THE EFFECT OF DISTANCE OF ARTICULATOR TRAVEL ON THE DURATION OF VOWELS IN CVC SEQUENCES

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IN CVC SEQUENCES

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PREFACE

Vowel durations were studied in the contexts of various amounts of articulatory travel required in movement from the initial to the final consonant in a CVC sequence. Vowel durations were found to differ significantly as the amount of articulatory travel changed. Vowel durations from minimal and maximal distance groups were not significantly different from one another. However, a significant difference was found between the durations of the vowels in the moderate distance group when compared to either of the other groups.

Further investigation is needed in order to completely understand these findings. Recommendations regarding further study are included in the body of the paper.

I wish to express my sincere gratitude to all the people who assisted me in this study and encouraged me throughout my education at Oklahoma State University. I would especially like to express my appreciation to my thesis adviser, Dr. Arthur L. Pentz, Jr., for the many hours spent helping to accomplish this endeavor.

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CHAPTER I

INTRODUCTION

All vowel sounds share some common characteristics which distinguish them from the consonants. They are all voiced and require a relatively unconstricted vocal tract. They also have relatively long durations with respect to consonants and are more intense in sound amplitude level. Vowels also have high spectral energy regions, called formants, which are not found in consonants. These acoustic dimensions help to provide the human auditory processing system with a means of distinguishing the vowel sounds from the consonant sounds in connected speech.

Frequency of Formants and Formant Configuration

Many characteristics of individual vowels help a listener discriminate one vowel from another. The primary acoustic dimension helpful in the distinction among vowels is the pattern of formant frequencies (Minifie, Hixon, and Williams, 1973). Formants are energy regions unique to vowels and semi-vowels and are produced by the changing shape of the vocal tract. Vowels are produced by passing a voiced air stream through a variable two chambered (Helmholtz) resonator. Changing the size of and shape of the chambers alters the vocal tract's resonant properties and results in a unique pattern for each vowel.

Tongue height (Howell, 1981), front-back position (Howel, 1981), lip rounding (Dew and Jensen, 1977), and retroflexion (Dew and Jensen, 1977) all contribute to the changing resonance patterns.

Formant frequencies and configurations, while very important, do not always provide sufficient information for listener identification of vowels (Borden and Harris, 1984). When this information is not enough to distinguish among the vowels, the listener must rely on such secondary cues as fundamental frequency, vowel intensity, formant band-width, formant transitions, and duration to help distinguish one vowel from another.

Fundamental Frequency

All voiced sounds are complex. The vibration of the vocal folds provides a sound source which consists of a fundamental frequency and multiples of that frequency (Borden and Harris, 1984). The fundamental frequency is the rate of oscillation of the lowest frequency component of a complex tone. Fundamental frequencies are related to length, mass, and tension of the vocal folds. Thus, two individuals with vocal folds of the same length and thickness will have similar fundamental frequencies during relaxed phonation.

Each individual speaker varies the length and tension of the vocal folds in order to produce the differing pitch patterns necessary for connected speech. These changes along with the changes in articulatory positioning of the tongue, cause differences in the fundamental frequencies of the various vowels. The multiples of the fundamental frequency are produced when the vocal folds simultaneously vibrate vertically and horizontally.

Intensity

Intensity is the overall sound pressure level of a vowel (Zemlin, 1968) which differs as the shape of the vocal tract changes. Fairbanks, House, and Stevens (1950) concluded that the openness of the anterior diameters of the vocal tract seem closely related to the intensity of vowels. A larger mouth opening was reflected by an increased intensity of the vowel. Although all the common American vowels were found to differ from one another in mean relative intensity, consonant context appeared to equally influence the relative intensity of the various vowels. House, and Fairbanks (1953) also found the relative power of the syllable nuclei to be greater when uttered in the context of voiced consonants (in initial and final positions) than when spoken in the context of voiceless consonants.

Formant Bandwidth

Formant bandwidths can also provide some acoustic information about specific vowels. While the formant represents the energy region (resonance frequency) caused by the resonance characteristics of the oral cavity (Minifie, et al., 1973) the formant bandwidth is the range (width) of the frequencies which span the entire formant. A resonating chamber which amplifies a wide range of frequencies will have a wider formant bandwidth than that of a chamber with a narrow range of frequencies resonated. The bandwidths of formants increase as formant frequencies progress from the first, to the second, to the third (Dunn, 1961). Although formant bandwidths seem to act as secondary acoustic cues in the identification of vowels, the exact relationship between vowel recognition and formant bandwidths has not been well defined.

Formant Transitions

Formant transitions also provide acoustical information helpful in the discrimination of vowels. These transitions are the shift in acoustic energy that occurs when the articulators move from a consonant to a vowel or from a vowel to a consonant. They provide extra information about vowels which Howell (1981) speculates might account for the better identification of vowels in consonant context.

Duration

Vowel duration is the length of time in milliseconds that it takes to produce the vowel and its accompanying transitions. Several investigators have studied the differences in duration of the various vowels. House (1961), House and Fairbanks (1953), and Black (1949) reported that individual vowels have inherent durations that make them different from one another.

CHAPTER II

REVIEW OF LITERATURE

One factor which affects vowel duration is the tenseness or laxness of a vowel. Tense vowels are vowels that require a higher degree of muscular tension when compared to other vowels that have the same place and degree of constriction. The vowels which are classified as "tense vowels" are longer in duration than those classified as "lax" vowels (Borden and Harris, 1984). Therefore, the lax vowels /I, ɛ, ʌ, and ʊ/ are shorter than the tense vowels /i, e, æ, a, ɔ, o, and u/.

Vowel duration also appears to be affected by the place and degree of constriction of a vowel (House, 1961; House and Fairbanks, 1953; and Black, 1949). As the degree of constriction of a vowel increases, the duration of the vowel decreases and as the height of the placement of the vowel is increased, the duration of the vowel is decreased. Thus, the vowels produced with a more open vocal tract will be longer than those with a constricted vocal tract.

Linguistic Aspects of Duration

Syntax

Various researchers have indicated that the duration of vowels also appears to be related to syntactic factors (Klatt, 1976; Klatt, 1975; Lindblom and Rapp, 1973; and Martin, 1970). Syllables at the end of utterances are longer than they would be within an utterance (Klatt, 1975 and 1976; Lindblom and Rapp, 1973; and Martin, 1970), and word final syllable nuclei are longer in duration than nuclei in other word positions (Klatt, 1975, and Oller, 1973).

This "pre-pausal lengthening" not only occurs at the end of an utterance but also is present at clause and phrase boundaries (Klatt, 1975; Lindblom and Rapp, 1973; Klatt, 1971; and Martin, 1970). Klatt (1975) also indicated lengthening to be present at the end of noun phrases and at the end of conjoined or embedded clauses. It is speculated that the speaker lengthens syllables at the ends of phrase boundaries to help the listener decode the message, or perhaps, there is a natural tendency for the speaker to slow down at the ends of motor sequences or planning units (Klatt, 1976).

Semantics

The meanings of words influence the duration of syllable nuclei. Umeda (1975), indicated that the "information load" that a word carries is an important factor affecting the length of vowels in connected speech. Semantic use of emphasis and stress also seem to prolong the duration of syllable nuclei (Leiberman, 1967 and Bolinger, 1972). This stressing factor may result in an increase in duration of 20 percent or more (Coker, Umeda, and Browman, 1973). Umeda (1975) also reported that "semantic novelty" has an influence on segmental duration. For example an unfamiliar word was found to be longer in duration the first time that it appeared in connected discourse than when it appeared subsequently (Umeda, 1975).

Prosody

Prosody is the use of rhythm and tonal patterns in the production of speech. Rhythm involves duration of syllables and pauses. Changes in rhythm occur as the duration of syllables and pauses differ. When the rhythm of speech is slow, the vowel durations increase. Allen (1975) states that durational aspects differ as a result of changing stress patterns. Therefore, English speakers tend to produce alternating patterns of stressed (long) and unstressed (short) syllables (Allen, 1975).

Phonetic Factors

Approximately 50 percent of the durational changes in English discourse are a function of segment type (Klatt, 1975). Each vowel phoneme has a set of phonological duration. When the vowels were studied in the same consonant context, the vowels /I, ɛ, \, and /ʊ/ were found to be shorter than the other English vowels /i, e, æ, a, ɔ, o, u,/ (Peterson and LeHiste, 1960).

Consonant Context

Vowels and consonants are considered by some to be independent productions (Perkell, 1969 and Ohman, 1965). However, many investigators report that the production characteristics of vowels and consonants influence one another. Sanders (1977) reported that various consonant environments will affect vowels differently. Some investigators (Borden and Harris, 1984; DiSimoni, 1972; and Ladefoged and Broadbent, 1957) reported that changes in vowel duration occur as a result of the consonantal environment in which they are produced. Vowels before continuents are longer in duration than those preceding stops (Peterson and LeHiste, 1960), and vowel durations are longer before voiced consonants than before voiceless consonants (Krause, 1982; House, 1961; and Peterson and LeHiste, 1960).

Delattre (1962) reported that vowel durations are decreased in anticipation of a greater articulatory effort following the vowel. He interpreted greater articulatory effort to be involved in the production of consonant blends and stops because they require more closure (Delattre, 1962).

Purpose

Vowel duration appears to be an important secondary cue in vowel discrimination and is influenced by numerous factors including consonant environment. However, there is little information about whether vowel duration is affected in a systematic way by the place of production of the consonants in an utterance (House and Fairbanks, 1953). No evidence was found regarding the effects of the magnitude of adjustment required by the articulators in the production of CVC sequences upon vowel duration.

It is uncertain whether the duration of the syllable nucleus will be longer, shorter, or unchanged as the place of constriction changes. It could be assumed that more articulatory effort is needed to produce a CVC syllable in which the consonants vary than a syllable in which the consonants remain the same. If this assumption is true, one might conclude that the vowel would be shorter in the context of a CVC syllable in which the consonants vary.

One might also speculate that a CVC combination which requires movement of the consonant constriction from the anterior to the posterior of the articulatory mechanism, will result in a longer duration intermediate sound (because of the further distance) than would a CVC combination which requires very little constriction change. If this assumption is true, vowel duration would be expected to be longer as the distance between places of constriction is increased. Unfortunately, no investigations were found that attempted to demonstrate such a relationship.

Vowel duration has been studied as syllable nuclei are produced in isolation, in various linguistic contexts, and in various consonant contexts. However, no information was found that describes the duration of vowels in CVC words with varying articulator travel from the initial to the final consonant place of constriction.

For instance, it is not known whether an /ʌ/ vowel produced in a CVC syllable will be longer in the context of same consonants or in the context of differing vowels. It is uncertain whether a /pʌp/ CVC combination will contain a vowel of shorter duration than a /pʌk/ CVC combination. The primary vowel articulator, the tongue, must make greater adjustments in moving from /p/ to /k/ than it does when making minimal adjustments for production of the vowel in the context of initial and final /p/ sounds.

It would seem that greater articulatory adjustments would correlate with longer vowel durations, However, no investigators were found that reported on this issue.

Therapeutically, CVC utterances which require minimal adjustment are probably simpler to produce physiologically. The articulators have less distance to travel from one place to another place of production. Practice materials for clients who exhibit unintelligible speech would need to be developed with this consideration in mind, especially when a client has difficulty adjusting articulator positions. Maximal changes in place of constriction in CVC sequences may cause vowel production to become distorted or become abnormally long in duration since the articulators require considerably longer to move from one consonant to the other. Information about vowel duration in the context of varying distances of articulator travel could be helpful in determining partial causes for vowel lengthening which may result in unintelligible speech.

The purpose of this paper was to contrast vowel duration in CVC combinations in an effort to determine the nature of the effects of variations in place of production of consonants on the duration of vowels.

The present investigation attempted to fulfill this purpose by addressing the following research hypotheses.

1. Vowel duration will change significantly as the place of constriction is shifted in order to produce the two consonants in a CVC combination.

2. Vowel duration will become longer as the place of constriction for the second consonant in the CVC combination is moved progressively further distances from that of the first consonant in the combination.

CHAPTER III

METHOD

Subjects

Forty college students from Oklahoma State University participated in this investigation. All of the 20 male and 20 female volunteer subjects were between the ages of 18 and 25 years. None of the subjects displayed evidence of communication problems or foreign accents.

Hearing acuity was determined by presenting pure tones at the frequencies of 500, 1000, 2000, and 4000 Hz bilaterally. Each participant received a conditioning tone of 40dB HTL at 1000Hz, in the right ear. Then tone presentations were made to both ears at 10dB HTL at 500Hz, 1000Hz, and 2000Hz. At 4000Hz presentation was made at 15dB. Listeners failed if they did not respond to one of the presentations at the specified frequencies and were thus, excluded from the study. From a total of 47 subjects, four were excluded from the study because of failing the hearing screening and three were excluded because of age.

Target Words

Target CVC words containing the neutral /ʌ/ vowel were used as stimulus material. The consonants /p/, /b/, /t/, /d/, /k/, and /g/ were combined with the vowel to provide various distances of articulator travel necessary to change the place of constriction from the initial to the final consonant. The following target words were used in this study: pup, put, puck, bub, bud, and bug (See Table I). These words represented three sub-groups (a) the word requiring maximum extent of articulator movement between production of the first and second consonant included "bug and puck"; (b) the words requiring moderate articulator movement included "bud and put"; and (c) the words with minimal articulator movement included "bub and pup".

The effects of word position in an utterance (Klatt, 1975), and word type on vowel duration were minimized by placing the target words in the same carrier phrase "The _____ is over there." The effects of sentence order were minimized by presenting each subject with a randomized list of sentences to be produced. No attempt was made to distinguish nonsense words from lexical words.

Acoustic Measures and Instrumentation

Each subject was given a randomized list of sentences to be produced. While seated in a sound treated room each subject was given the same tape recorded instructions. The instructions were as follows:

> Make sure you are sitting with your back against the chair. You are about to hear some sentences. The sentences you are about to hear are listed on your paper. Please, read along as the sentences are presented. After each sentence presentation, repeat the sentence. Make sure you are looking at the microphone when you repeat the sentences. The first two sentences you hear will be practice sentences. They are not listed on your paper.

TABLE I

STIMULI

Voicing	Minimal	Moderate	Maximal
Voiced	bub	bud	bug
Voiceless	pup	put	puck

Each carrier phrase was repeated only once.

After hearing the instructions the subjects repeated two practice sentences containing embedded words (tup and dub) similar to the ones used in this investigation. Practice words were embedded in the same carrier phrase used for the target words. The subjects were then asked to repeat each of the sentences after a live voice sample was given. Each target word was embedded in the carier phrase, "The _____ is over there." Recordings of their utterances were made using a Nagra reel-to-reel tape recorder and a Neumann model KM83 microphone. Presentation of the sample was transmitted through sound field speakers located at each side of the sound treated room.

Samples of the target words were analyzed using a 6061B Sonograph Sound Spectrum Analyzer. The criteria used in determining the initiation and cessation of a vowel were similar to those used by House (1961). The vowel was defined as that point at the onset and offset of the vowel, marked by the presence of the first and second formant transitions; aspirations were included as part of the vowel only if first and second formants were well defined. Examples of determined onset and offset of vowels can be found in Figures 1 and 2. The vowel segment of the target word was measured by the author of this paper. The length in millimeters was converted to duration in milliseconds by multiplying the length by 3.773.

Interobserver reliability was estimated by having two individuals independently measure the duration of vowels from 48 target words. Comparisons of these measurements revealed a Pearson r correlation of the two sets of measures of .984. All vowel durations were then compared using a three factor (sex x voicing x distance) mixed design analysis of variance (University of California). The sex factor

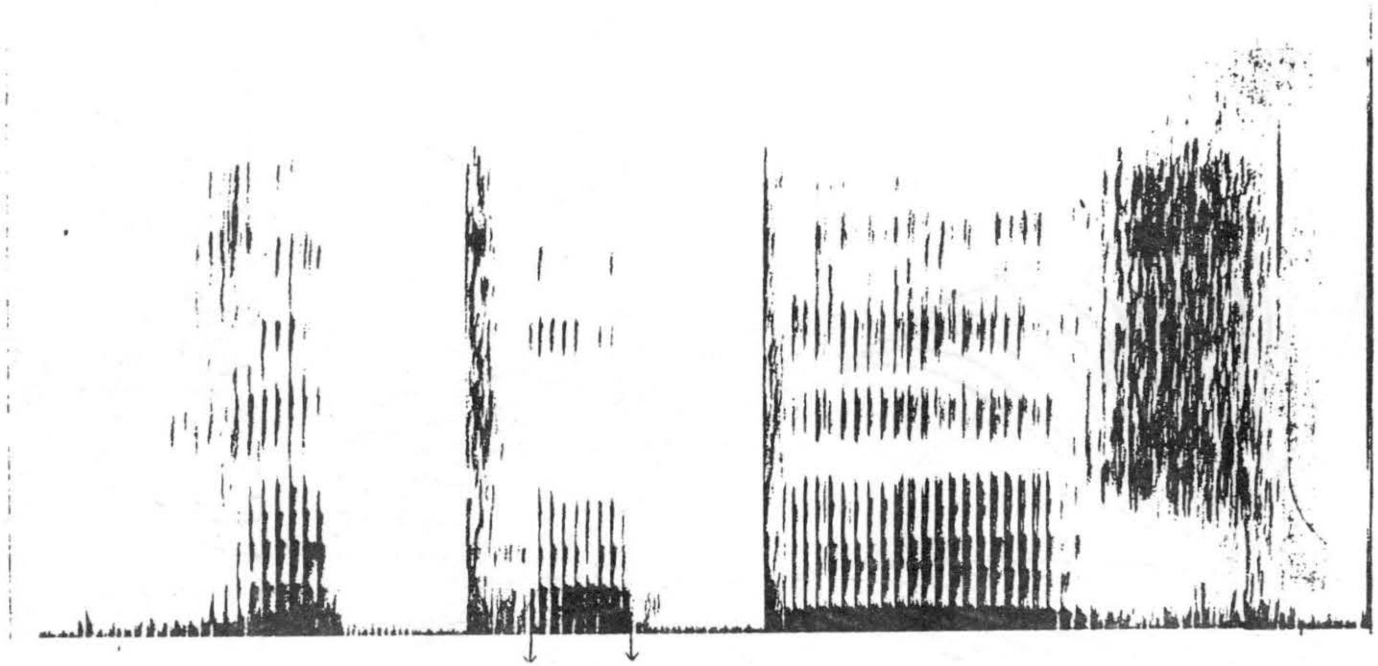

Figure 1. Onset and Offset of Vowel in the Phrase "The Pup is Over There."

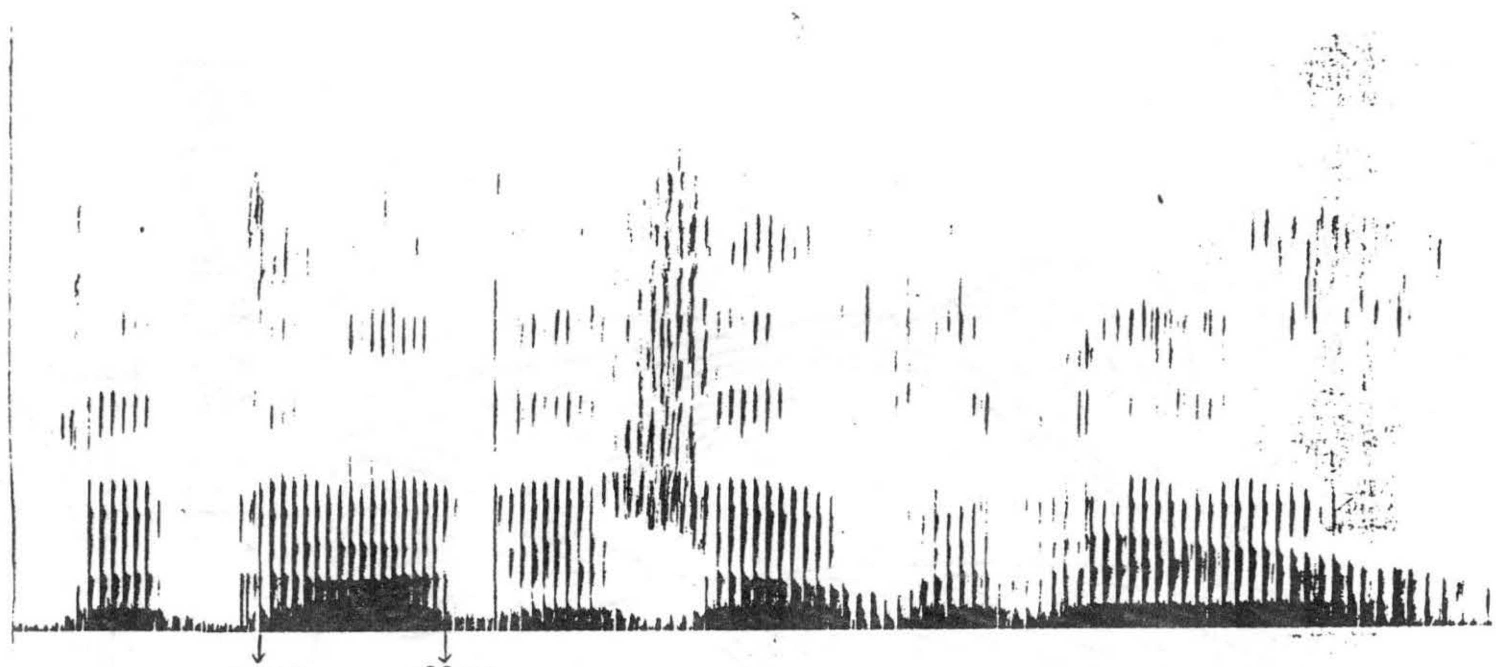

Figure 2. Onset and Offset of Vowel in the Phrase "The Gug is Over There."

constituted the only independent factor in the analysis. The voicing or non-voicing constituted two levels of one of the repeated measures. The minimal, moderate, and maximal distances which the primary articulator travels from the initial to the final consonant constriction of the CVC word, composed three levels of the second repeated measure.

CHAPTER IV

RESULTS

The data were analyzed using a 2x2x3 (sex x voicing x distance) mixed design, analysis of variance. A summary of the Analysis of Variance findings is included in Table II. The results revealed the following: (a) there were no significant differences in the durations of the vowels between the male and the female subjects of this study, (b) the duration of vowels in the context of voiced consonants differed significantly ($<.01$) from those in the context of voiceless consonants, and (c) there was also a significant difference ($<.01$) in the duration of the vowels related to the distance of articulator travel in moving from the initial to the final consonant. The mean durations of the vowels for each of the distance groups in both voiced and voiceless contexts are summarized in Table III and Table IV.

All significant differences were further analyzed using WSD-t follow-up tests. This analysis revealed the following: vowels requiring maximal change of place did not differ significantly from those requiring minimal change. Those in the context of moderate articulator adjustment differed significantly from those requiring both minimal and maximal change in place of constriction. Although there was a significant difference in the duration of vowels as a result of change of articulator placement, the vowels did not get progressively longer as the length of distance of travel increased. The main effect means

TABLE II

ANALYSIS OF VARIANCE SUMMARY

Source of Variance	df	F	P
Between subjects Sex (Male - Female)	1	2.46	.1254
Within subjects Voiced and Unvoiced	1	207.44	.01
Distance of Movement	2	34.83	.01
Interaction			
Sex x Voicing	1	.18	.6716
Sex x Distance	2	1.25	.2916
Voicing x Distance	2	1.37	.2595
Voicing x Sex x Distance	2	.34	.7106

TABLE III

DATA TABLE

Distance	Male	Female	Marginal
Voiced			
Minimal	130.66 (SD = 36.26)	126.00 (SD = 22.01)	128.30
Moderate	145.20 (SD = 31.46)	136.80 (SD = 18.82)	141.00
Maximal	136.55 (SD = 25.62)	129.50 (SD = 17.23)	133.03
Voiceless			
Minimal	85.40 (SD = 17.57)	78.25 (SD = 9.14)	81.83
Moderate	109.55 (SD = 19.19)	94.75 (SD = 14.24)	102.15
Maximal	92.30	86.55	89.43
Marginal	116.60	108.64	112.62

TABLE IV

AVERAGE DURATION OF VOWELS IN VOICING GROUPS AND GROUPS OF VARYING ARTICULATOR MOVEMENT

Subjects	Minimal Change in Placement	Moderate Change in Placement	Maximal Change in Placement
Female Subjects			
Voiced	126	136.8	129.5
Voiceless	78.25	94.75	86.55
Average durations	102.125	115.775	108.025
Male Subjects			
Voiced	130.6	145.2	136.55
Voiceless	85.4	78.25	81.825
Average durations	108	111.725	109.1875

of each level of distance traveled can be found in Table V. A summary of the durations of all female and male subjects in the various groups of constriction change can be found in Appendixes A and B.

TABLE V

DISTANCE OF TRAVEL/MAIN EFFECT MEANS

Distance	Minimal	Moderate	Maximal
Mean Duration	105.0625	*121.575*	111.2125

(mean vowel durations in msec., combined over voicing and sex factors)
WSD-T value df 3,78 = 7.0356832
* Significant at $<.01$ level

CHAPTER V

DISCUSSION

The results of this investigation appear to indicate that while the vowel durations of the female speakers were shorter than those of the male speakers, the reduction in length was not significant. Apparently there is little difference in vowel duration attributable to sex differences in subjects of this age group. There appears to be no previous research which either concurs with or refutes this finding.

The results of this study also indicate that the vowels in a voiced consonant environment were all significantly longer than those in a voiceless consonant environment. These results are consistent with the findings of Krause (1982), House (1961), and Peterson and LeHiste (1960). Although the precise reason for the lengthening of vowels before voiced consonants is unknown, House (1961) considered the lengthening of the vowel to be indicative of physiological or phonological process. Delattre (1962) thought that anticipation of a greater articulatory effort seemed to cause the reduction of preceding vowel durations. It is possible that vowels are shorter in the context of voiceless consonants because a greater articulatory effort may be required to stop the voicing of the vowel in order to produce the final voiceless consonant.

Finally, the present results indicated that the distance of articulator travel had a significant impact upon vowel duration.

Follow-up t-tests further indicated that the duration of the vowels in the context of bilabials only were shortest in both voiced and voiceless environments. When the primary articulator executed a minimal amount of adjustment when moving from the consonant to vowel to consonant, a relatively short vowel duration was present.

The durations of the vowels requiring a maximal amount of articulator travel in moving from the initial to the final consonant were somewhat longer than those requiring minimal change. However, the durations did not differ significantly from one another.

The durations of the vowels produced between bilabial and lingua-alveolar stops were the longest. These durations were significantly longer than those in the contexts requiring minimal or maximal articulator travel to move the place of constriction from the initial to the final consonant of the target words.

The fact that the utterance requiring moderate distance of articulator travel resulted in a duration significantly longer than those requiring minimal adjustments did not seem unusual. The initial consonant is produced and the vowel is sustained until the next consonant is produced. If minimal adjustment in articulator placement is necessary, a vowel could be sustained for a relatively short period. If moderate amount of adjustment is needed, it would follow that the intervening vowel would be longer.

However, one would then assume that when maximal articulator adjustment occurs, the vowel would then be even longer. Such a relationship was not apparent in the present investigation. Syllables requiring either maximal or minimal distance of articulator travel were found to be significantly shorter in duration than those requiring moderate change. The reasons for these differences remain unclear.

It appears that both place of production and magnitude of adjustment required to produce the constriction are related to vowel duration. The lingua-velar actions may be coarticulated with the bilabial and vowel movements thus permitting a more rapid execution of the movements of the two consonants and resulting in a shorter vowel duration. On the other hand, during bilabial productions, it would seem more difficult to coarticulate the movements required to make the lingua-alveolar sounds than those movements required for production on the lingua-velar sounds. Perhaps this difficulty stems from the forward movement required by the tongue to move from the vowel to the lingua-alveolar sounds. One would not be able to coarticulate the lingua-velar sounds during the production of the vowel without distorting the vowel to a certain degree. However, the /ʌ/ phoneme can be produced in the posterior of the vocal tract with minimal distortion thus, allowing the lingua-velar sounds to be more readily coarticulated during the production of the vowels.

In moving from bilabials to lingua-alveolar sounds, the tongue tip and blade must move from a somewhat neutral position in a relatively open vocal tract to a posture which requires the flattening and raising of the blade and tongue tip to a point where the middle to anterior portion of the vocal tract is completely constricted.

It would appear that the relative distance over which the place of constriction must move in order to produce a CVC combination is only one of the factors which influences the duration of the vowel. It seems the amount of segmented articulator movement as well as the intricacy of the adjustments required to achieve the postures necessary for consonant constriction also seem to have a strong influence on vowel durations in CVC combinations.

CHAPTER VI

SUMMARY

Tape recorded samples of the speech of 20 male and 20 female subjects were used to study the durations of vowels in the context of three different pairs of consonant articulator constrictions. Each pair required different amounts of articulatory travel in moving the place of constriction from the first to the final consonant.

The vowels were measured and converted into duration in milliseconds. The data were then analyzed using a three factor, mixed design, analysis of variance. Results of these analyses indicated the following: first, the vowel durations of the females were slightly but not significantly shorter than those for males. Second, the voiced consonant environment contained vowels which were significantly longer than those containing voiceless consonants. Finally, vowel durations in CVC environments which required moderate degrees of articulator movement were significantly longer than the other distance groups.

Follow-up tests indicated that durations in CVC environments were the shortest when both the preceding and final consonant were of a similar place of production. Vowel durations in CVC environments requiring maximum distance of movement of constriction from the first to the second consonant were slightly but not significantly longer than those requiring minimal distance of movement. The durations of vowels in CVC environments which required a moderate amount of travel in moving the constriction were significantly longer than those for either the large or minimum distances (see Hypothesis 2).

It would appear from these results that vowel duration in the present CVC combinations relates not only to the amount of distance required for the articulators to travel in moving from the first to the second consonant, but also to the amount of adjustment of the articulators required by the consonants produced.

Further investigation is needed to determine:

1. The impact of the variation of the manner of production of the consonants in CVC combinations upon vowel duration. In moving the constriction from the anterior--most position to the middle region of the oral cavity, it is not known whether a particular consonant has any impact on duration.

2. The effect of producing lingua-velars or lingua-alveolars in both the initial and final positions of CVC combinations.

3. The effect of moving the constrictions from a posterior to an anterior position in a CVC combination which includes both a lingua-velar and a bilabial consonant.

4. The actual articulator movements involved in the production of the CVC combinations.

Once these areas have been investigated, then the effect of articulator movement upon vowel duration will be better understood.

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APPENDIXES

APPENDIX A

SUMMARY OF FEMALE VOWEL DURATIONS

Sub-ject	Voiced Minimal	Voiced Moderate	Voiced Maximal	Voiceless Minimal	Voiceless Moderate	Voiceless Maximal
FS1	106	128	121	75	98	94
FS2	196	166	136	87	147	98
FS3	109	147	132	68	113	83
FS4	140	147	162	75	117	106
FS5	147	158	177	49	125	49
FS6	125	162	143	83	79	98
FS7	245	249	196	121	113	140
FS8	132	136	128	109	113	106
FS9	117	143	125	94	117	94
FS10	125	132	136	98	113	87
FS11	87	102	106	68	98	83
FS12	143	140	121	68	79	72
FS13	136	158	162	117	140	98
FS14	121	113	109	87	98	64
FS15	132	143	158	79	128	98
FS16	94	106	113	75	94	79
FS17	136	162	155	91	91	106
FS18	102	155	94	83	94	106
FS19	128	151	140	98	136	98
FS20	91	106	117	83	98	87

FS - Female Subject

APPENDIX B

SUMMARY OF MALE VOWEL DURATIONS

Subject	Voiced Minimal	Voiced Moderate	Voiced Maximal	Voiceless Minimal	Voiceless Moderate	Voiceless Maximal
MS1	128	106	140	75	106	87
MS2	132	117	128	60	68	79
MS3	132	136	125	83	83	98
MS4	162	174	143	87	106	75
MS5	121	136	113	68	102	64
MS6	132	177	155	87	106	91
MS7	113	132	106	87	83	84
MS8	177	162	151	94	113	113
MS9	140	147	147	72	102	94
MS10	109	140	117	68	75	68
MS11	106	140	140	83	91	94
MS12	132	132	132	72	98	72
MS13	136	132	140	83	98	79
MS14	136	136	94	75	83	72
MS15	147	143	151	91	121	121
MS16	106	109	128	79	109	75
MS17	91	143	117	64	94	121
MS18	98	113	117	83	72	87
MS19	166	136	140	75	98	83
MS20	94	125	106	79	87	75

MS - Male Subject

VITA

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