fundamentals of language. The Hague: Mouton.

Jakobson, R., Fant, G., and Halle, M. 1952. Preliminaries to speech analysis. Cambridge: MIT Press.

Javkin, H. 1977. Phonetic universals and phonological change. Ph.D. Dissertation, University of California, Berkeley.

Jespersen, O. 1904. Lehrbuch der Phonetik. Leipzig and Berlin: B. G. Teubner.

Jonasson, J. 1971. Perceptual similarity and articulatory reinterpretation as a source of phonological innovation. STL Quarterly Progress and Status Reports 1.30-41.

Jones, D. and Ward, D. 1969. The phonetics of Russian. Cambridge: Cambridge University Press.

Jones, L. 1967. English phonotactic structure and first-language acquisition. Lingua 19.1-59.

Joo, H. 1977. Gendai nihongo no on'in. In: S. Ono and T. Shibata (eds.), Iwanami koza nihongo, Vol. 5: on'in. 107-45. Tokyo: Iwanami Shoten.

Junod, H. 1896. Grammaire ronga. Lausanne: G. Bridel.

Katsura, M. 1973. Phonemes of the Alu dialect of Akha. Papers in South East Asian Linguistics 3.35-54. Canberra: Australian National University.

Kawasaki, H. 1978. The perceived nasality of vowels with gradual attenuation of adjacent nasal consonants. JASA 64.S19. To appear in J. Ohala (ed.), Experimental phonology. New York: Academic Press.

Kawasaki, H. 1981. Voicing in Japanese. Unpublished paper, University of California, Berkeley.

Kelkar, A. and Trisal, P. 1964. Kashmiri word phonology: a first sketch. Anthropological Linguistics 6.1.13-22.

Keller, K. 1959. The phonemes of Chontal (Mayan). IJAL 25.44-53.

Kelly, J. 1969. Urhobo. In: E. Dunstan (ed.), Twelve Nigerian languages. 153-61. New York: Africana.

Kennedy, N. 1960. Problems of Americans in mastering the pronunciation of Egyptian Arabic. Washington, D.C.: Center for Applied Linguistics.

Key, M. 1968. Comparative Tacanan phonology. The Hague: Mouton.

Kindaichi, K. 1960. Kindaichi Kyosuke senshu 1: Ainugo kenkyu. Tokyo: Sanseido.

Kindaichi, K. 1963. Kokugo on'inron. Revised edition. Tokyo: Toko Shoin.

Kinkade, M. 1963. Phonology and morphology of Upper Chehalis: I. IJAL 29.181-95.

Kiparsky, P. 1979. Metrical structure assignment is cyclic. Linguistic Inquiry 10.421-41.

Klagstad, H. 1958. The phonemic system of colloquial Standard Bulgarian. Slavic and East European Journal 16.42-54.

Klatt, D. and Stevens, K. 1969. Pharyngeal consonants. RLE-QPR 93.207-16. MIT.

Kokugogakkai. 1962. Hogengaku gaisetsu. Tokyo: Musashino Shoin.

Kondo, V. and Kondo, R. 1967. Guahibo phonemes. In: V. Waterhouse (ed.), Phonemic systems of Colombian languages. SIL-PLRF 14. 89-98. Norman: SIL.

Krámský, J. 1971. On the functional conception of the syllable. Linguistics 70.45-56.

Krejnovich, E. 1968. Ketskij jazyk. Jazyki narodov SSSR, Vol. 5. 453-73. Leningrad: Nauka.

Kropp, M. 1968. An analysis of the consonant system of Gã. Journal of West African Languages 5.59-61.

Kuipers, A. 1967. The Squamish language. The Hague: Mouton.

Kurath, H. and McDavid, R. 1961. The pronunciation of English in the Atlantic states. Ann Arbor: University of Michigan Press.

Langdon, M. 1970. A grammar of Diegueño: Mesa Grande dialect. UCPL 66. Berkeley and Los Angeles: University of California Press.

Lehiste, I. 1964. Acoustic characteristics of selected English consonants. Indiana University Publications in Anthropology, Folklore, and Linguistics, No. 34. Bloomington: Indiana University.

Lehtinen, M. 1964. Basic course in Finnish. Uralic and Atlaic Series, No. 27. Bloomington: Indiana University.

Lekach, A. 1979. Phonological markedness and the sonority hierarchy. In: K. Safir (ed.), MIT Working Papers in Linguistics, Vol. 1: papers on syllable structure, metrical structure and harmomy processes. 172-77.

Leslau, W. 1968. Amharic textbook. Berkeley and Los Angeles: University of California Press.

Liljencrants, J. and Lindblom, B. 1972. Numerical simulation of vowel quality systems: the role of perceptual contrast. Language 48.839-62.

Lindblom, B. 1963. On vowel reduction. STL Report, No. 29.

Lindblom, B. 1975. Experiments in sound structure. Paper presented at the 8th International Congress of Phonetic Sciences, Leeds, 1975.

Lindblom, B. 1979. Some phonetic null hypotheses for a biological theory of language. Proceedings of the 9th International Congress of Phonetic Sciences, Vol. 2. 33-40. Copenhagen: Institute of Phonetics, University of Copenhagen.

Lindblom, B. 1980. Discussion during Symposium 1 on phonetic universals in phonological systems and their explanation. Proceedings of the 9th International Congress of Phonetic Sciences, Vol. 3. 185-94. Copenhagen: Institute of Phonetics, University of Copenhagen.

Lindblom, B. In press. Economy of speech gestures. In: P. MacNeilage (ed.), The production of speech. New York: Springer Verlag.

Link, C. 1975. L'interprétation de la consonne médiane dans la structure syllabique CCV en wobé. Annales de l'Université d'Abidjan. Serie H. Linguistique 8.205-13.

Lisker, L. 1963. Introduction to spoken Telugu. New York: American Council of Learned Societies.

Loos, E. 1969. The phonology of Capanahua and its grammatical basis. SIL-PLRF 20. Norman: SIL.

Lounsbury, F. 1953. Oneida verb morphology. Yale University Publications in Anthropology, No. 48. New Haven: Yale University Press.

Maier, J. 1969. Cua phonemes. Mon-Khmer Studies III, Publication No. 4. 9-19. Saigon: Linguistic Circle of Saigon.

Malécot, A. 1974. Cross-language phonetics. In: T. Sebeok (ed.) Current trends in linguistics, Vol. 12. 2507-36. The Hague: Mouton.

Malkiel, Y. 1963-64. The interlocking of narrow sound change, broad phonological pattern, level of transmission, areal configuration, sound symbolism: diachronic studies in the Hispano-Latin consonant clusters cl-, fl-, pl-. Archivum Linguisticum 15.144-73, 16.1-33.

Malmberg, B. 1963. Structural linguistics and human communication: an introduction into the mechanism of language and the methodology of linguistics. Berlin: Springer Verlag.

Malmberg, B. 1965. Stability and instability of syllabic structures. Proceedings of the 5th International Congress of Phonetic Sciences. 403-8. New York: S. Karger.

Manley, T. 1972. Outline of Sre structure. Honolulu: University of Hawaii Press.

Markel, J. 1971. Formant trajectory estimation from a linear least squares inverse filter formulation. Speech communications Research Laboratory Monograph, No. 7.

Martin, S. 1951. Korean phonemics. Language 27.519-33.

Matisoff, J. 1973. The grammar of Lahu. UCPL 75. Berkeley and Los Angeles: University of California Press.

McElhanon, K. 1970. Selepet phonology. Pacific Linguistics, Series B, No. 14. Canberra: Australian National University.

McIntosh, J. 1945. Huichol phonemes. IJAL 11.31-35.

Mehta, B. and Mehta, B. 1925. The modern Gujerati-English dictionary, Vol. 1. Baroda: M. C. Kothari.

Meillet, A. 1964. Introduction à l'étude comparative des langues indo-européennes. University, Ala.: University of Alabama Press.

Meinhof, C. 1929. The basis of Bantu philology. Africa 2.39-56.

Meinhof, C. 1932. Introduction to the phonology of the Bantu languages. Translated by N. von Warmelo. New York: International Institute of African Languages and Cultures, Carnegie Corporation of New York; Johannesburg: Witwatersrand Council of Education.

Meyer-Lübke, W. 1890. Grammaire des langues romanes, Vol. 1. Paris: H. Welter.

Michailovsky, B. and Mazaudon, M. 1973. Notes on the Hayu language. Kailash 1.135-52.

Miller, G. and Selfridge, J. 1950. Verbal context and the recall of meaningful material. American Journal of Psychology 63.176-85.

Miller, W. 1965. Acoma grammar and texts. UCPL 40. Berkeley and Los Angeles: University of California Press.

Mohanan, K. 1979. On syllabicity. In: K. Safir (ed.), MIT Working Papers in Linguistics, Vol. 1: papers on syllable structure, metrical structure and harmony processes. 182-90.

Morgenstierne, G. 1945. Notes on Burushaski phonology. Norsk Tidsskrift for Sprogvidenskap 13.61-95.

Moshinsky, J. 1974. Grammar of Southeastern Pomo. UCPL 72. Berkeley and Los Angeles: University of California Press.

Nakamoto, M. 1976. Ryukyu hogen on'in no kenkyu. Tokyo: Hosei University Press.

Nakata, N. 1972. Sosetsu. In: N. Nakata (ed.), Koza kokugoshi, Vol. 2: on'inshi mojishi. 3-61. Tokyo: Taishukan Shoten.

Navarro Tomás, T. 1961. Manual de pronunciación española. Publicaciones de la Revista de Filología Española, Numero 3. Madrid: Consejo Superior de Investigaciones Científicas, Instituto "Miguel de Cervantes."

N'diaye, G. 1970. Structure du dialecte basque de Maya. The Hague: Mouton.

Newman, S. 1947. Bella Coola I: phonology. IJAL 13.129-34.

North, J. and Shilds, J. 1977. Silacayoapan Mixtec phonology. In: W. Merrifield (ed.), Studies in Otomanguean phonology. 21-33. Arlington: SIL and University of Texas.

Novikova, K. 1960. Ocherki dialektov èvenskogo iazyka: ol'skij govor (I). Moscow and Leningrad: Akademiia Nauk SSSR.

O'Connor, J., Gerstman, L., Liberman, A., Delattre, P., and Cooper, F. 1957. Acoustic cues for the perception of initial /w, j, r, l/ in English. Word 13.24-43.

Ohala, J. 1974. Phonetic explanation in phonology. In: A. Bruck, R. Fox, and M. La Galy (eds.), Papers from natural phonology parasession. 215-74. Chicago: Chicago Linguistic Society.

Ohala, J. 1975. Phonetic explanations for nasal sound patterns. In: C. Ferguson, L. Hyman, and J. Ohala (eds.), Nasálfest. 289-316. Stanford: Stanford Language Universals Project.

Ohala, J. 1978. Southern Bantu vs. the world: the case of palatalization of labials. Proceedings of the Annual Meeting of the Berkeley Linguistics Society 4.370-86.

Ohala, J. 1979a. The phonetics of dissimilation: a hypothesis. Paper presented at the 54th Annual Meeting of the Linguistic Society of America, Los Angeles, 27-29 December, 1979.

Ohala, J. 1979b. The contribution of acoustic phonetics to phonology. In: B. Lindblom and S. Öhman (eds.), Frontiers of speech communication research. 355-63. New York: Academic Press.

Ohala, J. 1980. The application of phonological universals in speech pathology. In: N. Lass (ed.), Speech and language: advance in basic research and practice, Vol. 3. 75-97. New York: Academic Press.

Ohala, J. 1981. The listener as a source of sound change. In: C. Masek, R. Hendrick, and M. Miller (eds.), Papers from the parasession on language and behavior. 178-203. Chicago: Chicago Linguistic Society.

Ohala, J. 1982. The phonological end justifies any means. Preprints of the Plenary Session Papers, the XIIIth International Congress of Linguists, Tokyo, 1982. 199-208.

Ohala, J. In press. The origin of sound patterns in vocal tract constraints. In: P. MacNeilage (ed.), The production of speech. New York: Springer Verlag.

Ohala, J. and Amador, M. 1981. Spontaneous nasalization. JASA 69.S55.

Ohala, J. and Lorentz, J. 1977. The story of [w]: an exercise in the phonetic explanation for sound patterns. Proceedings of the Annual Meeting of the Berkeley Linguistics Society 3.577-99.

Ohala, J. and Riordan, C. 1979. Passive vocal tract enlargement during voiced stops. In: J. Wolof and D. Klatt (eds.), Speech communication papers. 89-92. New York: Acoustical Society of America.

Ohala, J. Riordan, C., and Kawasaki, H. 1978. The influence of consonant environment upon identification of transitionless vowels. JASA 64.S18.

Öhman, S. 1966. Coarticulation in VCV utterances: spectrographic measurements. JASA 39.151-68.

Oishi, H. and Uemura, Y. (eds.) 1975. Hogen to hyojungo: nihongo hogengaku gaisetsu. Tokyo: Chikuma Shobo.

Okumura, M. 1972. Kodai no on'in. In: N. Nakata (ed.), Koza kokugoshi, Vol. 2: on'inshi mojishi. 63-171. Tokyo: Taishukan Shoten.

Okumura, M. 1977. On'in no hensen, II. In: S. Ono and T. Shibata (eds.), Iwanami koza nihongo, Vol. 5: on'in. 221-52. Tokyo: Iwanami Shoten.

Ott, W. and Ott, R. 1959. Fonemas de la lengua ignaciana. Notas Lingüísticas de Bolivia 1. La Paz: Publicaciones del Instituto Lingüístico de Verano.

Ott, W. and Ott, R. 1967. Phonemes of the Ignaciano language. Linguistics 35.56-60.

Panfilov, V. 1962. Grammatika nivkhskogo iazyka, I. Moscow and Leningrad: Akademiia Nauk SSSR.

Pankratz, L. and Pike, E. 1967. Phonology and morphophonemics of Ayutla Mixtec. IJAL 33.287-99.

Passy, P. 1890. Étude sur les changements phonétiques. Paris: Librairie Firmin-Didot.

Pease, H. and Betts, L. 1971. Parintintin phonology. In: D. Bendor-Samuel (ed.), Tupi studies I. SIL-PLRF 29. 1-14. Norman: SIL.

Peasgood, E. 1972. Carib phonology. In: J. Grimes (ed.), Languages of the Guianas. SIL-PLRF 35. 35-41. Norman: SIL.

Philipp, M. 1974. Phonologie des Deutschen. Stuttgart: W. Kohlhammer.

Pike, K. and Pike, E. 1947. Immediate constituents of Mazateco syllables. IJAL 13.78-91.

Pinnow, H.-J. 1964. Bemerkungen zur Phonetik und Phonemik des Kurukh. Indo-Iranian Journal 8.32-59.

Pokorny, J. 1959. Indogermanisches Etymologisches Wörterbuch. Bern: Francke Verlag.

Polome, E. 1967. Swahili language handbook. Washington, D.C.: Center for Applied Linguistics.

Pope, M. 1934. From Latin to Modern French with especial consideration of Anglo-Norman. Manchester: Manchester University Press.

Prokosch, E. 1938. A comparative Germanic grammar. Baltimore: Linguistic Society of America.

Prost, G. 1967. Phonemes of the Chacobo language. Linguistics 35.61-65.

Pulgram, E. 1965. Consonant cluster, consonant sequence, and the syllable. Phonetica 13.76-81.

Pulgram, E. 1970. Syllable, word, nexus, cursus. The Hague: Mouton.

Purnell, H. 1965. Phonology of a Yao dialect spoken in the Providence of Chiengrai, Thailand. Hartford Studies in Linguistics, No. 15. Hartford: Hartford Seminary Foundation.

Rabel, L. 1961. Khasi, a language of Assam. Louisiana State University Studies, Humanities Series, No. 10. Baton Rouge: Louisiana State University Press.

Rambaud, J.-B. 1903. La langue wolof. Paris: Imprimierie Nationale.

Rensch, C. 1977. Classification of the Otomanguean languages and the position of Tlapanec. In: D. Oltrogge and C. Rensch (eds.), Two studies in Middle American comparative linguistics. 53-108. Arlington: SIL and University of Texas.

Resnick, S., Weiss, M., and Heinz, J. 1979. Masking of filtered noise bursts by synthetic vowels. JASA 66.674-83.

Rischel, J. 1974. Topics in West Greenlandic phonology. Copenhagen: Akademisk Forlag.

Rivierre, J.-C. 1973. Phonologie comparée des dialectes de l'extrême-sud de la nouvelle caledonie. Marseille: Société d'Études Linguistiques et Anthropologiques de France.

Robins, R. and Waterson, N. 1952. Note on the phonetics of the Georgian word. BSOAS 15.55-72.

Ruhlen, M. 1975. A guide to the languages of the world. Stanford: Stanford University Language Universals Project.

Sadler, W. 1951. Untangled Loma. Monrovia, Liberia: Board of Foreign Missions of the United Lutheran Church in America.

Saito, S. 1961. Nihongo on'in ichohyo. Nippon Telegraph and Telephone Public Corporation, Electrical Communication Laboratory Technical Journal, Supplement 6.

Samarin, W. 1950. A provisional phonemic analysis of Kisi. Kroeber Anthropological Society Papers 2.89-102. University of California, Berkeley.

Samarin, W. 1966. The Gbeya language. UCPL 44. Berkeley and Los Angeles: University of California Press.

Sapir, E. and Hoijer, H. 1967. The phonology and morphology of the Navaho language. UCPL 50. Berkeley and Los Angeles: University of California Press.

Saporta, S. 1955. Frequency of consonant clusters. Language 31.25-30.

Saussure, F. 1916. Cours de linguistique générale. Paris: Payot. Translated into Course in general linguistics, 1959. New York: Philological Library.

Schachter, P. and Otanes, F. 1972. Tagalog reference grammar. Berkeley and Los Angeles: University of California Press.

Schauer, S. and Schauer, J. 1967. Yucuna phonemics. In: V. Waterhouse (ed.), Phomenic systems of Colombian languages. SIL-PLRF 14.61-71. Norman: SIL.

Senn, A. 1966. Handbuch der Litauischen Sprache: Band I: Grammatik. Heidelberg: Carl Winter Universitatsverlag.

Sherman, D. 1975. Stop and fricative systems: a discussion of paradigmatic gaps and the question of language sampling. Working Papers on Language Universals 17.1-31. Stanford University.

Shetler, J. 1976. Notes on Belangao grammar. Language Data, Asian-Pacific Series, No. 9.

Shibata, T. 1976. Hyojungo to hogen. In: T. Shibata (ed.), Gendai nihongo. Tokyo: Asahi Shinbunsha.

Shipley, W. 1964. Maidu grammar. UCPL 41. Berkeley and Los Angeles: University of California Press.

Shorto, H. 1960. Word and syllable patterns in Palaung. BSOAS 23.544-57.

Sievers, E. 1893. Grundzüge der Phonetik. Leipzig: Breitkopf und Härtel.

Sigurd, B. 1955. Rank order of consonants established by distributional criteria. Studia Linguistica 9.8-20.

Skinner, L. 1962. Usila Chinantec syllable structure. IJAL 28.251-55.

Slis, I. and Van Nierop, D. 1970. On the forward masking threshold of vowels in VC-combinations. Institute for Perception Research, Annual Progress Report 5.68-73.

Smith, K. 1968. Laryngealization and delaryngealization in Sedang Phonemes. Linguistics 38.52-69.

Smith, L. 1975. Labrador Inuttut surface phonology. IJAL 41.97-105.

Smith, N. 1969. Nupe. In: E. Dunstan (ed.), Twelve Nigerian Languages. 133-41. New York: Africana.

Snyder, W. 1968. Southern Puget Sound Salish: phonology and morphology. Sacramento Anthropological Society 8.2-22.

Sommer, B. 1969. Kunjen phonology: synchronic and diachronic. Pacific Linguistics, Series B, No. 11. Canberra: Australian National University.

Stahlke, H. 1971. Topics in Ewe phonology. Ph.D. Dissertation, UCLA.

Stevens, K. 1971. The role of rapid spectrum changes in the production and perception of speech. In: L. Hammerich, R. Jakobson, and E. Zwirner (eds.), Form and substance: festschrift for Eli Fischer-Jørgensen. 95-101. Copenhagen: Akademisk Forlag.

Stevens, K. 1972. The quantal nature of speech: evidence from articulatory-acoustic data. In: E. David, Jr. and P. Denes (eds.), Human communication: a unified view. 51-66. New York: McGraw-Hill.

Stevens, K. 1973. Further theoretical and experimental bases for quantal places of articulation for consonants. RLE-QPR 108.247-52. MIT.

Stevens, K. 1975. The potential role of property detectors in the perception of consonants. In: G. Fant and M. Tatham (eds.), Auditory analysis and perception of speech. 303-30. London: Academic Press.

Stevens, K. 1979. Bases for phonetic universals in the properties of the speech production and perception systems. Proceedings of the 9th International Congress of Phonetic Sciences, Vol. 2. 53-59. Copenhagen: Institute of Phonetics, University of Copenhagen.

Stevens, K. 1980. Discussion during Symposium 1 on phonetic universals in phonological systems and their explanation. Proceedings of the 9th International Congress of Phonetic Sciences, Vol. 3. 185-94. Copenhagen: Institute of Phonetics, University of Copenhagen.

Stevens, K. and Blumstein, S. 1975. Quantal aspects of consonant production and perception: a study of retroflex stop consonants. Journal of Phonetics 3.215-33.

Stevens, K. and Blumstein, S. 1978. Invariant cues for places of articulation in stop consonants. JASA 1358-68.

Stevens, K., House, A., and Paul, A. 1966. Acoustic description of syllabic nuclei: an interpretation in terms of a dynamic model of articulation. JASA 40.123-32.

Sweet, H. 1892. A new English grammar, logical and historical, Part I: introduction, phonology, and accidence. Oxford: Clarendon Press.

Taylor, D. 1955. Phonemes of the Hopkins dialect of Island Carib. IJAL 21.233-41.

Terbeek, D. and Harshman, R. 1971. Cross-language difference in the perception of natural vowel sounds. Working Papers in Phonetics 19.26-38. UCLA.

Ternes, E. 1970. Grammaire structrale du Breton de l'ile de Groix. Heidelberg: Carl Winter Universitatsverlag.

Thomas, C. 1947. An introduction to the phonetics of American English. New York: Ronald Press.

Thomas, F. 1948. Nam, an ancient language of the Sino-Tibetan Borderland. Publications of the Philological Society of London, No. 14. London: Oxford University Press.

Thompson, L. 1965. A Vietnamese grammar. Seattle: University of Washington Press.

Topping, D. 1973. Chamorro reference grammar. Honolulu: University of Hawaii Press.

Toyama, E. 1972. Kindai no on'in. In: N. Nakata (ed.), Koza kokugoshi, Vol. 2: on'inshi mojishi. 173-268. Tokyo: Taishukan Shoten.

Tracy, F. 1972. Wapishana phonology. In: J. Grimes (ed.), Languages of the Guianas. SIL-PLRF 35. 78-84. Norman: SIL.

Trager, F. 1971. The phonology of Picuris. IJAL 37.29-33.

Trnka, B. 1968. A phonological analysis of present-day Standard English. University, Ala.: University of Alabama Press.

Tryon, D. 1970. An introduction to Maranungku (Noth Australia). Pacific Linguistics, Series B, No. 15. Canberra: Australian National University.

Tucker, A. 1929. The comparative phonetics of the Suto-Chuana group of Bantu languages. London: Longmans, Green, and Co.

Tucker, A. and Ashton, E. 1942. Swahili phonetics. African Studies 1.77-103, 161-82.

Turner, R. 1921. Gujarati phonology. Journal of Royal Asiatic Society 1921.329-65, 505-44.

Vachek, J. 1966. Notes on one aspect of the internal structuration of the phonological system. In: To honor Roman Jakobson, Vol. 3. 2109-15. The Hague: Mouton.

Van Syoc, W. 1959. The phonology and morphology of the Sundanese language. Ph.D. Dissertation, University of Michigan.

Vanvik, A. 1972. A phonetic-phonemic analysis of Standard Eastern Norwegian. Norwegian Journal of Linguistics 26.2.119-64; 27.2.101-39.

Vennemann, T. 1972. On the theory of syllabic phonology. Linguistische Berichte 18.1-18.

Vestergaard, T. 1967. Initial and final consonant combinations in Danish monosyllables. Studia Linguistica 21.37-66.

Wallace, J. 1969. Katu phonemes. Mon-Khmer Studies III, Publication No. 4. 64-73. Saigon: Linguistic Circle of Saigon.

Watkins, C. 1969. Indo-European roots. In: W. Morris (ed.), The American heritage dictionary. 1505-50. Boston: Houghton Mifflin Co.

Watson, R. 1964. Pacŏh phonemes. Mon-Khmer Studies I. 135-48. Saigon: SIL and Linguistic Circle of Saigon.

Weimer, H. and Weimer, N. 1972. Yareba phonemes. Te Reo 15.52-57.

Welmers, W. 1962. The phonology of Kpelle. Journal of African Languages 1.69-93.

Welmers, W. 1968. Jukun of Wukāri and Jukun of Takum. Institute of African Studies, Occasional Publication, No. 16. Ibadan, Nigeria: University of Ibadan.

Whiteley, W. 1958. A short description of item categories in Iraqw. Kampala: East African Institute of Social Research.

Wiesemann, U. 1964. Phonological syllables and words in Kaingáng. Volkerkundliche Abhandlungen 1.307-13.

Williams, A. and Pike, E. 1968. The phonology of Western Popoloca. Lingua 20.368-80.

Wilson, W. and Bendor-Samuel, J. 1969. The phonology of the nominal in Dagbani. Linguistics 52.56-82.

Winitz, H. and Irwin, O. 1958. Syllabic and phonetic structures of infant's early words. Journal of Speech and Hearing Research 1.250-56.

Winitz, H. Scheib, M, and Reeds, J. 1972. Identification of stops and vowels for the burst portion of /p, t, k/ isolated from conversational speech. JASA 51.1309-17.

Wood, F. 1926. Post-consonantal w in Indo-European. Language Monographs, No. 3. Philadelphia: Linguistic Society of America.

Wright, J. 1980. The behavior of nasalized vowels in the perceptual vowel space. Report of the Phonology Laboratory 5.127-63. University of California, Berkeley.

Yoshimachi, Y. 1976. Kyushu no kotoba. Tokyo: Sobunsha.

Zeps, U. 1962. Latvian and Finnic linguistic convergences. Uralic and Altaic Series, No. 9. Bloomington: Indiana University.

Zipf, G. 1949. Human behavior and the principle of least effort. Cambridge: Addison-Wesley.

Zue, V. 1980. Acoustic characteristics of stop consonants: a controlled study. Bloomington: Indiana University Linguistics Club.

Zwicky, A. 1972. Note on a phonological hierarchy in English. In: R. Stockwell and R. Macaulay (eds.), Linguistic change and generative theory. 275-301. Bloomington: Indiana University Press.

Addenda:

Cho, S.-B. 1967. A phonological study of Korean. Acta Universitatis Upsaliensis, Studia Uralica et Altaica Upsaliensia, No. 2. Uppsala: Almqvist and Wiksell.

Dow, F. 1972. An outline of Mandarin phonetics. Oriental Monograph Series, No. 10. Canberra: Australian National University.

Tryon, D. 1968. Iai grammar. Pacific Linguistics, Series B, No. 8. Canberra: Australian National University.