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AN ACOUSTIC DESCRIPTION OF SELECTED PHONETIC TYPES COMPRISING /r/ IN THE GENERAL AMERICAN DIALECT

by

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A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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Abstract

AN ACOUSTIC DESCRIPTION OF SELECTED PHONETIC TYPES COMPRISING /r/ IN THE GENERAL AMERICAN DIALECT

by

Lorraine Hansen Russell

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General American /r/ is a complex composite consisting of at least five phonetic types: 1) prevocalic /r/, 2) intervocalic /r/, 3) stressed vocalic /r/, 4) unstressed vocalic /r/, and 5) postvocalic /r/. An acoustic description of each phonetic /r/ type would provide a comprehensive data base useful to those disciplines interested in how man produces speech sounds. Since existing acoustic specifications for General American /r/ were incomplete, the current study was undertaken.

Stimulus words representing the following phonetic contexts /rV/, /CrV/, /CCrV/, /VrV/, /C ɝ /, / ɝ C/, /C ɝC/, /Cɚ /, /C ɚC/, /V ɚ /, and /V ɚC/, were embedded in 230 natural American English sentences with surrounding phonetic contexts systematically varied. One adult male subject produced three repetitions of each of the stimulus sentences. These tape recorded utterances served as the main data for analysis. Three additional adult male speakers as well as the major subject, produced twenty-five per cent of the stimulus sentences as a control set. Broad

and narrow band spectrograms were prepared for all stimuli. Only the data for prevocalic /r/ were analyzed as part of this dissertation.

Prevocalic /r/ events were segmented from the sentence contexts and found to consist of three acoustic segments: transition one (TR 1), a steady-state segment (SS), and transition two (TR 2). Each of these segments were analyzed for fundamental and formant frequencies, segment durations, and acoustic feature characteristics.

Prevocalic /r/ duration analysis resulted in the following conclusions. First, duration was not significantly influenced by anticipatory co-articulation, or vowel nucleus type. Second, duration had to be broken down by acoustic segment type, and prevocalic /r/ type since significant variation resulted from both of these main effects, and in two-way interactions between them. Third, duration was significantly influenced by carryover co-articulation effects, particularly when clustered; specifically: 1) duration was significantly shortened in two-element word-initial clusters consisting of voiced stop + /r/; 2) duration was significantly shortened in three element clusters; and 3) the overall manner and place characteristics of cluster members had no significant influence on duration, although /pr/ was unique. Finally, the TR 2 segment duration was least affected by co-articulatory influences.

Prevocalic /r/ frequency analysis resulted in the following conclusions. First, frequency measurements were significantly influenced by anticipatory co-articulation, or vowel nucleus type. Therefore, all frequency evaluations had to be broken down by the main effects of prevocalic /r/ type, acoustic segment type, and vowel nucleus type.

Second, frequency measurements were significantly influenced by carryover co-articulation, particularly when clustered; specifically, 1) F_0 and F_1 were "cutback" following voiceless cluster members; 2) F_2 was influenced by the place feature of the preceding cluster member and may also have been somewhat influenced by the voicing characteristic of the preceding cluster member; and 3) F_3 was always close to F_2 in frequency value, and was subject to identical co-articulatory influences. Third, the average formant values for prevocalic /r/ (F_0, 133 Hz; F_1, 414 Hz; F_2, 1317 Hz; and F_3, 1798 Hz) paralleled values established in previous studies. Finally, the frequency values measured at the TR 2 onset were least influenced by carryover co-articulatory effects.

Prevocalic /r/ acoustic feature analysis resulted in the following conclusions. First, TR 1, SS, and TR 2 acoustic segment features were minimally influenced by anticipatory co-articulation effects; specifically, nasality was visible in the TR 2 segment of stimulus words having a word-final nasal. Second, the TR 1 and SS segments were substantially influenced by carryover co-articulatory effects when clustered; specifically, these segments were frequently observed to have the features of noise, fricative, and aspirate. Third, the TR 2 segment was least influenced by co-articulatory effects and always had the features of voice, vowel-like, transitional, and retroflexive.

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CHAPTER I

THE PHONETIC TYPES COMPRISING /r/ IN THE GENERAL AMERICAN DIALECT: A SIGNIFICANT SUBJECT FOR ACOUSTIC ANALYSIS

General American /r/ is a complex composite consisting of at least five phonetic types: 1) prevocalic /r/, usually transcribed as [r]; 2) intervocalic /r/ usually transcribed as [r]; 3) stressed vocalic [r], usually transcribed as [ɝ]; 4) unstressed vocalic /r/, usually transcribed as [ɚ]; and 5) postvocalic /r/, usually transcribed as [r] but also transcribed as [ɚ].[1] An acoustic description of each of these /r/ types would provide a comprehensive data base useful to those disciplines interested in how man produces speech sounds. Since existing acoustic specifications for General American /r/ are incomplete, an investigation designed to collect sufficient data from which a complete acoustic description of /r/ could be derived seemed justified.

The first section of this chapter will consist of a review of information concerning the phonetic types comprising the phoneme /r/ in the General American Dialect as described in 1) the literature of articulatory phonetics, 2) studies of disordered speech, 3) studies of normal speech development, and 4) previous acoustic studies. The second section of this chapter will consist of an overview of the current study.

<u>The Phonetic Types Comprising General American /r/ as Described in the Literature of Articulatory Phonetics</u>

Prevocalic /r/, intervocalic /r/, stressed vocalic /r/, unstressed vocalic /r/, and postvocalic /r/ are grouped together since they are often thought of as one phoneme. A phoneme is an abstract unit of structural linguistics which may be thought of as the smallest linguistic unit which may bring about a contrast within words.[2] Generative-transformational linguistics would also consider these phonetic types to be related to a single element in the underlying representation of the phonologic inventory of General American English. Furthermore, its phonetic representation would be observed to have the same range as that observed in the phoneme /r/ of structural linguistics. The generative-transformational movement in phonology has not resulted in more detailed observations of phonetic variations in sound types produced by the speaker but has simply provided more adequate observations regarding their treatment in the phonological component of a generative grammar. Both structural phonology and generative-transformational phonology are primarily concerned with an abstract, idealized level of language while the principal object of concern in this study is the physical surface realities of human speech. Therefore, the traditional descriptions of articulatory phonetics provide more appropriate background information concerning how people produce the phonetic types associated with General American /r/ than do the feature systems of either structural phonology or generative-transformational phonology. What follows, then, is a review of the articulatory and acoustic characteristics as traditionally described in the literature of articulatory phonetics for each of the five phonetic types comprising /r/ in the General American Dialect.

Prevocalic /r/. Prevocalic /r/ occurs in the word-initial context [rV] and in the word-initial cluster contexts [CrVC] and [sCrVC] . It is usually described as a voiced consonant with a manner classification that is alternatively described as a frictionless continuant[3], frictionless glide[4], approximant[5], or semi-vowel[6]. It may be produced with either of two articulatory maneuvers: tongue retroflexed or tongue bunched. In the former, the tongue-tip is elevated toward the hard palate-alveolar ridge juncture while in the latter the tongue-blade is elevated toward the hard palate and the tongue-tip is pointing downward.[7] In either case, the sides of the tongue are in contact with the bicuspid and molar teeth.[8] Both versions result in the same acoustic effect which is described as rhotacized, an acoustic property resulting from the lowering of the frequency of the third formant.[9] A speaker may use one of these two alternative articulatory patterns exclusively or he may alternate between the two depending on the influence of phonetic environment. Prevocalic /r/ production may also involve some degree of lip rounding.[10]

Prevocalic /r/ is subject to much co-articulatory influence, particularly when clustered. Three variants are typically described: 1) prevocalic /r/ may be produced as a fricative when the tongue forms a narrow orifice due to the influence of a preceding sound such as /t/, /d/, and /ʃ/; 2) prevocalic /r/ may be produced as a fricative or as a trill when preceded by /θ/; and 3) prevocalic /r/ may be completely or partially devoiced when preceded by voiceless sounds, particularly by the stops /p, t, k/ but also by the fricatives /f, θ, ʃ/.[11]

Intervocalic /r/. Intervocalic /r/ occurs in the word-medial, intersyllabic context [VrV] . It is typically considered a variant of either prevocalic /r/ or postvocalic /r/, depending on its location with respect to syllable boundary and syllable stress.

Intervocalic /r/ has been considered as a distinct phonetic type in this study, on the basis of data from a study of disordered /r/ articulation conducted by Curtis and Hardy. An analysis of error-type for the intervocalic, intersyllabic /r/, as in carrot, found a high percentage of omission or vowel substitution followed by a consonant substitution blended in such a way as to sound quite different from the errors noted with respect to other /r/ types. Therefore, Curtis and Hardy concluded that intersyllabic, intervocalic /r/ was closer to [V ɚrV] than [VrV] and should be considered as a distinct phonetic type.[12] Kantner and West support this view.

> In words like merry mɛrɪ and Erie ɪrɪ both types are present with the movement to the ɝ forming the end of the first syllable and the movement away from this position the beginning of the second. In furry fɝrɪ the mechanism is held in the position long enough to give the effect of a continuant and then moved on to the ɪ position, thus producing a glide r.[13]

The relationship of intervocalic /r/ to prevocalic /r/, stressed vocalic /r/, and unstressed vocalic /r/ may be dependent upon the position occupied by intervocalic /r/ with respect to syllable boundary and syllable stress; that is on whether intervocalic /r/ is pre-stressed, post-stressed, or pre-unstressed with respect to syllable boundary and syllable stress. For these reasons, intervocalic /r/ has been included in this study as a distinct phonetic type.

Stressed Vocalic /r/. Stressed vocalic /r/ serves as the nucleus of a syllable in such contexts as [C ɝ], [ɝC], and [C ɝC]. It is articulated in much the same manner as prevocalic /r/. However, since it is syllabic, a continuant sound of some length and produced through an orifice large enough to prevent the formation of friction it is considered by most phoneticians to be a vowel.[14] Ladefoged views it as simply the vowel [ə] that has r-coloring throughout. He would therefore transcribe it as [ər].

> But in "sir, here, fur" the whole vowel is rhotacized. Insofar as the quality of this vowel can be described in terms of features high-low and front-back, it appears to be a mid-central vowel and would be designated by a point that might be labeled [ə] in the middle of the chart. In the systematic phonetic transcription of Midwestern American English that we are using, [ə] does not occur in stressed syllables except before [r].[15]

Unstressed Vocalic /r/. Unstressed vocalic /r/ also serves as the nucleus of a syllable in the contexts [C ɚ] and [C ɚ C]. It is believed to be produced in a fashion identical to stressed vocalic /r/ but is limited to unstressed syllables and therefore reduced.[16]

Postvocalic /r/. Postvocalic /r/ occurs in the contexts [V ɚ] and [V ɚ C] which as previously described may also be transcribed as [Vr] and [VrC] . It may be considered a nonsyllabic, consonant glide[17].

Confusion as to the nature of postvocalic /r/, that is, whether it is more consonant-like or vowel-like, gives rise to some unresolved phonetic-phonemic symbolization problems, particularly when considering dialects other than General American and when comparing /r/ in relation to other glides or to other sounds that can act as syllabics. Bronstein has summarized the problems as follows:

> a. The use of a postvocalic [r] symbol in fear or fair calls for the use of a postvocalic [j] and [w], as Hultzén noted in an earlier study.
> b. Stressed [ɝ] and unstressed [ɚ] are the variant forms of [ɜ] and [ə], as in murmur and burner. Retaining the [r] symbol for one dialect and the vowels [ɜ-ə] for others, would not show the appropriate relationship.
> c. [ɝ] and [ɚ] are vowel symbols and are easily recognized as such.
> d. Although /l, m, n, r/ may function as syllabics in English, /l, m, n/ do so in unstressed syllables only. Syllabic /r/ appears, however, in both stressed and unstressed syllabics, in bird, and batter. And although the relationship of [ɪ-u- ɝ] to [j-w-r] seems clear, the special circumstances of [ɜ-ə], of "r-less" murmur and their relation to /r/ have no counterpart in the other glides.
>
> For these reasons, American phoneticians seem to prefer to retain the four vowel symbols [ɜ, ɝ, ə, ɚ]: the first two for the common allophonic variants of bird, the last two for the variants in father, and the [r] for the consonantal position found before and between vowels as in red and very.[20]

Thus, the phonetic types associated with /r/ in the General American Dialect represent an unusual composite since they encompass both vowel-like and consonant-like elements which seem to be articulated in a similar manner. For these reasons, they are a particularly interesting subject for acoustic analysis.

The Phonetic Types Comprising General American /r/: Evidence from Studies of Disordered Speech

Treatment programs for disordered /r/ provide further evidence that the phonetic types associated with /r/ encompass an unusual composite. Published programs for disordered /r/ treatment include: Slipakoff (1967)[21], Butt and Peterson (1970)[22], McDonald and McDonald (1971)[23], Baker and Ryan (1971)[24], Harryman and Kresheck (1971)[25], Gerber (1973)[26], and Bown (1975)[27]. Each of these programs recognizes that /r/ is comprised of several distinct phonetic types, at least [r], [ɝ] ,and [ɚ]. Most of the programs begin the therapeutic procedure by evoking the stressed vocalic /r/ in isolation although Harryman and Kresheck begin by evoking prevocalic /r/ in consonant blends and Bown begins by shaping whatever phonetic type has some existing correct productions. Each program then moves to syllable training, however the order of phonetic types to be presented is varied. All of the programs are based on the rationale that the sequence presented begins with the phonetic type that is easiest to produce and that the sequence is designed to allow for maximum transfer of learning to each subsequent phonetic type. These programs are for the most part based on clinical experience and recognize that systematic ordering of phonetic types may eliminate difficulty in acquiring accurate articulatory patterns. Additional acoustic data might well provide a data base beneficial to the evaluation of existing therapeutic programs for the treatment of disordered /r/ and to the development of more efficient programs.

In addition to clinical treatment programs for disordered /r/, there are three experimental studies of misarticulated /r/ which provide additional evidence as to the unusual nature of /r/ in the General American Dialect and further demonstrate the need for its acoustic study.

Curtis and Hardy (1959). In 1959, Curtis and Hardy reported on an investigation of thirty children who misarticulated /r/[28]. Their first significant result was that /r/ consisted of several phonetic events which could be differentiated on the basis of patterns of error.

There was the glide consonant /r/ which appeared in a prevocalic position, [rV] as in row or as a prevocalic element in a blend preceded by a consonant and followed by a vowel, [CrV] as in crow. An analysis of error types for prevocalic /r/ found them to be primarily of the consonant-type.

There was a stressed vocalic /r/ which in this study only occurred between consonants, [C ɝ C] as in bird. Error types for stressed vocalic /r/ were primarily of the vowel-type.

There was an unstressed vocalic /r/ which occurred as a post-consonantal, [C ɚ] as in mother; between two consonants, [C ɚ C] as in scissors; as a postvocalic, [V ɚ] as in bear; and as a postvocalic, pre-conconsonantal, [V ɚ C] as in fork. In these latter two contexts unstressed vocalic /r/ is frequently described as a consonant glide and transcribed as [Vr] and [VrC] . The Curtis and Hardy results justify use of unstressed vocalic /r/ since the majority of error types in the latter two cases were vowel-like as they were for the first two cases which are universally accepted as unstressed vocalic /r/.

Finally, there was an intersyllabic, intervocalic /r/ context, as in carrot. Curtis and Hardy made no attempt to describe their intervocalic /r/ stimuli as pre-stressed, post-stressed, or pre-unstressed with respect to syllable stress and syllable boundary but simply stated that the assignment to syllable was ambiguous. For this type of /r/, Curtis and Hardy felt that the situation was really [ɚr] as in [kɚrət]. An analysis of error-type for the intervocalic, intersyllabic /r/ found a high percentage of omission or a vowel followed by a consonant substitution blended in a way so as to sound quite different from the errors noted with respect to other /r/ types.

A second significant finding was that different types of /r/ can also be differentiated by the frequency of error response, i.e., speech defective individuals make a different percentage of correct response on the different /r/ types. A rank ordering by correct articulation for the three major /r/ types within six specific phonetic environments, finds the following order from most to least accurately articulated: [Cr], [C ɝ C], [rV], [V ɚ], [C ɚ], and [V ɚ C].[29]

Utilizing data from Tables Three and Seven of the Curtis and Hardy study, it is possible to re-tabulate the percentage of correct articulation for the four major /r/ types, without regard to specific phonetic contexts, though Curtis and Hardy did not present their data in this form. This data, presented in Table I-1, demonstrates the following rank order of correct articulation from most to least accurate, for the four Curtis and Hardy /r/ types, without regard to specific phonetic environment: prevocalic /r/, 27.6 per cent correctly articulated; stressed vocalic /r/, 18.6 per cent correctly articulated; intervocalic /r/, 13.9 per cent correctly articulated; and unstressed vocalic /r/, 10.1 per cent correctly articulated.[30]

TABLE I-1

PHONETIC /r/ TYPES RANK ORDERED ACCORDING TO PERCENTAGE OF CORRECT ARTICULATION-- CURTIS AND HARDY, 1959

/r/ Type	Percentage Correctly Articulated (30 Subjects)	Total Number of Observations
Prevocalic /r/, [r]	27.6	1,842
Stressed Vocalic /r/, [ɝ]	18.6	414
Intervocalic /r/, [ɚr]	13.9	144
Unstressed Vocalic /r/, [ɚ]	10.1	1,928

In summary, Curtis and Hardy have shown that on the basis of type of error response, [r], [ɝ], [ɚ], and perhaps [ɚr] are different phonetic events which should not be grouped for clinical or analytical purposes. Furthermore, both postvocalic /r/ and intervocalic, intersyllabic /r/ are best considered as vocalic rather than as consonantal elements. An acoustic analysis of these /r/ types might further illuminate these findings.

Sommers, Leiss, and Gerber (1969). In this study, each of the three major /r/ types, [ɝ], [r], and [ɚ], in six of the seven possible Curtis and Hardy phonetic environments, [rV], [Cr], [ɝ] [Vɚ], [Cɚ], and [VɚC], was evaluated by an extensive articulation test inventory in a multiple variant experimental design.[31]

One hundred and thirty-one subjects were divided into four cells: Mild /r/ defect, grades one through three; mild /r/ defect, grades four through six; severe /r/ defect, grades one through three; severe /r/ defect, grades four through six. Subjects in each cell were then randomly divided into a group who would remain in speech therapy and a group who would be immediately dismissed from speech therapy. The purpose of the study was to determine if it was possible to predict acceptable proficiency at a later date, both with and without further speech therapy, on the basis of level of current proficiency in any of the six general phonetic environments for /r/. All subjects, both experimental and control, were re-tested three, six, and twelve months following the original phonetic inventory.

The scores from phonetic condition [Cɚ] related most closely to total performance scores. Unstressed vocalic /r/, in two of its three phonetic environments [VɚC] and [Cɚ], was significantly different in terms of its value as an indicator for dismissal from therapy. Subjects who had high performance scores on these two /r/ types, both with and without speech therapy, showed little regression on later evaluations. Subjects who had not initially achieved a high level of performance on these two /r/ types, showed regression in total performance.

The authors hypothesize that these phonetic conditions, [C ɚ] and [V ɚC], require that both production and monitoring be performed under conditions of reduced duration and considerable co-articulation, and that once a subject has mastered this degree of speed and complexity of production the other /r/ allophones are predictably stable. An acoustic study of the phonetic types associated with /r/ would provide data from which to support or deny this hypothesis. Furthermore, such data could provide the specifications for synthetic stimuli which could be used in perceptual experiments designed to probe the crucial elements in production and perception of these phonetic types.

Elbert and McReynolds (1975). This study was designed to determine if training on any one specific /r/ phonetic type would result in transfer of training to other /r/ phonetic types without specific training. Twelve elementary school children with average intelligence and normal hearing served as subjects. All subjects misarticulated the /r/ sounds in all forty of the test stimuli. The test stimuli consisted of forty /r/ nonsense words, ten from each of four categories: 1) word-initial, prevocalic /r/, [rV]; prevocalic /r/ in word-initial clusters, [CrV]; stressed vocalic /r/ in a [C ɝC] context; and 4) unstressed vocalic /r/ as postconsonantal, word-final syllabic, [VCɚ]. Phonetic environments were held consonant for each phonetic /r/ type and represented ten vowels (high, low, front,and back) and four consonants (front, back, voiced,and voiceless stops). Within a multiple baseline design in which six of the twelve children served as controls before receiving training, three subjects were trained on stimulus type [re], three were trained on stimulus type [tre], three were trained on stimulus type [ɝ t], and three were trained on stimulus type [ʌ t ɚ]. The four training stimuli were not included in the forty item test stimuli used for pre-training and post-training evaluation. During the pre-training and post-training tests, subjects were asked to "Say ________." Training consisted of individual sessions, three times per week in which twenty verbal presentations of the selected /r/ training stimulus were presented in six sets (120 stimulus-response pairs). Subjects were reinforced initially for approximations of the correct response and finally for only correct responses with both token and verbal reinforcement. Criterion was reached when a subject correctly produced eighteen of twenty training stimuli in three consecutive sets of twenty. Training was terminated when criterion was reached, or if a child failed to reach criterion at the end of twenty-four sessions.[32]

The results of this study are displayed in Table I-2.[33] Examination of the data displayed in this table leads to several conclusions and a number of questions. Of the ten subjects reaching criterion, correct responses increased in non-trained as well as trained categories indicating that all of the experimental /r/ types were members of the same response class and may not be independent of one another. Nonetheless, differences within each training category and across training categories were apparent, though larger numbers of subjects would be required if such differences were to yield useful and significant information. For example: 1) prevocalic /r/ in training conditions [re] and [tre] produced more correct responses within and across experimental phonetic types; 2) sub-

TABLE I-2

NUMBER OF CORRECT RESPONSES IN EACH ALLOPHONIC CATEGORY ON THE POST-TRAINING PROBE FOR TWELVE SUBJECTS (C=CONSONANT, V=VOWEL) -- ELBERT AND McREYNOLDS, 1975

Trained Context	Subject	Age	Number of Probe Items by Allophonic Category: 10 [rV]	10 [CrV]	10 [ɝC]	10 [VCɚ]	Totals
/rV/ [re]	S_{11}	8-01	5	6	2	8	21
	S_{04}	8-04	4	4	3	1	12
	S_{12}	6-05	1	3	0	0	4
							37
/CrV/ [tre]	S_{03}	8-04	8	7	7	7	29
	S_{07}	8-10	0	8	2	2	12
	S_{05}*	11-06	0	0	0	0	0
							41
/ɝC/ [ɝt]	S_{10}	9-0	0	1	0	3	4
	S_{06}	8-04	0	2	0	0	2
	S_{02}	7-06	8	9	6	6	29
							35
/VCɚ/ [ʌtɚ]	S_{01}	8-04	0	8	1	10	19
	S_{08}	11-03	0	2	3	4	9
	S_{09}*	9-0	0	3	0	0	3
							31
Totals			26	53	24	41	144

* Subjects who did not reach criterion

jects not reaching criterion occurred only in the [ʌtɚ] and [tre] training categories; 3) subjects trained on [ɝt] demonstrated little improvement within that category, even though their correct responses improved in non-trained categories; 4) subjects trained in the vocalic categories, [ɝt] and [ʌtɚ], demonstrated maximum transfer to the non-trained vocalic category and to the prevocalic /r/ word-initial cluster category, while demonstrating miminal transfer of training to the word-initial prevocalic /r/ category; and 5) subjects within each training category demonstrated marked individual differences.

It is apparent that additional experimental studies of this type utilizing large numbers of subjects would establish a data base broad enough for within-cell and across-cell statistical evaluation. Such evaluation would add much to our knowledge of the phonetic types associated with /r/ in the General American Dialect and would enable the development of systematic treatment programs for misarticulated /r/. An acoustic study, such as the one undertaken in this dissertation, would provide a complementary data base from which to derive possible hypotheses concerning why certain /r/ types are easier to produce and provide greater transfer of learning to subsequent /r/ types.

<u>The Phonetic Types Comprising General American /r/: Evidence from Studies of Normal Speech Development</u>

In addition to evidence from experimental studies of misarticulated /r/, three phonetic studies of the acquisition of /r/ in the speech of normal children further support the conclusion that General American /r/ is a complex composite consisting of several related yet independent phonetic types.

<u>Stancyk</u> (<u>1969</u>). In 1969, at the 45th Annual Convention of the

American Speech and Hearing Association, Susan Stancyk reported on a study of the production of /r/ in the speech of preschool children.[34]

Stancyk's subjects were forty normal-speaking, normal-hearing pre-school children between the ages of three and one-half years and four and one-half years. All were enrolled in nursery school programs. Each child was individually tested with a picture articulation test designed to elicit a total of sixty-three /r/ responses, nine from each of the seven phonetic contexts: [rV], [CrV], [CɜC], [Vɚ], [VɚC], [Cɚ], and [CɚC]. Responses were marked as correct or incorrect and were not phonetically transcribed, hence, data as to developmental error types which could have been profitably compared to the Curtis and Hardy data on misarticulated error types were lost. Stancyk's findings are displayed in Table I-3.[35]

Study of Table I-3 leads to two significant conclusions. First, prevocalic /r/, stressed vocalic /r/, and unstressed vocalic /r/ are significantly discrete phonetic types since each has an independent developmental chronology. Stancyk reported that using non-parametric statistics the differences in percentages of correct production between prevocalic /r/ and stressed vocalic /r/ were statistically significant beyond the .001 level of confidence, while the differences in percentages of correct production between stressed vocalic /r/ and unstressed vocalic /r/ were statistically significant from between the .02 and the .01 levels of confidence.

Second, the developmental order of the three major phonetic types of /r/ from the most to the least accurately produced was prevocalic /r/, unstressed vocalic /r/, and stressed vocalic /r/. This finding was not predictable on the basis of the Curtis and Hardy study. Their data

TABLE I-3

PERCENTAGE OF CORRECT PRODUCTION OF /r/
WITHIN EACH OF SEVEN GENERAL PHONETIC
CONTEXTS BY AGE GROUP -- SUSAN STANCYK (1969)

General Phonetic Contexts	Group I (N = 20) Aged 3½ to 4 Percentage Correct	Group II (N = 20) Aged 4 to 4½ Precentage Correct
Prevocalic /r/, [r]	69.5	90.5
/rV/	70.9	88.8
/CrV/	68.2	92.2
Stressed Vocalic /r/, [ɝ]	71.6	73.6
/C ɝ C/	71.6	73.6
Unstressed Vocalic /r/, [ɚ]	73.4	75.6
/V ɚ /	68.9	77.8
/V ɚ C/	63.7	77.2
/C ɚ /	82.1	79.8
/C ɚ C/	78.8	67.8

ranked prevocalic /r/, stressed vocalic /r/, and unstressed vocalic /r/ from the most to the least accurate for articulatory defective speakers (Table I-1). One would have logically predicted the same order for the developmental sequence.

Stancyk's study would have been of greater interest had the age range for subjects been expanded to include two and one-half year olds and five and one-half year olds since the least accurately produced of the /r/ types, /Vɚ C/, was still correctly produced 63.77 per cent of the time at age three and one-half and the most accurately produced /r/, /CrV /, was correctly produced only 92.2 per cent of the time at age four and one-half years. An acoustic study of /r/ in adult speakers would provide a valuable data base on which to compare the development of /r/ in the speech of normal children since it would be useful to know which acoustic features lead to a judgement of correct or incorrect production, how the acoustic features of a child's /r/ compare with those of an adult's /r/, and what the developmental order of various acoustic parameters might be as a child's /r/ becomes more like that of an adult. In fact, Sarah Hawkins recently published a comparative study of the acoustic features of children's speech development in relation to those of the adult in an attempt to answer just such questions.

Hawkins (1973). Hawkins attempted to compare the speech of children to that of adults with respect to the duration of consonants in clustered and non-clustered environments.[36] Her stimuli consisted of English monosyllabic words containing /s/, /l/, and /r/ in clustered and non-clustered context. Seven normal-speaking children, four through seven years of age, served as subjects. Hawkins recorded their speech in their own homes at weekly intervals as they repeated words from stories that had just been read to them, until thirty-six utterances of each stimulus word had been collected. She then made oscillograms and measured all of the consonant durations and some of the vowel durations to compare with a similar adult study conducted by Haggard. Her chief conclusion was that mature forms of consonant timing were not acquired absolutely by children of this age where prevocalic or postvocalic /l/ was involved, and probably not acquired where /s/ was involved, while for /r/ there appeared "to be no strongly abnormal trends in the children's data."[37] However, she felt that the most revealing comparisons concerning /r/ could not be made since existing adult data was either not sufficient or had been reported with too little detail to allow for recalculation if exact comparisons were to be made. Clearly, a substantial data base for the acoustic parameters of /r/ in adult speech is necessary before the many exciting questions concerning children's speech sound acquisition may be answered via comparison between acoustic studies of the speech of children and those of the adult.

Dalston also compared the acoustic characteristics of English /w, r, l/ as correctly spoken by young children and adults.

Dalston (1975). Dalston's study was undertaken to determine if word-initial /w/, /l/, and /r/ were comparable in spectral and temporal characteristics in young children and adults.[38] His subjects were ten normal-speaking children (six male and four female) with a mean age of three years, eleven months and five normal-speaking adults (three male and two female). Each child subject named a set of twenty-nine stimulus pictures at least six times, while each adult subject read a list of twenty-nine corresponding words at least six times. Nine stimulus words were randomly incorporated within the twenty-nine word list. These nine stimulus words were of the /CV/ type, each initiated with /w/, /l/, or /r/ and combined with the vowels /i/, /a/, and /u/. All test words were tape recorded and spectrograms were made. The following measurements were then obtained from the spectrograms: 1) formant frequencies for F_1, F_2, and F_3 of the word-initial consonant steady-state, and of the vowel steady-state; 2) duration measurements of the steady-state portion, and of the transition for each of the first three formants of /w/, /l/, and /r/; and 3) transition rates for each of the first three formants of /w/, /l/, and /r/.

Dalston's frequency data, parallel for children and adults, demonstrated that: 1) F_1 has a characteristically low frequency value which does not serve to separate /w/, /r/, and /l/; 2) F_2 serves to distinguish /w/ from both /l/ and /r/; and 3) F_3 has a very low frequency value for /r/, which serves to distinguish /r/ from /l/.[39] These findings were identical to previous acoustic studies of adult /w, r, l, j/ which will be reviewed in the next section of this chapter.

The first significant finding in the Dalston study concerned /l/. Spectrograms of /lV/ stimuli had rapid F_1 transitions accompanied by a "click"; that is, by a transient noise source which was seen as a narrow vertical spike on the wideband spectrogram[40]. Transient noise sources were never observed in the spectrograms of /wV/ or /rV/ stimuli. This transient noise source was felt by Dalston to account for the fact that children rarely substitute /w/ or /r/ for /l/ during the process of speech sound acquisition.

The second significant finding in the Dalston study concerned /r/, but only as observed in spectrograms of the speech of children. The F_2 transition rate for /r/ was slower than that for either /w/ or /l/.

in the speech of children.[41] O'Connor, et al., had previously demonstrated that a slow transition rate was frequently heard as /wr/ at least before the vowels /i, e, ɛ /.[42] These temporal characteristics may well account for children's /w--r/ production confusions during the process of speech sound acquisition.

In summary, a review of the literature of articulatory phonetics, of studies of disordered articulation, and of studies of children's speech sound acquisition has lead to the conclusion that /r/ in the General American Dialect consists of a complex composite of phonetic types. Furthermore, it has been demonstrated that an acoustic study of each of these phonetic types as produced in the speech of adult speakers of the General American Dialect would provide a comprehensive data base useful to further study of speech sound production, speech sound acquisition, and speech sound misarticulation.

The Phonetic Types Comprising General American /r/: Previous Acoustic Studies

The sound spectrograph, the pattern playback, vocal tract analogues, and computer controlled resonance synthesizers have all been developed during the last thirty years. As a result of these advances in instrumentation, many acoustic studies were completed. These studies were of two main types: 1) acoustic studies of natural speech production, and 2) perceptual studies utilizing synthetic stimuli. A review of these studies established that existing data concerning the acoustic specification of /r/ in the General American Dialect were incomplete. What follows, then, is a chronological review of all previous acoustic and perceptual studies of the phonetic types comprising /r/.

Tarnóczy (1948). The first relevant acoustic study was completed prior to the development of refined instrumentation. Tarnóczy photographed the oscilloscope and laboriously subjected the resultant speech waves to Fourier analysis in order to study laterals, nasals, and glides.[43] He evaluated bisyllabic productions of the form /CVCV/ for six adult speakers, four male and two female. Tarnóczy compiled data concerning the formant structure of /r/ and found that it was unlike any vowel and similar to /l/ except that it did not have the high frequency F_4 found in /l/. Formant values for /r/ were as follows: F_1, 550 Hz; F_2, 1400 Hz; and F_3, 2000 Hz.[44]

This early study was primarily of historical interest since later work led to the discovery that formant loci and formant transitions were more important in identifying glides than were their steady-state segments. Furthermore, it was impossible to know which portion of the prevocalic /r/ event, steady-state onset or transition, Tarnóczy chose to inspect.

Peterson and Barney (1952). This classic acoustic and perceptual study of General American vowels was done at the Bell Laboratories in 1951.[45] Seventy-six speakers, including thirty-three males, twenty-eight females, and fifteen children, recorded word lists containing ten General American vowels embedded in the CVC frame /hVd/. The resultant 1520 tape recorded words were acoustically analyzed by means of a calibrated sound spectrograph. The taped word lists were also presented to seventy listeners over loud speakers for aural classification. Stressed vocalic /r/ as produced in the word herd was part of this study.

Acoustically, stressed vocalic /r/ behaved unlike any other vowel in that it had an F_3 closer in frequency to F_2 than for any other vowel. It was for this reason, that Peterson and Barney felt that stressed vocalic /r/ in the aural classification portion of the study had high intelligibility along with /i/ and /u/, which hold terminal positions in the vowel triangle making them difficult to displace. It is interesting to note that /i/,/u/, and /ɝ/ are also the stressed vocalic variants of the glides /j/, /w/, and /r/. Peterson and Barney speculated that /ɝ/ held its unique acoustic pattern among vowels since it was the only vowel with a marked degree of retroflexion; "...that is, in addition to the regular humping of the tongue the edges of the tongue are turned up against the gum ridge or hard palate."[46]

The specific acoustic parameters for [ɝ] are presented in Table I-4.[47]

Comparison of Peterson and Barney's formant frequency values for the stressed vocalic /r/ and Tarnóczy's formant frequency values for prevocalic /r/ finds them similar, except for F_3, which is 300 cps higher in the consonant glide /r/ of Tarnóczy's experiment. Since the O'Connor, et al., study, which will be reviewed next, indicates that for consonant glide /r/, F_3 begins at a point just above F_2 and usually rises to the steady-state of the vowel, we can estimate that the portion of the /r/ which Tarnóczy inspected was part of the transition as it approached the vowel steady-state.

O'Connor, Gerstman, Liberman, DeLattre, and Cooper (1957). In the first part of this perceptual study, pattern playback stimuli were prepared for the glides /w, j, l, r/.[48] All stimuli were of the CV type with each of the four glides being paired with each of seven cardinal vowels /i, e, ɛ, a, ɔ, o, u/. As had been previously shown in Haskins Laboratories' pattern playback experiments for consonants with other manner of productions, the frequency location for the onset of F_2 and F_3, and the nature of their transitions to the vowel steady-state were found to be equally

TABLE I-4

AVERAGE FUNDAMENTAL AND FORMANT FREQUENCIES
AND FORMANT AMPLITUDES OF VOWEL BY SEVENTY-SIX SPEAKERS
PETERSON AND BARNEY (1952)

	Men	Women	Children
Fundamental Frequency for /ɝ / (cps)	133	218	261
Formant Frequencies for /ɝ / (cps)			
F_1	490	500	560
F_2	1350	1640	1820
F_3	1690	1940	2160
Formant amplitudes (dB)			
L_1	- 5		
L_2	-15		
L_3	-20		

important cues in the preparation of identifiable synthetic glides.

Specifically, the F_2 onset frequency location was sufficient to distinguish /j/ from /w/ from /r-l/, but F_3 was needed to distinguish /r/ from /l/.

That is, F_2 began at a low frequency for /w/, 600 Hz; at a mid-frequency for /r-l/, 1800 Hz; and at a high frequency for /j/, 2400 Hz. The distinction between /l/ and /r/ was evidenced in an F_3 that began at a point just above F_2 and rose to the steady-state vowel location for /r/, and an F_3 that began at a point at least as high as the vowel steady-state for /l/.[49] To clarify the relationships between F_2 and F_3, the reader is referred to Figure I-2, page 39, which provides a map of these relationships as delineated by Lisker in a later study.[50]

The entire class /r, w, l, j/ was found to differ acoustically from stops and nasals in that the glides were all initiated by a steady-state onset which had the same frequency as the F_2 loci. These steady-state onsets had different durations depending on the glides in question. When this steady-state onset was omitted, a stop plus a glide cluster was frequently perceived.

When the steady-state onset was of a thirty millisecond duration, /w/ and /j/ were perceived. If the /w/ and /j/ steady-state onsets were increased to a forty millisecond duration, two vowels /u+V/ or /i+V/ were perceived. When the steady-state onset was of a fifty to sixty millisecond duration, /r/ and /l/ were perceived. If the /l/ and /r/ steady-state onsets were increased to longer than seventy milliseconds, syllabicity occurred and /əl+V/ or /ər+V/ were perceived.[51]

The frequency location of F_1 was found to be crucial only to the perception of /l/. /w/ and /j/ both had F_1 frequency locations of approximately 240 Hz which was also the F_1 value for /i/ and /u/. If the F_1 frequency location fell below 120 Hz then a stop + a glide tended to be perceived. /l/ absolutely required an F_1 of higher than 360 Hz if it were not to be perceived as a nasal. /r/ could have an F_1 frequency of anywhere from 120 Hz to 600 Hz with differences only affecting the "r-color" perceived.[52]

The formant transition durations did not distinguish among glides but between them and other consonant types. All glides could be perceived with a 100 millisecond duration; if the length of the formant transition was decreased, stops were perceived; if the length was increased too greatly, an impression of a vowel changing color was created. Thus, /w, l, r, j/ could all be perceived with formant transitions of 100 millisecond duration, though /l/ was clearer with a sixty to seventy millisecond duration, and /r/ was clearer with a duration of up to 300 milliseconds. The quality of /l/ was further improved when the F_1 duration was as brief as ten milliseconds.[53]

In Part II of this experiment, pattern playback stimuli for /w, r, l, j/ as combined with the vowels /e, a, o/ were varied in crucial acoustic parameters; six different F_2 loci (750 Hz, 840 Hz, 1200 Hz, 1560 Hz, 2040 Hz, and 2400 Hz) were paired with no F_3, a rising F_3, and a straight F_3. These stimuli were presented to phonetically naive undergraduate students for labeling as /w/, /l/, /r/, or /j/.

The values for the acoustic parameters of /w, r, l, j/ as presented in Part I of the experiment were those most frequently labeled as /w/, /r/, /l/, and /j/. That is, "the starting point of the second-formant transition distinguished /w/, /r-l/, and /j/. This formant starts at a low frequency for /w/, at a middle frequency for /r/ and /l/, and at a high frequency for /j/. The third formant tends to distinguish /r/ from /l/, /r/ being helped by the rising third formant and /l/ by the straight third formant."[54] However, perception of /l/ was noticeably inferior to the other three phonemes.[55] This difference was probably caused by too slow a transition for F_1, as well as the lack of transient noise source found consistently necessary to adult /l/ production and perception in later studies.[56]

In summary, pattern playback stimuli for the consonant glide /r/ in the initial position before a vowel, /rV/, consisted of the following acoustic parameters: a mid-frequency F_2 locus (1800 Hz) with an F_3 locus that initiates just above the F_2 locus and rises; a steady-state onset segment of the same general frequency as the F_2 locus which is of a fifty to sixty millisecond duration; and formant transitions from 100-300 milliseconds in duration.

Lisker (1957). In a companion perceptual study to the one just cited, Lisker specified the acoustic parameters for /w, r, l, j/ in the intervocalic position as determined by pattern playback investigation. Initially, his question was "To what extent can an isolated synthetic vowel depart from the acoustic steady-state condition without concomitant phonetic shift?"[57] In answering this question, Lisker prepared three formant vowels of 500 millisecond duration and systematically varied their middle portions. Certain minimal variations resulted in the perception of /w, l, r, j/. He then experimented to determine the acoustic features needed to synthesize these phonemes and to establish their acoustic boundaries.

In order to produce /w, r, l, j/ in a /VCV/ context, five segments of specific duration were required; thus five acoustic segments were needed to produce three phonetic segments. Segments one and five had to be of 150 millisecond duration while segments two, three, and four each had to be of fifty millisecond duration. Shorter durations for segments two, three, and four resulted in flaps; while greater durations were heard as geminates of /w, r, l, j/.[58] These acoustic requirements are easily visualized in a sample pattern playback stimulus presented as Figure I-1.

Pattern playback stimuli of the five segment type shown in Figure I-1 were prepared for /w, r, l, j/ in the contexts [i--i], [u--u] and [a--a] and presented to forty phonetically naive undergraduate students for identification. Segments one and five of the stimuli had formant structures (F_1, F_2, F_3) known to yield the vowels /i, a, u/; segment three had formant structures (R_1, R_2, R_3) that yielded the best /w, r, l, j/; and segments two and four had formant structures (T_1, T_2, T_3) of changing value, though of constant slope, since the initial and terminal frequency values were those of adjacent segments. The best values for segment three were similar to those values presented in the previously reviewed study of initial /w, r, l, j/ by O'Connor, et al.. The first formant frequency (R_1) was identical for /w, r, l, j/ but varied with the vowel-type; for /i/ and /a/ the frequency was 360 Hz, while for /u/ it was 180 Hz. The frequency locations for formants two and three (R_2, R_3) varied with glide-type; R_2 served to divide the stimuli into the subsets /w/, /l-r/, and /j/, while R_3 was needed to distinguish /r/ from /l/. Figure I-2 shows the necessary relationship between R_2 and R_3 in order to produce /w, r, l, j/.[59]

Two additional findings are important. First, synthetic /l/ was again poorly identified by listeners. Furthermore, when Lisker graphed

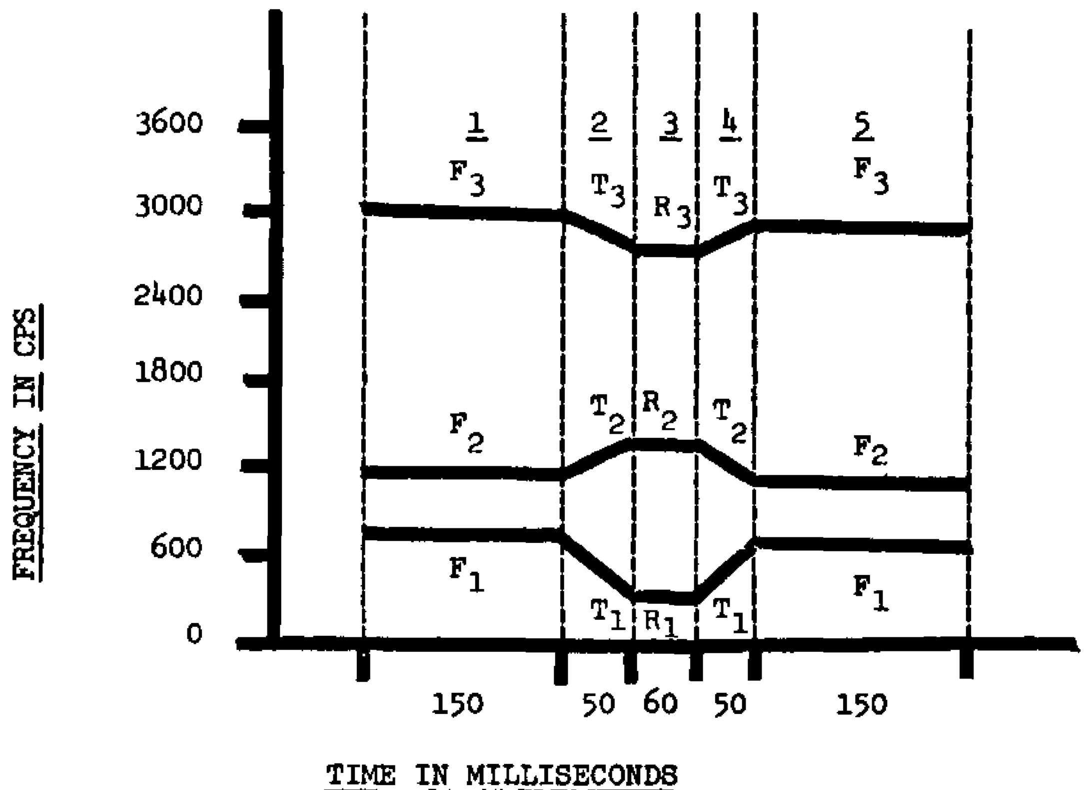


FIGURE I-1. SAMPLE STIMULUS SHOWING THE FIVE SEGMENTS AND THE ACOUSTIC FEATURES WHICH WERE MANIPULATED IN THE EXPERIMENTS - - LEIGH LISKER (1957).

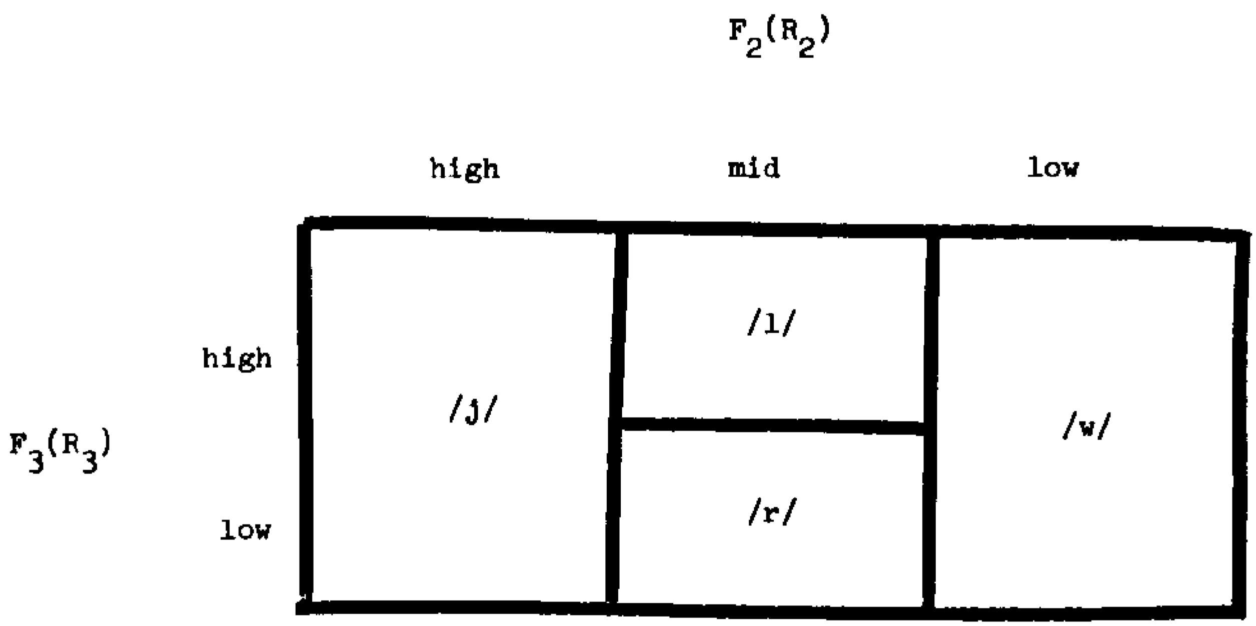


FIGURE I-2. MAP OF THE RELATIONSHIPS BETWEEN $F_2(R_2)$ AND $F_3(R_3)$ FOR THE GLIDES /w, r, l, j/ -- LEIGH LISKER (1957).

the R_2 - R_3 frequency locations common to each phone, independent of vowel contexts,/r, w, j/ each had a common area while /l/ had no one area common to its three vowel contexts.[60] Clearly, the acoustic parameters of synthetic /l/ are somewhat different from those of /r, w, j/.

The second finding is more pertinent to this dissertation. Since the identification of the intervocalic phone depended in part on the composition of the segments one and five (vowel steady-states), Lisker ran a small conjoint study to discover how identification would be affected by a context consisting of dissimilar vowels.

> Patterns of the kind already used in the /u--u/ test were altered by shifting F_2 and F_3 of segment 1 to values appropriate to /i/. These new patterns were played to a small group of listeners who made judgements of the consonant in the context /i--u/, and then in the context /u--i/ (by means of reversing the direction of movement of the patterns on the Playback). These judgements were then compared with the judgements obtained for the /i--i/ and /u--u/ situations. In all, 105 different patterns were evaluated in each of the asymetric contexts. For 65 of the patterns the same judgements were recorded for both /i--u/ and /u--i/ orders. In the remaining 40 cases the identification varied with the order in which the vowels were heard. There were four kinds of such "double entendre":
>
> uwi -- iru
> uwi -- ilu
> uri -- ilu
> uli -- iyu
>
> In 38 of these 40 cases the responses to /u--i/ were the same as the responses to the /i--i/ patterns having the same R_2 and R_3 values; in 30 of the cases responses to /i--u/ were the same as those to the corresponding /u--u/ patterns.[61]

This result adds support to other findings which show that the transitional segment following an intervocalic consonant contributes more to the identification of the consonant than does the transition preceding the consonant.

In summary, Lisker's contribution to the acoustic description of /r/ was to describe intervocalic /r/ in terms that were almost in complete agreement with the findings for initial /r/ as reported by O'Connor, <u>et</u>

al.. The relationship between F_2 and F_3 loci were identical; however, as could have been predicted, intervocalic /r/ consisted of three acoustic segments while initial /r/ consisted of only two. Intervocalic /r/ had one steady-state portion surrounded by two transitions, each segment being of fifty millisecond duration. The transition formant loci for intervocalic /r/ seemed to be more influenced by the adjacent vowel segments than did the transition formant loci for initial /r/. Furthermore, the transition to the second vowel segment had greater influence in identifying the glide perceived than did the transition from the first vowel segment.

Lehiste and Peterson (1961). Lehiste and Peterson acoustically analyzed 1263 monosyllabic CNC words (consonant phoneme-syllable nucleus -consonant phoneme) recorded by one male General American speaker and a control set of seventy words uttered by five speakers of the same general dialect. The purpose of their study was "to investigate the distinction between formant movements which serve as cues for consonant identification and formant movements which signal the presence of a complex syllable nucleus, such as a glide or a diphthong."[62] The results of this investigation reveal the complexity of co-articulation effects thereby demonstrating weaknesses in both the "hub" and "locus" theories. However, little was added to knowledge concerning the acoustic parameters of the consonant allophones of /r/ other than to demonstrate that the duration of onglides and offglides as well as the frequency locations of the formant structure, both at the consonant locus and at the vowel target, were subject to great fluctuation in absolute duration and value when measured from natural speech samples due to the influence of adjacent vowel and consonant elements upon each other. Consequently, Peterson and Lehiste questioned the validity of data gained from synthetic speech ideolects such as the pattern playback,since under these conditions vowel formant structure was held constant allowing only the constant transition to vary even though co-articulation effects disallow this possibility in natural speech. Nevertheless, Peterson and Lehiste did not publish sufficient data concerning the consonant allophones of /r/, in this article, to determine whether or not the data of O'Connor, et al., were supported or denied in natural contextual environments.

Having recognized the potential role of the transition on the syllable nucleus (vowel) as well as on the consonant, Peterson and Lehiste then differentiated between various syllable nuclei on the basis of transitional variations; herein lies their major contribution to the acoustic parameters of /r/ allophones. They concluded that the relationship among the durations of the onglide, target, and offglide of a syllable nucleus divided the syllable sounds of American English into

> ...fifteen syllable nuclei, subdivided into short and long. The long nuclei are further subdivided into simple and complex nuclei. The four short nuclei are lax monothongs. The five simple long nuclei are tense monothongs; the complex long nuclei consist of three single-target nuclei and three double-target nuclei. The single-target nuclei are glides. Only the double-target nuclei are diphthongs. The total inventory of stressed syllable nuclei might then be listed as follows:
>
> Short nuclei: (ɪ), (ɛ), (ə), (ʊ)
> Long nuclei:
> (1) Simple: (i), (æ), (ɑ), (ɔ), (u)
> (2) Complex:
> (a) Single target: (e^{I}), (o^{U}), (ɝ)
> (b) Double target: (ɑɪ), (ɑʊ), (ɔɪ).[63]

Thus, stressed vocalic /r/ was categorized as a complex single target syllable nucleus called a glide. Specifically, it was found to consist of a short steady-state followed by a rather long glide. It was unique among glides (/e^{I} ,o^{U} , ɝ / as classified by these authors) since the direction of this movement was markedly influenced by the terminating consonant. Unstressed vocalic nuclei were not considered in this study.

In summary, then, the contribution of Peterson and Lehiste was to define the relationship of stressed vocalic /r/ to other syllable nuclei (vowels), and to support the necessity to examine all acoustic features in natural speech samples.

Lehiste (1964). In 1964, Lehiste published an extensive acoustic study of "some initial, medial, and final allophones of /r/ in Midwestern American English,"[64] Her stimuli consisted of 135 words embedded in the sentence frame "Say the word ________ instead." The /r/ stimulus words represented the following twelve types, which are described in Lehiste's terms, followed in parentheses by one example taken from each category: 1) initial allophones of /r/, (ram); 2) final allophones of /r/, (bar); 3) the syllable nucleus [ɝ] in CNC words, (burn); 4) the syllable nucleus [ɜ] in CN words, (burr); 5) the derivative suffix -er (-r) added to vowels, (drawer); 6) the derivative suffix -er added to stems ending in /r/, (bearer); 7) the stem-final /r/ before the derivative suffix -y (-ie), (dearie); 8) intervocalic /r/ not associated with morpheme boundary, (arid); 9) stem-final /r/ before the derivative suffix -ing (boring); 10) postconsonantal final /r/, (author); 11) postconsonantal /r/ before vowels (syllabic allophones), (angry); and 12) postconsonantal /r/ before vowels (syllabic allophones), (bakery). Stimulus sentences were read in random order by five adult speakers of the Midwestern dialect of American English. The tape recorded utterances were then analyzed spectrographically and frequency measurements for the first three formants of each /r/ type were calculated.

The average formant positions associated with each of Lehiste's twelve /r/ allophones are presented in Table IV-5.[65] In addition to the formant frequency values, Lehiste also described what she called "dynamic patterns" of /r/ segments. However, she did not measure segment durations.

The initial allophones of /r/ (Lehiste's type one, e.g., ram, comparable to the word-initial prevocalic /r/ stimuli of this study) were characterized by low frequency values for the first three formants and by a close F_2 and F_3. The dynamic pattern consisted of a steady state segment followed by a rapidly moving transition to the following vowel. These prevocalic /r/ types were not influenced by the following vowel.[66]

Final allophones of /r/ (Lehiste's type two, e.g., bar, comparable to the postvocalic /r/ stimuli in the [V ɚ] context of this study) had a higher frequency value for all three formants than those found in initial /r/ allophones,with a second formant that was in the range of the third formant of the initial /r/ allophones. However, final /r/ allophones were influenced by the preceding vowel.[67]

The syllable nucleus [ɝ] in CNC words (Lehiste's type three, e.g., burn, comparable to the stressed vocalic /r/ stimuli in the [C ɝ] context of this study) had an F_1 and F_2 that was similar to the final allophones of /r/ while F_3 was higher. Dynamically, [ɝ] could not be defined by the steady state alone but consisted of an initial transition, a brief steady state and a relatively long glide toward the following consonant's frequency position.[68]

The syllable nucleus [ɝ] in CN words (Lehiste's type four, e.g., burr, comparable to the stressed vocalic /r/ stimuli in the [C ɝ] context of this study) differed from that in CNC words, type three, only in dynamic patterns. "In CN words, the syllable nucleus [ɝ] is not segmentable into

TABLE I-5

AVERAGE FORMANT POSITIONS, IN CYCLES PER SECOND, OF VARIOUS ALLOPHONES OF /r/. COLUMN NUMBERS REFER TO THE TWELVE /r/ STIMULUS WORD TYPES-I. Lehiste (1964)

	/r/ TYPES											
	1	2	3	4	5	6	7	8	9	10	11	12
FORMANT 1	280	460	445	425	435	425*	420	465	435*** 455	420	385	385
FORMANT 2	920	1260	1250	1255	1270	1115* 1270**	1110	1235	1120 1195***	1370	1280	1210
FORMANT 3	1350	1540	1605	1495	1530	1420* 1510**	1400	1510	1390 1460***	1600	1575	1480

* lowest value after syllable nucleus
** steady state value
*** initial-like allophone

a steady-state and a glide on the basis of formant positions."[69]

The formant structure of the derivative suffix -er (-r) added to vowels (Lehiste's type five, e.g., drawer, which has no comparable stimuli in study) occupied a middle position between the final /r/ allophones and the syllable nucleus [ɝ].[70]

In the derivative suffix -er added to stems ending in /r/ (Lehiste's type six, e.g., bearer, which has no comparable stimuli in this study) the final /r/ was identical in character to the derivative suffix added to vowels, while the stem final /r/ resembled an initial allophone of /r/ in that it had a low F_2 and F_3.[71]

All intervocalic /r/ types (Lehiste's type six, e.g., bearer; type seven, e.g., dearie; type eight, e.g., arid; and type nine, e.g., boring, of which type eight is comparable to the intervocalic /r/ stimuli of this study, while types six, seven, and nine have no comparable stimuli in this study) "could be roughly divided into two groups; one set of allophones appeared more similar to the initial allophones than the other set, and was classified as initial-like. These initial-like medial allophones occurred each time as the first member of sequences /r/ + /r/, when the sequence was the result of adding the derivative suffix -er to a stem ending in /r/. They also occurred sporadically in other sequences, particularly after /ɑʊ/ and /ɑɪ /, although their occurrence did not appear systematic as in the sequences /r/ + /r/."[72] The initial-like allophones had a lower formant frequency value for all formants than did the other intervocalic allophones.

The postconsonantal final /r/ types (Lehiste's type ten, e.g., author; type eleven, e.g., angry; and type twelve, e.g., bakery, of which type ten is comparable to postvocalic /r/ in the [C ɚ] context of this study; type eleven is somewhat comparable to prevocalic /r/ in the [CrV] context of this study although Lehiste's stimuli occurred in an unstressed syllable,while those of this study occurred in a stressed syllable; and type twelve which has no comparable stimuli in this study were

> ...studied in several types of words. The formant structure of final /r/ in monomorphemic, monosyllabic words was not appreciably different from that of final /r/ as derivative suffix added to vocalic stems. Two postconsonantal allophones of /r/ appeared in the analysis. The postconsonantal final allophone was identified with [ɝ] as syllable nucleus in monosyllabic words and considered syllabic. A contrast was observed in nonfinal postconsonantal position between a consonantal allophone and one considered in some ways similar to the postconsonantal final allophone. The contrast appeared to be defined in terms of formant structure as well as duration. The phonetic features that were associated with the sound similar to the postconsonantal final allophone, distinguishing it from the consonantal allophone, were assumed to constitute characteristics of syllabicity.[73]

In summary, then, Lehiste provided a detailed discussion of the formant frequency values and dynamic patterns for twelve /r/ types, including four varieties of unstressed vocalic /r/ not included in the current study. However, this study included unstressed /r/ in the context [CɚC], stressed vocalic /r/ in the context [ɝC] , and prevocalic /r/ in word-initial clusters which were not included in the Lehiste study. All twelve of Lehiste's /r/ types were described as phonetically similar. Their most common characteristic was a low F_3 frequency value which was very close in value to that of F_2, felt by Lehiste to be the acoustic correlate of retroflexion. However, "given this basic phonetic similarity, a great deal of individual variation is possible both from speaker to speaker and from positional variant to positional variant."[74] The only allophone always distinguishable from any other allophone on the basis of frequency data was the initial allophone, or prevocalic /r/ in a word-initial position. That allophone always had "relatively lower positions for the first three formants than were observed in other allophones of /r/".[75]

Ainsworth (1968). In 1968, Ainsworth published a perceptual study of the semi-vowels /w, r, l, j/ as they occur in /CV/ contexts.[76] Computer produced stimuli were modified over a large range of difference in three basic experimental conditions.

In the first experiment, the F_1 locus was held constant while the F_2 and F_3 loci were varied in frequency location and in the duration of the transition. In the second experiment, the F_1 locus was varied with the F_2 and F_3 loci in frequency location while all transitions were held constant at a 100 millisecond duration. In the third experiment, the transitions of F_1 were changed from their usual ramp-like shape to a step-like shape; that is, the locus of F_1 was held at a constant frequency until F_2 and F_3 transitions were complete, then it was changed in a single ten millisecond step.

The stimuli in each of these experiments were submitted to a board of naive listeners for labeling as /w, r, j, l/. Responses were plotted as a function of the experimental variants just described.

The results of experimental condition one found the relationships between the frequency locations of F_2 and F_3 as reported by O'Connor, et al., to be correct; absolute measurements in Hz for the frequency location of F_2 and F_3 loci varied with the subsequent vowel as previously reported by Peterson and Lehiste. Transition duration was found to have no relationship to accurate linguistic labeling. /l/ was again found to be poorly identified by listeners. The results of experiment two demonstrated once more that the frequency location of F_1 is unimportant. Furthermore, varying the F_1 locus did not improve the perception of /l/. The final experimental condition established that a step-like shape for F_1 markedly increased the percentage of correct perception for /l/ while decreasing the percentage of correct perception for /w, j, r/. The author theorized that sudden shift of the tongue-tip from the contact articulation point found only in production of the semivowel /l/, as it occurs in /CV/ contexts, was mirrored in the step-like function of the F_1 transition.[77]

In summary, Ainsworth substantiated the acoustic boundaries for initial consonant glide /r/ previously reported by O'Connor, et al., and offered further evidence that on both an acoustic and articulatory basis /l/ may not be appropriately grouped with the semivowels /w, r, j/.

Klatt (1973). In the Klatt study of the effects of clustering on prestressed word-initial /s/ and /r/ clusters, three male adult speakers of American English, dialect unspecified, recorded five examples of each of twenty-five different word-initial clusters and an additional thirteen words beginning with single consonants for reference purposes.[78] The five examples for each of the word-initial clusters included four words with the vowels /i, ɜ ,aɪ,u/ and a fifth word which added a second syllable to the end of one of the preceding four monosyllabic words; for example, street, stress, strike, strewn, and stressful. Prevocalic /r/ was included as a single consonant and as a member of a two element cluster with the stop consonants /p, b, t, d, k, g/ and in three element clusters with the consonants /sp, st, sk/. All stimulus words were spoken in the frame sentence Say X instead. Spectrograms were made and segmental durations defined by stated acoustic boundaries.

Klatt found that consonants were generally shorter in two and three element clusters than in a single /CV/ syllable. However, the shortening effect was not a simple one, as can be seen in Table I-6 in which the observed durational differences are summarized in a system of rules for

TABLE I-6

RULES FOR PREDICTING THE CHANGE IN BASIC DURATION OF A CONSONANT IN A PRESTRESSED WORD-INITIAL CLUSTER. TOTAL PERCENTAGE CHANGE IS OBTAINED BY ADDING THE CONTRIBUTIONS OF APPLICABLE RULES.--D.H. KLATT (1973)

RULE	EXAMPLE
1. General Consonantal Shortening	
In two-element clusters, C_1 = -12% and C_2 = -22%	--
In three-element clusters, C_1 = -15%, C_2 = -25% and C_3 = -30%	--
2. Sonorant Lengthening if Partially Voiceless	
If C is preceded by a voiceless aspirated stop, C = +28%	kr
3. Ballistic Shortening	
If C precedes a stop, C = -8%	sn
If C precedes a voiceless stop, C = =8%	sk
4. Incompressibility of Labials	
If C is a labial, C = +6%	sm
If C is adjacent to a labial, C = -6%	sm
5. Retroflexion Following Dental Stops	
If /r/ follows a dental stop, /r/ = + 13%	tr
If /r/ follows a dental stop, dental stop = -13%	tr

predicting the change in basic duration of a consonant in a prestressed word-initial cluster.[79]

Thus prevocalic /r/ was demonstrated to be of shorter duration in word-initial clusters than in a single /CV/ syllable. Furthermore, the shortening effect was influenced by the voicing characteristic of the preceding cluster member; that is, if preceded by a voiced cluster member in a two-element cluster, the duration of /r/ was shorter than if preceded by a voiceless, aspirated consonant. The shortening effect was greatest on /r/ as a member of a three element cluster. Finally, /r/ was of somewhat greater duration when its preceding cluster member was articulated in approximately the same place of articulation, that is when preceded by /t/ and /d/.

Haggard (1973). In the Haggard study of the effects of clustering on segment duration, eight male speakers of Southern British English recorded isolated stressed monosyllables in five random ordered lists.[80] Prevocalic /r/ was examined as a word-initial singleton and as a member of two element, word-initial clusters combined with the stop consonants /p, b, t, d, k, g/; three element clusters were not included. Haggard's acoustic analysis utilized oscillographic recordings from which acoustic segment boundaries were defined by a change in excitation type or at an abrupt shift in articulatory closure.

Haggard's results were identical with those reported by Klatt in that clustering shortened the duration of prevocalic /r/ and that the shortening effect was greater in the case of voiced stops + /r/ than in the case of voiceless stops + /r/, where place was held constant. While an analysis of variance did not show a general effect of place on the accompanying clustered consonant on prevocalic /r/ duration, non-parametric evaluation, taking only the less ambiguous voiced contexts /b, d, g/, showed the duration of /d/ to be longer.[81]

Thus, Haggard and Klatt both demonstrated the shortening effect of clustering on prevocalic /r/ duration including the surprising finding that abbreviation of /r/ was greater in the phonetic context of voiced stop + /r/ than in the case of voiceless stop + /r/ for cognate cluster types.

A Summary of Previous Acoustic Studies. The previous acoustic studies of /r/ clearly demonstrated that its phonetic types comprise a unique composite, which while acoustically similar, demonstrated many differences with regard to positional variation and contextual variation. Both temporal and spectral information were required to demonstrate the full range of these differences. While no previous study examined acoustic feature characteristics, it may be assumed that such aspects might also differntiate among /r/ types.

A second conclusion to be taken from the review of previous literature was that the major phonetic types associated with /r/ in the General American Dialect had not been thoroughly described acoustically. Some /r/ events had been excluded from previous studies.Some /r/ events were analyzed only temporally or spectrally. Even if every /r/ type had been investigated both spectrally and temporally, the results of these different studies were not in all cases comparable since several studies utilized natural speech, several utilized synthetic speech, and the majority utilized different analysis procedures. Furthermore, co-articulatory influences have been demonstrated to have great influence on /r/ types thereby necessitating the use of more natural stimuli; that is, stimulus words embedded in natural speech contexts with phonetically controlled environments.

If, then, as demonstrated in the first part of this chapter, /r/ does consist of a composite of phonetic types perhaps unlike any other American consonant, and if clarification of the nature of the acoustic features of that composite would be useful to several disciplines interested in how man produces speech sounds, further acoustic investigation of /r/ is certainly warranted.

AN OVERVIEW OF THE CURRENT STUDY

The current investigation was deisgned to provide a comprehensive acoustic data base describing the major phonetic types related to /r/ in the General American Dialect: 1) prevocalic /r/, 2) intervocalic /r/, 3) stressed vocalic /r/, 4) unstressed vocalic /r/, and 5) postvocalic /r/. Stimulus words representing the following phonetic contexts /rV/, /CrV/, /CCrV/, /VrV/, /Cɝ/, /ɝC/, /CɝC/, /Cɚ/, /CɚC/, /Vɚ/, and /VɚC/ were embedded in 230 natural American English sentences with surrounding phonetic contexts held constant. One adult male subject (General American Dialect) produced three repetitions of each of the stimulus sentences in random order. These tape recorded utterances served as the main data for analysis. Three additional adult male speakers (General American Dialect), as well as the major subject, produced twenty-five per cent of the stimulus sentences, randomly selected as a control set. Broad and narrow-band spectrograms were prepared for all stimuli.

Only the data for prevocalic /r/ were analyzed for this dissertation. Prevocalic /r/ events were segmented from the natural sentence contexts and analyzed for fundamental and formant frequencies, segment durations, and acoustic feature characteristics.

It is planned to analyze the data for the remaining four /r/ types later. The resultant acoustic data base for the major phonetic types associated with /r/ in the General American Dialect should provide the basis for the development of numerous testable hypotheses concerning vocal tract shape, articulatory movements,and perceptual judgements.

FOOTNOTES -- CHAPTER I

[1]It is acknowledged that the label, General American Dialect, is extremely broad and does not specifically reflect one dialect area. However, it was for precisely this reason that it was selected as a cover term, since it was simply meant to refer to any United States dialect which encompasses a full range of /r/ types. The specific dialect history for each subject is included in Appendix F.

While American phoneticians typically transcribe prevocalic /r/ and intervocalic /r/ as [ɾ], it is probably more accurately transcribed as [ɹ]. Furthermore, many phoneticians transcribe postvocalic /r/ as [Vɚ] and [VrC]; for example, John S. Kenyon and Thomas A. Knott in _A Pronouncing Dictionary of American English_ (Springfield, Mass.: F. and C. Merriam Company, Publishers, 1953): Charles Kenneth Thomas in _An Introduction to the Phonetics of American English_ (Second Edition, New York: The Ronald Press, 1958); Claude Merton Wise in _Introduction to Phonetics_ (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1957)). However, in this dissertation these contexts were transcribed as [Vɚ] and [Vɚ C] after the transcription system adopted by Arthur J. Bronstein in _The Pronounciation of American English_ (New York: Appleton-Century-Crofts, 1960).

[2]Peter Ladefoged, _A Course in Phonetics_ (New York: Harcourt, Brace, Javanovich, Inc., 1976), p. 23.

[3]Claude Wise, _Introduction to Phonetics_ (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1958), p. 132.

[4]Arthur Bronstein, _The Pronunciation of American English_ (New York: Appleton-Century-Crofts, Inc., 1960), p. 116.

[5]Ladefoged, p. 54.

[6]_Ibid_, p. 207.

[7]Charles Kenneth Thomas, _An Introduction to the Phonetics of American English_ (Revised Edition, New York: The Ronald Press, 1958), p. 87; Wise, p. 132; Bronstein, p. 116; and Ladefoged, p. 55.

[8]Bronstein, pg. 116.

[9]Ladefoged, p. 267.

[10]_Ibid_., p. 55.

[11]Claude E. Kantner and Robert West, _Phonetics_ (Revised Edition; New York: Harper Brothers, 1960), pp. 171-175; Wise, pp. 132-133; and Bronstein, pp. 116-118.

[12]James F. Curtis and James C. Hardy, "A Phonetic Study of Mis-Articulation of /r/," _Journal of Speech and Hearing Research_, II (September, 1959), p. 254.

[13]Kantner and West, p. 131.

[14]Kantner and West, p. 88; Bronstein, p. 176; Thomas, p. 94; Wise, p. 132; and Ladefoged, p. 71.

[15]Ladefoged, p. 71.

[16]Thomas, p. 96; and Bronstein, p. 177.

[17]Thomas, p. 93; and Kantner and West, p. 129.

[18]Bronstein, p. 119.

[19]Ibid.

[20]Arthur J. Bronstein, "Some Unresolved Phonetic-Phonemic Symbolization Problems," Quarterly Journal of Speech, XLVIII (January,1961), pp. 57-58.

[21]Ethel Levin Slipakoff, "An Approach to the Correction of the Defective /r/," Journal of Speech and Hearing Disorders, XXXII (February, 1967), pp. 71-74.

[22]D. Butt and D. Peterson, R-Kit for Articulation Therapy (Albuquerque, New Mexico: Speech Systems, 1970).

[23]G.C. McDonald and J.M. McDonald, The Teaching of "R" by a Programmed Method (Holidaysburg, Pennsylvania: Blair County Public Schools, 1971).

[24]R.D. Baker and B.P. Ryan, Programmed Conditioning for Articulation (Monterey, California: Monterey Learning Systems: 1971).

[25]E. Harryman and J. Kresheck, "A Structured Program for Modifying /r/ Misarticulations," Language, Speech and Hearing Services in the Schools. II (January, 1971), pp. 52-54.

[26]Adele Gerber, Goal: Carryover - - An Articulation Manual and Program (Philadelphia, Pennsylvania; Temple University Press, 1973).

[27]J. Clinton Bown, "Techniques for Correcting /r/ Misarticulations," Language, Speech and Hearing Services in the Schools, VI (April,1975), pp. 86-91.

[28]James F. Curtis and James C. Hardy, pp. 244-257.

[29]Ibid., p. 250

[30]Ibid., pp. 250-253.

[31]R.K. Sommers, R. Leiss and A. Gerber. Paper read by A. Gerber at the 45th Annual ASHA Convention, Chicago, November, 1969, "A Criteria for Dismissal of /r/ Defective Children from Therapy," pp. 1-10.

[32]Mary Elbert and Leija McReynolds, "Transfer of /r/ Across Contexts," Journal of Speech and Hearing Disorders, XL (August, 1975), pp. 380-384.

[33]Ibid., p. 385.

[34]Susan Stancyk, Paper read at the 45th Annual Convention of the American Speech and Hearing Association, Chicago, November 1969, "A Phonetic Study of the Production of /r/ in Preschool Children," pp. 1-6, plus slides.

[35]Ibid.,slide 5.

[36]Sarah Hawkins, "Temporal Coordination of Consonants in the Speech of Children: Preliminary data," Journal of Phonetics, I (July,1973), pp. 181-217.

[37]Ibid.,p. 196.

[38]Rodger M. Dalston, "Acoustic Characteristics of English /w, r, l/ Spoken Correctly by Young Children and Adults," Journal of the Acoustic Society of America, LVII (February, 1975), pp. 462-469.

[39]Ibid.,p. 464.

[40]Ibid.,p. 466.

[41]Ibid.,p. 467.

[42]J. O'Connor, L.J. Gerstman, A.M. Liberman, P.G. DeLattre and F.S. Cooper, "Acoustic Cues for the Perception of Initial /w, j, r, l/ in English," Word, XIII (April, 1957), pp. 24-43.

[43]Thomas Tarnóczy, "Resonance Data Concerning Nasals, Laterals and Trills," Word, IV (August,1948), pp. 71-77.

[44]Ibid.,p. 76.

[45]G.E. Peterson and H.L. Barney, "Control Methods Used in a Study of Vowels," Journal of the Acoustic Society of America, XXIV (March,1952) pp. 175-184.

[46]Ibid.,p. 178.

[47]Ibid.,p. 183.

[48]C. O'Connor, et al., pp. 24-43.

[49]Ibid.,pp. 27-29.

[50]Leigh Lisker, "Minimal Cues for Separating /w, r, l, y/ in Intervocalic Position," Word XIII (August,1957), p. 261.

[51]O'Connor, et al, pp. 30-31.

[52]Ibid.,pp. 31-32.

[53]Ibid.,p. 35-37.

[54]Ibid.,p. 40.

[55] *Ibid.*,p. 43

[56] Dalston, p. 466; and W.A. Ainsworth, "First Formant Transitions and the Perception of Synthetic Semivowels," *Journal of the Acoustic Society of America*, XLIV (September,1968), p. 693-694.

[57] Leigh Lisker, (August,1957), pp. 256-267.

[58] *Ibid.*,p. 258.

[59] *Ibid.*,p. 261.

[60] *Ibid.*,p. 264.

[61] Lisker, pp. 264 and 266.

[62] Ilse Lehiste and Gordon E. Peterson, "Transitions, Glides, and Diphthongs," *The Journal of the Acoustical Society of America*, XXXIII (March, 1961), pp. 268-277.

[63] *Ibid.*,pp. 276-277.

[64] Ilse Lehiste, "Acoustical Characteristics of Selected Consonants," *International Journal of American Linguistics*, XXX (July,1964), p. 51.

[65] *Ibid.*,pp. 51 and 54-55.

[66] *Ibid.*,p. 58.

[67] *Ibid.*,pp. 58 and 61.

[68] *Ibid.*,pp. 61 and 64.

[69] *Ibid.*,p. 64.

[70] *Ibid.*,p. 65.

[71] *Ibid.*,pp. 65 and 67.

[72] *Ibid.*,p. 110.

[73] *Ibid.*,pp. 110-111.

[74] *Ibid.*,p. 111.

[75] *Ibid.*

[76] Ainsworth, pp. 689-694.

[77] *Ibid.*,p. 692-694.

[78] D.H. Klatt, "Durational Characteristics of Prestressed Word-Initial Consonant Clusters in English," Research Laboratory of Electronics, *Quarterly Progress Report*, N.J., 108, MIT, pp. 253-260 (unpublished), 1973.

[79] Ibid.,p. 257.

[80] Mark Haggard, "Abbreviations of Consonants in English Pre- and Post- Vocalic Clusters," Journal of Phonetics, I (January,1973), pp. 9-24.

[81] Ibid.,p. 13.

CHAPTER II

DATA COLLECTION PROCEDURES

As described in Chapter I, this study was designed to collect adequate data from which to establish the acoustic definitions of the phonetic events comprising the phoneme /r/, which may be transcribed by the phonetic symbols [r], [ɝ] and [ɚ] for the General American Dialect.

To this end, common words representative of these phonetic types were selected, embedded in structurally similar sentences, and read by subjects who are speakers of the General American Dialect. These sentences were recorded on tape and later converted to spectrograms. The resultant spectrograms were divided into five types for the purpose of analysis: (1) prevocalic /r/, usually transcribed as [r]; (2) intervocalic /r/, usually transcribed as [r]; (3) stressed vocalic /r/, usually transcribed as [ɝ]; (4) unstressed vocalic /r/, usually transcribed as [ɚ]; and (5) postvocalic /r/, which has been transcribed as [ɚ] in this dissertation but may also be transcribed as [r].[1] The spectrograms for each /r/ type provided equivalent sets of data from which appropriate physical measurements could be made, statistically evaluated, and finally summarized as descriptive statements specifying the acoustic parameters of each /r/ type.

The remainder of this chapter will be used to explicate the procedures of stimulus preparation, data collection and data preparation. The design of parallel stimuli for each of the five /r/ types and the implementation of a unified data collection and preparation procedure constituted a major portion of the work of this dissertation. While spectrograph data for each of the five /r/ types were prepared, only the spectrographic data for prevocalic /r/, Type I, were analyzed as part of this dissertation.

Stimuli

Criteria for the Selection of Stimulus Words

The following criteria were established for the selection of stimulus words:

1) Stimulus words should be common American English words.

2) When pronounced in a General American Dialect, stimulus words should contain [r], [ɝ], and [ɚ] in a majority of their permissible phonetic environments. The phonetic environments [rV], [CrV], and [CCrV] were selected for Type I, prevocalic /r/ stimulus words; the environment [VrV] was selected for Type II, intervocalic /r/ stimulus words; the environments [Cɝ], [ɝC] and [CɝC] were selected for Type III, stressed vocalic /r/ stimulus words; the environments [Cɚ] and [CɚC] were selected for Type IV, unstressed vocalic /r/ stimulus words; and the environments [CVɚ] and [CVɚC] were selected for Type V, post-vocalic /r/ stimulus words.

3) The actual representations of the permissible phonetic environments should be representative of all possible phonetic contexts.

It was not possible to meet these stringent criteria consistently, although the stimulus words chosen provided the closest fit possible. All stimulus words and a detailed discussion of their approximation to the proposed criteria for stimulus words are presented in Appendix A, including the stimulus words for prevocalic /r/, Type I, which are analyzed in the subsequent chapters of this dissertation.

The stimulus words were embedded within sentences in order that they might be spoken in a manner similar to conversational speech. It was necessary to design the sentences carefully since it is well known that the length and linguistic structure of a sentence influences the articulation of words contained within that sentence. Moreover, the use of sentences further complicated the already difficult tasks of spectrogram preparation and segmentation of the spectrographically displayed acoustic events.[2]

Criteria for the Construction of Stimulus Sentences

The following criteria were used in constructing sentences for the stimulus words:

1) Each sentence was exactly six syllables long. Thus they were of uniform length and could easily be recorded within the 2.4 second time limit of the spectrograph.

2) The stimulus word or syllable occupied the second, third,or fourth syllable position of the sentence. This meant that no stimulus syllable or word would be at the onset of the utterance and thereby influenced by a prearticulatory set or at the termination of the utterance where the stimulus word or syllable would be influenced by the termination of the breath group.

3) The stimulus words occupied positions of comparable linguistic prominence. In thirty-one of the 230 stimulus sentences, the stimulus word served as either subject or primary verb of the sentence; for example, "He may <u>read</u> a novel " or "The new <u>pram</u> is larger "

Thus, sentences were designed so that the most probable reading would result in a (231#) intonational contour with a falling terminal.[3]

The stimulus word was intended to occupy a high stress position, level three. In the preceding examples, we would hope for the reading:

a) "He may read a novel." (231#)

b) "The new pram is larger." (231#)

The only instruction given to subjects was to read the sentence naturally. Therefore, the intonational pattern just described, which would allow for parallel production of stimulus words, was only one possible reading for the sentences. The actual intonational contour of each stimulus sentence was determined by listening to the subjects' tape recorded sentences. The stress levels of prevocalic /r/ stimulus words are presented in Appendix B.

4) The sentences were structured to aid in reliable segmentation of the acoustic units representing the stimulus phones in the spectrographically displayed sentences. To illustrate, prevocalic /r/ is difficult to segment if a vowel or a semi-vowel precedes it. Segmentation becomes more accurate if prevocalic /r/ is preceded by an easily identified stop. Therefore, the sentence "He did <u>read</u> a novel " was considered easier to segment than the sentence "He may <u>read</u> a novel ".

5) The sentences were structured to evaluate the effects of different phonetic contexts on those stimulus words initiated by the experimental /r/ condition. To illustrate with the same example utilized in rule four, prevocalic /r/ as in the word <u>read</u> might be produced differently when preceded by the more easily segmented stop than when preceded by a vowel. For this reason, three sentence contexts were included for words such as <u>read</u>: (1) "He may <u>read</u> a novel "; (2) "He did <u>read</u> a novel "; and (3) "He does <u>read</u> new novels " . Thus, in the first sentence the stimulus /r/ was preceded by a vowel; in the

second sentence the stimulus /r/ was preceded by a consonant that combines with /r/ to form a permissible cluster within a word; and in the third sentence the stimulus /r/ was preceded by a consonant that does not combine with /r/ to form a permissible cluster within a word. It would be too cumbersome to evaluate the construction of each sentence in terms of the sentence criteria. However, the sentences may be found in Appendix C.

Filler Sentences

A total of fifty-five filler sentences was added to the experimental corpus in order to minimize the /r/ loading effect so that subjects would not in some way emphasize or distort the repeated /r/ segments. The entire 285 sentence corpus was randomized. The dummy corpus will not be analyzed as part of the current experiment although it was constructed in a parallel fashion to the /r/ corpus in conditions where [r] would contrast with [l] , [ɝ] with[i], and [ɚ] with [ɪ]; it might well form data for a subsequent experiment. The filler sentences may also be found in Appendix C. The total randomized list appears as Appendix D.

Final Preparation of Stimulus Sentences

Each stimulus sentence was typewritten on a separate card and photographically enlarged. An example of a stimulus card is included as Figure II-1. The stimuli were large enough so that a subject seated in an IAC booth could read each stimulus through the window when it was exposed to him by the experimenter. Use of such large stimuli allowed subjects to keep their heads stabilized at a set distance from the microphone since they did not have to handle their own stimulus cards or lower their heads in order to read them. It also allowed the experi-

THEY MAY TREAT THEM BADLY.

FIGURE II-1. AN EXAMPLE OF A STIMULUS SENTENCE AS PRESENTED TO EXPERIMENTAL SUBJECTS.

menter to control the subjects' exposure to the stimuli in order to avoid the establishment of any rhythmic effect, to insert callibration tones and to interject rest periods.

Subjects

One major subject recorded three randomized repetitions of the entire 285 sentence corpus during the first data recording session. Three secondary subjects, with the major subject, recorded an abbreviated seventy-two sentence corpus (every fourth sentence of the entire 285 sentence corpus) during the second data recording session which was held six months after the first data recording session. The Abbreviated Corpus is found in Appendix E.

All subjects were adult male Caucasians, had equivalent educational backgrounds, and were raised in the same dialect area; that dialect area labelled by Thomas as the North Central Area[4], by Wise as General American[5], and by Bronstein as Northern Middle West.[6] All three authors described speakers of this dialect region as retaining all /r/ variants, whether transcribed as [r], [ɜ], or [ɚ]. A biographical description of each subject is found in Appendix F.

Data Recording Procedure

All data were recorded at the Temple University Speech Science Laboratory. Each subject was seated in a sound-treated room (IAC Series 400) with his head stabilized so that his mouth remained a constant twenty-four inches from the microphone (Bruel and Kjaer Type 4131, powered by Bruel and Kjaer power source Type 2801).

The experimenter placed the stimulus cards before the IAC booth window. Subjects were not asked to monitor their volume because natural readings were considered desirable.

The subjects' utterances were recorded on a Nagra magnetic tape recorder (Model IV-D) at seven and one-half ips, with a constant gain setting. TDK Super Dynamic Tape (SD 150H-7) with low noise, high output and low print-through characteristics was used. A 1,000 Hz calibration tone at 65dB SPL was produced by a Bruel and Kjaer oscillator and presented via a six inch electromagnetic loudspeaker positioned at the speaker's mouth. All data collection was monitored for optimum recording procedures by using a Bruel and Kjaer voltage preamplifier (Model 2416).

Spectrogram Preparation

A broad and narrow band, expanded scale spectrogram (0-4000 Hz) was made for each sentence.[7] The tape recorder used for the recording sessions was used to playback the recorded sentences to a Kay Sonograph (Model 6061-A). All spectrograms were made in a continuous process on the same spectrograph by the same person. That is, the spectrograph was not used for any other work during this time period; therefore, all settings remained constant.[8] A total of 1,840 spectrograms was made and stored for subsequent analysis.[9]

FOOTNOTES--CHAPTER II

[1]Many phoneticians transcribe postvocalic /r/ as [Vr] and [VrC] ; for example, John S. Kenyon and Thomas A. Knott in A Pronouncing Dictionary of American English (Springfield, Mass.: G. and C. Merriam Company, Publishers, 1953); Charles Kenneth Thomas in An Introduction to the Phonetics of American English (Second Edition, New York: The Ronald Press, 1958); Claude Merton Wise in Introduction to Phonetics (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1957). However, in this dissertation these contexts were transcribed as [Vɚ] and [VɚC] after the transcription system adopted by Arthur J. Bronstein in The Pronunciation of American English (New York: Appleton-Century-Crofts, 1960).

[2]The easier approach would have been to utilize a standard carrier phrase for each stimulus word, such as "Say the word ______ again.". However, this approach was felt to be no closer to natural conversational speech than use of a word list.

[3]Henry A. Gleason, Jr., An Introduction to Descriptive Linguistics (Revised Edition; New York: Holt, Rinehart and Winston, 1965), pp. 48-50.

[4]Charles Kenneth Thomas, An Introduction to the Phonetics of American English (Second Edition; New York: The Ronald Press, 1958), pp. 229-231.

[5]Claude Merton Wise, Applied Phonetics (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1957), p. 181.

[6]Arthur J. Bronstein, The Pronunciation of American English (New York: Appleton-Century-Crofts, Inc., 1960), pp.48-51.

[7]It was found during a pilot study that a combination of a wide and narrow band, expanded scale spectrogram leads to the most consistent segmentation and physical measurement for each of the major /r/ types.

[8]Sonograph settings were: Frequency Linear, Frequency Scale Normal, ACG Off, High Shaping, Expanded Scale, 600 Input, Normal Baseline, a 7-10 Reproduce Level and a 3-4 Mark Level.

[9]Though the major subject recorded five randomized lists of the 285 sentence battery, only three of those lists were converted to spectrograms. The two additional recorded lists were stored. Since spectrogram preparation, segmentation and measurement is such a time-consuming process, it was decided that if three repeated lists showed consistent production by the major speaker the remaining two lists would not be processed spectrographically. This proved to be the case. Furthermore, spectrograms were not made for the filler sentences.

CHAPTER III

DATA ANALYSIS PROCEDURES FOR PREVOCALIC /r/ STIMULUS WORDS, TYPE I

The spectrographic data for prevocalic /r/ were analyzed in order to provide a description of its acoustic parameters including: (1) duration in time, (2) frequency values and patterns for the fundamental of the source and for the first, second, and third formants of the vocal tract, and (3) acoustic features as produced by the source and transfer function of the vocal tract. The methods developed to accomplish these analyses included procedures: (1) to segment, or locate the relevant acoustic elements in the spectrographically displayed stimuli; (2) to measure duration; (3) to determine fundamental frequency values; (4) to determine formant frequency values; and (5) to define the acoustic features of the source and transfer function of the vocal tract. A detailed description of these procedures is presented in this chapter.

In order to facilitate the presentation of the analysis procedures, the stimulus words for prevocalic /r/, Type, I, are reviewed.

A Review of Prevocalic /r/ Data

The thirty-nine stimulus words for prevocalic /r/, transcribed as [r] , and their preceding phonetic environment are reviewed in Table III-1. The major subject recorded three repetitions of each stimulus sentence for prevocalic /r/ during the first data collection session; the secondary subjects, including the major subject as a test

TABLE III-1

TYPE I STIMULI FOR PREVOCALIC /r/, TRANSCRIBED AS [r], AND IMMEDIATE PHONETIC ENVIRONMENT

	/i/	/æ/	/u/
[rV]	may read*	may rat	be rude
	does read	does rat*	is rude
	did read	did rat	had rude*
[prV]	may preen	new pram	may prune*
[brV]	may breed	may brag	may brood
[trV]	may treat*	may trap	new troop
[drV]	may dream	may drag*	may droop
[krV]	may creak	may crack	new croup*
[grV]	may greet	may grab	may group
[frV]	Ray freed*	new frat	may frug
[θrV]	knew three	may thrash*	Marie threw
[ʃrV]	may shriek	too shrewd	Ray sharnk*
[sprV]	gay spree	new sprag	new spruce
[strV]	may streak*	may strap	Ray strewed
[skrV]	may scream	may scrap*	Ray screwed

*Denotes tokens recorded by secondary subjects.

of his reliability, recorded every fourth stimulus sentence for prevocalic /r/ during the second data collection session. A total of 366 spectrograms provided the data for the analysis of the forty-five different stimulus sentences for prevocalic /r/.

Segmentation Procedures

It is a difficult task to locate the acoustic segments associated with any given phoneme in a spectrographic display. Distinct boundaries do not exist in the speech wave. Indeed, few contemporary researchers, experienced in spectrography, would claim to be able to read the message in spectrograms without prior knowledge of the words. Sequences of acoustic segment boundaries can be identified but they do not necessarily coincide with the boundaries underlying the perception of a phoneme. According to Fant, possible acoustic segment boundaries occur in greater number than the number of phonemes in the message and "are related to switching events in the speech mechanism, such as a shift in the primary sound source, e.g., from voice to noise, or the opening or closing off of a passage within the vocal cavities, the lateral and nasal pathways included. Less distinct sound boundaries may be defined from typical changes in the pattern of formant frequencies."[1] Adjacent acoustic segments typically carry information on the same phoneme and any acoustic segment probably carries information on more than one adjacent phoneme. Nevertheless, it is possible to use spectrographic data to quantify the acoustic dimensions of a speech sound and thereby to gain a better understanding of the physiological and perhaps even the linguistic event. Commenting on the relationship between physiological and acoustic aspects of speech events, Fant concluded that:

> The rules relating speech waves to speech production are in general complex since one articulatory parameter, e.g., tongue height, affects several of the parameters of the spectrogram. Conversely, each of the parameters of the spectrogram is generally influenced by several articulatory variables. However, to establish and learn these analytical ties is by no means a hopeless undertaking. Some elementary knowledge in acoustics is valuable, but the main requirement is a sound knowledge of articulatory phonetics.[2]

Since the process of locating relevant acoustic segments is complicated, the first task in devising the analysis procedures necessary to quantify the acoustic parameters of prevocalic /r/ was to create rules for segmenting the spectrographically displayed utterances. The previous studies of Potter, Kopp and Kopp; Lisker; O'Connor, et al.; Lehiste; and Dalston provided valuable guidance for developing these rules.[3, 4, 5, 6, 7]

It was discovered during a pilot study completed as preparation for this investigation that the acoustic segments associated with all /r/ events were identified more easily when both a broad and narrow band, expanded scale spectrogram were used simultaneously. It was possible to use an expanded scale setting of approximately 0-4000 Hz when preparing the spectrograms since the pertinent acoustic information for /r/ events occurred below 4000 Hz. Use of the expanded scale setting magnified the resultant spectrograms and made all acoustic events more visible.

The following procedures were developed for segmenting the stimulus words for prevocalic /r/, which were primarily of the [rVC], [CrVC], and [sCrVC] type.

Step 1. Spectrogram Alignment

The first step in the segmentation process was to align the broad and narrow band, expanded scale spectrograms with respect to time.

This procedure made it possible to utilize the cues found in both the broad and narrow band displays when subsequently establishing segment boundaries as described in steps two through six.

The spectrograms were placed on a drawing board one above the other and aligned via the occlusion of the word-final stops, that terminated thirty-five of the forty-five stimulus words. Stop occlusions are easily identified spectrographically by the relative absence of acoustic energy on both the broad and narrow band spectrograms. A triangle and a T-square were used to align the spectrograms and to draw the vertical segmentation lines associated with all acoustic segment boundaries.

Ten stimulus words did not terminate with stops: preen, pram, prune, dream, three, thrash, threw, spree, spruce, and scream. The stop in the word-initial consonant cluster was used for alignment purposes for seven of these stimulus words. One of the three remaining stimulus words, thrash, was aligned via its terminal voiceless fricative. Voiceless friction was clearly identifiable even on expanded scale spectrograms by a high frequency noise patch visible in both the broad and narrow band displays. The two remaining stimulus words, three and threw, terminated with vowels. They were aligned via the onset of the /ʃ/ friction for the word following in the sentence contexts, "He knew three short stories" and "Marie threw Shawn's baseball".

Step 2. Segmentation Procedure for the Word-Final Phone of Stimulus Words.

The second step in the segmentation procedure was to locate the boundaries of the acoustic segments representing the phone that terminated each stimulus word. The stop occlusions which terminated thirty-five stimulus words were easily isolated by drawing vertical lines on each side of the relative absence of acoustic energy found on both the broad and narrow band spectrograms as a cue to stop occlusions.

The nasals which terminated five of the stimulus words were isolated by drawing vertical segmentation lines at the points where intensity dropped in the formant structure on the wide band spectrogram and in the harmonic structure on the narrow band spectrogram. The intensity was so low that only F_1 on the broad band spectrogram and the first three harmonics on the narrow band spectrogram were visible. An added resonance was also seen on the wide band spectrogram around 1000 Hz; this resonance did not make a good segment boundary cue as it always overlapped preceding acoustic segments.

The fricatives which terminated two of the stimulus words were isolated by drawing vertical segmentation lines at the points where high frequency noise patches were visible in both the broad and narrow band displays.

The two remaining stimulus words terminated with their vowel nuclei. The procedure for isolating vowel nucleus boundaries will be discussed in step three. However, the onset of the friction associated with the word-initial fricative of the word following each of these stimulus words in their sentence contexts was delineated.

<u>Step 3. Segmentation Procedure for the Vowel Nucleus of Stimulus Words</u>

The third step in the segmentation process was to delineate the onset and offset boundaries for the steady-state acoustic segment associated with the vowel nucleus of stimulus words. The result of this procedure was to isolate a vowel nucleus which included the transitional segment for the word-final consonants, or its lack.

The offset boundary, the common boundary with the word-final consonant or with the word-initial consonant of the following word in the sentence context, has already been described in step two.

The onset boundary for the steady-state segment of the vowel nucleus was identified at that location where the upper formants on the wide band spectrogram, above 2000 Hz, and the upper harmonic structure on the narrow band spectrogram, above 2000 Hz, were clearly visible and all formant and harmonic structure was parallel. Furthermore, F_3 was no longer rapidly rising. F_3 always rose rapidly during the preceding transitional acoustic segment linking the /r/ and vowel events. The onset boundary of the steady-state acoustic segment representing the vowel /u/ was difficult to locate. Much of the higher frequency formant and harmonic structure for the /u/ steady-state segment was not visible. Thus, intensity loss, typically causing F_3 to vanish, provided a segmentation cue. Furthermore, F_2 usually dipped, becoming lower in frequency value by approximately 50-100 Hz and then rising to its original frequency value during the /u/ steady-state in stimulus words spoken by the major subject. This difficulty in segmentation may have caused measurement error and therefore may be pertinent when considering the results of this analysis in Chapter IV.

Step 4. Segmentation Procedure for the Provocalic /r/ of Stimulus Words

Inspection of the spectrograms for all prevocalic /r/ stimuli lead to the conclusion that there were three distinct acoustic segments associated with prevocalic /r/: (1) a transitional segment separating the acoustic segment representing the preceding consonant and the /r/ steady-state segment, (2) the /r/ steady-state segment, and (3) a transitional segment separating the /r/ steady-state and the steady-state segment representing the following vowel. These three segments were identifiable for [rVC] , [CrVC], and [sCrVC] stimuli. For the sake of convenience, these segments will hereafter be called transition one, steady-state, and transition two. Transition one was a common segment for both prevocalic /r/ and its preceding clustered consonant in [CrVC] and [sCrVC] stimulus words. It was also a common segment for initial prevocalic /r/ and the word-final consonant or vowel for the preceding word of the stimulus sentence for [rVC] stimulus words. Transition two was a common segment for prevocalic /r/ and its following vowel. The steady-state segment was characteristic of prevocalic /r/ but was influenced by the preceding consonant clustered with prevocalic /r/. These co-articulatory effects are described in detail in Chapter IV.

Segmenting prevocalic /r/ into three distinct segments has some precedent in the acoustic phonetic literature. The O'Connor and the Dalston data consisted of isolated nonsense syllables or words initiated by prevocalic /r/ as a singleton. Therefore, they considered prevocalic /r/ to consist of only two segments, a steady-state and transition two.[8, 9] Potter, Kopp and Kopp in Unit Seven, "Reading Combinations of Glides, Stops and Fricatives," described transition one as occurring in both the cluster and the sentence embedded singleton context.[10] Lehiste embedded words initiated with a singleton prevocalic /r/ in the sentence frame, "Say the word ________ instead." One may conclude that she assigned transition one to the preceding

/d/ and did not think of it as also associated with /r/ although she did not discuss this issue directly.[11] Lisker did consider /r/ to have three acoustic segments and this was reasonable because he investigated intervocalic /r/ nonsense syllables of the /VrV/ type.[12] The present investigator found prevocalic /r/ to be represented by three distinct segments. The rules used to identify each of these segments follow.

The onset of transition two is located where F_2 begins to rise and the entire formant pattern has more intensity. F_3 is also visible and rising during the major portion of this transition; however, it is frequently merged with F_2 at the onset of the transition. F_1 is more intense and has a greater band width at the onset of transition two. These segmentation cues found in the formant structure visible in the wide band display are also reflected in changes in the harmonic structure in the narrow band display.

The onset of the steady-state segment is located on the wide band spectrogram where F_1 and F_2 are parallel, clearly visible and usually of lower intensity than in the preceding or following transitional segments. On the narrow band spectrogram, harmonic structure is not visible above the frequency location of F_2.

The onset of transition one is identified by different cues depending on the phone preceding prevocalic /r/. When prevocalic /r/ is preceded by a vowel, as in the sentence, "He may <u>read</u> a novel", the onset of transition one shared a common boundary with the offset of the steady-state segment representing the preceding vowel. Cues to the identity of this boundary have been described previously. When prevocalic /r/ is preceded by a voiced fricative, as in the sentence, "He does read a novel", the onset of transition one is located where the friction loses intensity and movement can be seen in the formant structure. The voice striations seen in the acoustic steady-state segment representing the friction on the wide band spectrogram are typically intensified at the onset of transition one. When prevocalic /r/ is preceded by a voiced stop, as in the sentence, "He did read a novel", the onset of transition one shared a common boundary with the stop occlusion offset. Cues to the identity of this boundary have been described previously.

The vowel steady-state, the steady state segment of the voiced fricative and the occlusion of the voiced stop, occurring inthe word-final position preceding prevocalic /r/ stimulus words, were also segmented in accordance with rules described previously.

Step 5. Segmentation Procedure for the Additional Members of Prevocalic /r/ Clusters of Stimulus Words

For the six stop-prevocalic /r/ clusters, /pr, br, tr, dr, kr, gr/, the onset of transition one is located following the burst of the stop release. This burst is recognized as a narrow vertical spike on the wide band spectrogram or as a narrow band of friction on the narrow band spectrogram. The voiced stops were not always exploded. In these cases, transition one shared a common boundary with the stop occlusion. Cues to the identity of this boundary have been described previously. Transition one and the steady-state segment associated with prevocalic /r/ were usually frictional following voiceless stops. These co-articulatory effects are illustrated in detail in Chapter IV.

A segmentation difference existed for /brVC/ stimulus words. Transition one of the prevocalic /r/ did not exist following /b/. The steady-state segment shared a common boundary with the /b/ release. These steady-state segments were identified by the previously described cues; that is, these segments did not resemble the description of transition one.

For the three voiceless fricative-prevocalic /r/ clusters, /fr, ʃr, θr/ the onset of transition one was identified by moving formant structure visible in the friction on the wide band spectrogram. Typically, the formant structure during this transitional segment had greater intensity than the formant structure in the steady-state segment representing the friction alone. The prevocalic /r/ steady-state segment was friction-like following fricatives. The clusters, /ʃr/ and /θr/, were easily segmented. However, the cluster, /fr/, provided the most difficult of all segmentation decisions. The steady-state acoustic segment representing the /f/ friction, the frictional transition one representing prevocalic /r/, and the frictional steady-state segment representing prevocalic /r/ were finally forced into the usual segmentation paradigm after comparing the stimulus words for /fr/ with parallel words without /r/ in sentences such as "Jim Ray <u>feeds</u> his parrot" and "Jim Ray <u>freed</u> his parrot". These comparison sentences were tape recorded by the major subject and converted to spectrograms after the segmentation problem associated with the prevlcalic /r/ in /fr/ clusters became apparent. Thus, the boundaries delineated for these segments may be contributing to measurement error.

The three element prevocalic /r/ clusters, /spr, str, skr/, were segmented in accordance with the same procedures described for the two element clusters. However, the initial steady-state friction segment associated with /s/ was also identified. Cues to the identity of this segment have been previously described.

The steady-state acoustic segment representing the word-final vowel preceding all stimulus words for prevocalic /r/ was also segmented. Cues to the identity of this segment were the same as those described for the steady-state segment representing the vowel nucleus of the stimulus word.

Step 6. Segmentation Procedure for Locating the Beginning and Ending of Stimulus Sentences

The onset of the acoustic segment beginning each stimulus sentence and the offset of the acoustic segment terminating each stimulus were located in order that total sentence duration and rate of speech could be determined for each subject. The following segmentation cues were used for identifying the sentence-initiating acoustic segment representing the phonemes:

1) /h, ð /: the onset of friction on the wide band spectrogram or, when absent, the first voice striation of the following vowel on the wide band spectrogram.

2) /d, t, dʒ /: the vertical spike of the burst following the stop occlusion on the wide band spectrogram.

3) /w, ɹ , m/: the first voice striation on the wide band spectrogram.

4) / ʃ /: The onset of friction on the wide band spectrogram.

The following segmentation cues were used for identifying the sentence-terminating acoustic segment representing the phonemes:

1) /l, ɹ ,z, ŋ ,e, ɚ ,n /: the last definite voice striation on the wide band spectrogram.

2) /s/: the offset of friction on the wide band spectrogram.

3) /p, t, d/: the release energy following the stop occlusion on the wide band spectrogram.

Figure III-1 is included as an illustration of the segmentation boundaries delineating acoustic segments relevant to the analysis of prevocalic /r/ in the sentence, "He may read a novel ". The spectrograms shown in Figure III-1 were photographically reproduced and are diminished in acoustic detail when compared to the original spectrograms.

Validity and Reliability of Segmentation Procedures

There was no obvious way to validate the segmentation procedures developed. However, they were developed in agreement with the segmentation cues described by previous researchers. Once these segmentation rules were specified, all spectrograms were segmented by rule in the hope that the segmentation process would be more reliable.

Inter- and intra-evaluator reliability could have been established for the segmentation procedure if multiple copies of the same spectrogram had been available. Original spectrograms produced from the tape recordings would have been required since, as previously mentioned, spectrograms reproduced by photograph or Xerox are greatly diminished in acoustic detail. The time and money needed to produce these additional spectrograms made establishing inter- and intra-evaluator reliability impractical.

Duration Measurement Procedure

Acoustic segments were measured in inches from boundary line to boundary line on the wide band spectrogram and then converted to milliseconds. Each thirty-second of an inch was equal to six

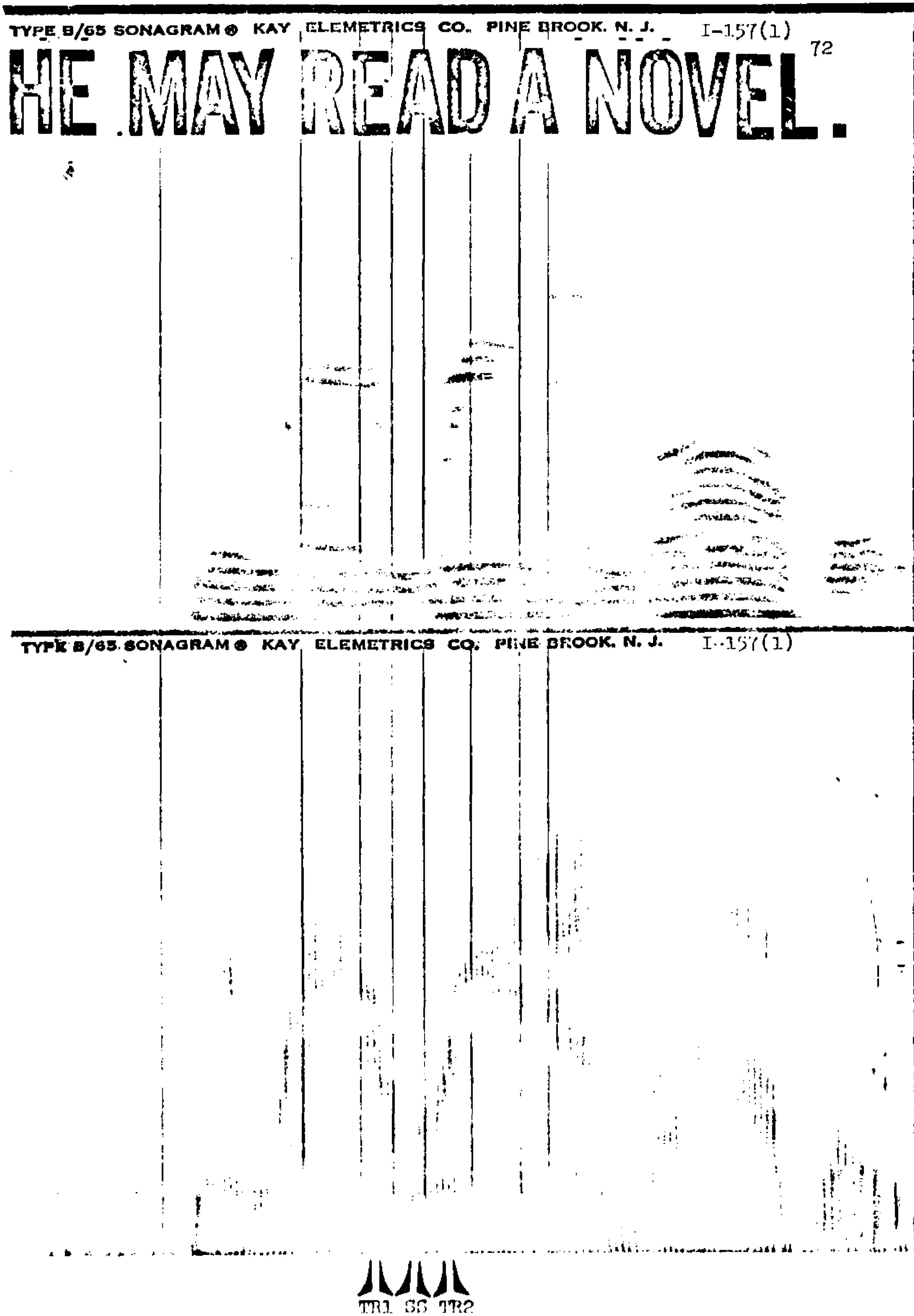


FIGURE III-1. AN EXAMPLE OF SPECTROGRAM ALIGNMENT AND ACOUSTIC SEGMENT BOUNDARIES.

milliseconds since the maximum recording length of the spectrograph is 2.4 seconds, or 2400 milliseconds, and the drum size of the spectrograph is 12.5 inches.

Formant Frequency Measurement Procedure

In order to determine the formant frequency values for a given acoustic segment, an acetate template with rulings at 500 Hz intervals was placed over the wide band spectrogram and aligned with the 500 Hz calibration signal. The mid-point of F_1, F_2, and F_3 was traced on the template and the frequency values calculated by measuring in inches from the nearest 500 Hz interval and converting to Hz. Each sixty-fourth of an inch was equal to 17 Hz since the distance between each 500 Hz interval on the template was equivalent to thirty sixty-fourths of an inch. Formant frequency values were calculated for the acoustic segments associated with prevocalic /r/ at the following five locations: 1) the onset of transition one, 2) the offset of transition one, 3) the middle of the steady-state, 4) the onset of transition two, and 5) the offset of transition two.

Fundamental Frequency Measurement Procedure

The fundamental frequency value for a given acoustic segment was determined by measuring in inches the distance between harmonics on the narrow band spectrogram, from the mid-point to the mid-point of each harmonic, and converting the measurement to Hz. The conversion procedure was the same as that described for formant frequency. Fundamental frequency values were also calculated for each of the acoustic segments associated with the prevocalic /r/ at the same five locations previously described for formant frequency values.

Reliability of Duration, Formant Frequency and Fundamental Frequency Measurements

Inter- and intra-evaluator reliability was established for all measurement procedures since five stimulus sentences, approximately one-tenth of the total number of stimulus sentences, were measured and re-measured at a later time by both the first evaluator (T.W.) and a second evaluator (L.R.). These measurements were statistically evaluated at the Temple University Computer Center by the Pearson product-moment correlation program from the Statistical Package for the Social Sciences.[13] Statistics computed in this program included the mean, standard deviation, Pearson correlation coefficient, and a two-tailed test of significance for the Pearson correlation coefficient. Results of these evaluations are presented in Tables III-2 through III-7.

Inspection of Tables III-2 through III-7 leads to the conclusion that the measurement procedures used for determining duration and frequency values were reliable since both inter-evaluator and intra-evaluator measurements were highly correlated.

It was expected that the inter-evaluator and intra-evaluator measurements for duration would have a high positive correlation as there was little possibility for error in the procedures used for determining reliability. The acoustic segments were simply remeasured since segmentation lines were not redrawn. Therefore, the high correlations of .99 which were statistically significant at the .001 level of confidence were predictable.

The measurement procedures used for determining the reliability of formant frequency values had a much greater likelihood of measurement

TABLE III-2

TOTAL SENTENCE DURATION MEASUREMENT RELIABILITY (MSEC)

	No. of Cases	Mean	Standard Deviation
T.W.$_1$*	5	1346.40	204.30
T.W.$_2$**	5	1350.00	202.86
L.R.$_1$*	5	1348.80	204.07
L.R.$_2$**	5	1347.80	207.44

Pearson product-moment correlations for the above data

T.W.$_1$	.99	L.R.$_1$	.99	T.W.$_1$	.99
with	N(5)	with	N(5)	with	N(5)
T.W.$_2$	Sig. .001	L.R.$_2$	Sig. .001	L.R.$_1$	Sig. .001

* Subscript$_1$ = original measurements

** Subscript$_2$ = re-measurements

TABLE III-3

ACOUSTIC SEGMENT DURATION MEASUREMENT REALIABILITY (MSEC)

	No. of Cases	Mean	Standard Deviation
T.W.$_1$*	36	60.58	30.25
T.W.$_2$**	36	60.75	30.40
L.R.$_1$*	36	60.75	30.52
L.R.$_2$**	36	60.67	30.52

Pearson product-moment correlations for the above data

T.W.$_1$ .99	L.R.$_1$ .99	T.W.$_1$ .99
with N(36)	with N(36)	with N(36)
T.W.$_2$ Sig. .001	L.R.$_2$ Sig. .001	L.R.$_1$ Sig. .001

* Subscript$_1$ = original measurements

** Subscript$_2$ = re-measurements

TABLE III-4

F_1 FREQUENCY MEASUREMENT RELIABILITY (HZ)

	No. of Cases	Mean	Standard Deviation
T.W.$_1$*	17	379.47	95.13
T.W.$_2$**	17	374.59	83.94
L.R.$_1$*	17	405.82	82.17
L.R.$_2$**	17	397.12	73.17

Pearson product-moment correlations for the above data

T.W.$_1$ .98	L.R.$_1$ .96	T.W.$_1$ .95
with N(17)	with N(17)	with N(17)
T.W.$_2$ Sig. .001	L.R.$_2$ Sig. .001	L.R.$_1$ Sig. .001

* Subscript$_1$ = original measurements

** Subscript$_2$ = re-measurements

TABLE III-5

F_2 FREQUENCY MEASUREMENT RELIABILITY (HZ)

	No. of Cases	Mean	Standard Deviation
$T.W._1$*	20	1452.60	392.60
$T.W._2$**	20	1436.65	349.61
$L.R._1$*	20	1436.45	357.07
$L.R._2$**	20	1432.45	358.23

Pearson product-moment correlations for the above data

$T.W._1$ .98	$L.R._1$ .99	$T.W._1$ .97
with N(20)	with N(20)	with N(20)
$T.W._2$ Sig. .001	$L.R._2$ Sig. .001	$L.R._1$ Sig. .001

* $Subscript_1$ = original measurements

** $Subscript_2$ = re-measurements

TABLE III-6

F_3 FREQUENCY MEASUREMENT RELIABILITY (HZ)

	No. of Cases	Mean	Standard Deviation
$T.W._1$*	6	1830.33	312.61
$T.W._2$**	6	1841.50	306.40
$L.R._1$*	6	1863.83	338.65
$L.R._2$**	6	1847.17	327.91

Pearson product-moment correlations for the above data

$T.W._1$ .99	$L.R._1$ .99	$T.W._1$ .99
with N(6)	with N(6)	with N(6)
$T.W._2$ Sig. .001	$L.W._2$ Sig. .001	$L.R._1$ Sig. .001

* $Subscript_1$ = original measurements

** $Subscript_2$ = re-measurements

TABLE III-7

FUNDAMENTAL FREQUENCY MEASUREMENT RELIABILITY (HZ)

	No. of Cases	Mean	Standard Deviation
T.W.$_1$*	17	130.88	18.84
T.W.$_2$**	17	131.44	18.95
L.R.$_1$*	17	127.44	15.29
L.R.$_2$**	17	128.53	14.67

Pearson product-moment correlations for the above data

T.W.$_1$ .98	L.R.$_1$ .97	T.W.$_1$ .85
with N(17)	with N(17)	with N(17)
T.W.$_2$ Sig. .001	L.R.$_2$ Sig. .001	L.R.$_1$ Sig. .001

* Subscript$_1$ = original measurements

** Subscript$_2$ = re-measurements

error as the template had to be aligned with the calibration signal and the midpoint of each formant located, measured,and converted to milliseconds. Thus, the formant structure was redrawn on the acetate template for each evaluation and then remeasured. Nevertheless, the correlations between the formant frequency estimates were all high enough to be statistically significant at the .001 level of confidence.

The fundamental frequency measurement procedures also had potential for measurement error as the measurements were made from the midpoint to mid-point of each harmonic. The only substantial difference in fundamental frequency measurements was found between evaluators. However, the Pearson produce-moment correlation of .85 obtained for these measurements did not lower the level of statistical significance from the .001 level. Therefore, all measurements may be considered satisfactory.

While certain acoustic parameters for prevocalic /r/ could be derived from this reliability data, the comparison data among subjects are better suited to this purpose. Therefore, such examination will be withheld until Chapter IV.

Procedure for Specifying Acoustic Features

In 1962, Fant proposed that in addition to segment feature patterns including formant frequency values, duration measurements, fundamental frequency values, and intensity measurements, segment type features could be specified for acoustic segments visualized in spectrograms.[14] For reasons of clarity, segment type features were called acoustic features in this dissertation. Acoustic features were felt by Fant to "reflect the constraints of the human speaking mechanism and correspond to what is commonly referred to as 'manner of production'".[15]

He divided acoustic features produced by the source function from those produced by the resonator, or transfer function, of the vocal tract. Included in source features were the categories of voice, noise, and transient; included in resonantor features were the categories of occlusive, fricative, lateral, nasal, vowel-like, and transitional.[16] To the resonator features, this author added the categories of retroflex and aspirate in order to describe the features associated with prevocalic /r/ adequately. The presence of each acoustic feature was indicated by acoustic cues found in the wide band spectrographic displays. When these cues were commonly assocaited with the acoustic feature in the acoustic phonetic literature, a reference was not cited. When the cues were less well know, Fant's own description has been quoted. The cues used to determine the presence of acoustic features included:

1) voice--voice striations.

2) noise--noise patches.

3) transient--a single vertical striation.

4) occlusive--relative absence of acoustic energy.

5) fricative--high frequency noise patch in which the formant pattern was often visible but of lower intensity.

6) lateral--"Sound segments of lateral articulation produced with a voice source possess the vowel-like feature except for a reduction of either second, third, or fourth formant intensity due to the first zero of the shunting mouth cavity behind the tongue. An additional high-frequency formant is generally seen. The oral break provides a typical discontinuity in the connection to a following vowel. The lateral sound segment is generally, but not always, of lower frequency F_1 than

a following or preceding vowel".[17]

7) nasal--split formants, lower intensity, and added resonances.

8) vowel--like--clearly visible formant structure.

9) transitional--rapidly moving formants.

10) retroflex--an F_3 that is of very low frequency. F_3 was always close to F_2 and sometimes it was merged with F_2.

11) aspirate--"Aspiration as distinct from friction may be recognized by a reduction of the intensity in the high frequency region above 4000 C/s and the appearance of formants that have a continuity with those of the following vowel. The first formant is generally very weak in aspirated sound intervals except in combinations with some back vowels."[18]

The acoustic features associated with each prevocalic /r/ stimulus word and with the phone that preceded the stimulus word in the sentence frame were established.

FOOTNOTES-CHAPTER III

[1]C. Gunnar M. Fant, "Descriptive Analysis of the Acoustic Aspects of Speech," Logos, V (April,1962), p. 8

[2]Ibid.,p. 5

[3]Ralph K. Potter, George A. Kopp and Harriet Green Kopp, Visible Speech (Corrected Re-publication; New York: Dover Publications, Inc., 1966), pp. 219-231 and pp. 251-269).

[4]Leigh Lisker, "Minimal Cues for Separating /w, r, l, y/ in Intervocalic Position," Word, XIII (August,1957), pp. 256-267.

[5]J.D. O'Connor, L.J. Gerstman, A.M. Liberman, P.C. DeLattre and F.S. Cooper, "Acoustic Cues for the Perception of Initial /w, j, r, l/ in English," Word, XIII (August,1957), pp. 24-43

[6]Ilse Lehiste, "Some Allophones of /r/ in American English," Chapter III in Acoustical Characteristics of Selected English Consonants, Part IV of International Journal of American Linguistics, XXX (July,1964), pp. 51-115

[7]Rodger M. Dalston,"A Spectrographic Analysis of the Spectral and Temporal Acoustic Characteristics of English Semivowels Spoken by Three Year Old Children and Adults," (Unpublished Ph.D. dissertation, Field of Communicative Disorders, Northwestern University, 1972), pp. 99-161.

[8]O'Connor, et al., pp. 27 - 29.

[9]Dalston, pp. 121-123.

[10]Potter, Kopp and Kopp, pp. 251-260.

[11]Lehiste, p. 58.

[12]Lisker, pp. 257-258.

[13]Norman H. Nie, Dale H. Bent and C. Hadlai Hull, "Bivariate Correlation Analysis: Pearson and Rank-Order Correlation," Chapter XIII in Statistical Package for the Social Sciences (New York: McGraw-Hill, Inc., 1970), pp. 143-156.

[14]C. Gunnar M. Fant, "Sound Spectrography," Procedings of the Fourth International Congress of Phonetic Sciences (Helsinki, 1961), ed. Antii Sovijarvi and Penti Aalto (The Hague: Mouton and Co., 1962), p. 26

[15]Fant, "Descriptive Analysis of the Acoustic Aspects of Speech," , p. 12.

[16]Ibid..

[17] *Ibid.*, p. 13

[18] C. Gunnar M. Fant, *Acoustic Theory of Speech Production* (The Hague: Mouton and Co., 1960), p. 23.

CHAPTER IV

PREVOCALIC /r/: RESULTS AND DISCUSSION

A description and statistical analysis of the data for prevocalic /r/ including discussion in terms of previous studies and theoretical constructs is presented in this chapter. To facilitate the presentation, certain terms and/or abbreviations were used. They are listed below with their referents.

1) Major subject--refers to the subject who recorded both the principal and comparison data for prevocalic /r/. These data were labeled with his initials, R.H..

2) Secondary subjects--refers to the three subjects who recorded only the comparison data for prevocalic /r/. Data recorded by these subjects were labeled with their initials: R.T., F.T., and D.H..

3) Principal data--refers to the data recorded by the major subject during the first data collection session. These data included three repetitions of each of the forty-five stimulus sentences for prevocalic /r/ and were labeled R.H.-Avg. since each figure represented an average of three repetitions.

4) Comparison data--refers to the data recorded by the major and secondary subjects during the second data collection session. These data included one repetition of each of twelve of the forty-five stimulus sentences for prevocalic /r/ and were labeled R.H., R.T., F.T., and D.H..

5) Acoustic segment type--refers to each of three acoustic seg-

ments associated with prevocalic /r/: transition one, steady-state, and transition two. These three acoustic segment types were abbreviated as TR 1, SS, and TR 2.

6) Prevocalic /r/ type--refers to each of fifteen different stimulus sentences for prevocalic /r/. These stimuli differed in terms of the stimulus word and/or in terms of the phonetic event which preceded the stimulus word in the stimulus sentence. Stimulus words were of two types in which the prevocalic /r/ occurred in either a word-initial position or as the prevocalic element of a word-initial cluster.

7) Vowel nucleus type--refers to each of three different vowels, /i, æ, u/, which served as the syllable nucleus for each of the forty-five prevocalic /r/ stimulus words.

Subject Comparisons

It was important to establish that the major subject was both a valid and reliable speaker of the General American Dialect since all of the stimulus sentences for prevocalic /r/ were tape recorded by only this subject. To establish the major subject's validity, the principal data recorded by the major subject were compared with the comparison data recorded by the three secondary subjects. To establish the major subject's reliability, the principal and comparison data recorded by the major subject were compared. These and subsequent data comparisons were statistically evaluated at the Temple University Computer Center by the Pearson product-moment correlation program from the Statistical Package for the Social Sciences.[1] Statistics computed in this program included the mean, standard deviation, Pearson product-moment correlation coefficient, and a two-tailed test of significance for the Pearson product-moment correlation coefficient.

The duration data used for subject comparison is presented in Table IV-1 and consists of mean sentence duration measurements and mean acoustic segment duration measurements for the major and secondary subjects. Mean sentence duration measurements reflect the averaged measurements of stimulus sentence length for each subject. Mean acoustic segment measurements reflect the mean length of acoustic segments for each sucject including: 1) the three acoustic segments associated with prevocalic /r/ of the stimulus words--TR 1, SS, and TR 2; 2) the vowel nuclei of stimulus words and of words preceding the stimulus word in its sentence context; 3) the stop occlusions of the word-final consonant of stimulus words and of the word-initial consonant cluster of stimulus words; 4) the stop releases of the stops in the word-initial clusters of stimulus words; and 5) the friction of the word-final fricatives of stimulus words and of the fricatives in the word-initial clusters of stimulus words.

The frequency data used for subject comparisons is also presented in Table IV-1 and consists of mean fundamental, first formant, second formant, and third formant frequency measurements for the major and secondary subjects. These measurements reflect fundamental and formant frequency values for each of fifteen prevocalic /r/ types as averaged at each of five acoustic segment measurement locations: 1) the onset of TR 1, 2) the offset of TR 1, 3) the mid-point of the SS, 4) the onset of TR 2, and 5) the offset of TR 2. It should be noted that it was not always possible to establish frequency values for each of the sampling points. Frequency measurements were only reported when the data were unequivocal. Thus, the total possible number of cases to have been compared would have been sixty while the actual number of comparisons ranged from twenty-two to fifty-two cases.

TABLE IV-1

MAJOR SUBJECT (R.H.-AVG.) RELIABILITY AND VALIDITY

	PRINCIPAL DATA	COMPARISON DATA			
		Reliability	Validity		
	R.H.-AVG.	R.H.	R.T.	F.T.	D.H.
MEAN SENTENCE DURATION	1437.08 Ms	1536.25 Ms	1325.73 Ms	1403.75 Ms	1610.45 Ms
No. of Cases	12	12	11	12	11
Correlation Coefficient		.93	.83	.69	.93
Statistical Significance		.001	.002	.012	.001
MEAN ACOUSTIC SEGMENT DURATION	60.23 Ms	64.79 Ms	55.06 Ms	62.06 Ms	68.20 Ms
No. of Cases	86	82	85	83	79
Correlation Coefficient		.85	.85	.80	.84
Statistical Significance		.001	.001	.001	.001
MEAN FUNDAMENTAL FREQUENCY	140.32 Hz	156.34 Hz	121.05 Hz	132.05 Hz	123.83 Hz
No. of Cases	37	38	38	40	36
Correlation Coefficient		.80	.69	.53	.54
Statistical Significance		.001	.001	.001	.001
MEAN F_1 FREQUENCY	436.43 Hz	395.42 Hz	393.31 Hz	414.18 Hz	396.63 Hz
No. of Cases	42	40	42	39	35
Correlation Coefficient		.79	.80	.84	.85
Statistical Significance		.001	.001	.001	.001
MEAN F_2 FREQUENCY	1489.27 Hz	1395.56 Hz	1400.98 Hz	1393.98 Hz	1383.30 Hz
No. of Cases	48	48	52	47	40
Correlation Coefficient		.94	.92	.93	.87
Statistical Significance		.001	.001	.001	.001
MEAN F_3 FREQUENCY	2064.83 Hz	2074.79 Hz	2186.76 Hz	1811.41 Hz	1961.74 Hz
No. of Cases	36	39	34	22	27
Correlation Coefficient		.89	.48	.74	.78
Statistical Significance		.001	.016	.001	.001

Major Subject Validity

The duration and frequency data presented in Table IV-1 indicate that the major subject was a valid speaker of the General American Dialect when compared with three comparison subjects.

While actual values of both mean sentence duration and mean acoustic segment duration between subjects differed, comparisons between the secondary subjects and the major subject for mean sentence duration resulted in correlations which ranged from .69 to .93 and were statistically significant from the .012 to the .001 levels of confidence. Even the low correlation of .69 which occurred in the comparison between F.T. and R.H.-Avg. and reached only the .012 level of significance, may be considered to show a substantial relationship between the mean sentence durations of the two subjects. Comparisons between the secondary subjects and the major subject for measurements of individual acoustic segments were such that all correlations were statistically significant at the .001 level of confidence. The stability of the duration data across subjects may be evaluated further in Table IV-2 where the mean duration in milliseconds is shown for sentence duration, for all measured acoustic segments, and for specific acoustic segments. The mean values for total duration of measured acoustic segments and for individual acoustic segment durations are also shown as a percentage of the sentence duration mean for each subject. The greatest difference in any one segment, when considered as a percentage of the total sentence duration, was found in the vowel steady-state comparison between R.H. and F.T.. That difference represented .012 percent of the total sentence duration. Since the averaged total sentence duration across all subjects was 1462.65 milliseconds, this difference was of the magnitude

TABLE IV-2

COMPARISON OF MAJOR AND SECONDARY SUBJECTS FOR ACOUSTIC SEGMENT DURATIONS (MSEC) AS A PERCENTAGE OF TOTAL SENTENCE DURATION

Subjects	Sentence Duration		Measured Acoustic Segments Total Duration			Vowel Steady-State Duration		
	No.of Cases	Mean (Msec)	No.of Cases	Mean (Msec)	% of Tot.Sent.	No.of Cases	Mean (Msec)	% of Tot.Sent.
R.H.	12	1536.25	82	403.13	.2624	22	86.59	.056
R.T.	11	1325.73	85	347.70	.2622	21	78.71	.059
F.T.	12	1403.75	83	378.63	.2697	21	95.43	.068
D.H.	11	1610.45	79	430.28	.2672	20	99.30	.062
R.H.-Avg.	12	1437.08	86	377.10	.2624	22	84.54	.059

	Stop Occlusion Duration			Stop Release Duration			Friction Duration		
	No.of Cases	Mean (Msec)	% of Tot.Sent.	No.of Cases	Mean (Msec)	% of Tot.Sent.	No.of Cases	Mean (Msec)	% of Tot.Sent.
R.H.	17	60.00	.039	4	6.75	.004	7	92.14	.060
R.T.	18	58.17	.044	5	8.40	.006	7	85.29	.064
F.T.	18	66.00	.047	6	7.00	.005	6	78.50	.056
D.H.	16	60.37	.037	5	9.60	.006	7	98.57	.061
R.H.-Avg.	18	60.61	.042	5	8.20	.006	7	83.86	.058

	Prevocalic /r/-TR 1 Duration			Prevocalic /r/-SS Duration			Prevocalic /r/-TR 2 Duration		
	No.of Cases	Mean (Msec)	% of Tot.Sent.	No.of Cases	Mean (Msec)	% of Tot.Sent.	No.of Cases	Mean (Msec)	% of Tot.Sent.
R.H.	10	42.20	.027	10	40.20	.026	12	75.25	.049
R.T.	11	33.54	.025	11	31.09	.023	12	52.50	.040
F.T.	10	27.60	.020	10	39.60	.028	12	64.50	.046
D.H.	10	38.10	.024	10	50.70	.031	11	73.64	.046
R.H.-Avg.	11	38.00	.026	11	39.81	.028	12	62.08	.043

of 17.55 milliseconds. Thus, the duration data presented in Tables IV-1 and IV-2 clearly indicate that the major subject was a valid speaker of the General American Dialect when compared with the three secondary subjects.

While the actual values of all frequency measurements between subjects differed, the relationships between the comparison data generated by the secondary subjects and the principal data generated by the major subject were such that the correlation coefficients ranged from .48 to .94 and were statistically significant at the .016 to the .001 levels of confidence. Only the low correlation of .48 for F_3 comparisons between R.H.-Avg. and R.T. failed to reach the .001 level of statistical confidence. While a correlation of .48 is weak, it is still an indication that a relationship between the two events existed.

One explanation for the preceding, lowered correlation coefficient might have been that the two subjects, R.H.-Avg. and R.T.,used divergent articulatory maneuvers in their prevocalic /r/ productions. It is well known that General American speakers may articulate /r/ phones with the tongue bunched or retroflexed. Furthermore, speakers may use one of those two alternative articulatory maneuvers exclusively or alternate between the two depending on the /r/ allophone being produced or on its phonetic environment.[2,3,4] The frequency location of F_3 is dependent on degree of retroflexion, with F_3 being lower in frequency in the case of greater retroflexion.[5] Therefore, a difference in articulatory maneuver between these two speakers might have caused the observed F_3 differences.

In order to examine this possibility, subjects were asked to determine which articulatory maneuver they used for each prevocalic /r/ type. The instructions given to subjects and the accompanying rating form may be found as Appendix G, while the actual responses of subjects may be found as Appendix H. Examination of the data presented in Appendix H forced the rejection of differing articulatory maneuvers as the reason for the F_3 discrepancies between R.H.-Avg. and R.T., since R.H. used different maneuvers in two of the twelve possible comparisons with each of the secondary subjects, R.T., F.T., and D.H.. No other explanation for the lowered correlation between the F_3 frequency values for R.H.-Avg. and R.T. can be offered at this time. Nonetheless, the frequency data presented in Table IV-1 clearly indicate that the major subject was a valid speaker of the General American Dialect when compared with the three secondary subjects.

Major Subject Reliability

The duration and frequency data presented in Table IV-1 also indicate that the major subject was a reliable speaker. While the actual values of the principal and comparison data recorded by the major subject, R.H., differed for both duration and frequency measurements, all relationships between the principal and comparison data reached correlation coefficients which were statistically significant at the .001 level of confidence indicating that the major subject was a reliable speaker.

Since it was established that the major subject was both a valid speaker of the General American Dialect and a reliable speaker, the principal data for prevocalic /r/ were analyzed. This analysis provided a description of the acoustic parameters for prevocalic /r/ including: 1) duration in time; 2) frequency values and patterns for the fundamental of the source and for the first, second, and third formants of the vocal tract; and 3) acoustic features as produced by the source and transfer function of the vocal tract. A description and statistical analysis of these data including discussion in terms of previous studies and theoretical constructs is presented in the following sections of this chapter. Prevocalic /r/ duration measurements are considered first.

Prevocalic /r/ Duration Measurements

Analysis by Replication

The duration of prevocalic /r/ was examined first for consistency during replication. This and all subsequent measurement evaluations was analyzed at the Temple University Computer Center by the Analysis of Variance Program from the Statistical Package for the Social Sciences.[6] Statistics computed in this program included the variable mean, standard deviation, variance as expressed by an F-ratio and the statistical significance of the F. The results of an analysis of variance for prevocalic /r/ duration as broken down by acoustic segment type and by replication are displayed in Table IV-3 and illustrated graphically in Figure IV-1. The mean duration of TR 1, SS, and TR 2 differed by a maximum of only six milliseconds, or fifteen per cent, when measured during each of three replications. Klatt, in a recent review of the linguistic uses of segmental duration as evidenced in previous acoustic and perceptual studies, concluded that:

> Before making any conjectures as to the preceptual significance of observed durational changes, it is necessary to estimate a just-noticeable difference (JND) for segmental duration in sentence contexts. If an observed rule-governed change is smaller than about one JND, then it can only have a small perceptual role, no matter how regular and potentially important the durational contrast may be.
>
> . . . .
>
> One must conclude that systematic changes of less

TABLE IV-3
PREVOCALIC /r/ DURATION AS BROKEN DOWN BY
ACOUSTIC SEGMENT TYPE AND REPLICATION
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
REPLICATION 1	135		
TR 1	45	31.37	16.21
SS	45	35.67	15.08
TR 2	45	59.06	18.99
REPLICATION 2	135		
TR 1	45	37.96	20.38
SS	45	38.87	13.07
TR 2	45	62.07	22.31
REPLICATION 3	135		
TR 1	45	34.87	18.88
SS	45	38.00	14.53
TR 2	45	60.60	20.55

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	55889.82	4	13972.45	42.99	.001
Replication	1062.82	2	531.41	1.64	.194
Acoustic Segment Type	54826.99	2	27413.50	84.35	.001
TWO-WAY INTERACTIONS	193.37	4	48.34	.15	.999
Replication with Acoustic Segment Type	193.37	4	48.34	.15	.999
RESIDUAL	128705.51	396	325.01		
TOTAL	184788.70	404	457.40		

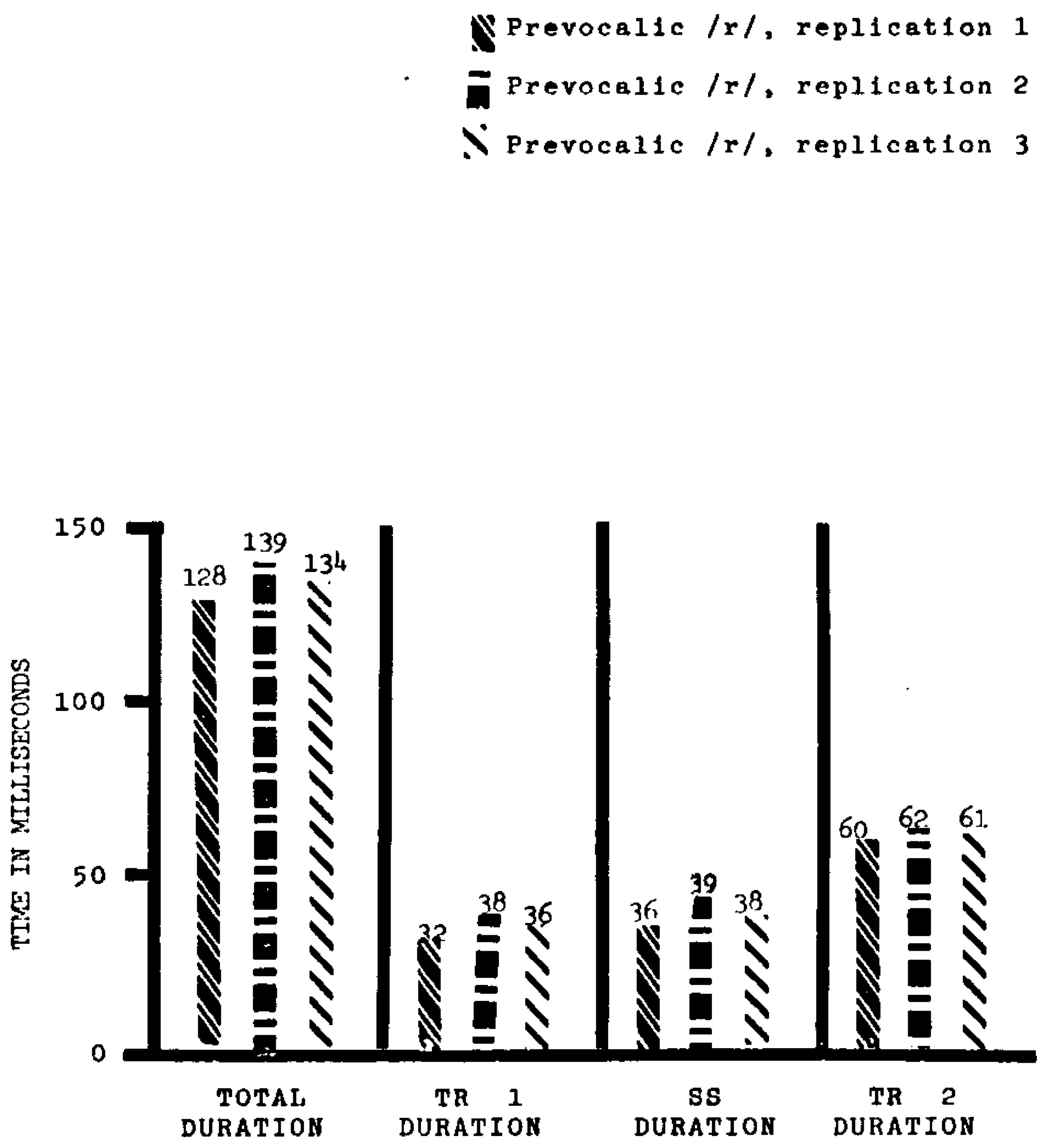


FIGURE IV-1. PRLVOCALIC /r/ DURATION DURING REPLICATION

> than about one JND, i.e., about 25 msec., are perceptually of considerably less importance than changes that exceed one JND. Since the JND for duration approximately follows Weber's law, this constraint might be rephrased such that only changes of about 20% or more may serve as primary perceptual cues.[7]

If we apply Klatt's JND guidelines, the variation in prevocalic /r/ acoustic segment duration during replication was not of perceptual significance. It was therefore possible to pool prevocalic /r/ stimulus types over replications increasing the number of cases for each prevocalic /r/ type from one to three. The results of the analysis of variance further substantiated the conclusion to pool prevocalic /r/ types over replications since the variation in prevocalic /r/ acoustic segment duration was not of statistical significance when examined by replication as a main effect or as a two-way interaction with acoustic segment type.

Analysis by Vowel Nucleus Type:
Anticipatory Co-Articulation Effects

The duration of prevocalic /r/ was also examined for each of three vowel nuclei, /i, æ, u/. The results of an analysis of variance for prevocalic /r/ duration as broken down by vowel nucleus type and by acoustic segment type are presented in Table IV-4 and illustrated graphically in Figure IV-2. Since the mean duration of TR 1, SS, and TR 2 differed by less than one JND regardless of vowel nucleus type, and was not of perceptual significance, it was possible to pool prevocalic /r/ stimulus types over vowel nucleus types. The results of an analysis of variance demonstrated that variation in prevocalic /r/ duration was not of statistical significance when examined by vowel nucleus type as either a main effect or as a two-way interaction with acoustic segment type. Therefore, the decision to pool prevocalic /r/ types over vowel nucleus

TABLE IV-4
PREVOCALIC /r/ DURATION AS BROKEN DOWN BY
ACOUSTIC SEGMENT TYPE AND VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Preceding /i/	135		
TR 1	45	36.80	19.28
SS	45	34.07	12.34
TR 2	45	59.00	21.56
Preceding /æ/	135		
TR 1	45	29.87	14.59
SS	45	37.87	14.01
TR 2	45	61.07	19.53
Preceding /u/	135		
TR 1	45	37.89	20.77
SS	45	40.80	15.61
TR 2	45	62.60	20.80

ANALYSES OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	56197.55	4	14049.39	43.80	.001
Vowel Nucleus Type	1370.55	2	685.28	2.14	.117
Acoustic Segment Type	54826.99	2	27413.50	85.48	.001
TWO-WAY INTERACTIONS	1592.31	4	398.08	1.24	.292
Vowel Nucleus Type With Acoustic Segment Type	1592.31	4	398.08	1.24	.292
RESIDUAL	126998.84	396	320.70		
TOTAL	184788.71	404	457.40		

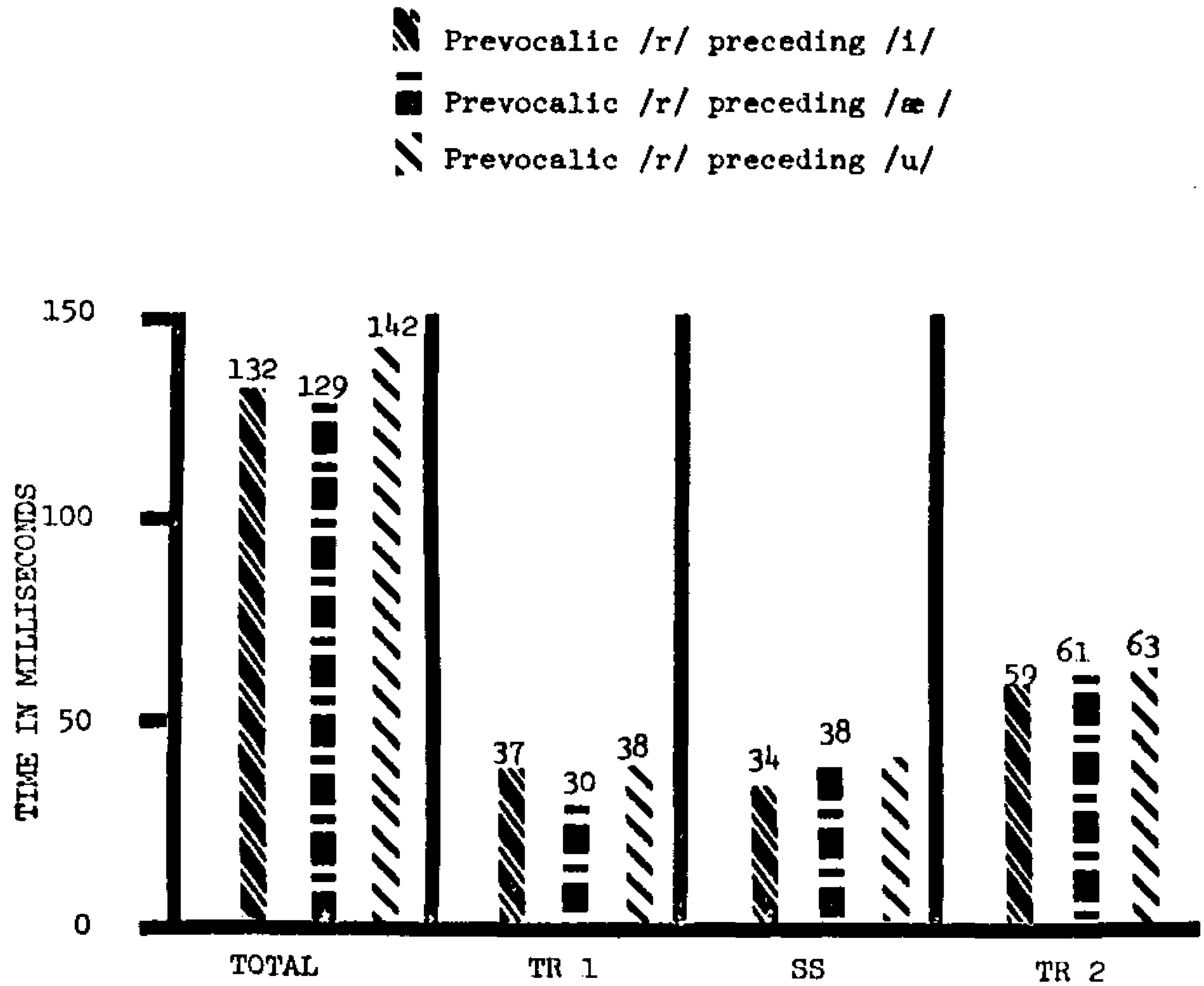


FIGURE IV-2. PREVOCALIC /r/ DURATION AS INFLUENCED BY VOWEL NUCLEUS TYPE: ANTICIPATORY CO-ARTICULATION EFFECTS types was further substantiated. Pooling over vowel nucleus type offered the advantage of simplifying the data analysis procedures and strengthening the data base for subsequent analyses, since the number of averaged cases for each prevocalic /r/ type was increased from three to nine.

Additional support for pooling over vowel nucleus type was provided by Klatt when he examined cluster data for various consonants including prevocalic /r/ and each of four vowels separately, /i,ɛ,aɪ,u/, and found no statistically significant modification of the average consonant durations. Klatt concluded that "large differences in vowel duration and differences in vowel features had no average effect on consonant duration." [8]

<u>Analysis by Acoustic Segment Type</u>

Prevocalic /r/ duration data were evaluated next for variation in acoustic segment type. This analysis was particularly important since previous studies of prevocalic /r/ were for total duration measurement only; TR 1,SS, and TR 2 segment durations had never been individually examined. The results of a one-way analysis of variance for prevocalic /r/ duration as broken down by acoustic segment type are displayed in Table IV-5 and illustrated graphically in Figure IV-3. The difference between the mean duration of TR 1, SS, and TR 2 was greater than one JND and should be considered perceptually significant. This variance was also statistically significant at the .001 level of confidence. Therefore, it is important to consider TR 1, SS, and TR 2 segment durations individually considered.

Further examination of Figure IV-3 resulted in development of the hypothesis that the durational differences among prevocalic /r/ acoustic segment types were primarily contributed by contrasts with the TR 2 seg-

TABLE IV-5

PREVOCALIC /r/ DURATION AS BROKEN DOWN BY ACOUSTIC SEGMENT TYPE
MEASUREMENTS GIVEN IN MILLISECONDS

ACOUSTIC SEGMENT TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
TR 1	135	34.85	18.61
SS	135	37.51	14.21
TR 2	135	60.76	20.53

ANALYSIS OF VARIANCE

PREVOCALIC /r/ DURATION AS BROKEN DOWN BY ACOUSTIC SEGMENT TYPE

	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE
BETWEEN GROUPS	54826.99	2	27413.50
WITHIN GROUPS	.129E+06	402	323.29

F = 84.80

SIG = .001

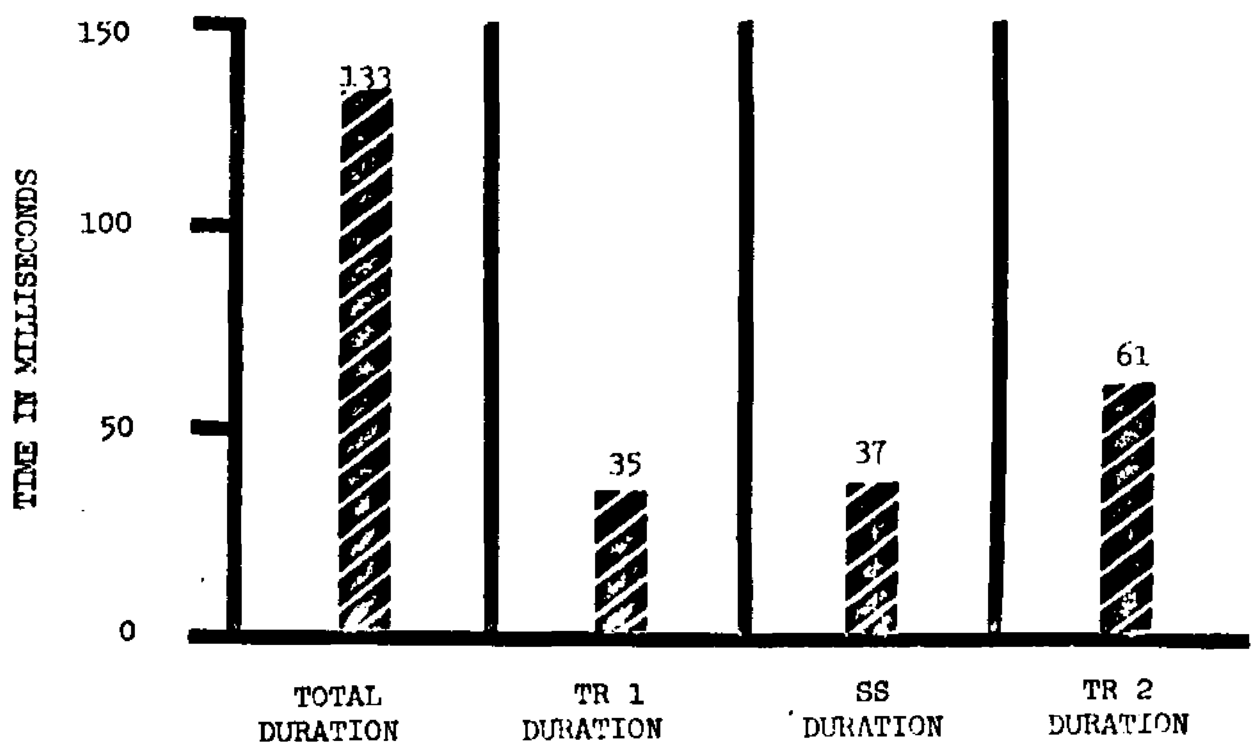


FIGURE IV-3. PREVOCALIC /r/ DURATION AS BROKEN DOWN BY ACOUSTIC SEGMENT TYPE ment. However, Figure IV-4, in which prevocalic /r/ duration is broken down by acoustic segment type and by prevocalic /r/ type, demonstrated comparable variation of more than one JND in each of the three acoustic segment types, TR 1, SS, and TR 2 and denied this hypothesis. Table IV-6 contains an analysis of variance for prevocalic /r/ duration as broken down by acoustic segment type and by prevocalic /r/ type. Variance in prevocalic /r/ duration was found to be statistically significant at the .001 level of confidence for the main effects of prevocalic /r/ type and acoustic segment type, and in two-way interactions between acoustic segment type and prevocalic /r/ type. Therefore, the conclusion that each of the acoustic segment types, TR 1, SS, and TR 2 contributed to the variation seen across prevocalic /r/ types was substantiated, and all subsequent exploration of prevocalic /r/ duration required that duration be examined as broken down by prevocalic /r/ type and by acoustic segment type. This was particularly important when evaluating the carryover co-articulation effect of the preceding phonetic event on prevocalic /r/ in word-initial clusters.

The carryover co-articulation effects of clustering on the duration of the acoustic segments associated with prevocalic /r/ were examined next with respect to the voicing, manner, and place features of specific cluster members. Since these effects were compared with the results of two previous studies, one by Haggard[9], and one by Klatt[10], a review of the data collection and analysis procedures utilized within these studies follows.

In the Haggard study of the effects of clustering on segment duration, eight male adult speakers of Southern British English recorded isolated stressed monosyllables in five random ordered lists. Prevocalic /r/ was examined as a word-initial singleton and as a member of two element

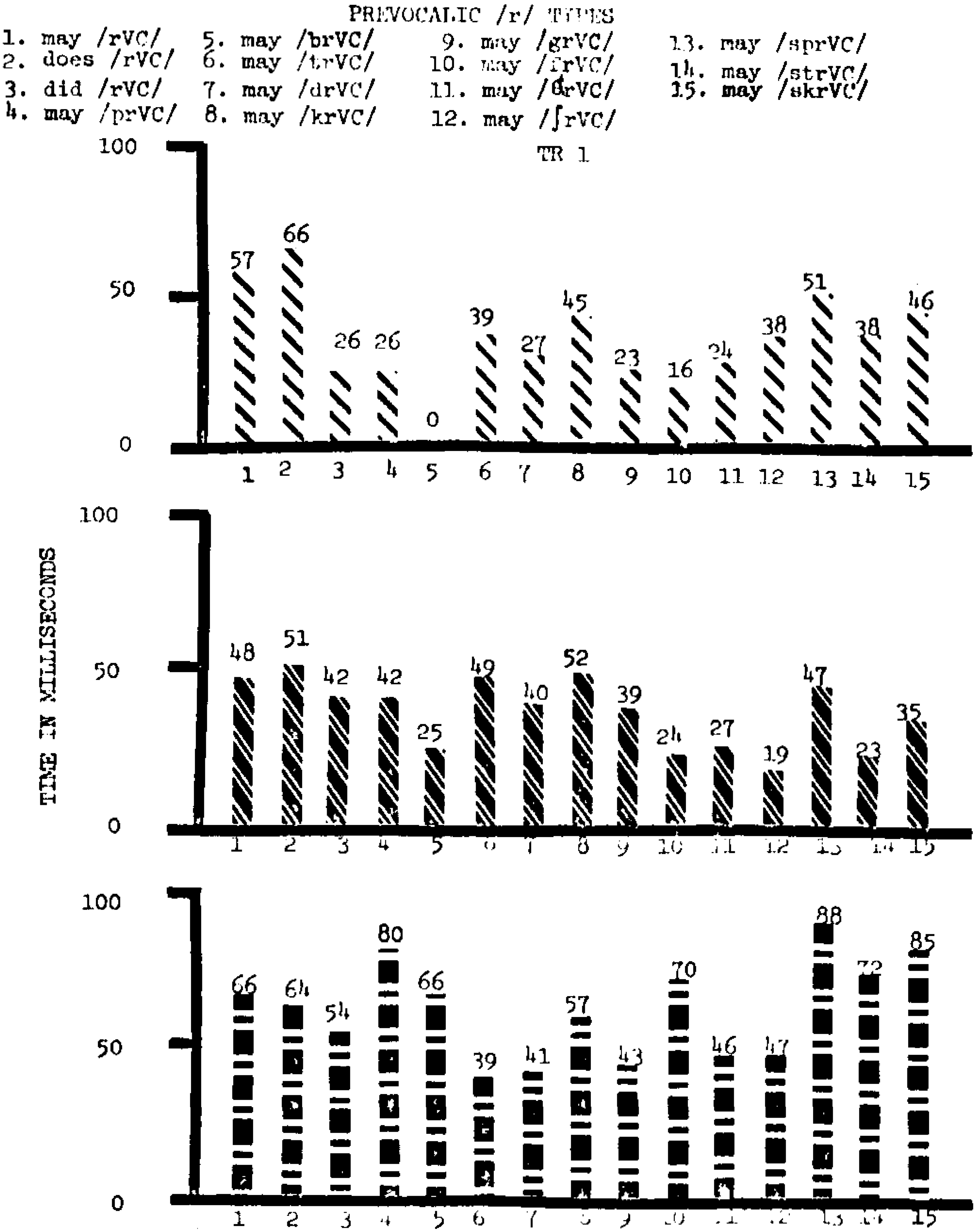


FIGURE IV-4. PREVOCALIC /r/ DURATION AS INFLUENCED BY THE INTERACTION OF PREVOCALIC /r/ TYPE WITH ACOUSTIC SEGMENT TYPE: CARRYOVER CO-ARTICULATION EFFECTS

TABLE IV-6
ANALYSIS OF VARIANCE OF PREVOCALIC /r/ DURATION
AS BROKEN DOWN BY PREVOCALIC /r/ TYPE
AND BY ACOUSTIC SEGMENT TYPE

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	SIGNIFICANCE of F
MAIN EFFECTS	97124.51	16	6070.28	46.95	.001
Prevocalic /r/ Types	42297.52	14	3021.25	23.37	.001
Acoustic Segment Types	54826.99	2	27413.50	212.032	.001
TWO-WAY INTERACTIONS	41119.96	28	1468.57	11.36	.001
Prevocalic /r/ Type with Acoustic Segment Type	41119.96	28	1468.57	11.36	.001
RESIDUAL	46544.22	360	129.29		
TOTAL	184788.70	404	457.40		

word-initial clusters combined with the stop consonants /p, b, t, d, k, g/; three element clusters were not included. Haggard's acoustic analysis utilized oscillographic recordings from which acoustic segment boundaries were defined by a change in excitation type or at an abrupt shift in articulatory closure. In an unpublished version of this study, the specific onset boundaries for prevocalic /r/ were identified as at the beginning of periodic vibration for word-initial singleton prevocalic /r/ and after the burst in the speech trace for prevocalic /r/ in two element, word-initial clusters. The offset boundary was identified at the amplitude increase in the speech trace, accompanied by a change in waveform.[12] While the Haggard study provided excellent comparison data, differences with the current study may be anticipated since Haggard's speakers were British, the acoustic analysis was done by oscillograph, the offset boundary for prevocalic /r/ differed, and the stimuli were not embedded in sentences.

In the Klatt study of the effect of clustering on consonant duration, three male adult speakers of American English, dialect unspecified, recorded five examples of each of twenty-five different word-initial clusters, and an additional thirteen words beginning with single consonants for reference purposes. The five examples for each of the word-initial clusters included four words with the vowels /i, ɛ, æ, u/, and a fifth word which added a second syllable to the end of one of the preceding four monosyllabic words; for example, *street*, *stress*, *strike*, *strewn*, and *stressful*. Prevocalic /r/ was included as a single consonant, as a member of a two element cluster with the stop consonants /p, b, t, d, k, g/, and in three element clusters with the consonants /sp, st, sk/. All stimulus words were spoken in the frame sentence *Say X instead*. Spectrograms were made and segmental durations defined by stated acoustic boundaries. The acoustic segment boundary for the onset of prevocalic /r/ was identified as after the closure interval of the stops in all clusters. Thus, clustered prevocalic /r/ included both burst and aspiration. The onset of prevocalic /r/ as a single word-initial consonant was not identified since the vowel-sonorant boundary which occurred when a /rVC/ stimulus word was embedded in the frame Say X instead was not described. The offset boundary, or the sonorant-vowel boundary, was defined as the time when the second formant passed through a frequency halfway between the estimated initial and final frequency values for the transition. When the second formant did not change significantly in frequency, the third formant was used.[13] Since the sonorant-vowel boundary was identified as the mid-point of the frequency shift between the two events, it might be inferred that the vowel-sonorant boundary, while not actually described in the article, was located at the same point; that is, the mid-point of the frequency shift between the two events. The Klatt study provided better comparison data for the current investigation than the Haggard study since Klatt's speakers were American males and since Klatt utilized spectrographic analysis procedures. However, differences may still be expected as Klatt's speakers were not specifically identified as speakers of the General American Dialect, Klatt's stimulus words were embedded in a single frame rather than in varied sentences, and Klatt's onset and offset boundaries for prevocalic /r/ differed from those of this study.

Analysis by Prevocalic /r/ Type; Carryover Co-Articulation Effects

The next evaluation in the present study considered variation in prevocalic /r/ duration in each of fifteen different stimulus sentences. These stimuli varied in terms of stimulus words and/or in terms of the phonetic event which preceded identical stimulus words in different stimulus sentences. Stimulus words were of two main types in which the prevocalic /r/ occurred in either a word-initial position or as the prevocalic element of a word-initial cluster. Since each of the fifteen prevocalic /r/ types was preceded by different phonetic events, an analysis by prevocalic /r/ type may also be considered as an analysis of carryover co-articulation effects.

Word-initial Prevocalic /r/ Types

There were three different stimulus sentence types for word-initial prevocalic /r/ in which the word immediately preceding the stimulus word of the stimulus sentence varied as follows: 1) may /rVC/, 2) does /rVC/, and 3) did /rVC/. Prevocalic /r/ duration measurements as broken down by word-initial prevocalic /r/ type and by acoustic segment type are displayed in Table IV-7 and illustrated graphically in Figure IV-5. These data established that the duration of the did /rVC/ utterances differed from the duration of the may /rVC/ utterances and the duration of the does /rVC/ utterances by more than one JND and should be considered perceptually significant. In fact, the did /rCV/ utterances behaved in the identical manner to the may /drVC/ utterances which are displayed in the following section, Prevocalic /r/ and the Influence of Clustering. However, the duration of the may /rVC/ utterances and the does /rVC/ utterances did not differ from each other by more than one JND. Therefore, carryover co-articulation was demonstrated to influence word-initial prevocalic /r/ duration where there was a permissible cluster as if the word boundary were not there.

Inasmuch as the durational differences between some word-initial

TABLE IV-7
MEAN DURATION OF WORD-INITIAL PREVOCALIC /r/ TYPES AS BROKEN DOWN BY ACOUSTIC SEGMENT TYPES
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Word-initial, may /rVC/			
TR 1	9	56.67	14.88
SS	9	48.00	16.84
TR 2	9	66.00	14.46
Word-initial, does /rVC/			
TR 1	9	66.00	14.07
SS	9	51.00	15.52
TR 2	9	63.67	19.94
Word-initial, did /rVC/			
TR 1	9	26.33	7.91
SS	9	41.67	11.07
TR 2	9	53.67	13.20

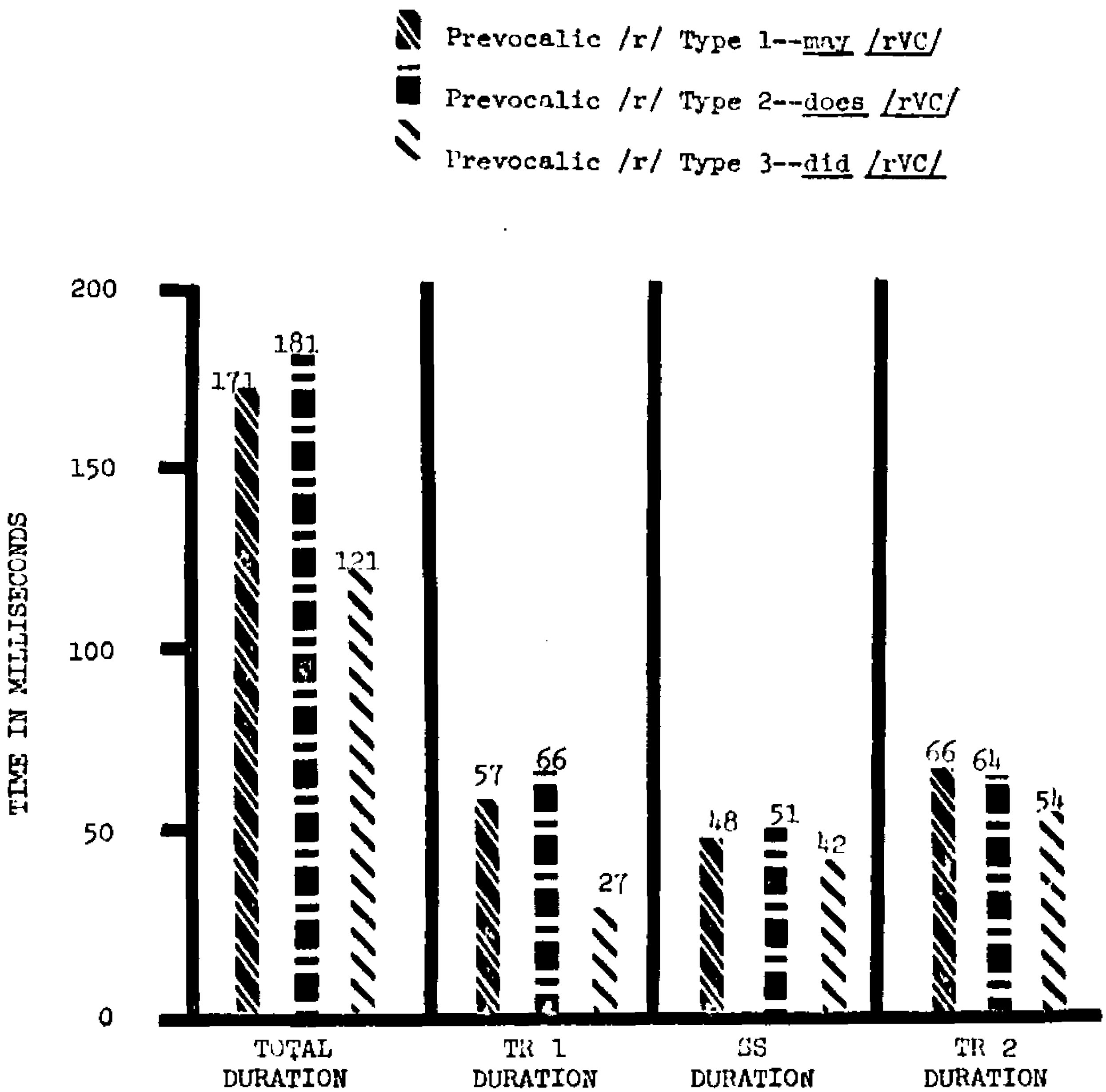


FIGURE IV-5. WORD-INITIAL PREVOCALIC /r/ DURATION AS INFLUENCED BY PRECEDING WORD IN STIMULUS SENTENCE: CARRYOVER CO-ARTICULATION EFFECTS prevocalic /r/ types were of perceptual significance it might have been best to pool the data from all word-initial /r/ types as the resultant mean might more accurately represent word-initial prevocalic /r/ as it occurs in an infinite number of sentences. However, only the may /rVC/ condition for word-initial prevocalic /r/ was used in subsequent comparisons since the majority of the stimulus words for prevocalic /r/ word-initial clusters were preceded by may, or another word ending in /e/, in the stimulus sentences. Thus, an attempt was made to hold the phonetic event proceding all prevocalic /r/ stimulus words as constant as possible.

Prevocalic /r/ and the
Influence of Clustering

The durational effects of placing prevocalic /r/ in two and three element word-initial clusters are displayed in Table IV-8 and illustrated graphically in Figure IV-6. The main effect demonstrated by this data was that including prevocalic /r/ as part of a word-initial cluster substantially shortened its total duration. Thus, prevocalic /r/ when located in a two element word-initial cluster was shortened by twenty-two percent of the total duration of word-initial prevocalic /r/, while prevocalic /r/ when located in a three element word-initial cluster was shortened by thirty-nine percent of the total duration of word-initial prevocalic /r/. Since these durational differences were greater than one JND, the carryover coarticulatory influence of previous cluster members on the total duration of prevocalic /r/ may be considered to be of perceptual significance.

Consideration of the shortening effect of clustering on the duration of prevocalic /r/ when broken down by acoustic segment type demonstrated that the cluster influencewas not equal on each of the acoustic segment types. The mean duration of the TR 1 and SS segments across cluster types

TABLE IV-8
MEAN DURATION OF PREVOCALIC /r/ TYPES
IN WORD-INITIAL AND WORD-INITIAL CLUSTERS
AS BROKEN DOWN BY ACOUSTIC SEGMENT TYPES
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Word-initial, may /rVC/			
TR 1	9	56.67	14.88
SS	9	48.00	16.84
TR 2	9	66.00	14.46
Two-element, word-initial clusters--may /CrVC/			
TR 1	81	32.86	17.05
SS	81	39.15	12.15
TR 2	81	62.74	22.13
Three-element, word-initial clusters--may /sCrVC/			
TR 1	27	26.00	11.07
SS	27	23.22	7.79
TR 2	27	54.44	18.51

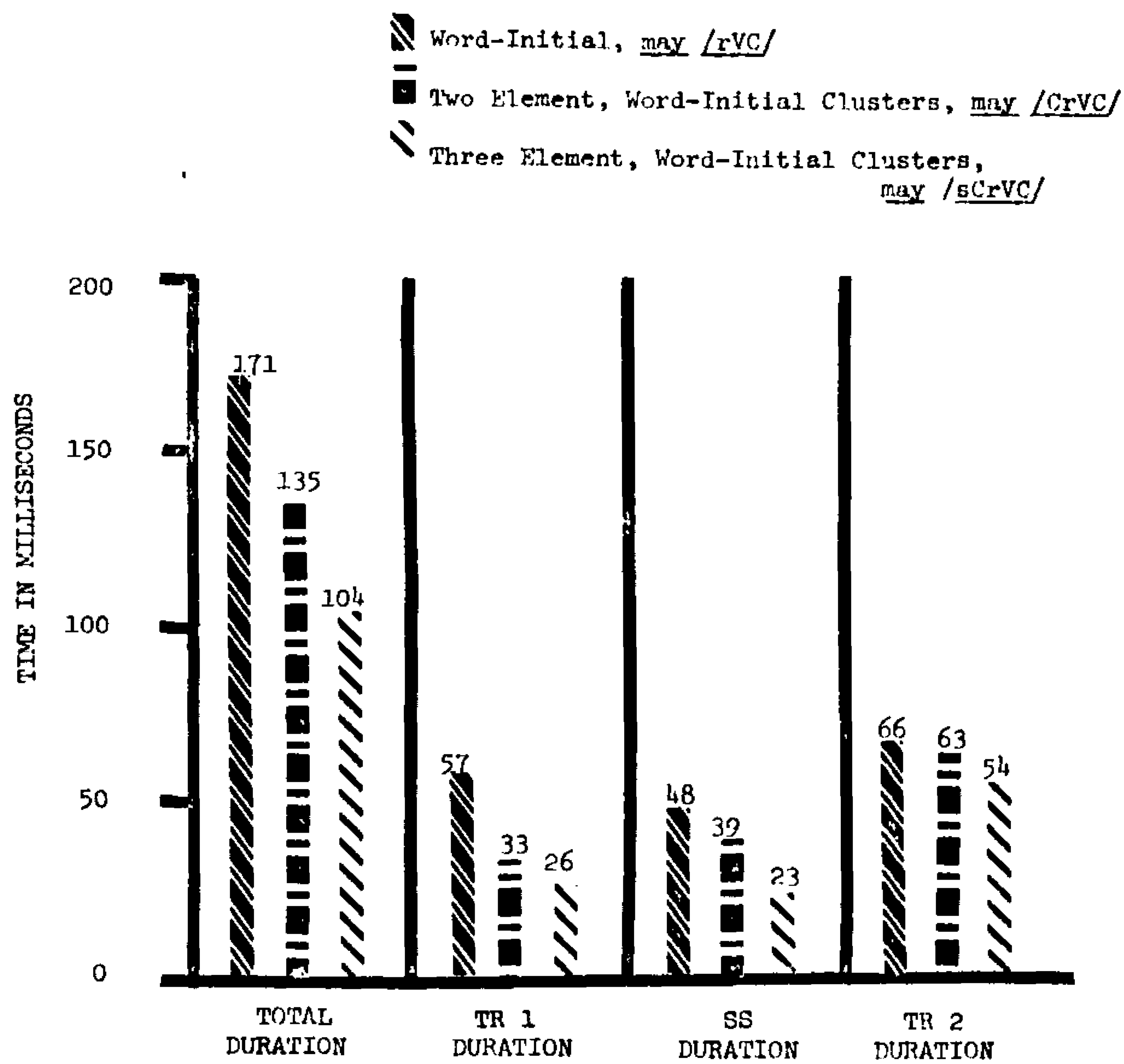


FIGURE IV-6. PREVOCALIC /r/ DURATION AS INFLUENCED BY CLUSTERING: CARRYOVER CO-ARTICULATION EFFECTS may be seen to decrease by more than one JND in all but the SS segment of two element clusters, while the duration of the TR 2 segment decreased by less than one JND in all cases. In Table IV-9, the influence of clustering on the mean duration of prevocalic /r/ acoustic segment types is expressed as a percentage of total prevocalic /r/ duration. Considered in this manner, the TR 1 and SS segment durations decreased or remained more or less stable while the TR 2 duration actually increased.

One explanation for this result might be that TR 2 was far enough removed from its preceding clustered consonant to diminish the shortening effect. This possibility seems unlikely since Daniloff and Hammarberg in a recent review of co-articulation as evidenced in acoustic and perceptual studies found that left-to-right co-articulation effects were quite common and extensive over a one to two segment range.[13] Another explanation might be that while TR 2 is shared by both prevocalic /r/ and its following vowel, that it is more appropriately assigned to the vowel in terms of duration. Lisker in a recent chapter on timing in speech concluded that "so far as place and manner of articulation are concerned, the transition is primarily consonantal, but so far as length goes, it is part of the vowel."[14] Therefore, it is possible that the TR 2 segment was resistant to temporal alteration by reason of constraints imposed by the vowel nucleus. Another alternative might be that the TR 2 segment was resistant to temporal alteration in order that it begin at a specific point in time, and that it be of sufficient duration to allow for certain spectral features essential to prevocalic /r/ production. Subsequent analyses of the data were supportive of this later alternative.

The data from this study concerning the influence of clustering on the duration of prevocalic /r/ were compared with the data from the

TABLE IV-9
INFLUENCE OF CLUSTERING ON THE MEAN DURATION OF ACOUSTIC SEGMENTS
ASSOCIATED WITH PREVOCALIC /r/
EXPRESSED AS A PERCENTAGE OF TOTAL PREVOCALIC /r/ DURATION
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPES	NO. OF CASES	TOTAL DURATION	TRANSITION ONE		STEADY-STATE		TRANSITION TWO	
			MEAN	% OF TOT.DUR.	MEAN	% OF TOT.DUR.	MEAN	% OF TOT.DUR.
Word Initial-- may /rVC/	27	170.67	56.67	.33	48.00	.28	66.00	.39
Two Element, Word-Initial Clusters-- may /CrVC/	81	134.75	32.86	.24	39.15	.29	62.74	.47
Three Element, Word-Initial Clusters-- may /sCrVC/	81	103.66	26.00	.25	23.22	.22	54.44	.52

Haggard and from the Klatt studies in Table IV-10. An attempt to minimize procedural differences between studies was made by retabulating the results of the current study as follows: 1) the two element fricative clusters were eliminated since Klatt and Haggard included only two element stop clusters, 2) the TR 1 and SS segments were summed for comparison with the Haggard study, 3) one-half of the TR 2 duration was subtracted for comparison with Klatt's clustered prevocalic /r/ data; and 4) an additional one-half of TR 1 was subtracted for comparison with Klatt's word-initial prevocalic /r/ data. The actual values for prevocalic /r/ durations as presented in Table IV-10 differed despite corrections for token type and boundary location. However, a remarkably similar shortening effect on clustered prevocalic /r/ was demonstrated, across studies, particularly when the clustered prevocalic /r/ durations were considered as a percentage of the word-initial prevocalic /r/ duration.

Voicing and the Cluster Effect.--The decrease in total duration of prevocalic /r/ when serving as the second member of a two element word-initial cluster varied with the voicing feature of the first cluster member. This variation was clearly demonstrated in the comparison between word pairs which contrasted only in the voicing feature of the word-initial stop of the cluster; that is, in comparisons between /prVC, trVC, krVC/ and /brVC, drVC, grVC/ words. These data are displayed in Table IV-11 and illustrated graphically in Figure IV-7. While both two element word-initial clusters, voiceless stop plus prevocalic /r/ and voiced stop plus prevocalic /r/, abbreviated the total duration of prevocalic /r/ from its word-initial total duration mean of 171 milliseconds, the shortening effect was minimized in the voiceless stop plus prevocalic /r/

TABLE IV-10
THE INFLUENCE OF CLUSTERING ON THE DURATION OF PREVOCALIC /r/ ACROSS STUDIES
MEASUREMENTS GIVEN IN MILLISECONDS

	WORD-INITIAL	TWO ELEMENT, WORD-INITIAL STOP CLUSTERS		THREE ELEMENT, WORD-INITIAL STOP CLUSTERS	
	MEAN	MEAN	% OF INITIAL /r/	MEAN	% OF INITIAL /r/
RUSSELL-TR 1, SS AND TR 2*	171	122	.71	104	.61
RUSSELL--FOR COMPARISON WITH HAGGARD**	105	72	.69	49	.47
HAGGARD	87	67	.77	——	——
RUSSELL--FOR COMPARISON WITH KLATT***	109	103	.94	76	.70
KLATT	102	98	.96	73	.72

* Two element fricative clusters were eliminated since Klatt and Haggard included only two element stop clusters.

** An attempt to minimize discrepancies in acoustic segment boundary locations was made by including only TR 1 and SS for comparison with Haggard's data.

*** An attempt to minimize discrepancies in acoustic segment boundary locations was made by including only one-half of the duration of TR 2 when clustered and only one-half of the duration of TR 1 for word-initial prevocalic /r/ comparisons with Klatt's data.

TABLE IV-11
MEAN DURATION OF PREVOCALIC /r/ IN TWO ELEMENT WORD-INITIAL CLUSTERS AS BROKEN DOWN BY THE VOICING CHARACTERISTICS OF THE CLUSTER MEMBER PRECEDING PREVOCALIC /r/ AND BY ACOUSTIC SEGMENT TYPE
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Word-initial, prevocalic /r/ -- *may* /*rVC*/			
TR 1	9	56.67	14.88
SS	9	48.00	16.84
TR 2	9	66.00	14.46
Word-initial clusters, voiceless stop + prevocalic /r/ -- *may* /*prVC*, *trVC*, *krVC*/			
TR 1	27	36.81	12.81
SS	27	47.89	7.37
TR 2	27	58.44	22.00
Word-initial clusters, voiced stop + prevocalic /r/ -- *may* /*brVC*, *drVC*, *grVC*/			
TR 1	27	16.78	13.19
SS	27	34.56	10.20
TR 2	27	49.79	16.52

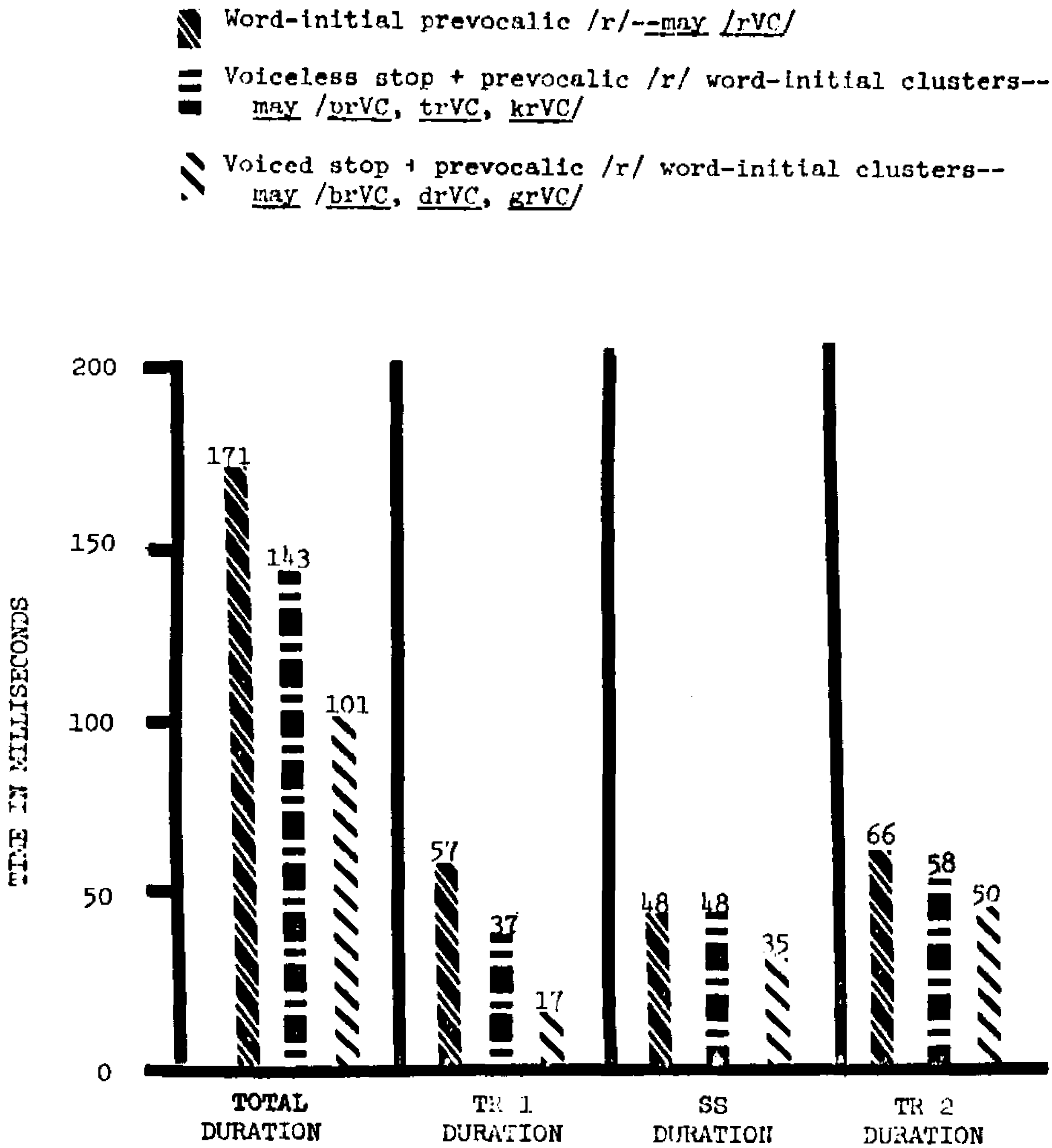


FIGURE IV-7. PREVOCALIC /r/ DURATION AS INFLUENCED BY VOICED AND VOICELESS STOPS IN TWO ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS clusters. Clustering prevocalic /r/ with voiceless stops abbreviated prevocalic /r/ total duration by .16 per cent of its word-initial total duration while clustering prevocalic /r/ with the cognate, voiced stops abbreviated prevocalic /r/ total duration by .41 per cent of its word-initial total duration. Therefore, the shortening effect of clustering on prevocalic /r/ duration was only greater than one JND in the case of the word-initial voiced stop + prevocalic /r/ clusters.

This effect was examined across studies in Table IV-12. The actual millisecond means for total prevocalic /r/ durations differed across the Russell, Haggard, and Klatt studies even though corrections for boundary locations were applied. However, the differences between the effect of clustering prevocalic /r/ with voiceless stops and with voiced stops upon the total duration of prevocalic /r/ were remarkably similar. One difference was demonstrated. In the Haggard data, and in the Russell data as retabulated for comparison with the Haggard data, prevocalic /r/ total duration when clustered with either voiceless or voiced stops was shortened from its word-initial total duration, although the degree of shortening in the voiceless stop environment did not reach one JND, or twenty per cent, and may therefore not be of perceptual significance. However, the shortening effect was actually eliminated and/or reversed when prevocalic /r/ was clustered with voiceless plosives in both the Klatt data and in the Russell data as retabulated for comparison with the Klatt data. It should be remembered that differences in these data were in acoustic segment boundary locations with approximately one-half of TR 1 included in the word-initial stimulus sentence types. Klatt's word-initial prevocalic /r/ had a 102 millisecond mean total duration which was actually increased to 110 milli-

TABLE IV-12
THE INFLUENCE OF VOICED AND VOICELESS TOPS ON THE DURATION OF PREVOCALIC /r/ IN WORD-INITIAL AND IN TWO ELEMENT WORD-INITIAL CLUSTERS ACROSS STUDIES
MEASUREMENTS GIVEN IN MILLISECONDS

	Word-Initial /r/	Two element cluster voiceless stop + /r/	Two element cluster voiced stop + /r/	
	Mean	Mean	Mean	% of voiceless cluster
RUSSELL--TR1, SS AND TR 2	171	143	101	.71
RUSSELL--for comparison with Haggard*	105	85	51	.60
HAGGARD	87	71	64	.90
RUSSELL--for comparison with Klatt**	109	114	76	.67
KLATT	102	110	85	.77

* An attempt to minimize discrepancies in acoustic segment boundary locations was made by including only TR 1 and SS for comparison with Haggard's data.

** An attempt to minimize discrepancies in acoustic segment boundary locations was made by including only one-half of the duration of TR 2 when clustered and only one-half of the duration of of TR 1 for word-initial prevocalic /r/ comparisons with Klatt's data.

seconds when prevocalic /r/ served as the second member of a two element word-initial cluster preceded by a voiceless stop. The Russell data as retabulated for comparison with the Klatt data, had a 109 millisecond mean total duration for word-initial prevocalic /r/, which was increased to 114 milliseconds when clustered with voiceless stops.

Haggard offered the following explanation for longer total prevocalic /r/ duration in clusters following voiceless plosives in the unpublished version of his study, although he did not include this explanation or offer any substitute in the paper's later published version:

> The /r/ duration of sublist (ii) produced a surprising pattern. Longer /r/ in voiceless stop context can not be explained aerodynamically. The durations were measured from the burst offset, hence it is necessary to postulate that a systematic lengthening of the /r/ gesture is employed, possibly to hold roughly constant the duration of the voiced portion. While the chief means of creating a distinct voiceless stop appears to be glottal opening, force and duration of the supraglottal articulation must have similar effects as they act to increase the intraoral pressure and hence the burst amplitude on release. This 'tenseness' could conceivably spread to the adjacent /r/ and hense explain its greater duration.[15]

Klatt provided the following explanation:

> A phonological rule of English states that the voiceless plosives [p, t, k] are strongly aspirated in prestressed position unless preceded by an [s] in the same word. Thus strong aspiration is present in the words 'top' and 'tried' but not in 'stop' and 'stride'. The second duration rule in Table XIX-4 indicates that the presence of this aspiration is accompanied by a 28% increase in the duration of the sonorant. The duration of the sonorant is actually longer in words such as 'tried' than its basic duration in words such as 'ride'. Haggard[4] noted this same tendency in British English.
>
> It may be that the aspiration should more properly be assigned to the duration of the plosive and not to the following segment. Peterson and Lehiste[5] found, however, in plosive vowel sequences, that the vowel was only slightly longer if preceded by an aspirated plosive. A more likely explanation is that the formant motions for the sonorant-vowel transition are delayed so that they take place during voicing rather than in the presence of aspiration.[16]

The more logical explanation would seem to be that of Klatt; Tr 2, or the sonorant-vowel transition, was simply delayed until the intra-oral pressure was such that voicing could onset. Further support for this explanation was found in the acoustic feature data from the current investigation, presented later in this chapter, in which the voicing feature was always present in the TR 2 segment, while the TR 1 and the SS segments were seemingly free to vary with the carry-over co-articulatory influence of the preceding phone and were frequently minus the voicing feature. The fact that the typical shortening effect of clustering on prevocalic /r/ total duration was diminished or totally eliminated in voiceless stop + prevocalic /r/ clusters was felt to be further evidence that the TR 2 onset was delayed to coincide with the onset of voicing. Therefore, the temporal constraints on the TR 1 and SS segments permitted accommodation to this requirement.

The shortening effect of clustering prevocalic /r/ with word-initial voiced and voiceless stops in two element word-initial clusters on the duration of prevocalic /r/, when broken down by acoustic segment type was generally supportive of prevocalic /r/ total duration results. These data were also displayed in Table IV-11 and Figure IV-7. The duration of prevocalic /r/ when clustered with word-initial voiceless stops differed from its word-initial duration by more than one JND in only the TR segment. The duration of prevocalic /r/ when clustered with word-initial voiced stops differed from its word-initial duration by more than one JND in all three of its acoustic segments, TR 1, SS, and TR 2. Comparisons of prevocalic /r/ acoustic segment duration in the two cluster situations, voiceless stop + /r/ and voiced stop + /r/, differed by more than one JND in both the TR 1 and SS segments. Thus, the shortening effect of clustering on prevocalic /r/ duration when broken down by acoustic segment type would seem to be an effect of voiced consonant + prevocalic /r/ rather than an effect that is simply conditioned by the total number of elements within the cluster.

The shortening effect of clustering is further explored in Figure IV-8, in which the duration of prevocalic /r/ when combined with a voiced stop in a two element word-initial cluster is compared with the duration of prevocalic /r/ when a member of a three element word-initial cluster. The duration measurements used in this figure were obtained from Tables IV-8 and IV-11. In this comparison, the total duration of prevocalic /r/ types did not differ significantly. Individual acoustic segment differences were primarily the result of a missing TR 1 segment for /brVC/ tokens, which resulted in a zero measurement being averaged with the TR 1 duration measurements for the voiced stop + prevocalic /r/ stimulus types. The /brVC/ acoustic segment differences will be discussed in a subsequent section, Place and the Cluster Effect. However, it seems clear that the two element word-initial voiced stop + prevocalic /r/ clusters have the same general shortening effect on prevocalic /r/ acoustic segment durations as three element word-initial clusters.

Manner and the Cluster Effect.--As prevocalic /r/ may occur in two element word-initial clusters with both voiceless stops and voiceless fricatives, comparisons between these prevocalic /r/ cluster types provided data for evaluating the influence of manner on the shortening effect of clustering. The data for this comparison are displayed in Table IV-13 and illustrated graphically in Figure IV-9. The means for total prevocalic /r/ duration whether clustered with voiceless stops or voiceless fricatives did not differ by more than one JND. Thus the

TABLE IV-13
MEAN DURATION OF PREVOCALIC /r/ IN TWO ELEMENT WORD-INITIAL CLUSTERS AS BROKEN DOWN BY THE MANNER CHARACTERISTICS OF THE CLUSTER MEMBER PRECEDING PREVOCALIC /r/ AND BY ACOUSTIC SEGMENT TYPE
MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Word-initial clusters voiceless stop + prevocalic /r/ -- may /prVC, trVC, krVC/			
TR 1	9	36.81	12.81
SS	9	47.89	7.37
TR 2	9	58.44	22.00
Word-initial clusters voiceless fricative + prevocalic /r/ -- may /frVC, θrVC, ʃrVC/			
TR 1	9	45.00	10.88
SS	9	35.00	18.29
Tr 2	9	80.00	15.70

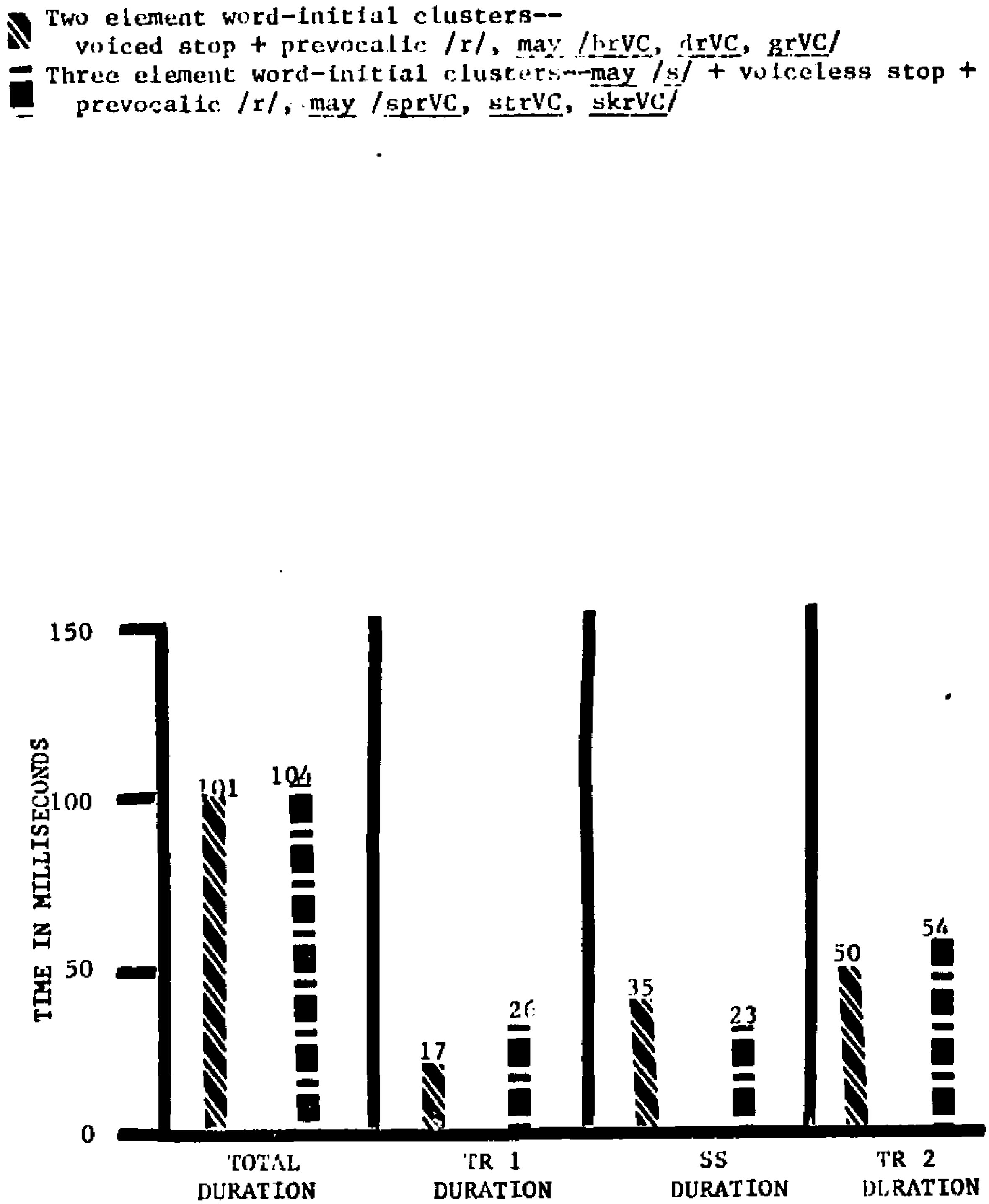


FIGURE IV-8. PREVOCALIC /r/ DURATION AS INFLUENCED BY VOICED AND VOICELESS STOPS IN TWO AND THREE ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS

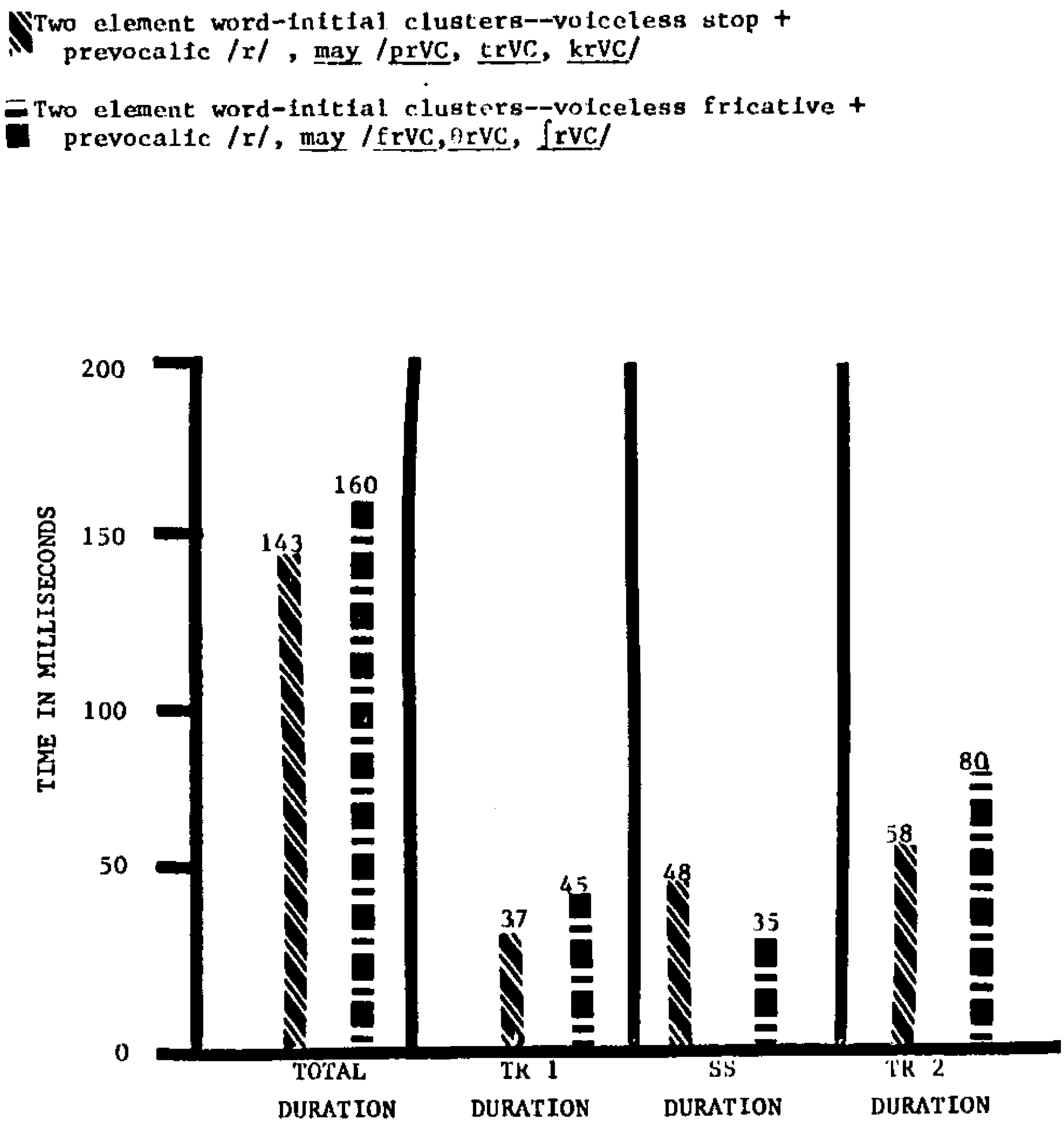


FIGURE IV-9. PREVOCALIC /r/ DURATION AS INFLUENCED BY VOICELESS STOPS AND VOICELESS FRICATIVES IN TWO ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS shortening effect of clustering on the total duration of prevocalic /r/ was not influenced by tne manner of the other cluster member. However, when prevocalic /r/ duration was broken down by acoustic segment type, duration differences greater than one JND did occur; that is, the duration of the TR 1, SS, and TR 2 segments differed in comparisons between the cluster conditions. These variations in the duration of the individual acoustic segment types within total duration constraints, may be the result of articulatory re-organization as conditioned by carryover co-articulation. Prevocalic /r/ has been described as changing in manner when clustered with certain stops and fricatives. For example, Kantner and West described prevocalic /r/ when clustered with lingua-dental and lingua-alveolar consonants such as /t, d, θ/ as fricative, since the orifice for prevocalic /r/ production is narrow enough following such consonants to produce additional friction.[17] Whether such manner changes in prevocalic /r/ production caused the actual differences in prevocalic /r/ acoustic segment duration is questionable, since the observed differences might also reflect measurement error, inasmuch as prevocalic /r/ was difficult to segment and required additional segmentation procedures when clustered with the voiceless fricatives, particularly with /f/. The additional segmentation procedures utilized were described in Chapter III. In any case, it was clear that in two element word-initial clusters, voiceless stops and voiceless fricatives had more or less the same influence on prevocalic /r/ duration.

Place and the Cluster Effect.-- As prevocalic /r/ may be clustered with the complete stop set of American English in both two and three element word-initial clusters, the influence of place on the shortening effect of clustering may be examined by averaging prevocalic /r/ types over the place feature of the preceding stop in word-initial clusters; i.e., bilabial, /prVC, brVC, sprVC/; lingua-alveolar, /trVC, drVC, strVC/; and lingua-velar /krVC, grVC, skrVC/. The data for these comparisons are displayed in Table IV-14 and illustrated graphically in Figure IV-10. Prevocalic /r/ total duration means in word-initial clusters did not differ by more than one JND regardless of the place of articulation for the stop preceding prevocalic /r/. However, when prevocalic /r/ duration was broken down by acoustic segment type, duration differences greater than one JND occurred in the TR 1 and TR 2 segments of the word-initial, bilabial stop plus prevocalic /r/ cluster types. The TR 1 segment duration differences were primarily the result of the missing /brVC/ tokens which resulted in a zero measurement being averaged with the TR 1 duration measurements, while the TR 2 segment duration differences were contributed by all of the bilabial stop plus prevocalic /r/ tokens. Differences in the influence of place of articulation of preceding cluster members on prevocalic /r/ duration in two and three element word-initial clusters may be examined specifically when prevocalic /r/ duration data are broken down by each individual prevocalic /r/ type. Data for such comparisons are displayed in Table IV-15. An analysis of variance for this data was already presented in Table IV-6. This analysis supported the conclusion that the evaluation of prevocalic /r/ duration was a complex process since statistically significant differences were found for prevocalic /r/ type, acoustic segment type, and for the two-way interaction between prevocalic /r/ type and acoustic segment type. With respect to these variances, several deviations deserved consideration.

In the /brVC/ tokens, TR 1 did not occur. This was not surprising since the articulation of /b/ and of prevocalic /r/ utilize dif-

TABLE IV-14

MEAN DURATION OF PREVOCALIC /r/ IN TWO AND THREE ELEMENT WORD-INITIAL CLUSTERS AS BROKEN DOWN BY THE PLACE CHARACTERISTICS OF THE CLUSTER MEMBER PRECEDING PREVOCALIC /r/ AND BY ACOUSTIC SEGMENT TYPE MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	MEAN DURATION	STANDARD DEVIATION
Word-initial clusters, bilabial stop + prevocalic /r/ -- *may* /*prVC*, *brVC*, *sprVC*/			
TR 1	27	14.04	11.70
SS	27	30.44	10.97
TR 2	27	72.00	17.79
Word-initial clusters, lingua-alveolar stop + prevocalic /r/ -- *may* /*trVC*, *drVC*, *strVC*/			
TR 1	27	30.11	10.21
SS	27	38.44	11.29
TR 2	27	41.89	9.17
Word-initial clusters, lingua-velar stop + prevocalic /r/ -- *may* /*krVC*, *grVC*, *skrVC*/			
TR 1	27	35.44	13.05
SS	27	36.78	15.84
TR 2	27	48.78	14.88

Word-initial clusters, bilabial stop + prevocalic /r/ --
may /prVC, brVC, sprVC/

Word-initial clusters, lingua-alveolar stop + prevocalic /r/ --
may /trVC, drVC, strVC/

Word-initial clusters, lingua-velar stop + prevocalic /r/ --
may /krVC, grVC, skrVC/

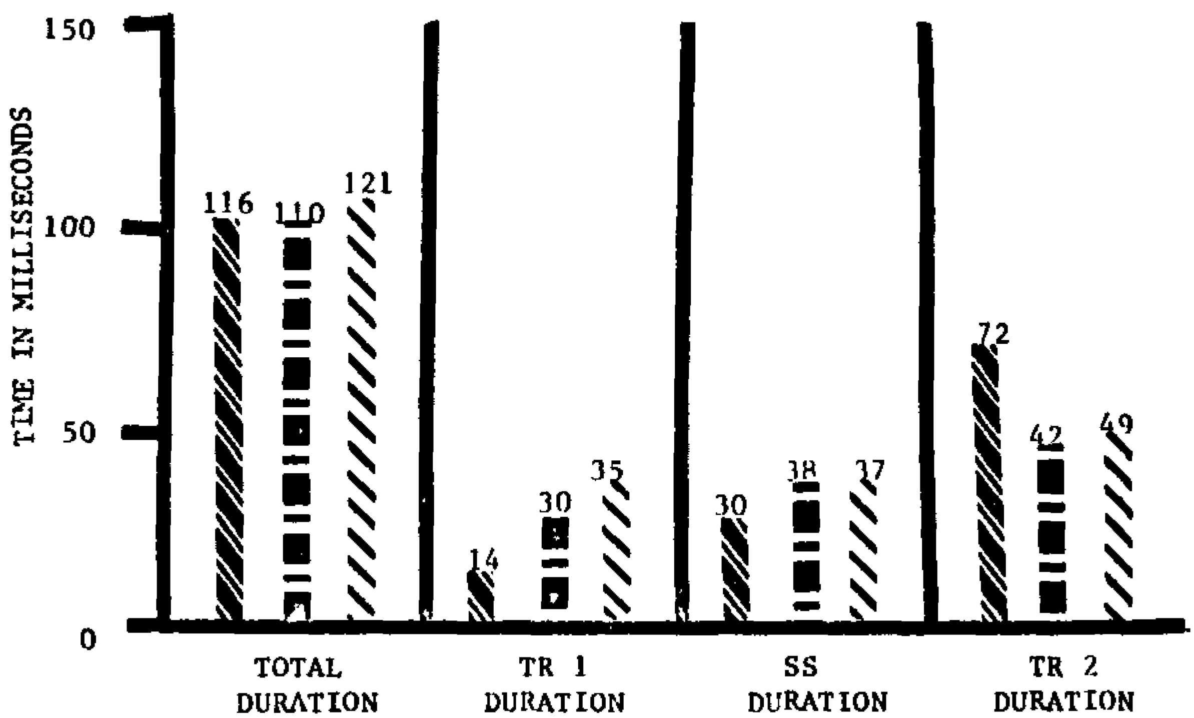


FIGURE IV-10. PREVOCALIC /r/ DURATION AS INFLUENCED BY BILABIAL, LINGUA-ALVEOLAR, AND LINGUA-VELAR STOPS IN TWO AND THREE ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS

TABLE IV-15

MEAN DURATION OF ACOUSTIC SEGMENTS ASSOCIATED WITH PREVOCALIC /r/ IN DIFFERENT CONSONANT CLUSTERS AND IN DIFFERENT CONSONANT ENVIRONMENTS MEASUREMENTS GIVEN IN MILLISECONDS

PREVOCALIC /r/ TYPE	NO. OF CASES	TRANSITION ONE MEAN (STAND.DEV.)	STEADY STATE MEAN (STAND.DEV.)	TRANSITION TWO MEAN (STAND.DEV.)	TOTAL DURATION MEAN
/e rVC/	9	56.67 (14.88)	48.00 (16.84)	66.00 (14.47)	170.66
/z rVC/	9	66.00 (14.07)	51.00 (15.52)	63.67 (19.94)	180.66
/d rVC/	9	26.33 (7.91)	41.67 (11.07)	53.67 (13.20)	146.66
/e prVC/	9	26.44 (4.80)	42.33 (5.50)	80.00 (17.30)	148.77
/e brVC/	9	TR 1 SEGMENT MISSING	25.00 (6.00)	65.67 (14.50)	90.66
/e sprVC/	9	15.67 (4.92)	24.00 (9.25)	70.33 (19.96)	109.99
/e trVC/	9	38.67 (10.76)	49.00 (4.00)	38.67 (6.78)	126.32
/e drVC/	9	27.33 (6.27)	39.67 (8.19)	41.00 (11.33)	107.99
/e strVC/	9	24.33 (7.42)	26.67 (6.95)	46.00 (8.22)	96.99
/e krVC/	9	45.33 (13.71)	52.33 (8.50)	56.67 (16.19)	154.32
/e grVC/	9	23.00 (6.36)	39.00 (9.00)	42.67 (11.00)	104.66
/e skrVC/	9	38.00 (5.81)	19.00 (5.41)	47.00 (14.85)	104.00
/e frVC/	9	51.00 (7.50)	47.33 (7.91)	88.33 (11.53)	186.66
/e θrVC/	9	38.00 (9.25)	22.67 (7.37)	72.00 (12.55)	132.66
/e ʃrVC/	9	46.00 (12.09)	35.00 (10.72)	79.67 (18.98)	160.66
Entire Population	135	34.85 (18.61)	37.51 (14.21)	60.76 (20.53)	133.12

ferent articulators and could therefore be produced concurrently. What was surprising was that this was not the case for the /prVC/ tokens. Hawkins commented on /pr/ articulation when discussing Haggard's model for the cluster effect as follows:

> There is no allowance made for the components of the gesture for a single phone to be controlled by at least partially independent channels. For example, in a nonhomorganic cluster, particularly a closed-open one such as /pr/ the major components of the C_2 gesture may be formed with or during the C_1 articulation. But, in the case of /pr/, the tongue tip will not be raised to execute the complete /r/ until after the /p/ release. What governs this comparatively delayed tongue-tip movement is a moot question. But whether it is some form of context-sensitive inhibition, the relative delay of a separate or semi-independent onset command channel, or some other factor, it seems mistaken to try to treat the /r/ gesture in this context as an entity.[18]

It might be hypothesized that the aspiration associated with word-initial /p/ accounts for the inability to articulate both phones simultaneously. However, then it might also be predicted that the /sprVC/ tokens would be minus the TR 1 segment since /p/ is not aspirated in that environment. But this was not the case, possibly due to the influence of the /s/ with its lingua-alveolar place of articulation. Therefore, the reason for delayed tongue-tip movement in the /prVC/ and /sprVC/ clusters remained unknown.

Secondly, prevocalic /r/ duration in the /trVC/ and /drVC/ contexts in this study were not elongated as they were in the studies of Klatt and of Haggard. Klatt explained the slightly longer /r/ durations following the lingua-alveolar stops as follows:

> The dental consonants [s, t, d, n, l] share approximately the same place of articulation. Another consonant that involves the tongue tip is the retroflex consonant [r]. The fifth rule states that a cluster involving a dental consonant followed by [r] is restructured so that [r] is 13% longer and the dental is 13% shorter. Haggard[4] found a similar tendency in his data and proposed the distinction that, although [r]-dental clusters are homorganic, they involved incompatible articulatory gestures.[19]

Since the /trVC/ and /drVC/ tokens in the current study did not behave in agreement with this rule, perhaps the major subject in this study produced the /tr/ and /dr/ tokens as affricates rather than as two-phone sequences. While the cause remains moot, it was clear that the data supported one of Haggard's final conclusions in that "the degree of abbreviation of homorganics appears to be something which depends not upon feature specifications but upon compatibility in the individual's production of the phones in particular clusters investigated."[20]

In summary, the analysis of prevocalic /r/ duration measurements resulted in several major conclusions. First, prevocalic /r/ duration was not significantly influenced by anticipatory co-articulation, or vowel nucleus type. Second, prevocalic /r/ duration had to be broken down by acoustic segment type (TR 1, SS, and TR 2) since significant variation in prevocalic /r/ duration resulted from both the main effects of prevocalic /r/ type and acoustic segment type, and in two-way interactions between acoustic segment type and prevocalic /r/ type. Third, prevocalic /r/ duration was significantly influenced by carryover co-articulation effects, particularly when clustered; specifically: 1) prevocalic /r/ duration was significantly shortened in two-element word-initial clusters consisting of voiced stop + /r/; 2) prevocalic /r/ was significantly shortened in three element clusters; and 3) the overall manner and place characteristics of cluster members had no significant influence on prevocalic /r/ duration, although /pr/ was unique. Finally, the TR 2 segment of prevocalic /r/ appeared to be the most stable in terms of duration; that is, it was least effected by co-articulatory influences.

Prevocalic /r/ data were evaluated next for frequency values and patterns for the fundamental, first formant, second formant, and third formant.

Prevocalic /r/ Frequency Measurements

Fundamental and formant frequency values for the acoustic segments associated with prevocalic /r/ were calculated at five locations: 1) the onset of transition one, 2) the offset of transition one; 3) the middle of the steady-state; 4) the onset of transition two; and 5) the offset of transition two. These five sampling points are referred to as acoustic segment measurement locations.

Three kinds of null data occurred with respect to frequency measurements: 1) when an acoustic segment was missing, frequency data for that segment were treated as "missing values" and were not included when calculating data means; 2) when a frequency measurement was uncertain it was omitted from consideration and treated as a "missing value" and was not included when calculating data means; and 3) when a frequency measurement was missing due to a meaningful difference, clearly observable in the spectrogram, the value was recorded as zero, which was included when calculating data means. For example, zero values were recorded for F_0 and F_1 frequency values in the case of "cutback" following voiceless consonants. While this later procedure gave rise to artificial mean frequency values when averaged across prevocalic /r/ type or vowel nucleus type, it preserved genuine cell differences in comparisons which were broken down by individual acoustic segment measurement location, prevocalic /r/ type, and vowel nucleus type.

Analysis by Replication

The frequency data for prevocalic /r/ were examined first for consistency during replication. These data are displayed in Tables IV-16 through IV-19. For replication as broken down by acoustic segment measure-

TABLE IV-16
MEAN FUNDAMENTAL FREQUENCY VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY REPLICATION AND ACOUSTIC SEGMENT MEASUREMENT LOCATION
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/	REPLICATION 1	REPLICATION 2	REPLICATION 3
TR 1 ONSET			
Mean	33.00*	32.21*	29.65*
Standard Deviation	53.09	59.19	55.14
No. of Cases	(45)	(45)	(43)
TR 1 OFFSET			
Mean	49.02*	42.04*	39.05*
Standard Deviation	61.70	61.87	51.18
No. of Cases	(45)	(45)	(44)
SS MID-POINT			
Mean	74.42*	77.13*	75.20*
Standard Deviation	65.85	66.66	62.77
No. of Cases	(45)	(45)	(45)
TR 2 ONSET			
Mean	143.31	139.29	143.22
Standard Deviation	23.88	30.47	22.37
No. of Cases	(45)	(45)	(45)
TR 2 OFFSET			
Mean	142.04	135.16	143.11
Standard Deviation	22.27	23.31	21.10
No. of Cases	(45)	(45)	(45)

TABLE IV-16 CONTINUED

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	1101853.04	6	183642.17	86.24	.001
Replication	3735.96	2	1867.98	.88	.999
Acoustic Segment Measurement Location	1097141.12	4	274285.28	128.80	.001
TWO-WAY INTERACTIONS	5665.85	8	708.23	.33	.999
Replication with Acoustic Segment Measurement Location	5665.85	8	708.23	.33	.999
RESIDUAL	1007257.21	473	2129.51		
TOTAL	2114776.10	487	4342.46		

* mean includes zero value data.

TABLE IV-17
MEAN FIRST FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY REPLICATION AND ACOUSTIC SEGMENT MEASUREMENT LOCATION
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/	REPLICATION 1	REPLICATION 2	REPLICATION 3
TR 1 ONSET			
Mean	113.26*	94.19*	91.65*
Standard Deviation	181.67	176.31	170.73
No. of Cases	(45)	(43)	(43)
TR 1 OFFSET			
Mean	198.87*	204.00*	177.93*
Standard Deviation	200.17	210.44	208.21
No. of Cases	(45)	(44)	(43)
SS MID-POINT			
Mean	254.47*	258.18*	250.76*
Standard Deviation	206.18	198.88	202.18
No. of Cases	(45)	(45)	(45)
TR 2 ONSET			
Mean	429.71	425.18	427.00
Standard Deviation	65.90	61.95	67.06
No. of Cases	(45)	(45)	(45)
TR 2 OFFSET			
Mean	474.87	462.96	469.22
Standard Deviation	111.61	96.65	102.50
No. of Cases	(45)	(45)	(45)

TABLE IV-17 CONTINUED

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	10365757.67	6	1727626.28	68.90	.001
Replication	5446.35	2	2723.17	.11	.999
Acoustic Segment Measurement Location	10358427.06	4	2589606.77	103.28	.001
TWO-WAY INTERACTIONS	56054.36	8	7006.80	.279	.999
Replication with Acoustic Segment Measurement Location	56054.36	8	7006.80	.279	.999
RESIDUAL	11859914.25	473	25073.81		
TOTAL	22281726.28	487	45753.03		

* Mean included zero value data.

TABLE IV-18
MEAN SECOND FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY REPLICATION AND ACOUSTIC SEGMENT MEASUREMENT LOCATION
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/	REPLICATION 1	REPLICATION 2	REPLICATION 3
TR 1 ONSET			
Mean	1477.62	1452.75	1467.77
Standard Deviation	537.70	521.83	552.97
No. of Cases	(37)	(36)	(35)
TR 1 OFFSET			
Mean	1277.70	1287.95	1292.54
Standard Deviation	392.39	399.41	423.62
No. of Cases	(43)	(43)	(41)
SS MID-POINT			
Mean	1307.40	1319.87	1315.63
Standard Deviation	175.76	176.76	206.01
No. of Cases	(43)	(45)	(41)
TR 2 ONSET			
Mean	1347.16	1358.16	1346.73
Standard Deviation	191.16	176.86	204.26
No. of Cases	(45)	(45)	(44)
TR 2 OFFSET			
Mean	1581.84	1645.89	1666.04
Standard Deviation	374.35	362.68	401.16
No. of Cases	(44)	(45)	(45)

TABLE IV-18 CONTINUED

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	7157542.64	6	1192923.77	8.23	.001
Replication	114128.82	2	57064.41	.39	.999
Acoustic Segment Measurement Location	6985502.68	4	1746375.67	12.05	.001
TWO-WAY INTERACTIONS	131384.37	8	16423.05	.11	.999
Replication with Acoustic Segment Measurement Location	131384.37	8	16423.05	.11	.999
RESIDUAL	68536967.25	473	144898.45		
TOTAL	75825894.26	487	155699.988		

TABLE IV-19
MEAN THIRD FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY REPLICATION AND ACOUSTIC SEGMENT MEASUREMENT LOCATION
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/	REPLICATION 1	REPLICATION 2	REPLICATION 3
TR 1 ONSET			
Mean	1986.22	1940.93	1904.64
Standard Deviation	707.64	733.33	754.93
No. of Cases	(32)	(29)	(28)
TR 1 OFFSET			
Mean	1743.24	1706.61	1709.58
Standard Deviation	602.38	612.63	690.11
No. of Cases	(34)	(31)	(26)
SS MID-POINT			
Mean	1815.50	1775.03	1799.08
Standard Deviation	226.20	250.36	284.98
No. of Cases	(28)	(29)	(25)
TR 2 ONSET			
Mean	1816.41	1776.94	1701.17
Standard Deviation	193.94	200.35	354.55
No. of Cases	(42)	(36)	(35)
TR 2 OFFSET			
Mean	2150.36	2122.80	2184.80
Standard Deviation	234.41	189.83	212.15
No. of Cases	(42)	(40)	(40)

TABLE IV-19 CONTINUED

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	13375458.98	6	2229243.16	10.91	.001
Replication	171208.29	2	85604.15	.42	.999
Acoustic Segment Measurement Location	13273126.19	4	3318281.55	16.24	.001
TWO-WAY INTERACTIONS	318108.02	8	39763.50	.20	.999
Replication with Acoustic Segment Measurement Location	318108.02	8	39763.50	.20	.999
RESIDUAL	96657668.28	473	204350.25		
TOTAL	110351235.28	487	226593.91		

ment locations, and excluding those acoustic segment measurement locations where the mean included zero values: 1) mean F_0 frequencies varied by a maximum of six per cent; 2) mean F_1 frequencies varied by a maximum of three per cent; 3) mean F_2 frequencies varied by a maximum of two per cent; and 4) F_3 frequencies varied by a maximum of three per cent. Since Flanagan has described the difference limen (DL) for formant frequency as being from three to five per cent of the formant frequency value,[21] variations in F_1, F_2, and F_3 mean values during replications were not of perceptual significance. If this DL also holds for F_0 frequency values, then the F_0 differences during replications were of perceptual significance. However, Fant believes that the DL for F frequency is probably larger than the Flanagan estimate. Fant has discussed the contrasting point of view as follows:

> From experiments with synthetic speech (Miller, 1953), it is known that a shift in voice fundamental frequency from e.g., F_0=144c/s to F_0=288c/s, the spectrum envelope held constant causes a small shift in phonetic quality towards that of a sound of slightly lower F_1 and F_2. The size of this shift is of the order of 75 males, i.e., it is barely noticeable. Our own experiments confirm in part these observations but indicate the need of further studies before this effect can be taken into account in formulas for the normalization of formant data.[22]

Accordingly, the F_0 variations during replication may not have been of perceptual significance.

Since the analyses of variance for F_0, F_1, F_2, and F_3 frequency values during replications indicated that none of the differences were of statistical significance, it was assumed that prevocalic /r/ frequency data could be pooled over replication.

Analysis by Acoustic Segment Measurement Location

The data presented in Tables IV-16 through IV-19 included a break-down for F_0 through F_3 frequency values by acoustic segment measurement location. The differences between acoustic segment measurement locations were greater than the DL for formant frequency and were also of statistical significance at the .001 level of confidence. This was not surprising since the TR 1 onset and TR 2 offset locations are more properly assigned to the phonetic segments preceding and following prevocalic /r/. While the TR 1 offset, SS mid-point, and TR 2 onset locations reflect prevocalic /r/ more directly and vary to a lesser degree, particularly for F_3, it was considered best to evaluated all subsequent frequency data by specific acoustic segment measurement location.

Prevocalic /r/ frequency data could not be further collapsed since a series of analyses of variance revealed that F_0 through F_3 frequency values as examined at each acoustic segment measurement location varied to a degree that frequently reached statistical significance when broken down by the main effects of prevocalic /r/ type and vowel nucleus type, and occasionally reached statistical significance in two-way interactions between prevocalic /r/ type and vowel nucleus type. These analyses of variance for prevocalic /r/ frequency data have been included in Appendix I and will be referred to throughout the remainder of this chapter.

Analysis by Fundamental Frequency

Mean fundamental frequency values for prevocalic /r/ as evaluated at each acoustic segment measurement location and as broken down by prevocalic /r/ type and by vowel nucleus type are displayed in Table IV-20. While the DL for the fundamental frequency is questionable, these data established that vowel nucleus type, or anticipatory co-articulation, had a substantial influence on prevocalic /r/ mean F_0 frequency

TABLE IV-20
MEAN FUNDAMENTAL FREQUENCY VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/ TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
Entire Population	122	128	127	141	140
/i/	121	127	123	142	145
/æ/	140	134	133	135	129
/u/	114	116	122	146	147
may /rVC/	122	112	114	122	131
/i/	120	114	114	117	128
/æ/	120	111	117	130	128
/u/	128	111	111	120	136
does /rVC/	132	121	119	121	133
/i/	134	128	122	120	117
/æ/	133	122	119	119	125
/u/	100	114	117	125	158
did /rVC/	137	136	129	117	129
/i/	139	130	128	128	125
/æ/	167	156	142	105	111
/u/	105	122	117	119	150
may /prVC/	000	000	000	146	141
/i/	000	000	000	139	150
/æ/	000	000	000	139	117
/u/	000	000	000	161	155
may /brVC/			122	124	142
/i/	TR 1	TR 1	122	131	133
/æ/	SEGMENT	SEGMENT	128	122	138
/u/	MISSING	MISSING	117	119	156
may /trVC/	000	000	000	149	152
/i/	000	000	000	150	172
/æ/	000	000	000	156	136
/u/	000	000	000	142	147
may /drVC/	100	115	121	131	138
/i/	103	108	111	119	125
/æ/	000	131	133	145	144
/u/	97	106	120	128	144

TABLE IV-20 CONTINUED

PREVOCALIC /r/

TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
may /krVC/	000	000	000	172	162
/i/	000	000	000	164	175
/æ/	000	000	000	150	155
/u/	000	000	000	203	128
may /grVC/	108	108	128	127	132
/i/	108	108	111	117	119
/æ/	000	000	125	111	111
/u/	000	000	147	153	167
may /sprVC/	134	128	122	126	122
/i/	000	177	129	136	133
/æ/	000	133	133	128	117
/u/	134	105	105	114	117
may /strVC/	000	150	142	151	150
/i/	000	150	142	161	161
/æ/	000	000	142	142	136
/u/	000	000	139	150	150
may /skrVC/	000	154	151	148	145
/i/	000	158	175	161	164
/æ/	000	150	154	156	144
/u/	000	000	125	128	128
may /frVC/	000	000	000	160	133
/i/	000	000	000	156	134
/æ/	000	000	000	125	105
/u/	000	000	000	200	161
may /θrVC/	000	000	000	175	159
/i/	000	000	000	181	186
/æ/	000	000	000	178	144
/u/	000	000	000	167	147
may /ʃrVC/	000	000	000	145	142
/i/	000	000	000	147	150
/æ/	000	000	000	130	117
/u/	000	000	000	158	158

values at the TR 2 offset, where vowel nucleus type /æ/ differed from vowel nucleus types /i/ and /u/. Mean F_0 measurements sampled at this point were 145 Hz for /i/, 129 Hz for /æ/, and 147 Hz for /u/. These mean F_0 vlaues paralleled the mean F_0 values as established by Peterson and Barney: /i/, 136 Hz/; /æ/, 127 Hz/; and /u/, 141 Hz. Moreover, mean F_0 frequency values for the entire prevocalic /r/ population at those measurement points most reflective of prevocalic /r/, TR offset, SS mid-point and TR 2 onset, had an average value of 132 Hz which correlated highly with the mean F_0 for /ɝ/, 133 Hz, as reported by Peterson and Barney.[23]

Mean F_0 measurements were substantially influenced by prevocalic /r/ type, or carryover co-articulation, at each acoustic segment measurement location since mean F_0 values varied by more than five per cent. Furthermore, the statistical significance of these differences in mean F_0 values as broken down by prevocalic /r/ type at each acoustic segment measurement location were substantiated in analyses of variance (Table I-1, Appendix I). The F_0 variations contributing to the observed differences across prevocalic /r/ type included: 1) zero values, where F_0 frequency measurements were nonexistent in the TR 1 and SS segments due to the "cut-back" effect in voiceless clusters, 2) higher values in all acoustic segments when clustered, 3) higher values in all acoustic segments in voiceless clusters than in the voiced, cognate clusters, and 4) zero values, where F_0 frequency measurements were nonexistent in the TR 1 segment of /gr/ clusters, particularly in interactions with vowel nucleus types, /æ/ and /u/.

While prevocalic /r/ fundamental frequency variations are like those previously observed in vowels, the reason for this variation and its perceptual significance is no clearer for prevocalic /r/ than it is for vowels. Atkinson has speculated that the vowel effect on F_0 frequency may be due to the direct mechanical interaction between the tongue, or hyoid, and the larynx causing an increase in vocal fold tension in the case of high vowels, or that it may also be accounted for in aerodynamic terms caused by the proximity of the tongue to the pharyngeal wall in the case of low vowels resulting in a pressure build up with a concomitant reduction in airflow through the glottis.[24] Similarly, the effect of voiceless vs. voiced cluster members on the F_0 frequency values for prevocalic /r/ may be an aerodynamic effect or may be the direct effect of mechanical interaction between the laryngeal devoicing muscles and those of the tongue, or hyoid.

Analysis by First Formant

Mean first formant frequency values for prevocalic /r/ as evaluated at each segment measurement location, and as broken down by prevocalic /r/ type and by vowel nucleus type are presented in Table IV-21. The F_1, F_2, and F_3 data points for the three acoustic measurement locations most directly related to prevocalic /r/, TR 1 offset, SS mid-point, and TR 2 onset are also illustrated graphically in Figure IV-11, averaged over vowel nucleus type. These data in Table IV-21 show that vowel nucleus type, or anticipatory co-articulation, had a perceptually significant influence on prevocalic /r/ mean F_1 frequency values at each acoustic segment measurement location. Specifically, mean F_1 frequency values for prevocalic /r/ were always larger than the DL for first formant frequency when preceding /æ/, than when preceding /i/ or /u/. Since a less restricted orifice produces higher F_1 frequency values, it may be implied that prevocalic /r/ articulation was more open preceding the less res-

TABLE IV-21
MEAN FIRST FORMANT FREQUENCY VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/ TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
Entire Population	387	409	407	427	469
/i/	395	387	388	397	397
/æ/	434	447	449	490	594
/u/	365	363	370	394	416
may /rVC/	452	420	433	452	513
/i/	478	389	389	422	400
/æ/	478	500	506	539	695
/u/	400	372	406	394	445
does /rVC/	378	394	389	415	493
/i/	364	389	383	411	439
/æ/	386	428	433	456	606
/u/	383	350	350	378	433
did /rVC/	394	375	380	398	485
/i/	400	406	400	389	411
/æ/	439	378	411	467	606
/u/	344	344	328	339	439
may /prVC/	000	467	450	420	443
/i/	000	000	000	372	383
/æ/	000	467	450	478	539
/u/	000	000	000	411	406
may /brVC/	TR 1 SEGMENT MISSING	TR 1 SEGMENT MISSING	407	426	485
/i/			383	383	394
/æ/			467	506	644
/u/			372	389	417
may /trVC/	000	000	000	469	474
/i/	000	000	000	417	400
/æ/	000	000	000	584	633
/u/	000	000	000	406	389
may /drVC/	336	370	387	404	444
/i/	367	361	367	378	389
/æ/	000	428	461	489	583
/u/	305	322	333	344	361

TABLE IV-21 CONTINUED

PREVOCALIC /r/

TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
may /krVC/	000	000	000	439	481
/i/	000	000	000	411	405
/æ/	000	000	000	494	633
/u/	000	000	000	411	405
may /grVC/	367	399	374	402	433
/i/	367	372	367	378	395
/æ/	000	475	378	428	506
/u/	000	350	378	400	400
may /sprVC/	394	398	411	428	441
/i/	000	367	378	394	350
/æ/	000	450	456	484	561
/u/	394	394	400	405	411
may /strVC/	000	426	426	443	465
/i/	000	417	411	417	394
/æ/	000	450	461	506	583
/u/	000	411	405	406	417
may /skrVC/	000	394	411	428	467
/i/	000	394	411	411	417
/æ/	000	000	467	506	605
/u/	000	000	356	367	378
may /frVC/	000	000	000	433	495
/i/	000	000	000	372	367
/æ/	000	000	000	478	600
/u/	000	000	000	450	517
may /θrVC/	000	000	000	424	459
/i/	000	000	000	367	372
/æ/	000	000	000	483	584
/u/	000	000	000	422	422
may /ʃrVC/	000	000	000	430	457
/i/	000	000	000	433	433
/æ/	000	000	000	461	539
/u/	000	000	000	394	400

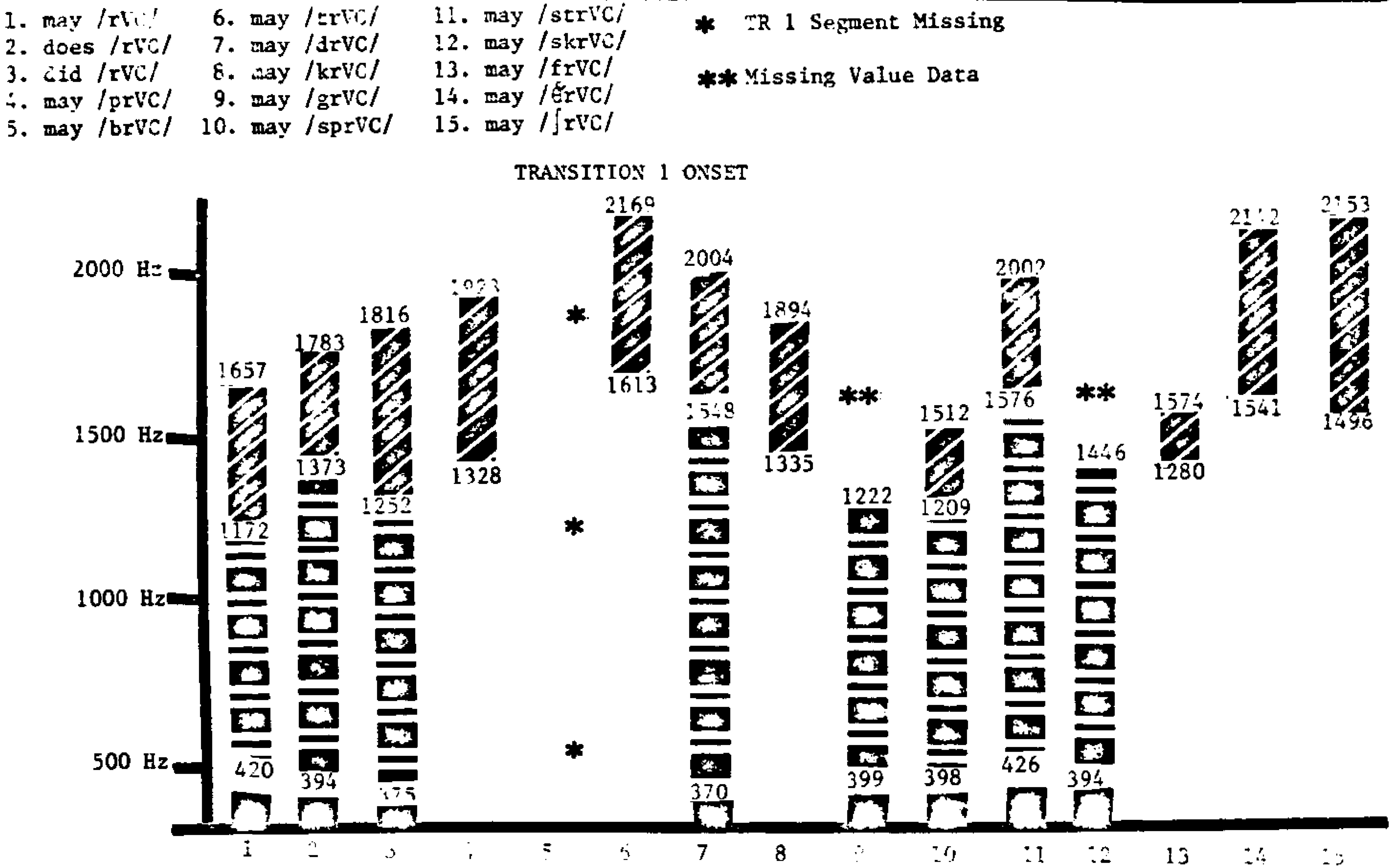


FIGURE IV-11. MEAN F_1, F_2 AND F_3 FREQUENCY VALUES AS BROKEN DOWN BY PREVOCALIC /r/ TYPES AND ACOUSTIC SEGMENT TYPES

1. may /rVC/
2. does /rVC/
3. did /rVC/
4. may /prVC/
5. may /brVC/
6. may /trVC/
7. may /drVC/
8. may /krVC/
9. may /grVC/
10. may /sprVC/
11. may /strVC/
12. may /skrVC/
13. may /frVC/
14. may /θrVC/
15. may /ʃrVC/

FIGURE IV-11, CONTINUED

1. may /rVC/
2. does /rVC/
3. did /rVC/
4. may /prVC/
5. may /brVC/
6. may /trVC/
7. may /drVC/
8. may /krVC/
9. may /grVC/
10. may /sprVC/
11. may /strVC/
12. may /skrVC/
13. may /frVC/
14. may /θrVC/
14. may /ʃrVC/

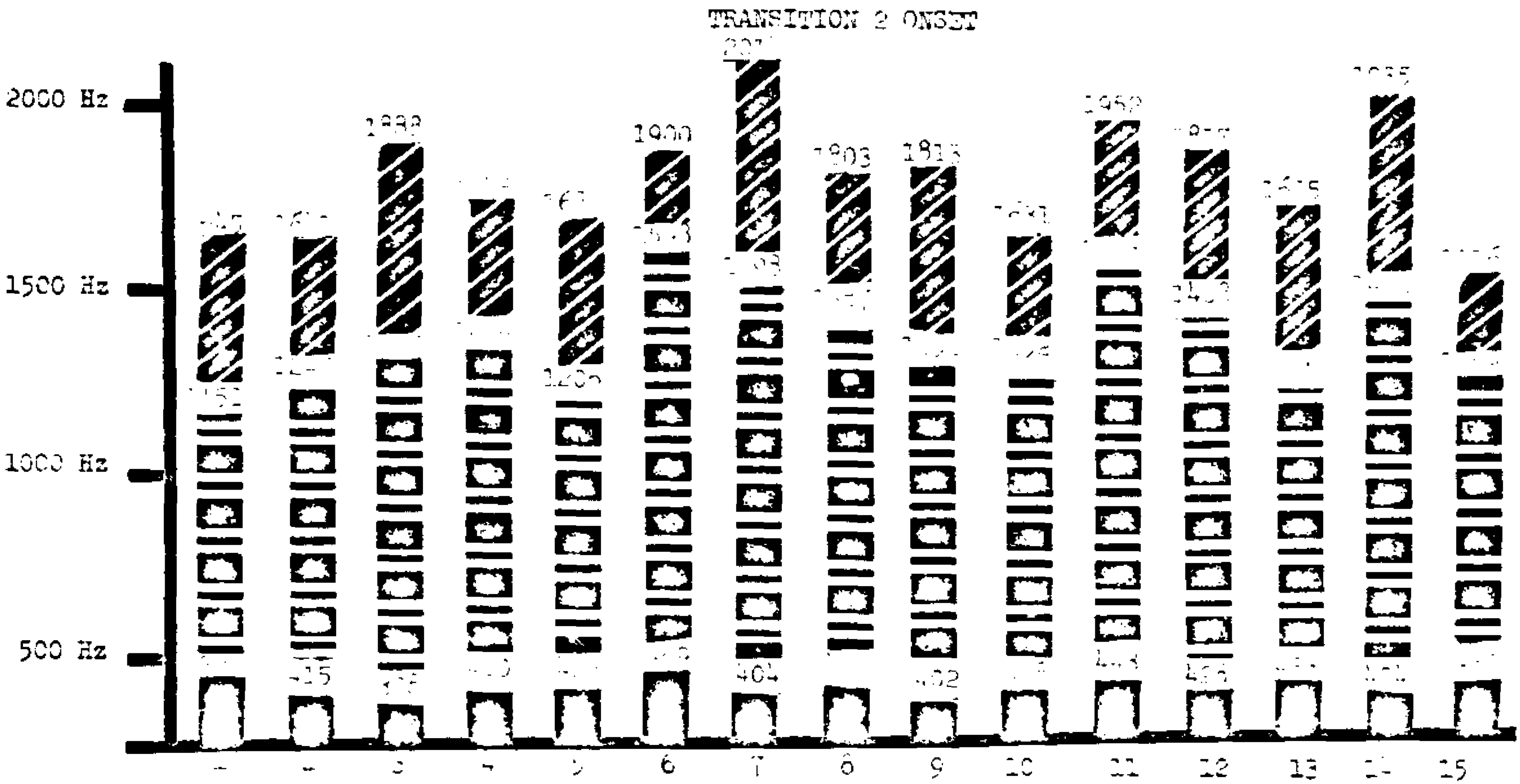


FIGURE IV-11--CONTINUED

tricted, low tongue position vowel nucleus types.

Mean F_1 frequency values for prevocalic /r/ as influenced by prevocalic /r/ type, or carryover co-articulation, varied by more than the DL for first formant frequency for most prevocalic /r/ types at the TR 1 onset, TR 1 offset, and SS mid-point acoustic segment measurement locations. Specifically F_1 was "cut-back" at these measurement locations when prevocalic /r/ followed voiceless cluster members. This absence of voicing with its concomitant lack of low frequency energy was principally evidenced when prevocalic /r/ was clustered with voiceless aspirated stops, i.e., /p, t, k/, and voiceless fricatives, i.e., /f, θ, ʃ/, two element word-initial clusters. The "cut-back" effect was restricted to the TR 1 acoustic segment following voiceless, unaspirated stops, i.e. /p, t, k/ in three element word-initial clusters.

Mean F_1 frequency values for the entire prevocalic /r/ population averaged across the TR 1, SS, and TR 2 acoustic segment measurement locations ranged from 387 to 469 Hz with an averaged value of 414 Hz. These mean values were higher in frequency than the 280 Hz, F_1 mean reported by Lehiste[25] or the 348 Hz, F_1 mean reported by Dalston[26]. Since the F_2 and F_3 frequency values were parallel across studies, it may be assumed that the subjects' vocal tract lengths were similar. Therefore, the observed F_0 frequency differences might be an indication that the major subject in the current experiment produced prevocalic /r/ with little lip-rounding since O'Connor, et al. based on experiments utilizing synthetic stimuli, reported that

> The influence of the first-formant starting frequency on /r/ was small. If a pattern contained second- and third-formant transitions satisfactory for /r/, the only difference made by a first-formant onset between 120 and 600 cps was a difference of "color", corresponding at the bottom of the range to extreme lip-rounding and at the top to lip-spreading.[27]

The fact that the first formant of prevocalic /r/ varied over a wide range was not surprising since for all semi-vowels with the exception of /l/, F_1 variation has been found to change only the semi-vowel quality and has little effect on the sound perceived.[28]

Analysis by Second Formant

Mean second formant frequency values for prevocalic /r/ as evaluated at each acoustic segment measurement location and as broken down by prevocalic /r/ type and by vowel nucleus type are presented in Table IV-22. The F_1, F_2, and F_3 data for the TR 1 offset, SS mid-point, and TR 2 onset, as averaged over vowel nucleus type are also graphically displayed in Figure IV-11. These data in Table IV-22 show that both vowel nucleus type, or anticipatory co-articulation, and prevocalic /r/ type, or carry-over co-articulation, had a perceptually and statistically significant influence on prevocalic /r/ mean F_2 frequency values. This fact was not surprising since the second formant is sensitive to front-to-back tongue position and to lip rounding, and /r/ has been described as particularly vulnerable to such-co-articulatory influences. In fact, Kantner and West stated that "we will not be wrong if we think of /r/ as being dragged all over the mouth cavity by the various sounds with which it happens to associate."[29] Therefore, examination of mean F_2 frequency values offered an excellent opportunity to assess co-articulatory influences.

Mean F_2 frequency data for prevocalic /r/ as broken down by vowel nucleus type have been illustrated graphically in Figure IV-12. These data establish that vowel nucleus type, or anticipatory co-articulation, had the greatest influence on the TR 2 onset and TR 2 offset acoustic segment measurement locations.

TABLE IV-22
MEAN SECOND FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/ TYPE	TR 1 ONSET		TR 2 OFFSET		SS MID-POINT		TR 2 ONSET		TR 2 OFFSET	
Entire Population	1466		1286		1314		1351		1636	
/i/		1536		1341		1375		1462		2098
/æ/		1485		1274		1295		1344		1548
/u/		1365		1238		1274		1248		1263
may /rVC/	2078		1172		1056		1152		1698	
/i/		2083		1222		1083		1150		2156
/æ/		2044		1238		1067		1233		1694
/u/		2106		1055		1017		1072		1244
does /rVC/	1605		1373		1175		1247		1615	
/i/		1704		1400		1200		1384		2078
/æ/		1542		1385		1221		1236		1522
/u/		1633		1333		1106		1122		1244
did /rVC/	1331		1254		1204		1317		1544	
/i/		1472		1400		1389		1422		1861
/æ/		1389		1300		1217		1478		1533
/u/		1133		1061		1006		1050		1239
may /prVC/	1396		1328		1369		1439		1742	
/i/		1459		1361		1378		1511		2304
/æ/		1286		1280		1356		1406		1683
/u/		1442		1344		1372		1400		1239
may /brVC/					1120		1206		1611	
/i/	TR 1		TR 1			1122		1244		2056
/æ/	SEGMENT		SEGMENT			1139		1267		1528
/u/	MISSING		MISSING			1100		1106		1249
may /trVC/	1896		1613		1578		1598		1611	
/i/		2106		1772		1717		1917		2056
/æ/		1911		1517		1517		1433		1528
/u/		1672		1550		1500		1444		1249
may /drVC/	1720		1548		1457		1498		1676	
/i/		1717		1528		1487		1605		2033
/æ/		1817		1628		1461		1489		1672
/u/		1628		1489		1433		1400		1322

TABLE IV-22 CONTINUED

PREVOCALIC /r/

TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
may /krVC/	1361	1335	1341	1387	1570
/i/	1656	1372	1372	1550	2145
/æ/	1378	1300	1333	1383	1500
/u/	1050	1333	1317	1228	1067
may /grVC/	1374	1222	1233	1294	1465
/i/	1389	1361	1372	1433	1778
/æ/	1359	1211	1183	1332	1472
/u/	*	1094	1142	1117	1142
may /sprVC/	1183	1209	1184	1252	1606
/i/	1308	1117	1155	1228	2056
/æ/	*	1359	1192	1311	1561
/u/	1059	1200	1206	1217	1200
may /strVC/	1580	1576	1546	1563	1611
/i/	*	1705	1728	1800	2078
/æ/	1606	1517	1444	1456	1511
/u/	1500	1505	1467	1433	1395
may /skrVC/	1429	1446	1364	1408	1623
/i/	1450	1467	1525	1559	2125
/æ/	*	*	1228	1344	1472
/u/	1367	1383	1409	1372	1439
may /frVC/	1361	1280	1251	1226	1525
/i/	1594	1434	1378	1356	2090
/æ/	1374	1162	1162	1217	1378
/u/	1292	1225	1192	1105	1105
may /θrVC/	1667	1541	1488	1421	1652
/i/	1667	1506	1409	1430	2194
/æ/	1667	1545	1495	1361	1422
/u/	1667	1572	1534	1472	1339
may /ʃrVC/	1907	1496	1390	1259	1746
/i/	1906	1472	1372	1372	2161
/æ/	2089	1500	1458	1217	1750
/u/	1728	1517	1350	1189	1328

* Since the F_2 frequency measurement was uncertain, it was treated as a "missing value" and as such did not influence the data means.

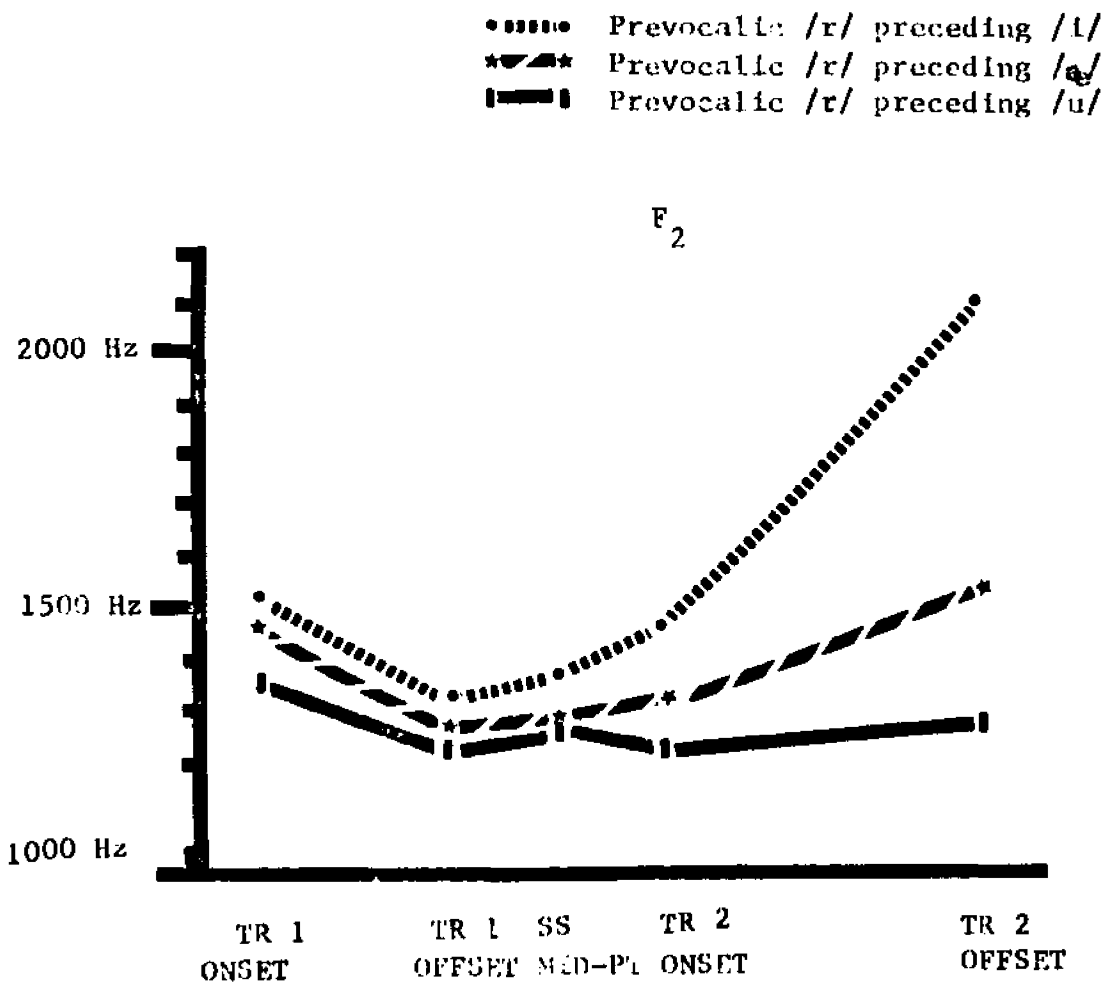


FIGURE IV-12. MEAN F_2 FREQUENCY VALUES FOR PREVOCALIC /r/ AS INFLUENCED BY VOWEL NUCLEUS TYPE: ANTICIPATORY CO-ARTICULATION EFFECTS

The data presented in Table IV-22 also establish that prevocalic /r/ type, or carryover co-articulation, had a perceptually and statistically significant influence on the mean F_2 frequency values for prevocalic /r/ over four acoustic segment locations: TR 1 onset, TR 1 offset, SS mid-point, and TR 2 onset. These co-articulatory effects were not equal in all prevocalic /r/ types. Differences in prevocalic /r/ cluster types were explored in Figures IV-13 and IV-14.

In Figure IV-13, the effect of the place of articulation of the cluster member preceding prevocalic /r/ on the mean F_2 frequency values for prevocalic /r/ was explored in contrasts between bilabial, lingua-alveolar, and lingua-velar stops when clustered with prevocalic /r/ in two and three element word-initial clusters. Word-initial prevocalic /r/ was included for the sake of comparison. This figure demonstrated substantial variation in the mean F_2 frequency values for prevocalic /r/ at the TR 1 onset, TR 1 offset, SS mid-point, and TR 2 onset acoustic segment measurement locations. The fact that carryover co-articulation effects were more extensive than those of anticipatory co-articulation was in agreement with the findings of a recent acoustic and electromyographic study of Bell-Berti and Harris.[34]

The greatest contribution to prevocalic /r/ mean F_2 variance came from the lingua-alveolar cluster contexts, /tr, dr, str/. This was a completely predictable finding since F_2 reflects front-to-back tongue movement. As we might also expect, the bilabial cluster contexts /br/ and /spr/ caused little variation in the mean F_2 frequency values for prevocalic /r/. Surprising though somewhat predictable from the prevocalic

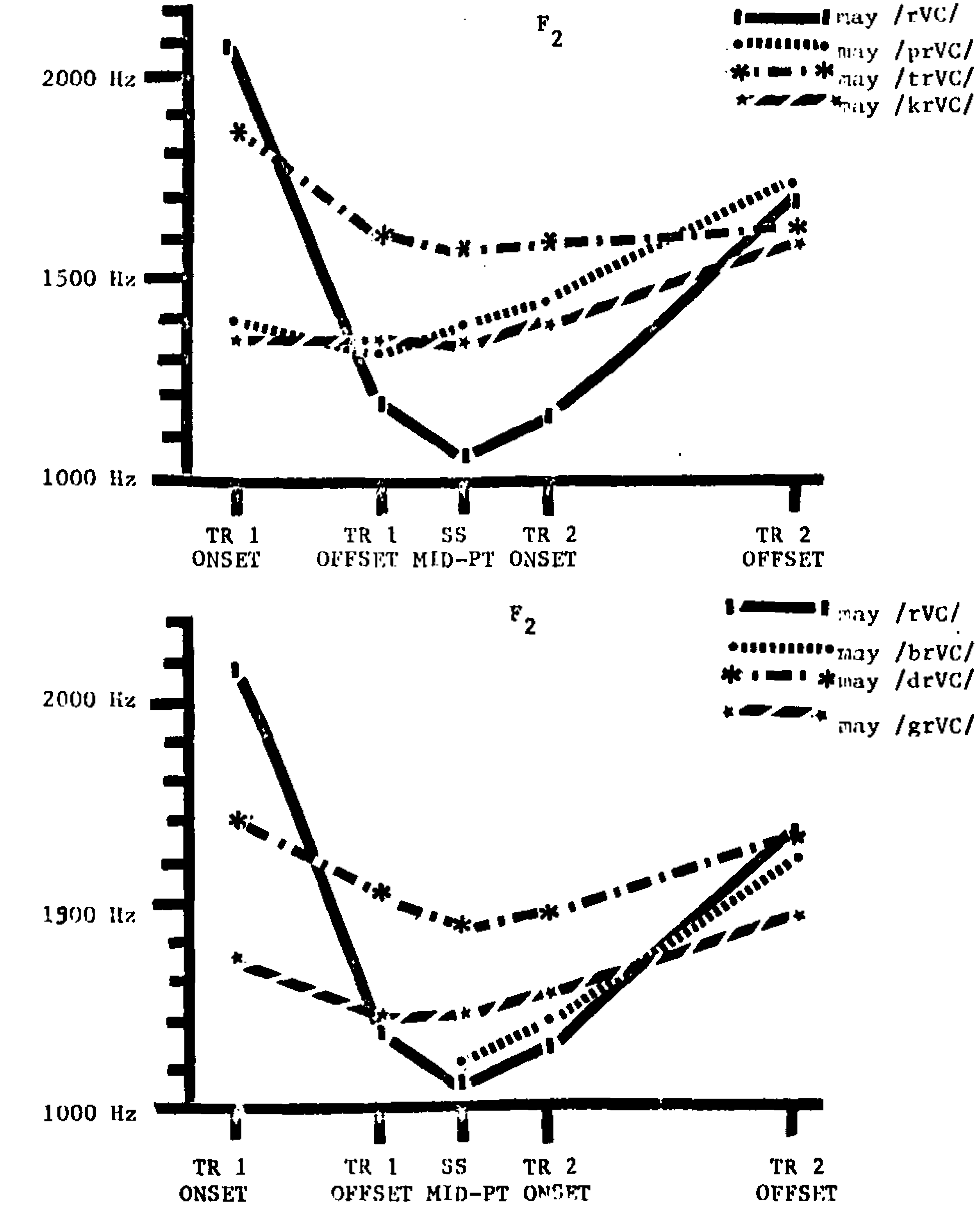


FIGURE IV-13. MEAN F_2 FREQUENCY VALUES FOR PREVOCALIC /r/ AS INFLUENCED BY BILABIAL, LINGUA-ALVEOLAR AND LINGUA-VELAR STOPS IN TWO AND THREE ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS

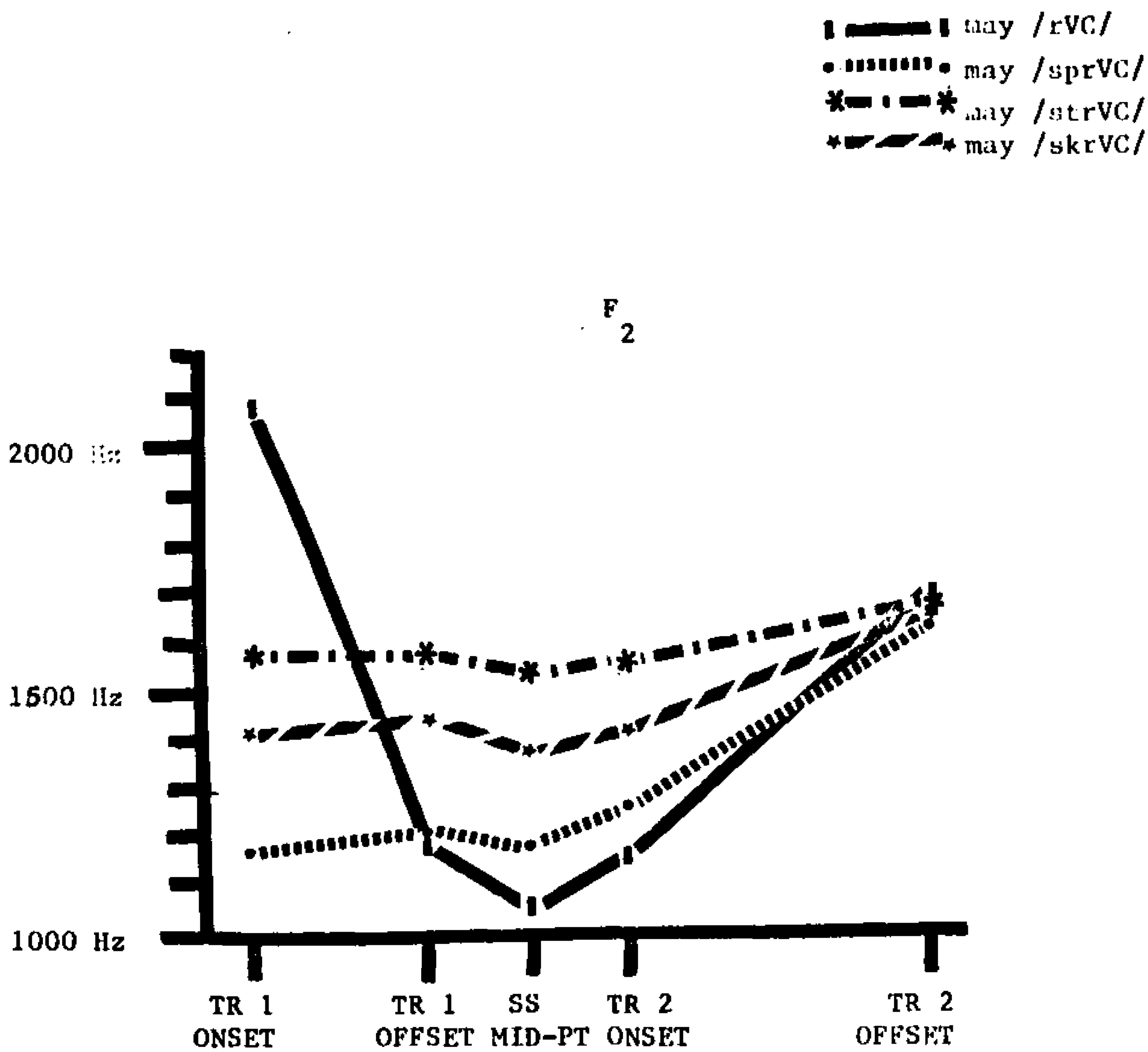
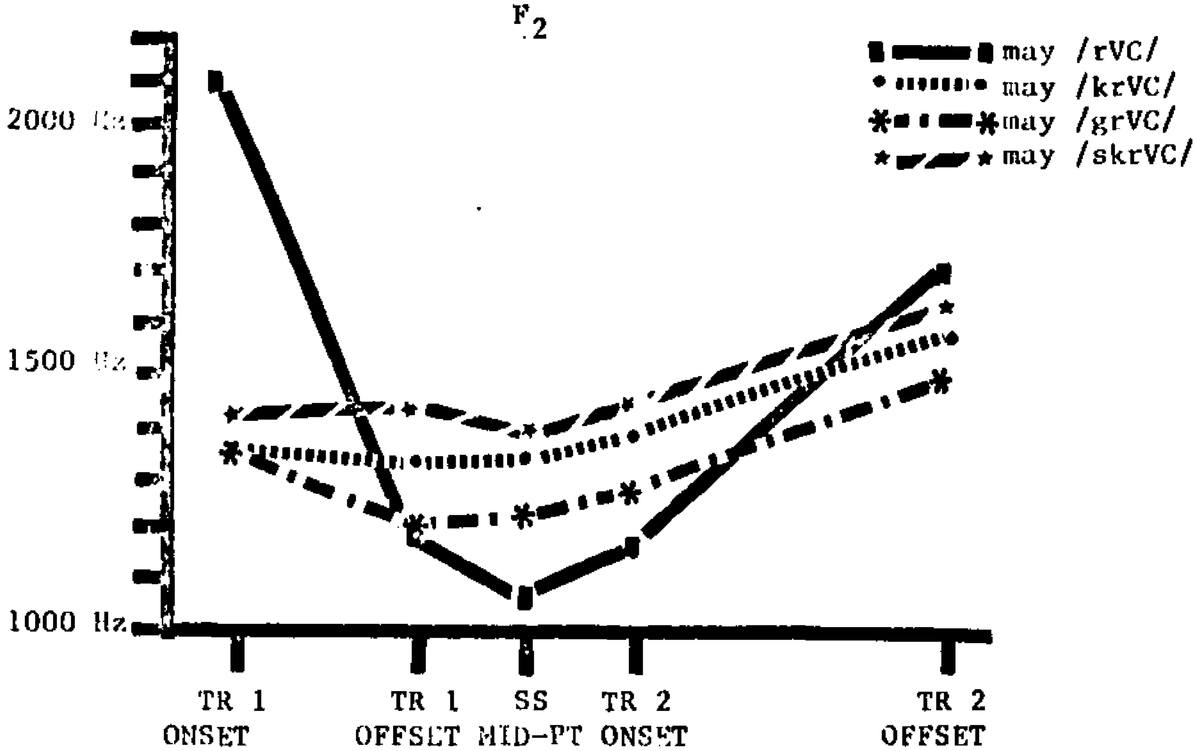


FIGURE IV-13, CONTINUED



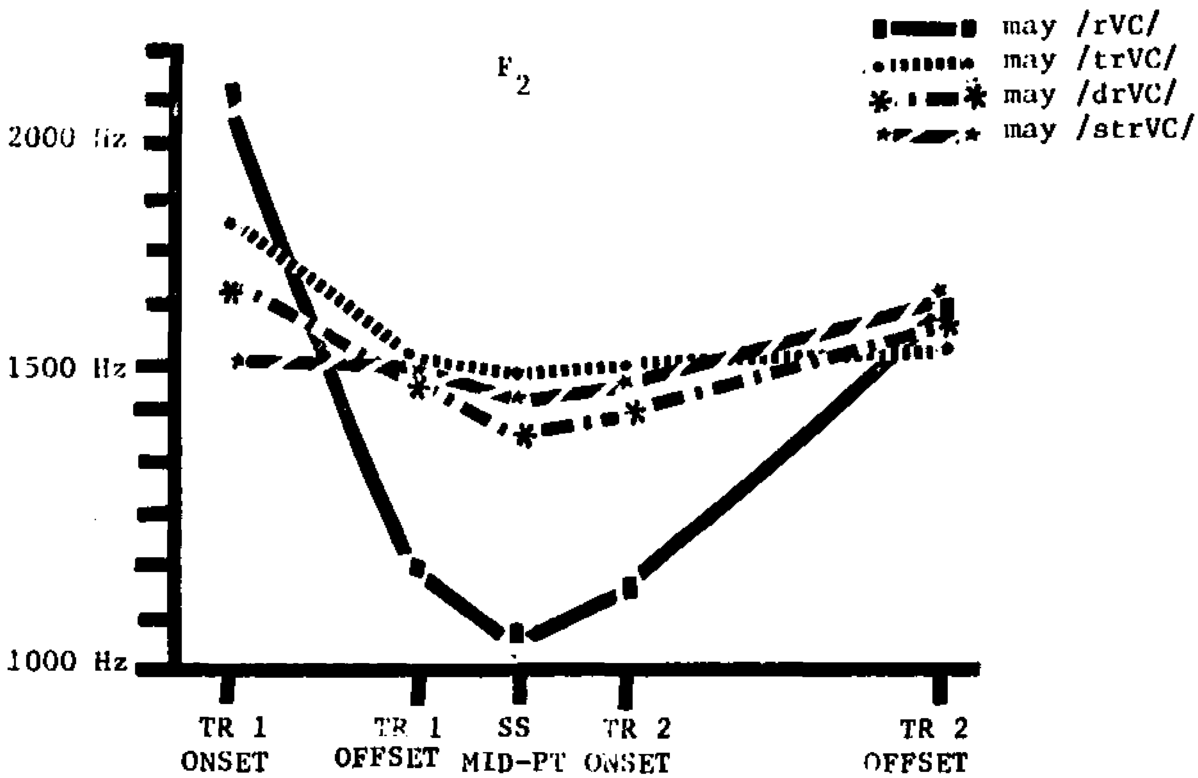


FIGURE IV-14. MEAN F_2 FREQUENCY VALUES FOR PREVOCALIC /r/ AS INFLUENCED BY VOICED AND VOICELESS STOPS IN TWO AND THREE ELEMENT WORD-INITIAL CLUSTERS: CARRYOVER CO-ARTICULATION EFFECTS

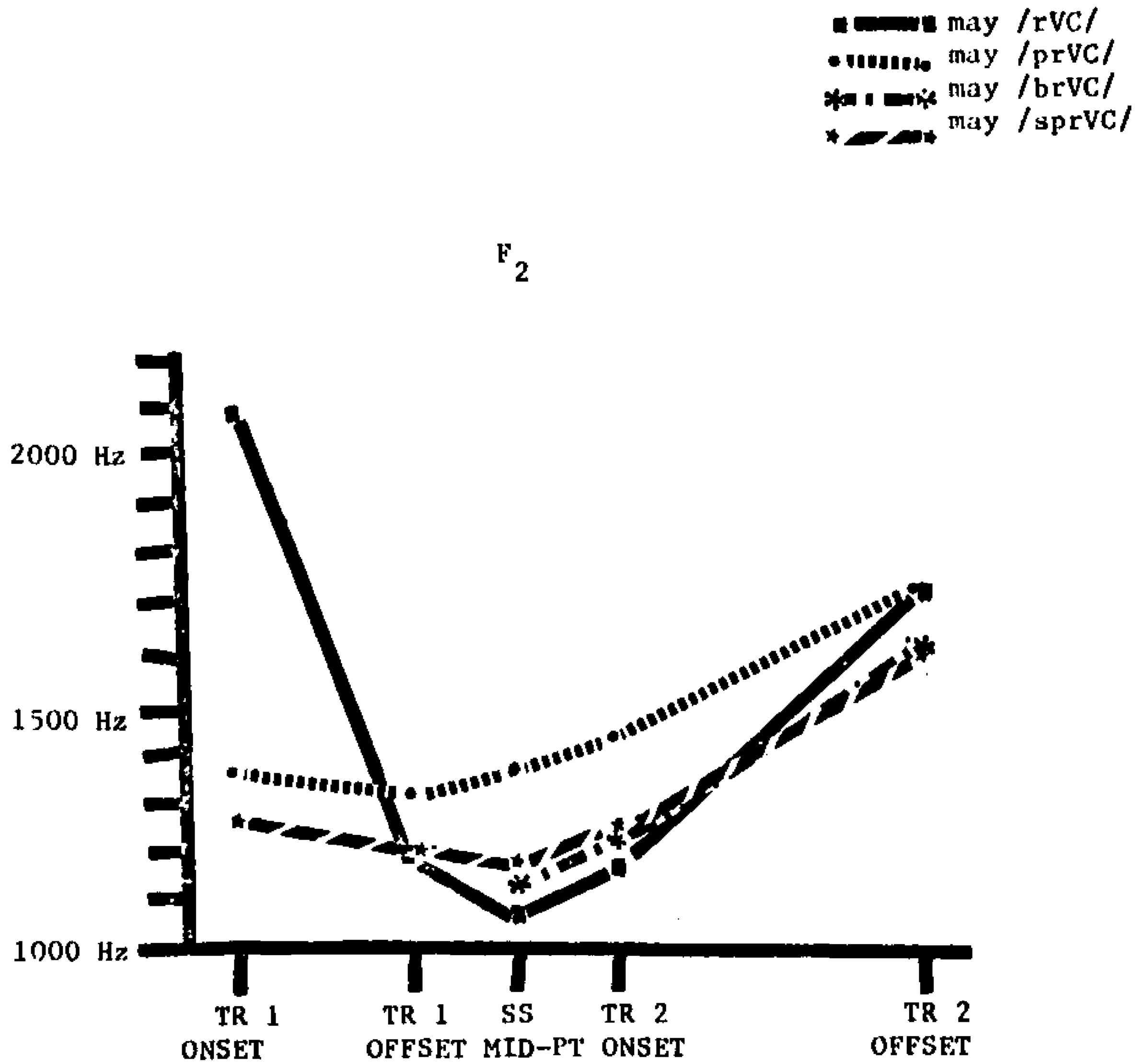


FIGURE IV-14, CONTINUED

/r/ duration data, was the degree of co-articulatory influence that the bilabial cluster context, /pr/, had on the mean F_2 frequency values of prevocalic /r/. The fact that mean F_2 frequency values for prevocalic /r/ were influenced by carryover co-articulation during /prVC/ utterances raises questions concerning the action of the tongue during the lengthy TR 1 transition since one would not expect co-articulatory influence in the second formant on a purely aerodynamic basis.

In Figure IV-14, the effect of the voicing characteristic of the cluster member preceding prevocalic /r/ on the mean F_2 frequency values for prevocalic /r/ was demonstrated in contrasts between two and three element word-initial clusters matched in their place features, i.e., /pr, br, spr/, /br, dr, str/, and /kr, gr, skr/. Word-initial prevocalic /r/ was again included for the sake of comparison. This figure demonstrated co-articulatory influences on mean F_2 frequency values for prevocalic /r/, though with the exception of /pr/, the differences due to voicing are smaller than those due to place. If these differences are in fact real, and are not due to measurement error, the result is surprising since upper vocal tract differences between cognate stops are thought to be purely aerodynamic and should not produce co-articulatory influences on mean F_2 frequency values for prevocalic /r/.

Mean F_2 frequency values sampled at the three acoustic segment measurement locations most reflective of prevocalic /r/ production, TR 1 offset, SS mid-point, and TR 2, ranged from a low of 1056 Hz, in word-initial prevocalic /r/, to a high of 1613 Hz, in /tr/ clusters, with an average value of 1317 Hz for the entire prevocalic /r/ population. Thus, the mean F_2 frequency values lay about in the middle of the range used when synthesizing /r/, from 600 Hz to 1560 Hz for word-initial prevocalic /r/ and from 850-1300 Hz for intervocalic /r/.[31,32] The unclustered word-initial mean F_2 value of 1056 Hz fell mid-way between the real speech values for word-initial prevocalic /r/ as estimated by Lehiste, 920 Hz, and as estimated by Dalston, 1165 Hz.[33,34]

Analysis by Third Formant

Mean third formant frequency values for prevocalic /r/ as evaluated at each acoustic segment measurement location, and as broken down by prevocalic /r/ type and by vowel nucleus type are presented in Table IV-23. The F_1, F_2, and F_3 data for the TR 1 offset, SS mid-point, and TR 2 onset, as averaged over vowel nucleus type, were also illustrated graphically in Figure IV-11. These data established that both vowel nucleus type, or anticipatory co-articulation, and prevocalic /r/ type, or carryover co-articulation, had a perceptually and statistically significant influence on the mean F_3 frequency values of prevocalic /r/.

Vowel nucleus type, or anticipatory co-articulation, influenced the mean F_3 frequency values of prevocalic /r/ at the SS mid-point, TR 2 onset, and TR 2 offset acoustic segment measurement locations. Furthermore, contribution to this variance came only from vowel nucleus type /i/ which caused higher frequency F_3 values in prevocalic /r/ than did /æ/ and /u/. This was a predictable finding since /i/ has the highest F_3 frequency value of all the vowels and could therefore be expected to influence prevocalic /r/ in this fashion.

Prevocalic /r/ type, or carryover co-articulation, substantially influenced the mean F_3 frequency values of prevocalic /r/ at the TR 1 onset, TR 1 offset, SS mid-point, and TR 2 onset acoustic segment measurement locations. These variances more or less followed the same pattern as did the variances found in F_2 with the place of articulation of the

TABLE IV-23
MEAN THIRD FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

PREVOCALIC /r/ TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
Entire Population	1946	1727	1796	1798	2153
/i/	1992	1820	1917	1922	2157
/æ/	1977	1650	1716	1731	2103
/u/	1857	1691	1780	1740	2028
may /rVC/	2381	1657	1391	1645	2294
/i/	2444	1792	*	1649	2457
/æ/	2456	1567	1391	1642	2244
/u/	2175	*	*	*	2125
does /rVC/	2616	1783	1605	1641	2152
/i/	2636	1967	1797	1767	2311
/æ/	2579	1704	1551	1607	2100
/u/	2660	1840	*	1633	2044
did /rVC/	1994	1816	1934	1888	2235
/i/	1975	1958	1950	1969	2133
/æ/	1850	1833	1917	1942	2283
/u/	2175	1513	*	1684	2189
may /prVC/	1933	1923	1977	1748	2325
/i/	2117	2042	2017	1851	2601
/æ/	1850	1928	1683	1633	2250
/u/	1834	1800	1500	1795	2217
may /brVC/	TR 1	TR 2	1444	1683	2153
/i/	SEGMENT	SEGMENT	1425	1767	2234
/æ/	MISSING	MISSING	1492	1650	2111
/u/			1417	1650	2133
may /trVC/	2283	2169	2077	1900	2041
/i/	2544	2367	2292	2150	2415
/æ/	2394	2106	2011	1872	1856
/u/	2210	2033	2000	1845	1978
may /drVC/	2111	2004	1960	2014	2182
/i/	2106	2006	1989	2022	2283
/æ/	2139	2017	1889	2011	2206
/u/	2089	1984	2025	2008	2056

TABLE IV-23 CONTINUED

PREVOCALIC /r/ TYPE	TR 1 ONSET	TR 1 OFFSET	SS MID-POINT	TR 2 ONSET	TR 2 OFFSET
may /krVC/	1950	1894	1800	1803	2178
/i/	2061	1994	1922	1983	2492
/æ/	1839	1672	1661	1756	2044
/u/	*	2017	1850	1783	2067
may /grVC/	*	*	1884	1813	2019
/i/	*	*	*	2059	2191
/æ/	*	*	1817	1701	1928
/u/	*	*	1950	1734	1896
may /sprVC/	1500	1512	1561	1631	2093
/i/	1500	1475	1534	1594	2317
/æ/	*	1534	1589	1706	2083
/u/	1500	1522	1550	1594	1878
may /strVC/	2120	2002	1948	1952	2189
/i/	2117	2117	2122	2161	2439
/æ/	2117	1959	1866	1883	2139
/u/	2133	1917	1809	1811	1989
may /skrVC/	*	*	1783	1817	2094
/i/	*	*	1800	1934	2483
/æ/	*	*	1529	1733	1867
/u/	*	*	1567	1822	1933
may /frVC/	1658	1574	1574	1625	2143
/i/	1789	1625	1625	1700	2347
/æ/	1555	1529	1529	1633	2050
/u/	1567	1567	1567	1566	2033
may /ərVC/	2404	2142	2069	1935	2003
/i/	2445	2200	2200	2200	*
/æ/	2367	2150	1992	1700	1967
/u/	2388	2078	1989	1906	2039
may /ʃrVC/	2331	2153	1725	1516	2152
/i/	2517	2308	*	*	2500
/æ/	2439	2000	*	1500	2311
/u/	2100	2100	1725	1533	1878

* Since the F_3 frequency measurement was uncertain, it was treated as a "missing value" and as such did not influence the data means.

preceding lingua-alveolar cluster member causing the variance.

Mean F_3 frequency values for prevocalic /r/ across prevocalic /r/ types ranged from a low of 1516 Hz, in the /ʃr/ context, to a high of 2014 Hz in the /dr/ context, with an average value of 1798 Hz for the entire population. These values fall within the F_3 range, approximately 850 - 1950 Hz, used in synthesizing /r/.[35,36] The mean F_3 frequency value for word-initial prevocalic /r/ of 1645 Hz was higher in frequency than the 1350 Hz mean established by Lehiste or the 1546 Hz mean established by Dalston in studies of real speech.[37,38]

The mean value of F_3 minus F_2 is illustrated graphically as broken down by prevocalic /r/ type and by vowel nucleus type in Figure IV-15. For the three acoustic segment measurement locations most reflective of prevocalic /r/, TR 1 offset, SS mid-point, and TR 2 onset, mean F_2 frequency values and mean F_3 frequency values were at their closest points. The least variation between the two may be found at the TR 2 onset where the range was more or less from 300-600 Hz, with an average difference of 498 Hz. Using only word-initial prevocalic /r/ comparisons, the mean difference between F_3 and F_2 values across studies of real speech was 493 Hz for the current study, 485 Hz for the Dalston study and 430 Hz for the Lehiste study.[39,40] This close proximity of F_3 to F_2 also is found in the vowel /ɝ/, but in no other vowel or semi-vowel; it is clearly a distinguishing spectral cue for prevocalic /r/ production.

In summary, the analysis of prevocalic /r/ frequency data resulted in several conclusions. First, prevocalic /r/ frequency measurements were significantly influenced by anticipatory coarticulation, or vowel nucleus type. Therefore, all frequency evaluations had to be broken down by the main effects of prevocalic /r/ type, acoustic segment measurement location

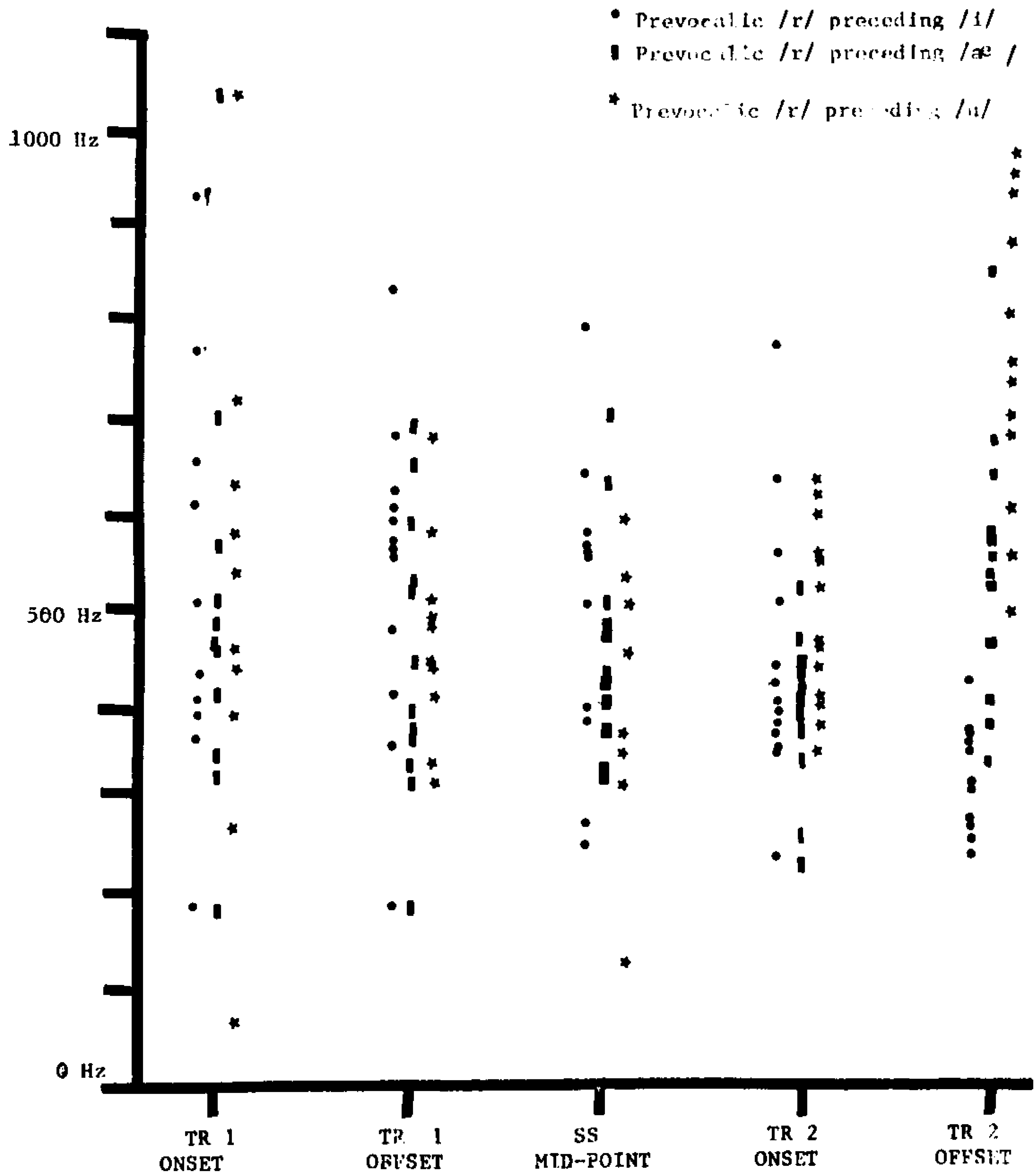


FIGURE IV-15. MEAN VALUE OF F_3 MINUS F_2 FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND VOWEL NUCLEUS TYPE

type, and by vowel type. Second, prevocalic /r/ frequency measurements were significantly influenced by carryover co-articulation, particularly when clustered; specifically; 1) F_0 and F_1 were "cutback" following voiceless cluster members; 2) F_2 was influenced by the place feature of the preceding cluster member and may also have been somewhat influenced by the voicing characteristics of the preceding cluster member; and 3) F_3 was always close to F_2 in frequency value and was subject to the same co-articulatory influence as F_2. Third, the average formant values for prevocalic /r/ across all fifteen stimulus types were F_0, 133 Hz; F_1, 414 Hz; F_2, 1317 Hz; and F_3, 1798 Hz. These values paralleled those established in previous studies. Finally, the TR 2 onset appeared to have the most stable frequency values; that is, frequency values at the TR 2 onset were least influenced by co-articulatory effects.

Prevocalic /r/ data were analyzed next in terms of acoustic segment features.

Prevocalic /r/ Acoustic Segment Features

Acoustic segment features refer to Fant's segment type features.[41] These features reflect constraints of the human vocal tract in terms of both source and transfer function, "and correspond to what is commonly referred to as 'manner of production'".[42] Each of the acoustic segments associated with prevocalic /r/, TR 1, SS, and TR 2, were described in terms of the following acoustic segment features: voice, noise, transient, occlusive, fricative, lateral, nasal, vowel-like, transitional, retroflexive, and aspirate. The spectrographic cues used to identify the presence of each of these features were previously described in Chapter III.

The acoustic segment features characteristic of the TR 1, SS, and

TR 2 segments as broken down by prevocalic /r/ type, and by vowel nucleus type are illustrated graphically in Figures IV-16, IV-17, and IV-18. Since the acoustic segment features associated with prevocalic /r/ were for the most part consistent over replications, the data seen in Figures IV-16, IV-17, and IV-18 have been averaged over replications. The data displayed in these figures will be considered in terms of anticipatory co-articulation, or vowel nucleus type, and in terms of carryover co-articulation, or prevocalic /r/ type.

Analysis by Vowel Nucleus Type:
Anticipatory Co-Articulation Effects

There was only one observed vowel associated effect which occurred for the /gr/ stimulus types; /gri/ tokens were voiced throughout all three acoustic segments, while /græ/ and /gru/ tokens were voiceless in the TR 1 segment.[43] This effect was not surprising since /g/ is sometimes partially devoiced due to the proximity of the tongue to the pharyngeal wall during the articulation of /g/, which causes a build-up of pressure in the vocal tract, and a concomitant reduction in airflow through the glottis.

While the influence of vowel nucleus type on prevocalic /r/ was minimal, word-final nasals were observed to exert a consistent anticipatory co-articulatory influence on the TR 2 segment of prevocalic /r/. Thus, TR 2 in the stimulus words preen, pram, prune, dream, and scream was always observed to be nasal-like; that is, to have split formant structure on the wide-band spectrographic display.

Analysis by Prevocalic /r/ Type:
Carryover Co-Articulation Effects

The most substantial variation in the acoustic segment features observed for prevocalic /r/ was due to prevocalic /r/ type, or carry-

TR 1
ACOUSTIC SEGMENT FEATURES

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
HEY MAY READ A NOVEL.	O							O	O	O	
HE MAY RAT ON CONVICTS.	O							O	O	O	
DON'T BE RUDE TO SALLY.	O							O	O	O	
HE DOES READ NEW NOVELS.	O				O			O	O	O	
HE DOES RAT ON CONVICTS.	O				O			O	O	O	
HE IS RUDE TO SALLY.	O				O			O	O	O	
HE DID READ A NOVEL.	O							O	O	O	
HE DID RAT ON CONVICTS.	O							O	O	O	
HE HAD RUDE THINGS TO SAY.	O							O	O	O	
SHE MAY PREEN ALL DAY LONG.		O						O	O	O	O
THE NEW PRAM IS LARGER.		O						O	O	O	O
SHE MAY PRUNE THE ARBOR.		O						O	O	O	O
SHE MAY BREED THE POODLE.	*	*	*	*	*	*	*	*	*	*	*
SHE MAY BRAG ABOUT IT.	*	*	*	*	*	*	*	*	*	*	*
SHE MAY BROOD ABOUT IT.	*	*	*	*	*	*	*	*	*	*	*
THEY MAY TREAT THEM BADLY.		O			O			O	O	O	
THEY MAY TRAP THE PIGEON.		O			O			O	O	O	
THE NEW TROUP LEFT BOOT CAMP.		O			O			O	O	O	
SHE MAY DREAM ABOUT IT.	O				O			O	O	O	
SHE MAY DRAG THEM OUTSIDE.	O				O			O	O	O	
SHE MAY DROOP FROM HUNGER.	O				O			O	O	O	
IT MAY CREAK WHEN WINDY.		O						O	O	O	O
IT MAY CRACK WITH PRESSURE.		O						O	O	O	O

FIGURE IV-16. TR 1 ACOUSTIC SEGMENT FEATURES AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE.

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
					TR 1 ACOUSTIC SEGMENT FEATURES						
THE NEW CROUP IS CATCHING.		○						○	○	○	●
HE MAY GREET THE PEOPLE.	○							○	○	○	
HE MAY GRAB THE COOKIES.		○						○	○	○	
HE MAY GROUP THE CHILDREN.		○						○	○	○	
JIM RAY FREED HIS PARROT.		○			○			○	○	○	
THE NEW FRAT NEEDS MEMBERS.		○			○			○	○	○	
SHE MAY FRUG WITH MARTIN.		○			○			○	○	○	
WE KNEW THREE SHORT STORIES.		○			○			○	○	○	
WE MAY THRASH THE HARVEST.		○			○			○	○	○	
MARIE THREW SHAWN'S BASEBALL.		○			○			○	○	○	
HE MAY SHRIEK AT SHELDON.		○			○			○	○	○	
HE'S TOO SHREWD TO WORRY.		○			○			○	○	○	
JIM RAY SHRANK HIS TROUSERS.		○			○			○	○	○	
THE GAY SPREE IS ENDLESS.		○						○	○	○	
THE NEW SPRAG IS WOODEN.		○						○	○	○	
THE NEW SPRUCE IS GROWING.		○						○	○	○	
SHE MAY STREAK HER WIGLET.		○						○	○	○	
SHE MAY STRAP HER SUITCASE.		○						○	○	○	
JIM RAY STREWED THE GRASS SEED.		○						○	○	○	
SHE MAY SCREAM FOR HELP SOON.		○						○	○	○	
SHE MAY SCRAP HER CAR SOON.		○						○	○	○	
JIM RAY SCREWED THE CAP ON.		○						○	○	○	
TOTAL - - -	13	29	0	0	18	0	0	42	42	42	6

FIGURE IV-16. CONTINUED

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
	SS ACOUSTIC SEGMENT FEATURES										
HE MAY READ A NOVEL.	●							●		●	
HE MAY RAT ON CONVICTS.	●							●		●	
DON'T BE RUDE TO SALLY.	●							●		●	
HE DOES READ NEW NOVELS.	●							●		●	
HE DOES RAT ON CONVICTS.	●							●		●	
HE IS RUDE TO SALLY.	●							●		●	
HE DID READ A NOVEL.	●							●		●	
HE DID RAT ON CONVICTS.	●							●		●	
HE HAD RUDE THINGS TO SAY.	●							●		●	
SHE MAY PREEN ALL DAY LONG.		●						●		●	●
THE NEW PRAM IS LARGER.		●						●		●	●
SHE MAY PRUNE THE ARBOR.		●						●		●	●
SHE MAY BREED THE POODLE.	●							●		●	
SHE MAY BRAG ABOUT IT.	●							●		●	
SHE MAY BROOD ABOUT IT.	●							●		●	
THEY MAY TREAT THEM BADLY.		●			●			●		●	
THEY MAY TRAP THE PIGEON.		●			●			●		●	
THE NEW TROUP LEFT BOOT CAMP.		●			●			●		●	
SHE MAY DREAM ABOUT IT.	●							●		●	
SHE MAY DRAG THEM OUTSIDE.	●							●		●	
SHE MAY DROOP FROM HUNGER.	●							●		●	
IT MAY CREAK WHEN WINDY.		●						●		●	●
IT MAY CRACK WITH PRESSURE.		●						●		●	●

FIGURE IV-17. SS ACOUSTIC SEGMENT FEATURES AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE.

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
	SS ACOUSTIC SEGMENT FEATURES										
THE NEW CROUP IS CATCHING.		●						●		●	●
HE MAY GREET THE PEOPLE.	●							●		●	
HE MAY GRAB THE COOKIES.	●							●		●	
HE MAY GROUP THE CHILDREN.	●							●		●	
JIM RAY FREED HIS PARROT.		●			●			●		●	
THE NEW FRAT NEEDS MEMBERS.		●			●			●		●	
SHE MAY FRUG WITH MARTIN		●			●			●		●	
WE KNEW THREE SHORT STORIES.		●			●			●		●	
WE MAY THRASH THE HARVEST.		●			●			●		●	
MARIE THREW SHAWN'S BASEBALL.		●			●			●		●	
HE MAY SHRIEK AT SHELDON.		●			●			●		●	
HE'S TOO SHREWD TO WORRY.		●			●			●		●	
JIM RAY SHRANK HIS TROUSERS.		●			●			●		●	
THE GAY SPREE IS ENDLESS.	●							●		●	
THE NEW SPRAG IS WOODEN.	●							●		●	
THE NEW SPRUCE IS GROWING.	●							●		●	
SHE MAY STREAK HER WIGLET.	●							●		●	
SHE MAY STRAP HER SUITCASE.	●							●		●	
JIM RAY STREWED THE GRASS SEED.	●							●		●	
SHE MAY SCREAM FOR HELP SOON.	●							●		●	
SHE MAY SCRAP HER CAR SOON.	●							●		●	
JIM RAY SCREWED THE CAP ON.	●							●		●	
TOTAL - - -	27	18	0	0	12	0	0	45	0	45	6

FIGURE IV-17. CONTINUED.

TR 2
ACOUSTIC SEGMENT FEATURES

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
HE MAY READ A NOVEL.	●							○	○	○	
HE MAY RAT ON CONVICTS.	●							○	○	○	
DON'T BE RUDE TO SALLY.	●							○	○	○	
HE DOES READ NEW NOVELS.	●							○	○	○	
HE DOES RAT ON CONVICTS.	●							○	○	○	
HE IS RUDE TO SALLY.	●							○	○	○	
HE DID READ A NOVEL.	●							○	○	○	
HE DID RAT ON CONVICTS.	●							○	○	○	
HE HAD RUDE THINGS TO SAY.	●							○	○	○	
SHE MAY PREEN ALL DAY LONG.	●						○	○	○	○	
THE NEW PRAM IS LARGER.	●						○	○	○	○	
SHE MAY PRUNE THE ARBOR.	●						○	○	○	○	
SHE MAY BREED THE POODLE.	●							○	○	○	
SHE MAY BRAG ABOUT IT.	●							○	○	○	
SHE MAY BROOD ABOUT IT.	●							○	○	○	
THEY MAY TREAT THEM BADLY.	●							○	○	○	
THEY MAY TRAP THE PIGEON.	●							○	○	○	
THE NEW TROUP LEFT BOOT CAMP.	●							○	○	○	
SHE MAY DREAM ABOUT IT.	●						○	○	○	○	
SHE MAY DRAG THEM OUTSIDE.	●							○	○	○	
SHE MAY DROOP FROM HUNGER.	●							○	○	○	
IT MAY CREAK WHEN WINDY.	●							○	○	○	
IT MAY CRACK WITH PRESSURE.	●							○	○	○	

FIGURE IV-18. TR 2 ACOUSTIC SEGMENT FEATURES AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE.

TR 2

STIMULUS SENTENCES	VOICE	NOISE	TRANSIENT	OCCLUSIVE	FRICATIVE	LATERAL	NASAL	VOWEL-LIKE	TRANSITIONAL	RETROFLEXIVE	ASPIRATE
	ACOUSTIC SEGMENT FEATURES										
THE NEW CROUP IS CATCHING.	●							●	●	●	
HE MAY GREET THE PEOPLE.	●							●	●	●	
HE MAY GRAB THE COOKIES.	●							●	●	●	
HE MAY GROUP THE CHILDREN.	●							●	●	●	
JIM RAY FREED HIS PARROT.	●							●	●	●	
THE NEW FRAT NEEDS MEMBERS.	●							●	●	●	
SHE MAY FRUG WITH MARTIN.	●							●	●	●	
WE KNEW THREE SHORT STORIES.	●							●	●	●	
WE MAY THRASH THE HARVEST.	●							●	●	●	
MARIE THREW SHAWN'S BASEBALL.	●							●	●	●	
HE MAY SHRIEK AT SHELDON.	●							●	●	●	
HE'S TOO SHREWD TO WORRY.	●							●	●	●	
HIM RAY SHRANK HIS TROUSERS.	●							●	●	●	
THE GAY SPREE IS ENDLESS.	●							●	●	●	
THE NEW SPRAG IS WOODEN.	●							●	●	●	
THE NEW SPRUCE IS GROWING.	●							●	●	●	
SHE MAY STREAK HER WIGLET.	●							●	●	●	
SHE MAY STRAP HER SUITCASE.	●							●	●	●	
HIM RAY STREWED THE GRASS SEED.	●							●	●	●	
SHE MAY SCREAM FOR HELP SOON.	●						●	●	●	●	
SHE MAY SCRAP HER CAR SOON.	●							●	●	●	
JIM RAY SCREWED THE CAP ON.	●							●	●	●	
TOTAL - - -	45	0	0	0	0	5	45	45	45	0	

FIGURE IV-18. CONTINUED.

over co-articulation, particularly in the case of clustering. The data displayed in Figures IV-16, IV-17, and IV-18 show that the TR 1 and SS segments vary consistently, while the TR 2 segment is not influenced by carryover co-articulation effects. Specifically, TR 1 and SS segments were voiceless following voiceless consonants in two element word-initial clusters, while only the TR 1 segment was voiceless following voiceless consonants in the three element word-initial clusters, /spr, str, skr/.[44] The TR 1 and SS segments were either frictional or aspirate when preceded by stop plosives or fricatives in two element word-initial custers. All three prevocalic /r/ acoustic segments were always vowel-like and retroflexive regardless of phonetic context, while the two transitions, TR 1 and TR 2, as expected were observed to be transitional. The TR 2 segment never varied, except in the case of anticipatory nasality; that is, TR 2 was consistently described as having the features of voice, vowel-like, transitional, and retorflexive.

In summary, the acoustic segment features associated with TR 1, SS, and TR 2 segments of prevocalic /r/ were only minimally influenced by anticipatory co-articulation effects; specifically, in the case of anticipatory nasality visible in only the TR 2 segment. However, the TR 1 and SS segments were substantially influenced by carryover co-articulation effects when clustered, while TR 2 was observed to be stable. That is, TR 2 always had the features of voice, vowel-like, transitional, and retroflexive regardless of context.

FOOTNOTES--CHAPTER IV

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[33]Lehiste, p. 58.

[34]Dalston, p. 464.

[35]O'Connor, *et al*., p. 34.

[36]Lisker, "Minimal Cues for Separating /w, j, r, l/ in Intervocalic Position," p. 265.

[37]Lehiste, p. 58.

[38]Dalston, p. 464.

[39]*Ibid*.

[40]Lehiste, p. 58.

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[42]*Ibid*., p. 12.

[43]The TR 1 segments of /græ/ and /gru/ tokens were either voiceless throughout, or voiceless for at least one-half of their total durations.

[44]The TR 1 segment of the three element word-initial clusters was either voiceless throughout, or voiceless at its onset.

CHAPTER V

IMPLICATIONS

On the basis of the acoustic data base established for prevocalic /r/ in this investigation, there are several implications for further experimentation.

First, since the TR 2 segment of prevocalic /r/ was observed to be the most consistent segment in terms of duration measurements, frequency values, and acoustic segment features, it would be important to test the hypothesis that word-initial prevocalic /r/ could be identified by listeners from only the TR 2 segment in a synthesis experiment.

Second, since the TR 1 and SS segment of clustered prevocalic /r/ were observed to vary in duration measurements, frequency values, and acoustic segment features, it would be important to test the hypothesis that prevocalic /r/ cluster types in a synthesis experiment could be identified by listeners from only the three segments associated with prevocalic /r/ (TR 1, SS, TR 2). In such an experiment, duration measurements, frequency values, and acoustic feature types would be systematically varied in order to determine which acoustic aspects cause shifts in listeners' idenification of prevocalic /r/ cluster types.

Third, it would be important to conduct an electromyographic investigation of prevocalic /r/ production in word-initial cluster contexts, in order to establish the underlying muscle events of both the upper articulatory and the laryngeal mechanisms, since prevocalic /r/ acoustic segments varied over a large range in both of these dimensions due to the carryover and anticipatory co-articulatory influence of prevocalic /r/ type and vowel nucleus type.

Fourth, it would be important to gather acoustic data on childrens' emerging prevocalic /r/ articulation, in both word-initial and clustered contexts, for comparison with the adult data. If the tape recorded developmental utterances were also identified by listeners as correct or incorrect prevocalic /r/ productions, it would be possible to establish those aspects of the acoustic wave which are related to correct and incorrect prevocalic /r/ production. Furthermore, it would be possible to rank order the appearance of adult-like durational, frequency, and acoustic segment characteristics.

Fifth, it would be important to do an acoustic analysis of prevocalic /r/ production in both word-initial and word-initial clusters of adult speakers with disordered articulation, for comparison with the normal adult data, since prevocalic /r/ defects are one of the few articulation disorders observed in adult populations. Furthermore, since speech therapy usually produces gradual changes in target productions, it would be interesting to do an acoustic evaluation of emerging prevocalic /r/ approximations as they gradually change from disordered to correct, in order to rank order the appearance of various durational, spectral, and acoustic feature changes associated with correct productions.

APPENDIX A

STIMULUS WORDS

While every stimulus word for the complete study is presented in this appendix, only stimuli for prevocalic /r/, Type I, were analyzed in this dissertation.

Type I Stimulus Words for Prevocalic /r/, Transcribed as [r]

The stimulus words for prevocalic /r/, transcribed as [r] and represented by the sequences [rV], [CrV], and [CCrV], are presented in Table A-1. Most are common words. Those words that were less familiar were placed in sentences where context would help to establish their definitions. Subjects had no difficulty reading the sentences in a natural manner.

The stimuli generated would have been too numerous to handle if one had varied each of the permissible sequence types with every possible vowel of the General American Dialect. Therefore, the representative vowels /i/, /æ/, and /u/ were selected since they occupy extreme positions in the vowel triangle. All consonants that cluster with [r] in the contexts [CrV] and [CCrV] were used.

The contexts [rV], [CrV] and [CCrV] were located in monosyllabic closed syllable words of the CVC type. Most were terminated with a stop for the purpose of simplifying the segmentation process during spectrographic analysis. If a common word could not be found terminating with a single stop, a single nasal, or a nasal-stop cluster was

TABLE A-1

TYPE I STIMULUS WORDS FOR PREVOCALIC /r/, TRANSCRIBED AS [ɾ]

	[i]	[æ]	[u]
[rV]	read [rid]	rat [ræt]	rude [rud]
[CrV]			
[prV]	preen [prin]	pram [præm]	prune [prun]
[brV]	breed [brid]	brag [bræg]	brood [brud]
[trV]	treat [trit]	trap [træp]	troup [trup]
[drV]	dream [drim]	drag [dræg]	droop [drup]
[krV]	creak [krik]	crack [kræk]	croup [krup]
[grV]	greet [grit]	grab [græb]	group [grup]
[frV]	freed [frid]	frat [fræt]	frug [frug]
[θrV]	three [θri]	thrash [θræʃ]	threw [θru]
[ʃrV]	shriek [ʃrik]	shrank [ʃræŋk]	shrewd [ʃrud]
[CCrV]			
[sprV]	spree [spri]	sprag [spræg]	spruce [sprus]
[strV]	streak [strik]	strap [stræp]	strewed [strud]
[skrV]	scream [skrim]	scrap [skræp]	screwed [skrud]

substituted as in the words: preen, pram, prune, dream, shrank and and scream. The words thrash, spruce, three, threw and spree were exceptions. All thirty-nine of the cells generated were filled.

Type II Stimulus Words for Intervocalic /r/, Transcribed as [r]

The stimulus words for intervocalic /r/, transcribed as [r] and represented by the sequence [VrV], are all common words or familiar names. Vowels in the sequence [VrV] were again represented by /i/, /æ/ and /u/.

The intervocalic context [VrV] can only be filled by words of more than one syllable. The contexts [ɪrɪ], [æræ], and [uru] would have minimized co-articulatory influences and would have provided parallel structure for comparison with the prevocalic /r/ stimuli. Eerie, arable and Uruguay, while inadequate, provided the best possible fit for these cells.

Locating the actual syllable boundaries in these and subsequent words of more than one syllable was difficult. While it was simple to identify the vocalic nucleus of a syllable, identification of the exact boundaries of many syllables was problematic since one can not construct rules governing the production of releasing, arresting, or abutting function for English. Sometimes English syllable boundary division does follow etymology, but etymology is often violated and many unexpected divisions occur. Abercrombie noted the following examples of unusual syllable boundary locations that violate etymology: "There is a good deal of personal variation in this point, but the following examples of unexpected syllable division have been notes within words: war.drobe, teas.poon, hemis.phere, ea.chother, aw.kward, mi.stake, and between words: Extre.me Unction (from Catholics), a.t least, not a.t all, a.t home, thi.s afternoon, Sain.t Andrews."[1]

Brubaker, in a 1966 study of syllable structure, concluded that very few vowel-initiated syllables occur in polysyllabic words or in monosyllabic words placed in context. For example, tip on may be symbolized as [tɪp-pɔn] where the ligature indicates that the consonant is distributed to both syllables. Vowel-to-vowel boundaries are also frequently altered by consonant glide instrusions, as in safety is [sef-ti-jiz] or after all [æf-tɚ-rɔl].[2]

Since an exact rule system for determining syllable boundaries did not exist, the syllable boundaries of polysyllabic stimulus words were determined by the author on a perceptual basis following the system suggested by Brubaker: "In judging syllable boundaries, the author read the material aloud in a conversational manner attempting to locate the relative restriction which separated syllables. The phoneme attributable to the restriction was identified and assigned to the vowel with which it seemed associated. In general, it is more difficult to describe how one judged than to perform the judgment."[3]

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[1]David Abercrombie, Elements of General Phonetics (Chicago, Ill.: Aldine Publishing Company, 1967), p. 78.

[2]Robert S. Brubaker, "A Preliminary Study of Syllable Structure," The Pennsylvania Speech Annual; Journal of the Pennsylvania Speech Association, XXIII (September, 1966), pp. 18-20.

[3]Ibid., p. 18.

Consonant-consonant and vowel-consonant margins were decided with relative ease; vowel-vowel or consonant-vowel margins presented difficulty. Syllable boundaries were questionable in forty-five of the 230 stimulus words. The syllable boundaries thought most reasonable may be seen in the transcriptions of stimulus words found in Tables A-2 through A-5. The highly controversial vowel-vowel or consonant-vowel margins are shown as questionable by utilizing Brubaker's transcription convention where the double transcription with ligature is meant to indicate uncertainty concerning syllable boundary, and is intended to mean that the consonant might be disturbed to either or both syllables.[4] For example, the stimulus word <u>eerie</u> was transcribed [ˈɪɚ‿-ɾɪ] in order to indicate questionable syllable boundary. To emphasize the difficulty in making such syllable boundary decisions, it should be noted that one generally accepted source, Kenyon and Knott, avoid the difficulty of assigning syllable boundaries by simply not indicating them and transcribing a word such as <u>eerie</u> as [ˈɪrɪ].[5] While the system used for assigning syllable boundaries is controversial and may well be in error, the Kenyon and Knott alternative was not followed as it was felt that tentative syllable boundary assignment would help to illustrate the equivalence, or lack of equivalence, among stimuli. It is hoped that data analysis for stimuli Types II-V will assist in providing a solution for the syllable boundary dilemma.

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[4]<u>Ibid.</u>, p. 19.

[5]John Samuel Kenyon and Thomas Albert Knott, <u>A Pronouncing Dictionary of American English</u> (Springfield, Mass.: G. and C. Merriam Company, Publishers, 1953), p. 142.

The stimuli for intervocalic /r/, Type II, are presented in Table A-2.

TABLE A-2

TYPE II STIMULUS WORDS FOR INTERVOCALIC /r/, TRANSCRIBED AS [r]

	eerie*	arable*	Uruguay
	[ˈɪɚ-ɹɪ]	[ˈæɚ-ɹə-bl̩]	[ˈjʊɚ-ɹə-gwaɪ]

* The double transcription with ligature is meant to indicate uncertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllables.

<u>Type III Stimulus Words for Stressed Vocalic /r/, Transcribed [ɝ]</u>

The stimulus words for stressed vocalic /r/, transcribed as [ɝ] and represented by the phonetic sequencies [Cɚ], [ɜC], and [CɜC], are presented in Table A-3. It was not possible to fill every stimulus cell with common American English words. In order that as few cells as possible remain vacant, less familiar words were used and placed in context defining sentence; American English proper names were also used. Subjects had no difficulty reading the sentences in a natural manner. Nevertheless, two cells, [dɜp] and [gɜp], remained vacant.

The stimuli generaged would again have been an unreasonable number for analysis if every possible consonant had been represented in each of the phonetic contexts for [ɜ]. Therefore, it was decided that only the six American English stops, [p], [b], [t], [k], and [g], would be used. It was felt that these stops were sufficiently representative of the entire consonant set to demonstrate possible co-articulatory influences on [ɝ]. Furthermore, the use of

TABLE A-3

TYPE III STIMULUS WORDS FOR STRESSED VOCALIC /r/, TRANSCRIBED AS [ɝ]

		[Cɝ]	[ɝC]	[Cɝp]	[Cɝb]
Monosyllabic	[p]	purr [pɝ]	Earp [ɝp]		
Within syllable boundary					superb [su-pɝb]
Across syllable boundary				purpose [pɝ-pəs]	
Monosyllabic	[b]	burr [bɝ]	herb [ɝb]	burp [bɝp]	
Within syllable boundary					
Across syllable boundary					burberry* [bɝ-bɝ‿rɪ]
Monosyllabic	[t]				
Within syllable boundary		inter [ɪn-tɝ]	inert [ɪn-ɝt]		
Across syllable boundary				turpentine [ˈtɝ-pən-ˌtaɪn]	turban [ˈtɝ-bn̩]
Monosyllabic	[d]	Derr [dɝ]	erred [ɝd]		
Within syllable boundary					
Across syllable boundary					derby [dɝ-bɪ]
Monosyllabic	[k]	cur [kɝ]	irk [ɝk]		curb [kɝb]
Within syllable boundary					
Across syllable boundary				Kerpis [ˈkɝ-pɪs]	
Monosyllabic	[g]		erg [ɝg]		
Within syllable boundary		de rigueur [də-rɪ-gɝ]			
Across syllable boundary					Gerber [gɝ-bɚ]

* The double transcription with ligature is meant to indicate uncertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllable.

TABLE A-3 -- CONTINUED

TYPE III STIMULUS WORDS FOR STRESSED VOCALIC /r/, TRANSCRIBED AS [ɝ]

		[Cɝt]	[Cɝd]	[Cɝk]	[Cɝg]
Monosyllabic Within syllable boundary	[p]	pert [pɝt]	purred [pɝd]	perk [pɝk]	
Across syllable boundary	[p]				pergola [ˈpɝ-gə-lə]
Monosyllabic Within syllable boundary	[b]	Bert [bɝt]	bird [bɝd]	Burk [bɝk]	burg [bɝg]
Across syllable boundary	[b]				
Monosyllabic Within syllable boundary	[t]			Turk [tɝk]	
Across syllable boundary	[t]	turtle [ˈtɝ-tl̩]	interred [ɪn-ˈtɝd]		tergal [ˈtɝ-gl̩]
Monosyllabic Within syllable boundary	[d]	dirt [dɝt]		dirk [dɝk]	
Across syllable boundary	[d]		Durden [ˈdɝ-dn̩]		Durgan [ˈdɝ-gn̩]
Monosyllabic Within syllable boundary	[k]	curt [kɝt]	curd [kɝd]	Kirk [kɝk]	
Across syllable boundary	[k]				Kurgan [ˈkɝ-gn̩]
Monosyllabic Within syllable boundary	[g]	Gert [gɝt]			
Across syllable boundary	[g]		girdle [ˈgɝ-dl̩]	Gherkin [ˈgɝ-kɪn]	gurgle [ˈgɝ-gl̩]

stops offered an invaluable aid during segmentation of the spectrograms.

The ideal situation would have been to locate each of these contexts, [Cɝ] , [ɝC], and [CɝC] , within a monosyllabic word. When this was impossible, the context was then positioned within the stressed syllable boundaries of a word with more than one syllable, for example, superb [sʊ-ˈpɝb] . It was felt that this condition should influence [ɝ] in a fashion similar to that of the monosyllabic condition. However, it was frequently necessary to embed the context within a word of more than one syllable across the stressed syllable boundary, for example, purpose [ˈpɝ-pəs] . This condition might well have a different influence on [ɝ] than the preceding conditions. There were sufficient numbers of words in each of these three conditions (N^1 = 25, N^2 = 5, N^3 = 16) to allow for intra-group comparisons in order to determine the significance of such syllable boundary differences when the data are analyzed.

Type IV Stimulus Words for Unstressed Vocalic /r/, Transcribed as [ɚ]

The stimulus words for unstressed vocalic /r/, transcribed as [ɚ] and represented by the phonetic sequences [Cɚ] and [CɚC], are presented in Table A-4. All are common words or proper names. Those that were less familiar were placed in context-defining sentences. Subjects had no difficulty reading the sentences in a natural manner. Stops were again used to represent the entire consonant set to keep the number of stimuli generated at a reasonable number; to serve as an aid in segmentation; and to allow for parallel structure between words in which the stressed [ɝ] and unstressed [ɚ] contrasted, for example, Bert [bɝt] versus Robert [ˈrɑ-bɚt] .

All phonetic contexts for unstressed vocalic /r/ were embedded in words of more than one syllable since they only occur in unstressed syllables. However, all stimulus words did not offer parallel contexts, as some contexts occurred within the unstressed syllable boundaries, i.e., standard [ˈstæn-dɚd] and some occurred across one boundary of the unstressed syllable, i.e., pertains [pɚ-ˈtenz] . There were sufficient stimulus words in each of the conditions (N^1 = 13, N^2 = 29) to allow for intra group comparisons when the data are analyzed.

Type V Stimulus Words for Postvocalic /r/, Transcribed as [ɚ]

The stimulus words for postvocalic /r/, transcribed as [ɚ] and represented by the phonetic contexts [CVɚ] and [CVɚC] are presented in Table A-5. All are common words or familiar names. As for the stressed and unstressed vocalic /r/ contexts, stops were again used to represent all permissible initial consonants while only [t] and/or [d] were used to represent the permissible final consonant set. The use of stops limited the number of stimuli generated, allowed for parallel structure between the stimuli in this category and other /r/ categories, and served as an aid for segmentation. However, all permissible vowels were varied in each of the contexts, [CVɚ] and [CVɚC] , rather than limiting the vowels to [i] , [æ] and [u] as had been done for the prevocalic /r/ stimuli. The use of all permissible vowels greatly increased the total number of stimuli consequently encumbering the experiment and so deserves further justification.

In order to adequately examine postvocalic /r/, as it occurs in both the [CVɚ] and [CVɚC] contexts, it is essential to include those vowels which form the sequences frequently referred to as centering

TABLE A-4

TYPE IV STIMULUS WORDS FOR UNSTRESSED VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[Cɚ]	[Cɚp]	[Cɚb]	[Cɚt]	[Cɚd]	[Cɚk]	[Cɚg]
Within syllable boundary	[p]	copper* [ˈkap͜-pɚ]						
Across syllable boundary	[p]		perplex [pɚ-ˈplɛks]	superballs [ˈsu-pɚ-ˌbɔlz]	pertains [pɚ-ˈtaɪnz]	Purdue [pɚ-ˈdu]	percale [pɚ-ˈkel]	aspergum [ˈæs-pɚ-ˌgʌm]
Within syllable boundary	[b]	rubber* [ˈrʌb͜-bɚ]			Robert [ˈrɑ-bɚt]	cupboard [ˈkʌ-bɚd]		Ellsburg [ˈɛlz-bɚg]
Across syllable boundary	[b]		rubberplant* [ˈrʌb͜-bɚ-ˌplænt]	rubberball* [ˌrʌb͜-bɚ-ˈbɔl]			Abercrombies [ˌæ-bɚ-ˌkrɑm-biz]	
Within syllable boundary	[t]	matter* [ˈmæt͜-tɚ]				Mustard [ˈmʌs-tɚd]		
Across syllable boundary	[t]		enterprise [ˈɛn-tɚ-ˌtaɪnz]	interbred [ˌɪn-tɚ-ˈbrɛd]	entertains [ˌɛn-tɚ-ˈtaɪnz]		interconnect [ˌɪn-tɚ-kə-ˈnɛkt]	intergrade [ˌɪn-tɚ-ˈgred]
Within syllable boundary	[d]	ladder* [ˈlæd͜-dɚ]				standard [ˈstæn-dɚd]		
Across syllable boundary	[d]		powderpuff [ˈpau-dɚ-ˌpʌf]	underbid [ˌʌn-dɚ-ˈbɪd]	undertow [ˈʌn-dɚ-ˌto]		undercoat [ˈʌn-dɚ-ˌkot]	undergo [ˌʌn-dɚ-ˈgo]
Within syllable boundary	[k]	lacquer [ˈlæk͜-kɚ]				record [ˈrɛ-kɚd]		
Across syllable boundary	[k]		kerplunk [kɚ-ˈplʌŋk]	anchorbill [ˈæŋ-kɚ-ˌbɪl]	lockertop* [ˈlɑk͜-kɚ-ˌtɑp]		lockerkey* [ˈlɑk͜-kɚ-ˌkɪ]	soccergame* [ˈsɑk͜-kɚ-ˌgem]
Within syllable boundary	[g]	logger* [ˈlɑg͜-gɚ]				angered [ˈæŋ-gɚd]		
Across syllable boundary	[g]		fingerpaint [ˈfɪŋ-gɚ-ˌpent]	sugarbeet* [ˈʃʊg͜-gɚ-ˌbit]	braggert* [ˈbræg͜-gɚt]		fingercot [ˈfɪŋ-gɚ-ˌkɑt]	Luger-gun* [ˈlug͜-gɚ-ˌgʌn]

* The double transcription with ligature is meant to indicate undertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllables.

TABLE A-5

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS

		[p-ɚ]	[p-ɚt]	[p-ɚd]	[b-ɚ]	[b-ɚt]	[b-ɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɪɚ]	peer [piɚ]		peared [piɚd]	beer [biɚ]		beard [biɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɛɚ]	pair [pɛɚ]		pared [pɛɚd]	bear [bɛɚ]		bared [bɛɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɑɚ]	par [pɑɚ]	part [pɑɚt]	parred [pɑɚd]	bar [bɑɚ]	Bart [bɑɚt]	bard [bɑɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɔɚ]	pore [pɔɚ]	port [pɔɚt]	pored [pɔɚd]	bore [bɔɚ]		board [bɔɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ʊɚ]	poor [pʊɚ]		poured [pʊɚd]			
Monosyllabic Within syllable boundary Across syllable boundary	[iɚ]						

TABLE A-5 -- CONTINUED

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[p-ɚ]	[p-ɚt]	[p-ɚd]	[b-ɚ]	[b-ɚt]	[b-ɚd]
Monosyllabic Within syllable boundary	[eɚ]						
Across syllable boundary		payer* ['pe-jɚ]			Bayer* ['be-jɚ]		
Monosyllabic Within syllable boundary	[uɚ]						
Across syllable boundary							
Monosyllabic Within syllable boundary	[oɚ]						
Across syllable boundary					bow-er* ['bo-wɚ]		
Monosyllabic Within syllable boundary	[aɪɚ]	pyre [paɪɚ]					
Across syllable boundary					buyer* ['baɪ-jɚ]		
Monosyllabic Within syllable boundary	[aʊɚ]						
Across syllable boundary		power* ['paʊ-wɚ]		powered ['paʊ-wɚd]	bower* ['baʊ-wɚ]		
Monosyllabic Within syllable boundary	[ɔɪɚ]						
Across syllable boundary					Boyer* ['bɔɪ-jɚ]		

* The double transcription with ligature is meant to indicate uncertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllables

** May also be pronounced [duɚ] and [dʊɚ].

TABLE A-5 -- CONTINUED

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[t-ɚ]	[t-ɚt]	[t-ɚd]	[d-ɚ]	[d-ɚt]	[d-ɚd]
Monosyllabic Within syllable boundary	[ɪɚ]	tear [tɪɚ]		teared [tɪɚd]	deer [dɪɚ]		
Across syllable boundary							endeared [ɪn-dɪɚd]
Monosyllabic Within syllable boundary	[ɛɚ]	tear [tɛɚ]			dare [dɛɚ]		dared [dɛɚd]
Across syllable boundary							
Monosyllabic Within syllable boundary	[ɑɚ]	tar [tɑɚ]	tart [tɑɚt]	tarred [tɑɚd]		dart [dɑɚt]	
Across syllable boundary							
Monosyllabic Within syllable boundary	[ɔɚ]	tore [tɔɚ]	torte [tɔɚt]		door [dɔɚ]		
Across syllable boundary							adored [ə-dɔɚd]
Monosyllabic Within syllable boundary	[ʊɚ]	tour [tʊɚ]		toured [tʊɚd]			
Across syllable boundary					endure [ɪn-dʊɚ]		endured [ɪn-dʊɚd]
Monosyllabic Within syllable boundary	[iɚ]						
Across syllable boundary							

TABLE A-5 -- CONTINUED

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[t-ɚ]	[t-ɚt]	[t-ɚd]	[d-ɚ]	[d-ɚt]	[d-ɚd]
Monosyllabic Within syllable boundary	[eɚ]						
Across syllable boundary							
Monosyllabic Within syllable boundary	[uɚ]				do-er* [ˈdu-wɚ]		
Across syllable boundary							
Monosyllabic Within syllable boundary	[oɚ]						
Across syllable boundary							
Monosyllabic Within syllable boundary	[aɪɚ]	tire [taɪɚ]			dire [daɪɚ]		
Across syllable boundary				tired* [ˈtaɪ-jɚd]			
Monosyllabic Within syllable boundary	[aʊɚ]				dour** [daʊɚ]		
Across syllable boundary		tower* [ˈtaʊ-wɚ]		towered [ˈtaʊ-wɚd]			
Monosyllabic Within syllable boundary	[ɑɚ]						
Across syllable boundary							

* The double transcription with ligature is meant to indicate uncertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllables.

** May also be pronounced [duɚ] and [dʊɚ].

TABLE A-5 -- CONTINUED

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[k-ɚ]	[k-ɚt]	[k-ɚd]	[g-ɚ]	[g-ɚt]	[g-ɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɪɚ]				gear [gɪɚ]		geared [gɪɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɛɚ]	care [kɛɚ]		cared [illegible]			
Monosyllabic Within syllable boundary Across syllable boundary	[ɑɚ]	car [kɑɚ]	cart [kɑɚt]	card [kɑɚd]	gar [gɑɚ]		guard [gɑɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ɔɚ]	core [kɔɚ]	court [kɔɚt]	cored [kɔɚd]	gore [gɔɚ]		gourd [gɔɚd]
Monosyllabic Within syllable boundary Across syllable boundary	[ʊɚ]						
Monosyllabic Within syllable boundary Across syllable boundary	[iɚ]						

TABLE A-5 -- CONTINUED

TYPE V STIMULUS WORDS FOR POST VOCALIC /r/, TRANSCRIBED AS [ɚ]

		[k-ɚ]	[k-ɚt]	[k-ɚd]	[g-ɚ]	[g-ɚt]	[g-ɚd]
Monosyllabic	[eɚ]						
Within syllable boundary							
Across syllable boundary					gayer* [ˈge-jɚ]		
Monosyllabic	[uɚ]						
Within syllable boundary							
Across syllable boundary		coo-er* [ˈku-wɚ]					
Monosyllabic	[oɚ]						
Within syllable boundary							
Across syllable boundary							
Monosyllabic	[aɪɚ]						
Within syllable boundary							
Across syllable boundary							
Monosyllabic	[aʊɚ]						
Within syllable boundary							
Across syllable boundary		cower* [ˈkaʊ-wɚ]			coward [ˈkaʊ-wɚd]		
Monosyllabic	[ɔɪɚ]						
Within syllable boundary							
Across syllable boundary		coyer* [ˈkɔɪ-jɚ]					

* The double transcription with ligature is meant to indicate uncertainty concerning syllable boundary and is intended to mean that the consonant might be distributed to either or both syllables.

** May also be pronounced [dɯɚ] and [dʊɚ].

diphthongs: [ɪɚ], [ɛɚ], [ɑɚ], [ʊɚ], and [ɔɚ].[5] The centering diphthongs seem always to occur within the stressed syllable of a word with more than one syllable or in a monosyllabic word. Postvocalic /r/ is a subject of disagreement among phoneticians. Some prefer to transcribe the centering diphthongs as [ɪr], [ɛr], [ɑr], [ʊr] and [ɔr] and to reserve the unstressed vocalic symbol, [ɚ], for situations in which it is syllabic.[6] Postvocalic /r/ seems to be the most difficult member of the phoneme for people with defective /r/ articulation.[7] Postvocalic /r/ has also been eliminated from most previous acoustic study.[8] For all these reasons, it was felt imperative to maintain the complete vowel set in the centering diphthong context.

The stressed vowels [i, e, u and o] are followed only by unstressed syllabic /r/ as in <u>payer</u>. It is always transcribed as [ɚ] but the syllable boundary is questionable for it may be [pe-jɚ] and be a form of postvocalic /r/ even though clearly syllabic, or it may be [pe-ɚ] and be a true unstressed syllabic /r/. For this reason, the stressed vowel stimuli offered further data on syllable boundaries in vowel-vowel margins and offered interesting comparisons to the

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[5]The combination [oɚ] frequently replaces [ɔɚ] in many dialects. Thus, for examples, the stimuli <u>pore</u>, <u>bore</u>, <u>tore</u>, <u>door</u>, <u>core</u> and <u>gore</u> shown to occupy the [oɚ] cells in Table A-5 would actually occupy the [ɔɚ] cells. While it is quite possible for any stimulus word to shift its cell location due to a dialectal variation or mispronunciation, it is a likely possibility in this instance. Therefore, all stimulus words will have to be transcribed as they occur in the subjects' tape recordings in order to determine the absolute cell in which they belong.

[6]See Chapter I, pages

[7]See Chapter I, pages

[8]See Chapter I, pages

unstressed vocalic /r/ context stimuli, as in <u>copper</u> [kɑp-pɚ], and to the postvocalic centering dipthong stimuli, as in <u>pair</u> [pɛɚ].

Finally, the true dipthongs [aɪ, aʊ and ɔɪ] seem to permit postvocalic /r/ to follow either within the syllable or as an unstressed syllable; for example, tire [taɪɚ], [taɪ-ɚ] or [taɪ-jɚ]. Therefore, they also provided interesting contrasts.

APPENDIX B

STRESS LEVELS FOR PREVOCALIC /r/ STIMULUS WORDS

The intonational contour given to each stimulus sentence for prevocalic /r/ when read by the major and secondary subjects was determined by listening to the tape recorded sentences. The stress level of each prevocalic /r/ stimulus word is shown in Table B-1.

TABLE B-1

STRESS LEVELS FOR PREVOCALIC /r/ STIMULUS WORDS

	Stimulus Word	Principal Data Major Subject R.H. List 1	List 2	List 3	Comparison Data R.H.	R.T.	F.T.	D.H.
[rV]	may read	3	2	2	3	2	2	3
	may rat	3	3	3				
	be rude	2	3	3				
	does read	3	3	3				
	does rat	3	3	3	2	3	3	3
	is rude	3	3	3				
	did read	3	3	3				
	did rat	3	3	3				
	had rude	3	3	3	3	3	3	3
[prV]	may preen	3	3	3				
	new pram	3	2	3				
	may prune	3	3	3	3	3	2	3

TABLE B-1--Continued

	Stimulus Word	Principal Data Major Subject R.H. List 1	List 2	List 3	Comparison Data R.H.	R.T.	F.T.	D.H.
[brV]	may breed	3	3	3				
	may brag	3	3	3				
	may brood	3	3	3				
[trV]	may treat	3	3	3	3	3	3	3
	may trap	3	3	3				
	new troop	3	3	3				
[drV]	may dream	3	3	3				
	may drag	3	3	3	3	2	3	3
	may droop	2	3	3				
[krV]	may creak	3	3	3				
	may crack	3	3	3				
	new croup	3	3	3	3	3	3	3
[grV]	may greet	3	2	3				
	may grab	3	3	3				
	may group	3	3	3				
[frV]	Ray freed	2	3	2	2	3	2	2
	new frat	3	3	3				
	may frug	3	3	3				
[θrV]	new three	2	3	3				
	may thrash	3	3	3	3	3	2	3
	Marie threw	3	3	3				

TABLE B-1--Continued

	Stimulus Word	Principal Data Major Subject R.H. List 1	List 2	List 3	Comparison Data R.H.	R.T.	F.T.	D.H.
[ʃrV]	may shriek	3	3	3				
	Ray shrank	3	2	2				
	too shrewd	3	3	3	3	3	3	2
[sprV]	gay spree	2	2	2				
	new sprag	3	3	3				
	new spruce	3	3	3				
[strV]	may streak	3	3	3	3	3	3	3
	may strap	3	3	2				
	Ray strewed	3	2	2				
[skrV]	may scream	3	3	3				
	may scrap	3	3	3	3	3	3	3
	Ray screwed	3	2	2				

APPENDIX C

SENTENCES FOR STIMULUS AND FILLER WORDS, COMPLETE AND ABBREVIATED LISTS*

Type I Stimulus Words for Prevocalic /r/

[rV]

1. He may read a novel.
2. He may rat on convicts.
3. Don't be rude to Sally.

4. He does read new novels.
5. He does rat on convicts.
6. He is rude to Sally.

7. He did read a novel.
8. He did rat on convicts.
9. He had rude things to say.

[prV]

19. She may preen all day long.
20. The new pram is larger.
21. She may prune the arbor.

[brV]

22. She may breed her poodle.
23. She may brag about it.
24. She may brood about it.

[trV]

25. They may treat them badly.
26. They may trap the pigeon.
27. The new troup left boot camp.

Type I Filler Words for Prevocalic /l/

[lV]

55. He may lead the marchers.

56. Don't be lewd to Sally.

57. He does lead the marchers.

58. He is lewd to Sally.

59. He did lead the marchers.

60. He had lewd things to say.

[plV]

61. She may plead all day long.
62. She may plait her pigtails.
63. Birds may plume their feathers.

[blV]

64. He may bleed the sapling.
65. She may blab about it.
66. Jim Ray blued the laundry.

*The abbreviated list consists of those sentences which are underlined.

[drV]

28. She may dream about it.
29. She may drag them outside.
30. She may droop from hunger.

[krV]

31. It may creak when windy.
32. It may crack with pressure.
33. The new croup is catching.

[grV]

34. He may greet the people.
35. He may grab the cookies.
36. He may group the children.

[frV]

37. Jim Ray freed his parrot.
38. The new frat needs members.
39. She may frug with Martin.

[θrV]

40. We knew three short stories.
41. We may thrash the harvest.
42. Marie threw Shawn's baseball.

[ʃrV]

43. He may shriek at Sheldon.
44. He's too shrewd to worry.
45. Jim Ray shrank his trousers.

[sprV]

46. The gay spree is endless.
47. The new sprag is wooden.
48. The new spruce is growing.

[strV]

49. She may streak her wiglet.
50. She may strap her suitcase.
51. Jim Ray strewed the grass seed.

[skrV]

52. She may scream for help soon.
53. She may scrap her car soon.
54. Jim Ray screwed the cap on.

[klV]

67. He may cleat his track shoes.
68. He may clap with pleasure.
69. Jim Ray clued the actors.

[glV]

70. She may glean the wheatfield.
71. She may gladden mourners.
72. Jim Ray glued the pieces.

[flV]

73. The navy fleet moved out.
74. The new flat needs painting.
75. She may flute the piecrust.

[splV]

76. The man's spleen was damaged.
77. The new splat is wooden.

Type II Stimulus Words for Intervocalic /r/

[VrV]

10. We see eerie old ghosts.
11. We see arable land.
12. We see Uruguay's coast.

13. He sees eerie old ghosts.
14. He sees arable land.
15. He sees Uruguay's coast.

16. We viewed eerie old ghosts.
17. We viewed arable land.
18. We viewed Uruguay's coast.

Type II Filler Words for Intervocalic /l/

[VlV]

Type III Stimulus Words for Stressed Vocalic /r/

[Cɝ]

78. Puff's deep purr is soothing.
79. The drab burr is wilting.
80. They inter indigents.
81. Ronald Derr is twenty.
82. The black cur is barking.
83. That's "de rigueur" indeed.

84. Puff's deep purr got louder.
85. The drab burr can prick you.
86. They inter bodies there.
87. Ronald Derr became rich.
88. The black cur could bite you.
89. The "de rigueur" got him.

[ɝC]

90. Wyatt Earp is on now.
91. The ripe herb is bitter.
92. The matter's inert now.
93. The group erred twice over.
94. The sheep irk their master.
95. The first erg was measured.

[pɝC]

96. The purpose is novel.
97. The superb image paled.
98. Tabby purred in rhythm.
99. The pert image faded.
100. The perk of the pot stopped.
101. The pergola's trimmed now.

Type II Filler Words for the Vowel /i/

[Ci]

130. The drab bee is buzzing.
131. Ronald Dee is twenty.
132. The black key is missing.

133. The drab bee can sting you.
134. Ronald Dee became rich.
135. The black key could fit it.

[iC]

136. The baby can eat now.
137. Rip ekes out a living.

[piC]

138. The peak of the heat passed.

[bɝC]

102. To burp is impolite.
103. The burberry coat came.
104. Baby Bert is hungry.
105. The bird is a robin.
106. Mary Burk is her aunt.
107. The burg is abandoned.

[tɝC]

108. The turpentine ran out.
109. The turban is pretty.
110. The turtle is hungry.
111. They interred a body.
112. The Turk is a soldier.
113. The tergal tones were lost.

[dɝC]

114. The derby is cleaned now.
115. The dirt is from smoking.
116. Rebecca Durden left.
117. A dirk is for stabbing.
118. Nora Durgan's her friend.

[kɝC]

119. Marty Kerpis left town.
120. The curb is eroded.
121. The curt insult hurt John.
122. The curd is settled now.
123. The Kirk infant slept well.
124. Rita Kurgan bought pie.

[gɝC]

125. The Gerbers are leaving.
126. He saw Gert in London.
127. The girdle is laundered.
128. A gherkin's a pickle.
129. The gurgle's a baby's.

[biC]

139. To beep is impolite.
140. Mary Beaton vanished.
141. The bead is of amber.
142. Mary Beacon's her aunt.

[tiC]

143. The teak's from India.

[diC]

144. Nora Deagon's her friend.

[kiC]

145. Rita Keegan bought pie.

[giC]

Type IV Stimulus Words for Unstressed Vocalic /r/

[Cɚ]

146. The copper is tarnished.
147. The rubber is worn out.
148. The matter is settled.
149. The ladder is broken.
150. The lacquer is dry now.
151. The logger is hungry.

152. The copper can tarnish.
153. The rubber can wear out.
154. The matter could scare him.
155. The ladder can reach it.
156. The lacquer can dry now.
157. The logger can eat now.

[pɚC]

158. Mary perplexes Bob.
159. Superballs are playthings.
160. Envie pertains to that.
161. The Purdue student passed.
162. The percale is pure white.
163. The aspergum helped Jill.

[bɚC]

164. The rubber plant was tall.
165. The rubberball is green.
166. Give Robert a carrot.
167. The cupboard is empty.
168. It's Abercrombie's box.
169. The Ellsberg family left.

[tɚC]

170. The enterprise commenced.
171. The interbred plant won.
172. She entertains often.
173. The mustard is spicy.
174. The lines interconnect.
175. It's an intergrade stage.

Type IV Filler Words for the Vowel /I/

[Cɪ]

194. The copy is tarnished.

195. Tom Matty is seven.
196. The laddie is Scottish.
197. The lackey is foreign.

198. The copy can tarnish.

199. Tom Matty could scare him.
200. The laddie can help him.
201. The lackey can help him.

[pɪC]

202. The pique is pure white.

[bɪC]

203. Give Rabbit a carrot.

[tɪC]

[dɚC]

176. The powderpuff vanished.
177. They underbid the price.
178. The undertow was strong.
179. The standard was high.
180. The undercoat was grease.
181. Don't undergo those tests.

[dɪC]

[kɚC]

182. The kerplunk was frightening.
183. The anchorbill broke off.
184. His locker top is filled.
185. The record was broken.
186. Her locker key was lost.
187. The soccer game ended.

[kɪC]

204. The Kipling was famous.
205. Her locket top was gold.
206. The locket key was lost.

[gɚC]

188. The fingerpaint was dry.
189. The sugarbeet was picked.
190. The braggert is boring.
191. That angered Ina's aunt.
192. The fingercot was soiled.
193. The luger-gun is mine.

[gɪC]

<u>Type V Stimulus Words for Postvocalic /r/</u>

[pVɚ]

207. The peer paid her homage.
208. The pair took the payment.
209. The par could be lowered.
210. The pore could be open.
211. The poor can be helped now.
212. The pyre could burn quickly.
213. The power could falter.
214. The payer took credit.

[pVɚC]

216. They peered into the room.
217. They pared a red apple.
218. The part belongs to Sue.
219. They parred the first match.
220. The port takes twenty ships.
221. They pored over the books.
222. They poured a glass of gin.
223. They powered the engines.

<u>Type V Filler Words for the Vowels /i/ and /I/</u>

[pVɪ]

215. The payee took payment.

[bVɚ]

224. The beer tastes very good.
225. The bear paced back and forth.
226. The bar can not serve girls.
227. The bore put them to sleep.
228. The buyer paid his bill.
229. The bower can give joy.
230. The bow-er played his bass.
231. The boo-er called insults.
232. Boyer Park's a landmark.
234. Bayer pills are helpful.

[bVː]

233. Bowie Park's a race track.

[bVɚC]

235. The beard looks very good.
236. He bared his hairy chest.
237. Mary Bart is her mother.
238. The bard composed a song.
239. The board was made of pine.

[tVɚ]

240. The tear began to fall.
241. The tear began to rip.
242. The tar began to smell.
243. They tore both branches off.
244. The tour began at six.
245. The tire blew out today.
246. The tower burned last year.

[tVː]

[tVɚC]

247. His eyes teared from smoking.
248. The tart was filled with cream.
249. The torte was filled with cream.
250. They toured the old churchyard.
251. They tarred the old pavement.
252. The tired old man fainted.
253. He towered over Jill.

[dVɚ]

254. The deer began to fight.
255. The dare brought quick action.
256. The door began to close.
257. Please endure both members.
258. The dire blow was struck.
259. The dour banker faltered.
260. The do-er baked cookies.

[dVː]

261. Jane Dewey baked cookies.

[dVɚC]

262. He endeared them to me.
263. They dared to go away.
264. The dart hit the target.
265. He adored his mother.
266. They endured the burden.

[kVɚ] [kVɪ]

267. Her care became complex.
268. The car began to stop.
269. The core began to shrink.
270. Don't cower beneath it.
271. The coo-er dove flew out.
272. The coyer girl caught John.

[kVɚC]

273. He cared for baby Jane.
274. The cart began to stop.
275. The card was signed by them.
276. The court meets on Monday.
277. They cored the ripe apple.
278. The coward ran away.

[gVɚ] [gVɪ]

279. The gear began to stick.
280. The gar began to swim.
281. The gore gave width inside.
282. The gayer buffoon laughed.

[gVɚC]

283. They geared the motor up.
284. The guard caught the old thief.
285. The gourd was painted blue.

APPENDIX D

STIMULUS SENTENCES PRESENTED IN RANDOM ORDER, COMPLETE FORM

Practice

1 (P). Please be frank with Mother.

2 (P). The Boyer boys have grown.

3 (P). The army flank moved out.

Begin List

Calibrate

1 (177). They underbid the price.

2 (125). The Gerbers are leaving.

3 (-54). Jim Ray screwed the cap on.

4 (162). The percale is pure-white.

5 (117). A dirk is for stabbing.

6 (168). It's Abercrombie's box.

7 (169). The Ellsberg family left.

8 (201). The lackey can help him.

9 (-5). He does rat on convicts.

10 (137). Rip ekes out a living.

11 (170). The enterprise commenced.

12 (-26). They may trap the pigeon.

13 (-35). He may grab the cookies.

14 (228). The buyer paid his bill.

15 (261). Jane Dewey baked cookies.

16 (-92). The matter's inert now.

17 (188). The fingerpaint was dry.

18 (203). Give rabbit a carrot.

19 (272). The coyer girl caught John.

20 (128). A gherkin's a pickle.

21 (200). The laddie can help him.

22 (265). He adored his mother.

23 (-45). He's too shrewd to worry.

24 (-44). Jim Ray shrank his trousers.

25 (-89). The "de rigueur" got him.

26 (-17). We viewed arable land.

27 (212). The pyre could burn quickly.

28 (-64). He may bleed the sapling.

29 (-14). He sees arable land.

30 (275). The card was signed by them.

Calibrate

31 (-41). We may thrash the harvest.

32 (-88). The black cur did bite him.

33 (-7). He did read a novel.

34 (-15). He sees Uruguay's coast.

35 (154). The matter could scare him.

36 (124). Rita Kurgan bought pie.

37 (241). The tear began to rip.

38 (240). The tear began to fall.

39 (-25). They may treat them badly.

40 (186). Her locker key was lost.

41 (152). The copper can tarnish.

42 (227). The bore put them to sleep.

43 (202). The pique is pure-white.

44 (-50). She may strap her suitcase.

45 (153). The rubber can wear out.

46 (-98). Tabby purred in rhythm.

47 (235). The beard looks very good.

48 (-20). The new pram is larger.

49 (-49). She may streak her wiglet.

50 (-55). He may lead the marchers.

51 (257). Please endure both members.

52 (282). The gayer buffoon laughed.

53 (-65). She may blab about it.

54 (136). The baby can eat now.

55 (254). The deer began to fight.

56 (141). The bead is of amber.

57 (-67). He may cleat his track shoes.

58 (-9). He had rude things to say.

59 (-43). He may shriek at Sheldon.

60 (171). The interbred plant won.

Calibrate

61 (172). She entertains often.

62 (-57). He does lead the marchers.

63 (-16). We viewed eerie old ghosts.

64 (252). The tired old man fainted.

65 (263). They dared to go away.

66 (159). Superballs are playthings.

67 (-23). She may brag about it.

68 (-97). The superb image paled.

69 (269). The core began to shrink.

70 (167). The cupboard is empty.

71 (113). The tergal bones were lost.

72 (161). The Purdue student passed.

73 (271). The coo-er dove flew out.

74 (173). The mustard is spicy.

75 (226). The bar can not serve girls.

76 (224). The beer tastes very good.

77 (176). The powderpuff vanished.

78 (-81). Ronald Derr is twenty.

79 (-72). Jim Ray glued the pieces.

80 (190). The braggert is boring.

81 (187). The sockergame ended.

82 (-42). Marie threw Shawn's baseball.

83 (194). The copy is tarnished.

84 (193). The Luger-gun is mine.

85 (-39). She may frug with Martin.

86 (114). The derby is cleaned now.

87 (160). Envie pertains to that.

88 (-90). Wyatt Earp is on now.

89 (259). The dour banker faltered.

90 (-71). She may gladden mourners.

<u>Calibrate</u>

91 (183). The anchorbill broke off.

92 (131). Ronald Dee is twenty.

93 (-70). She may glean the wheatfield

94 (-91). The ripe herb is bitter.

95 (-34). He may greet the people.

96 (118). Nora Durgan's her friend.

97 (258). The dire blow was struck.

98 (123). The Kirk infant slept well.

99 (191). That angered Ina's aunt.

100 (276). The court meets on Monday.

101 (192). The fingercot was soiled.

102 (229). The bower can give joy.

103 (180). The undercoat was grease.

104 (-69). Jim Ray clued the actors.

105 (179). The standard was high.

106 (221). They pored over the books.

107 (-38). The new frat needs members.

108 (164). The rubberplant was tall.

109 (-12). We see Uruguay's coast.

110 (107). The burg is abandoned.

111 (151). The logger is hungry.

112 (-18). We viewed Uruguay's coast.

113 (119). Marty Kerpis left town.

114 (120). The curb is eroded.

115 (175). It's an intergrade stage.

116 (110). The turtle is hungry.

117 (-60). He had lewd things to say.

118 (150). The lacquer is dry now.

119 (101). The Pergola's trimmed now.

120 (-53). She may scrap her car soon.

Calibrate

121 (178). The undertow was strong.

122 (147). The rubber is worn out.

123 (-75). She may flute the piecrust.

124 (-59). He did lead the marchers.

125 (-46). The gay spree is endless.

126 (266). They endured the burden.

127 (189). The sugarbeet was picked.

128 (285). The gourd was painted blue.

129 (-47). The new sprag is wooden.

130 (-2). He may rat on convicts.

131 (182). The kerplunk was frightening.

132 (-61). She may plead all day long.

133 (270). Don't cower beneath it.

134 (-66). Jim Ray blued the laundry.

135 (106). Mary Burk is her aunt.

136 (-11). We see arable land.

137 (195). Tom Matty is seven.

138 (102). To burp is impolite.

139 (225). The bear paced back and forth.

140 (156). The lacquer can dry now.

141 (283). They geared the motor up.

142 (100). The perk of the pot stopped.

143 (-28). She may dream about it.

144 (-68). He may clap with pleasure.

145 (-63). Birds may plume their feathers.

146 (-82). The black cur is barking.

147 (-83). That's "de rigueur" indeed.

148 (253). He towered over Jill.

149 (149). The ladder is broken.

150 (236). He bared his hairy chest.

<u>Calibrate</u>

151 (260). The do-er baked cookies.

152 (242). The tar began to smell.

153 (-31). It may creak when windy.

154 (-30). She may droop from hunger.

155 (108). The turpentine ran out.

156 (-37). Jim Ray freed his parrot.

157 (-1). He may read a novel.

158 (-24). She may brood about it.

159 (-19). She may preen all day long.

160 (267). Her care became complex.

161 (157). The logger can eat now.

162 (-62). She may plat her pigtails.

163 (277). They cored the ripe apple.

164 (-32). It may crack with pressure.

165 (140). Mary Beaton vanished.

166 (145). Rita Keegan bought pie.

167 (246). The tower burned last year.

168 (214). The payer took credit.

169 (207). The peer payed her homage.

170 (121). The curt insult hurt John.

171 (279). The gear began to stick.

172 (209). The par could be lowered.

173 (-93). The group erred twice over.

174 (-40). We knew three short stories.

175 (135). The black key did fit it.

176 (-27). The new troup left boot camp.

177 (-87). Ronald Derr became rich.

178 (126). He saw Gert in London.

179 (-21). She may prune the arbor.

180 (222). They poured a glass of gin.

Calibrate

181 (138). The peak of the heat passed.

182 (213). The power could falter.

183 (255). The dare brought quick action.

184 (-10). We see eerie old ghosts.

185 (-22). She may breed her poodle.

186 (262). He endeared them to me.

187 (185). The record was broken.

188 (139). To beep is impolite.

189 (273). He cared for baby Jane.

190 (280). The gar began to swim.

191 (-77). The new splat is wooden.

192 (155). The ladder can reach it.

193 (274). The cart began to stop.

194 (196). The laddie is Scottish.

195 (132). The black key is missing.

196 (268). The car began to stop.

197 (-96). The purpose is novel.

198 (-73). The navy fleet moved out.

199 (250). They toured the old churchyard.

200 (122). The curd is settled now.

201 (158). Mary perplexes Bob.

202 (-29). She may drag them outside.

203 (251). They tarred the old pavement.

204 (-95). The first erg was measured.

205 (256). The door began to close.

206 (284). The guard caught the old thief.

207 (-33). The new croup is catching.

208 (-78). Puff's deep purr is soothing.

209 (166). Give Robert a carrot.

210 (197). The lackey is foreign.

<u>Calibrate</u>

211 (-84). Puff's deep purr got louder.

212 (174). The lines interconnect.

213 (181). Don't undergo those tests.

214 (112). The turk is a soldier.

215 (184). His lockertop is filled.

216 (-80). They inter indigents.

217 (-36). He may group the children.

218 (-94). The sheep irk their master.

219 (-86). They inter bodies there.

220 (237). May Bart is her mother.

221 (127). The girdle is laundered.

222 (116). Rebecca Durden left.

223 (-76). The man's spleen was damaged.

224 (-52). She may scream for help soon.

225 (148). The matter is settled.

226 (133). The drab bee did sting them.

227 (278). The coward ran away.

228 (-3). Don't be rude to Sally.

229 (198). The copy can tarnish.

230 (-8). He did rat on convicts.

231 (144). Nora Deagon's her friend.

232 (281). The gore gave width inside.

233 (204). The Kipling was famous.

234 (165). The rubberball is green.

235 (143). The teak's from India.

236 (216). They peered into the room.

237 (-6). He is rude to Sally.

238 (111). They interred a body.

239 (-51). Jim Ray strewed the grass seed.

240 (239). The board was made of pine.

Calibrate

241 (210). The pore could be open.

242 (115). The dirt is from smoking.

243 (233). Bowie Park's a race track.

244 (-13). He sees eerie old ghosts.

245 (220). The port takes twenty ships.

246 (109). The turban is pretty.

247 (-99). The pert image faded.

248 (211). The poor can be helped now.

249 (103). The burberry coat came.

250 (-48). The new spruce is growing.

251 (104). Baby Bert is hungry.

252 (238). The bard composed a song.

253 (134). Ronald Dee became rich.

254 (142). Mary Beacon's her aunt.

255 (219). They parred the first matches.

256 (218). The part belongs to Sue.

257 (105). The bird is a robin.

258 (-79). The drab burr is wilting.

259 (215). The payee took payment.

260 (249). The torte was filled with cream.

261 (248). The tart was filled with cream.

262 (247). His eyes teared from smoking.

263 (208). The pair took the payment.

264 (231). The boo-er called insults.

265 (163). The aspergum helped Jill.

266 (205). Her locket-top was gold.

267 (-56). Don't be lewd to Sally.

268 (243). They tore both branches off.

269 (264). The dart hit the target.

270 (230). The bow-er played his bass.

Calibrate

271 (232). Boyer Park's a landmark.

272 (-4). He does read new novels.

273 (130). The drab bee is buzzing.

274 (217). They pared a red apple.

275 (199). Tom Matty could scare him.

276 (129). The gurgle's a baby's.

277 (146). The copper is tarnished.

278 (206). Her locket-key was lost.

279 (245). The tire blew out today.

280 (234). Bayer pills are helpful.

281 (-85). The drab burr did prick them.

282 (244). The tour began at six.

283 (-74). The new flat needs painting.

284 (223). They powered the engine.

285 (-58). He is lewd to Sally.

<u>Calibrate</u>

APPENDIX I

STIMULUS SENTENCES PRESENTED IN RANDOM ORDER, ABBREVIATED FORM

Practice

1 (P). Please be frank with mother.

2 (P). The Boyer boys have grown.

3 (P). The army flank moved out.

Begin List

Calibrate

1 (177). They underbid the price.

2 (125). The Gerbers are leaving.

3 (117). A dirk is for stabbing.

4 (169). The Ellsberg family left.

5 (201). The lackey can help him.

6 (-5). He does rat on convicts.

7 (137). Rip ekes out a living.

8 (261). Jane Dewey baked cookies.

9 (265). He adored his mother.

10 (-45). He's too shrewd to worry.

11 (-89). The "de rigueur" got him.

12 (-17). We viewed arable land.

13 (-41). We may thrash the harvest.

14 (241). The tear began to rip.

15 (-25). They may treat them badly.

16 (153). The rubber can wear out.

17 (-49). She may streak her wiglet.

18 (257). Please endure both members.

19 (-65). She may blab about it.

20 (141). The bead is of amber.

Calibrate

21 (-9). He had rude things to say.

22 (-57). He does lead the marchers.

23 (-97). The superb image paled.

24 (269). The core began to shrink.

25 (113). The tergal bones were lost.

26 (161). The Purdue student passed.

27 (173). The mustard is spicy.

28 (-81). Ronald Derr is twenty.

29 (193). The Luger-gun is mine.

30 (229). The tower can give joy.

31 (-69). Jim Ray clued the actors.

32 (221). They poured over the books.

33 (101). The pergola's trimmed now.

34 (-53). She may scrap her car soon.

35 (189). The sugarbeet was picked.

36 (285). The gourd was painted blue.

37 (-61). She may plead all day long.

38 (225). The bear paced back and forth.

39 (253). He towered over Jill.

40 (149). The ladder is broken.

Calibrate

41 (-37). Jim Ray freed his parrot.

42 (-1). He may read a novel.

43 (157). The logger can eat now.

44 (277). They cored the ripe apple.

45 (145). Rita Keegan bought pie.

46 (121). The curt insult hurt John.

47 (209). The par could be lowered.

48 (-93). The group erred twice over.

49 (-21). She may prune the arbor.

50 (213). The power could falter.

51 (185). The record was broken.

52 (273). He cared for baby Jane.

53 (-77). The new splat is wooden.

54 (-73). The navy fleet moved out.

55 (-29). She may drag them outside.

56 (-33). The new croup is catching.

57 (197). The lackey is foreign.

58 (181). Don't undergo those tests.

59 (237). May Bart is her mother.

60 (133). The drab bee did sting them.

Calibrate

61 (281). The gore gave width inside.

62 (165). The rubberball is green.

63 (233). Bowie Park's a race track.

64 (-13). He sees eerie old ghosts.

65 (109). The turban is pretty.

66 (105). The bird is a Robin.

67 (249). The torte was filled with cream.

68 (205). Her locket-top was gold.

69 (217). They pared a red apple.

70 (129). The gurgle's a baby's.

71 (245). The tire blew out today.

72 (-85). The drab burr did prick them.

Calibrate

End List

APPENDIX F

SUBJECT BIOGRAPHIES

Major Subject

R.H.--Male; Caucasian; born in 1938; raised in Kendall, Wisconsin; holder of the Ph.D. degree in Speech Pathology and Audiology.

Secondary Subjects

R.T.--Male: Caucasian; born in 1930; raised in Princeton, Illinois; holder of the Ph.D. degree in Rhetoric and Public Address.

F.T.--Male; Caucasian; born in 1936; raised in Tomahawk, Wisconsin; holder of the Ph.D. degree in Rhetoric and Public Address.

D.H.--Male; Caucasian; born in 1943; raised in Coldwater, Michigan; currently enrolled in a Ph.D. program in Speech Pathology and Audiology.

APPENDIX G

SUBJECT INSTRUCTIONS AND RESPONSE FORM FOR DETERMINING TONGUE POSITION DURING /r/ ARTICULATION

The stimulus sentences that you read six weeks ago as part of an acoustic investigation contained at least four major allophonic variants of the General American phoneme /r/; prevocalic /r/ as in read; stressed vocalic /r/ as in purr; unstressed vocalic /r/ as in copper; and post-vocalic /r/ as in peer. Each of these /r/ variants may be produced with either of two articulatory maneuvers; tongue retroflexed or tongue bunched. A speaker may use one of these two alternative articulatory patterns exclusively or he may possibly alternate between the two depending on the /r/ allophone being produced and on its phonetic environment. It is said to be impossible to detect a difference between a retroflexed /r/ or a bunched /r/ solely by listening provided the speaker is using that variety typical of his usual articulatory pattern.[1]

It is important to establish the pattern of /r/ articulation used by each subject in order to accurately interpret the results of the acoustic analysis of /r/ in this investigation. Therefore, an explanation of how to evaluate your own tactile and kinesthetic feedback in order to determine whether your /r/ articulation is retro-

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[1]Charles Kenneth Thomas. An Introduction to the Phonetics of American English (Second Edition; New York: The Ronald Press Company, 1958), p. 87.

flexed or bunched follows.

Retroflexed Versus Bunched /r/ Articulation

Both retroflexed and bunched /r/ are produced with the lateral margins of the back portion of the tongue in firm contact with the upper molars just as in the articulation of / i /, the vowel in s*ee*. Please say */ i /* aloud in order to feel the tactile sensation produced by lateral tongue margin-upper molar contact. This contact provides the predominant feedback sensation associated with /r/ production. Since the same contact occurs during both retroflexed and bunched /r/ articulation, it will not contribute to your ability to separate the two. It is the action of the tongue tip that provides the less dominant kinesthetic feedback which will enable you to make this decision.

Please say *deep* aloud. Your tongue tip will have touched either your alveolar ridge, your palate or the back of your upper incisors. Now say *reap* while allowing your tongue tip to move only enough so that it is no longer in contact but still pointing up toward the same location that it touched when you pronounced *deep*. Say *deep-reap* aloud being careful that your tongue touches during *deep* and just misses the same location during *reap*. The tongue tip elevation sensation that you have just experienced while pronouncing the sequence *deep-reap* is the main kinesthetic sensation by which you can identify a retroflexed /r/. If it was difficult for you to keep your tongue tip up while you said *reap*, that is if your tongue tip tried to move to the floor of your mouth, you are probably typically an /r/ tongue buncher.

Please say goof aloud. You will feel that your tongue tip is lowered and possibly in contact with the floor of your mouth or the back of your lower incisors. Leave it there and say roof. Now say goof-roof being careful not to move your tongue tip at all. When the tongue tip is down, the central portion of the tongue blade rises up toward the hard palate in order to produce a bunched /r/. If the /r/ you made while pronouncing roof with your tongue tip down sounded strange, or if your tongue tip tried hard to rise, you are probably typically an /r/ tongue retroflexer[2].

Directions for Completing Form

Please practice both types of /r/ articulation, retroflexed in the deep-reap sequence and bunched in the goof-roof sequence, several times until you can identify the tactile and kinesthetic sensations associated with each. Then, read each of the following /r/ stimulus sentences aloud in your natural manner of articulation. The stimulus sentences are part of the random ordered Abbreviated Form Stimulus Sentences which you read during the data collection process. As you

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[2]This discussion is based primarily on the articulatory descriptions of /r/ found in Arthur Bronstein's, The Pronunciation of American English (New York: Appleton-Century-Crofts, Inc., 1960), p. 116; in Charles Kenneth Thomas's, An Introduction to The Phonetics of American English (Second Edition; New York: The Ronald Press Company, 1958), p. 87 and p. 94; in Claude Merton Wise's Applied Phonetics (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1957), pp. 119-120 and pp. 132-133; and in the author's clinical experience in teaching /r/ articulation.

read each sentence aloud, determine which articulatory pattern you are using during the underlined segment and check the appropriate column. Please use the UNCERTAIN column whenever you find that you cannot decide whether your tongue is retroflexed or bunched.

SUBJECT RESPONSE FORM

SENTENCE	RETRO-FLEXED	BUNCHED	UNCERTAIN
1 (1-177). They underbid the price.	___	___	___
2 (2-125). The Gerber's are leaving.	___	___	___
3 (5-117). A dirk is for stabbing.	___	___	___
4 (7-169). The Ellsberg family left.	___	___	___
5 (9- 5). He does rat on convicts.	___	___	___
6 (22-265). He adored his mother.	___	___	___
7 (23- 45). He's too shrewd to worry.	___	___	___
8 (25- 89). The "de rigueur" got him.	___	___	___
9 (26- 17). We viewed arable land.	___	___	___
10 (31- 41). We may thrash the harvest.	___	___	___
11 (37-241). The tear began to rip.	___	___	___
12 (39- 25). They may treat them badly.	___	___	___
13 (45-153). The rubber can wear out.	___	___	___
14 (49- 49). She may streak her wiglet.	___	___	___
15 (51-257). Please endure both members.	___	___	___
16 (58- 9). He had rude things to say.	___	___	___

SUBJECT RESPONSE FORM -- CONTINUED

SENTENCE	RETRO-FLEXED	BUNCHED	UNCERTAIN
17 (68- 97). The superb image paled.	___	___	___
18 (69-269). The core began to shrink.	___	___	___
19 (71-113). The tergal bones were lost.	___	___	___
20 (72-161). The Purdue student passed.	___	___	___
21 (74-173). The mustard is spicy.	___	___	___
22 (78- 81). Ronald Derr is twenty.	___	___	___
23 (84-193). The luger-gun is mine.	___	___	___
24 (102-229). The bower can give joy.	___	___	___
25 (106-221). They poured over the books.	___	___	___
26 (119-101). The Pergola's trimmed now.	___	___	___
27 (120- 53). She may scrap her car soon.	___	___	___
28 (127-189). The sugarbeet was picked.	___	___	___
29 (128-285). The gourd was painted blue.	___	___	___
30 (139-215). The bear paced back and forth.	___	___	___
31 (148-253). He towered over Jill.	___	___	___
32 (149-149). The ladder is broken.	___	___	___
33 (156- 37). Jim Ray freed his parrot.	___	___	___
34 (157- 1). He may read a novel.	___	___	___
35 (161-157). The logger can eat now.	___	___	___
36 (163-277). They cored the ripe apple.	___	___	___
37 (170-121). The curt insult hurt John.	___	___	___
38 (172-209). The par could be lowered.	___	___	___

SUBJECT RESPONSE FORM -- CONTINUED

SENTENCE	RETRO-FLEXED	BUNCHED	UNCERTAIN
39 (173- 93). The group erred twice over.	___	___	___
40 (179- 21). She may prune the arbor.	___	___	___
41 (182-213). The power could falter.	___	___	___
42 (187-185). The record was broken.	___	___	___
43 (189-273). He cared for baby Jane.	___	___	___
44 (202- 29). She may drag them outside.	___	___	___
45 (207- 33). The new croup is catching.	___	___	___
46 (213-181). Don't undergo those tests.	___	___	___
47 (220-237). May Bart is her mother.	___	___	___
48 (232-281). The gore gave width inside.	___	___	___
49 (234-165). The rubberball is green.	___	___	___
50 (244- 13). He sees eerie old ghosts.	___	___	___
51 (246-109). The turban is pretty.	___	___	___
52 (257-105). The bird is a Robin.	___	___	___
53 (260-249). The torte was filled with cream.	___	___	___
54 (274-217). They pared a red apple.	___	___	___
55 (276-129). The gurgle's a baby's.	___	___	___
56 (279-245). The tire blew out today.	___	___	___
57 (281- 85). The drab burr did prick them.	___	___	___

APPENDIX H

THE ARTICULATORY MANEUVERS FOR GENERAL AMERICAN /r/ AS PRODUCED BY THE MAJOR AND SECONDARY SUBJECTS

Each of four subjects (major subject, R.H., and secondary subjects, R.T., F.T., D.H.) in an experiment designed to discover the acoustic definitions of /r/ in the General American Dialect were given instructions and then asked to judge whether their /r/ articulation was retroflexed or bunched. The instructions and rating forms given each subject appear as Appendix H . Subjects' judgements are shown in Table H-1.

TABLE H-1
THE ARTICULATORY MANEUVERS FOR GENERAL AMERICAN /r/
AS PRODUCED BY THE MAJOR AND SECONDARY SUBJECTS

/r/ Type	Stimulus Word and Immediate Environment	Articulatory Maneuvers: Retroflexed(R) Bunched(B) Uncertain(U) — Subjects: R.H.	R.T.	F.T.	D.H.
Prevocalic /r/	may read	R	R	R	R
	does rat	R	R	B	R
	had rude	R	R	R	R
Unstressed vocalic /r/	prune	R	R	R	R
	treat	R	R	R	R
	drag	R	R	R	R
	croup	R	R	R	R
	freed	R	U	R	R
	thrash	R	R	R	R
	shrewd	R	R	R	B
	streak	R	R	R	R
	scrap	R	B	B	B
Intervocalic /r/	eerie	R	R	R	R
	arable	R	U	R	R
Stressed vocalic /r/	Derr	R	R	R	R
	burr did	R	R	R	B

TABLE H-1 -- CONTINUED

/r/ Type	Stimulus Word and Immediate Environment	Articulatory Maneuvers: Retroflexed(R) Bunched(B) Uncertain(U) — Subjects: R.H.	R.T.	F.T.	D.H.
	"de rigueur" got	R	R	B	R
	group erred	R	B	B	R
	superb	R	R	R	B
	pergola's	R	B	B	R
	bird	R	R	R	R
	turban	R	R	R	B
	tergal	R	R	R	R
	dirk	R	R	R	B
	curt	R	R	R	R
	Gerbers	R	R	B	B
	gurgles	R	R	R	B
Unstressed vocalic /r/	ladder is	R	R	R	B
	rubber can	R	R	B	B
	logger can	R	B	B	B
	Purdue	R	R	R	R
	rubberball	R	R	R	B
	Ellsburg	R	R	B	B
	mustard	R	R	R	B
	underbid	R	R	R	B
	undergo	R	R	R	U
	record	R	B	R	B
	sugarbeet	R	R	B	B
	luger-gun	R	R	R	B
Postvocalic /r/	par-could	R	B	B	B
	power could	R	R	R	R
	pared	R	U	R	B
	pored	R	B	R	R
	bear paced	R	B	R	U
	bower can	R	R	R	U
	Bart	R	B	R	R
	tear began	R	R	B	B
	tire blew	R	R	R	R
	torte	R	R	R	R
	towered	R	R	R	R
	endure both	R	R	B	R
	adored	R	R	R	R
	core began	R	B	R	B
	cared	R	B	R	B
	cored	R	B	R	R
	gore gave	R	B	B	B
	gourd	R	R	B	R

APPENDIX I

ANALYSIS OF VARIANCE TABLES FOR PREVOCALIC /r/ FREQUENCY DATA

Frequency values for the fundamental, first formant, second formant, and third formant were determined for the acoustic segments associated with prevocalic /r/ at each of five measurement locations: 1) TR 1 onset, 2) TR 1 offset, 3) SS mid-point, 4) TR 2 onset, and 5) TR 2 offset. Analysis of variance tables for these data as broken down by prevocalic /r/ type, and by vowel nucleus type are displayed in Tables I-1 through I-4.

TABLE I-1
MEAN FUNDAMENTAL FREQUENCY VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

TR 1 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	322731.09	16	20170.69	105.52	.001
Prevocalic /r/ Type	321186.44	14	22941.89	120.01	.001
Vowel Nucleus Type	2453.49	2	1226.75	6.42	.003
TWO-WAY INTERACTIONS	63277.84	28	2259.92	11.82	.001
Prevocalic /r/ Type with Vowel Nucleus Type	63277.84	28	2259.92	11.82	.001
RESIDUAL	16631.33	87	191.17		
TOTAL	402640.27	131	3073.69		

TR 1 OFFSET -- ANALYSIS OF VARIANCE

SOURCE VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	373791.12	16	23361.95	26.78	.001
Prevocalic /r/ Type	373524.46	14	26680.32	30.58	.001
Vowel Nucleus Type	472.88	2	236.44	.27	.999
TWO-WAY INTERACTIONS	32373.12	28	1156.18	1.33	.161
Prevocalic /r/ Type with Vowel Nucleus Type	32373.12	28	1156.18	1.33	.161
RESIDUAL	77652.00	89	872.49		
TOTAL	483816.24	133	3637.72		

TABLE I-1 CONTINUED

SS MID-POINT -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	527899.19	16	32993.70	135.43	.001
Prevocalic /r/ Type	526851.88	14	37632.28	154.47	.001
Vowel Nucleus Type	1047.30	2	523.65	2.15	.120
TWO-WAY INTERACTIONS	9991.59	28	356.84	1.47	.091
Prevocalic /r/ Type with Vowel Nucleus Type	9991.59	28	356.84	1.47	.091
RESIDUAL	21926.00	90	243.62		
TOTAL	559816.77	134	4177.74		

TR 2 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	42418.43	16	2651.15	10.44	.001
Prevocalic /r/ Type	41197.53	14	2942.68	11.59	.001
Vowel Nucleus Type	1220.90	2	610.45	2.41	.094
TWO-WAY INTERACTIONS	23165.76	28	827.35	3.26	.001
Prevocalic /r/ Type with Vowel Nucleus Type	23165.76	28	827.35	3.26	.001
RESIDUAL	22847.33	90	253.86		
TOTAL	88431.53	134	659.94		

TABLE I-1 CONTINUED

TR 2 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	22215.99	16	1388.50	6.58	.001
Prevocalic /r/ Type	13292.55	14	949.47	4.50	.001
Vowel Nucleus Type	8923.44	2	4461.72	21.14	.001
TWO-WAY INTERACTIONS	25775.90	28	920.57	4.36	.001
Prevocalic /r/ Type with Vowel Nucleus Type	25775.90	28	920.57	4.36	.001
RESIDUAL	18998.67	90	211.10		
TOTAL	66990.55	134	499.93		

TABLE I-2
MEAN FIRST FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPES
MEASUREMENTS GIVEN IN HERTZ

TR 1 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	3310702.11	16	206918.88	151.22	.001
Prevocalic /r/ Type	3298276.74	14	235591.20	172.17	.001
Vowel Nucleus Type	32481.56	2	16240.78	11.87	.001
TWO-WAY INTERACTIONS	565828.13	28	20208.15	14.77	.001
Prevocalic /r/ Type with Vowel Nucleus Type	565828.13	28	20208.15	14.77	.001
RESIDUAL	117680.67	86	1368.38		
TOTAL	3994210.90	130	30724.70		

TR 1 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	4277541.70	16	267346.36	44.00	.001
Prevocalic /r/ Type	4216927.59	14	301209.11	49.57	.001
Vowel Nucleus Type	59060.75	2	29530.37	4.86	.010
TWO-WAY INTERACTIONS	698427.38	28	24943.84	4.11	.001
Prevocalic /r/ Type with Vowel Nucleus Type	698427.38	28	24943.84	4.11	.001
RESIDUAL	538661.17	87	6076.57		
TOTAL	5504630.24	131	42020.08		

TABLE I-2 CONTINUED

SS MID-POINT -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARES	F	SIGNIFICANCE OF F
MAIN EFFECTS	4882142.44	16	305133.90	112.60	.001
Prevocalic /r/ Type	4739074.71	14	338505.34	124.91	.001
Vowel Nucleus Type	143067.73	2	71533.88	26.40	.001
TWO-WAY INTERACTIONS	286348.49	28	10226.73	3.77	.001
Prevocalic /r/ Type with Vowel Nucleus Type	286348.49	28	10226.73	3.77	.001
RESIDUAL	243900.67	90	2710.01		
TOTAL	5412391.60	134	40390.98		

TR 2 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	314368.52	16	19648.03	9.90	.001
Prevocalic /r/ Type	45052.59	14	3218.04	1.62	.088
Vowel Nucleus Type	269315.93	2	134657.96	67.84	.001
TWO-WAY INTERACTIONS	65214.30	28	2329.08	1.17	.280
Prevocalic /r/ Type with Vowel Nucleus Type	65214.30	28	2329.08	1.17	.280
RESIDUAL	178651.33	90	1985.02		
TOTAL	558234.15	134	4165.93		

TABLE I-2 CONTINUED

TR 2 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	1138164.96	16	71135.31	35.07	.001
Prevocalic /r/ Type	67110.19	14	4793.59	2.36	.008
Vowel Nucleus Type	1071054.77	2	535527.39	264.01	.001
TWO-WAY INTERACTIONS	103831.01	28	3708.25	1.83	.017
Prevocalic /r/ Type with Vowel Nucleus Type	103831.01	28	3708.25	1.83	.017
RESIDUAL	182558.00	90	2028.43		
TOTAL	1424553.97	134	10631.00		

TABLE I-3
MEAN SECOND FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

TR 1 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	28596443.01	16	1787277.69	92.92	.001
Prevocalic /r/ Type	28059360.31	14	2004240.02	104.20	.001
Vowel Nucleus Type	634249.83	2	317124.92	16.49	.001
TWO-WAY INTERACTIONS	*	*	*	*	*
Prevocalic /r/ Type with Vowel Nucleus Type	*	*	*	*	*
RESIDUAL	1750337.90	91	19234.48		
TOTAL	30346780.92	107	283614.78		

TR 1 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	18782499.27	16	1173906.20	100.58	.001
Prevocalic /r/ Type	18523918.41	14	1324565.60	113.49	.001
Vowel Nucleus Type	204036.63	2	102018.32	8.74	.001
TWO-WAY INTERACTIONS	598878.37	27	22180.68	1.90	.014
Prevocalic /r/ Type with Vowel Nucleus Type	598878.37	27	22180.68	1.90	.014
RESIDUAL	968707.17	83	11671.17		
TOTAL	20350084.80	126	161508.61		

TABLE I-3 CONTINUED

SS MID-POINT -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	3357960.89	16	209872.56	38.13	.001
Prevocalic /r/ Type	3116195.25	14	222585.38	40.43	.001
Vowel Nucleus Type	262359.86	2	131179.93	23.83	.001
TWO-WAY INTERACTIONS	552956.15	28	19748.43	3.59	.001
Prevocalic /r/ Type with Vowel Nucleus Type	552956.15	28	19748.43	3.59	.001
RESIDUAL	462406.83	84	5504.84		
TOTAL	4373323.88	128	34166.59		

TR 2 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	3318625.10	16	207414.07	29.68	.001
Prevocalic /r/ Type	2303053.66	14	164503.83	23.54	.001
Vowel Nucleus Type	1029805.32	2	514902.66	73.69	.001
TWO-WAY INTERACTIONS	841493.39	28	30053.34	4.30	.001
Prevocalic /r/ Type with Vowel Nucleus Type	841493.39	28	30053.34	4.30	.001
RESIDUAL	621881.17	89	6987.43		
TOTAL	4781999.65	133	35954.89		

TABLE I-3 CONTINUED

TR 2 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	16918645.88	16	1057415.37	70.58	.001
Prevocalic /r/ Type	893189.69	14	63799.26	4.26	.001
Vowel Nuelcus Type	16042435.81	2	8021217.91	535.42	.001
TWO-WAY INTERACTIONS	975865.46	28	34852.34	2.33	.002
Prevocalic /r/ Type with Vowel Nucleus Type	975865.46	28	34852.34	2.33	.002
RESIDUAL	1333326.00	89	14981.19		
TOTAL	19227836.34	133	144570.21		

* The two-way interactions were not calculated since the inversion of the cross-product matrix failed. This failure was the result of missing values in the F_2 data at the TR 1 onset reaching a level of twenty percent. It was a purely mathematical failure which resulted from the analysis of variance program formant utilized in the Statistical Package for the Social Sciences. The two-way interactions could have been obtained if a different analysis of variance computer program was utilized. However, the two-way interactions in all other analyses of variance for prevocalic /r/ frequency data were statistically significant when the main effects were statistically significant at the .001 level of confidence. Since the main effects in this case were statistically significant at the .001 level, it was assumed that the two-way interaction between prevocalic /r/ type and vowel nucleus type would also have been significant and an additional analysis of variance was not undertaken.

TABLE I-4
MEAN THIRD FORMANT VALUES FOR PREVOCALIC /r/ AS BROKEN DOWN BY PREVOCALIC /r/ TYPE AND BY VOWEL NUCLEUS TYPE
MEASUREMENTS GIVEN IN HERTZ

TR 1 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	44786115.41	14	3199008.24	238.33	.001
Prevocalic /r/ Type	44477407.61	12	3706450.63	276.13	.001
Vowel Nucleus Type	300985.66	2	150492.83	11.21	.001
TWO-WAY INTERACTIONS	584788.12	22	26581.28	1.98	.022
Prevocalic /r/ Type with Vowel Nucleus Type	584788.12	22	26581.28	1.98	.022
RESIDUAL	697982.82	52	13422.75		
TOTAL	46068886.36	88	523510.07		

TR 1 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	33712163.01	14	2408011.64	137.28	.001
Prevocalic /r/ Type	33227700.39	12	2768975.03	157.85	.001
Vowel Nucleus Type	372453.40	2	186226.70	10.62	.001
TWO-WAY INTERACTIONS	525021.80	23	22827.04	1.30	.212
Prevocalic /r/ Type with Vowel Nucleus Type	525021.80	23	22827.04	1.30	.212
RESIDUAL	929698.33	53	17541.48		
TOTAL	35166883.14	90	390743.15		

TABLE I-4 CONTINUED

SS MID-POINT -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	4195071.89	16	262191.99	18.64	.001
Prevocalic /r/ Type	3610303.77	14	257878.84	18.33	.001
Vowel Nucleus Type	332582.75	2	166291.37	11.82	.001
TWO-WAY INTERACTIONS	*	*	*	*	*
Prevocalic /r/ Type with Vowel Nucleus Type	*	*	*	*	*
RESIDUAL	914260.37	65	14065.54		
TOTAL	5109332.26	81	63078.18		

TR 2 ONSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	2629099.24	16	164318.70	3.21	.001
Prevocalic /r/ Type	1627814.66	14	116272.48	2.27	.013
Vowel Nucleus Type	837337.40	2	418668.70	8.18	.001
TWO-WAY INTERACTIONS	1264930.33	26	48651.17	.95	.999
Prevocalic /r/ Type with Vowel Nucleus Type	1264930.33	26	48651.17	.95	.999
RESIDUAL	3584556.17	70	51207.95		
TOTAL	7478585.74	112	66773.09		

TABLE I-4 CONTINUED

TR 2 OFFSET -- ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIFICANCE OF F
MAIN EFFECTS	3114554.34	16	194659.65	8.60	.001
Prevocalic /r/ Type	855379.91	14	61098.57	2.70	.002
Vowel Nucleus Type	2190423.78	2	1095211.89	48.39	.001
TWO-WAY INTERACTIONS	*	*	*	*	*
Prevocalic /r/ Type with Vowel Nucleus Type	*	*	*	*	*
RESIDUAL	2376304.55	105	22631.47		
TOTAL	5490858.89	121	45379.00		

* The two way-interactions were not calculated since the inversion of the cross-product matrix failed. This failure was the result of missing values in the F_3 data at the SS mid-point reaching a level of 39 percent. It was a purely mathematical failure which resulted from the analysis of variance program format utilized in the _Statistical Package for the Social Sciences_. The two-way interactions could have been obtained if a different analysis of variance computer program was utilized. However, the two-way interactions in all other analyses of variance for prevocalic /r/ frequency data were statistically significant when the main effects were statistically significant at the .001 level of confidence. Since the main effects in this case were statistically significant at the .001 level, it was assumed that the two-way interaction between prevocalic /r/ type and vowel nucleus type would also have been significant and an additional analysis of variance was not undertaken.

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