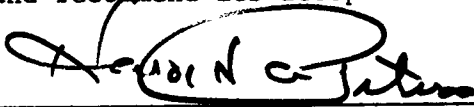


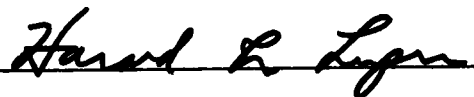
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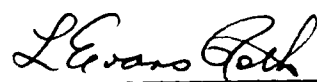
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ACOUSTIC ANALYSIS OF DURATIONAL CHARACTERISTICS IN
NORMAL AND ARTICULATORY DEFECTIVE
ADULT SPEAKERS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Marcia Ohle Burns

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ABSTRACT

The purpose of this study was to investigate the differences between durational characteristics of phonemically accurate productions of vowel + stop consonant + vowel (V_1CV_2) sequences in adult speakers with articulatory defects and adult speakers with normal articulation. Durational measurements on the following subsegments were obtained: steady state of the preconsonantal vowel; transition of the preconsonantal vowel; consonant; transition of the postconsonantal vowel; steady state of the postconsonantal vowel; and total disyllable.

Ten adults with articulation errors sufficient to place them one standard deviation below the mean score for an eight year old child on the Templin-Darley Tests of Articulation comprised the experimental group. Ten adults with no articulation errors and no history of articulation errors comprised the control group. All subjects met the following criteria: no significant deviation in the structure or function of the oral mechanism; normal hearing; normal voice and fluency; normal intelligence; and negative history of neurologic damage or symptoms. The stimuli used in this investigation were eighteen vowel + stop consonant + vowel sequences embedded in the phrase, "Say the word V_1CV_2 please." The subjects read each of the stimuli five times. These responses were tape recorded and later analyzed on the Voice Identification Unit. All durational measurements made from the broadband spectrograms were obtained at the second formant. The duration

measurements were used to infer timing of articulatory movements during the subsegments of the V_1CV_2 sequence.

The major findings of this study were:

1. The duration of the steady state of the preconsonantal vowel (SSV_1) was significantly longer in the articulatory defective speakers than in the normal speakers.
2. The duration of the transition of the preconsonantal vowel (TV_1) was not significantly different in the group of normal speakers and the group of articulatory defective speakers.
3. The duration of the intervocalic consonant (CD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.
4. The duration of the transition of the postconsonantal vowel (TV_2) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.
5. The duration of the steady state of the postconsonantal vowel (SSV_2) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.
6. The total disyllable duration (TDD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.
7. Two speakers in the articulatory defective group exhibited durational values similar to those exhibited by speakers in the group of normal speakers. One speaker in the group of normal speakers exhibited durational values similar to those obtained by the articulatory defective speakers.

In general, the group of articulatory defective speakers had significantly longer mean durations of all subsegments measured in the V_1CV_2 sequence with the exception of transition of the preconsonantal vowel (TV_1) for which there was no significant difference between groups of speakers. These results indicate an involvement in the planning and/or integration of articulatory movements in the group of articulatory defective speakers.

Further research is needed to: (1) investigate the consistency of these results in other phonemic sequences; (2) investigate the consistency of these results in groups of normal speaking and articulatory defective children; and (3) investigate the consistency of these results under imposed rate conditions.

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CHAPTER I

INTRODUCTION, REVIEW OF THE LITERATURE, AND STATEMENT OF THE PROBLEM

I. INTRODUCTION

Articulatory gestures have been studied physiologically using x-ray motion pictures (Koshevnikov and Chistovich, 1965; Moll and Daniloff, 1971; Carney and Moll, 1971; Kuehn and Tomblin, 1974) and by identifying aerodynamic correlates of articulatory movement patterns (Barry and Kuenzel, 1975; Agnello, 1975). Also, inferences concerning the dynamic as well as static temporal aspects of speech have been made from perceptual (Cooper et al., 1952; Tiffany, 1953; Delattre et al., 1955; Liberman, 1959; Bastian et al., 1959; Stevens, 1959; Gay, 1967; Bennet, 1968; Koenigsknecht, 1968; Powell and Tosi, 1970; Zlatin and Koenigsknecht, 1976) and acoustic studies (Lehiste, 1962; Öhman, 1966; Stevens, House and Paul, 1966; Schwartz, 1969; DiSimoni, 1974; Dalston, 1974; Tingley and Allen, 1975).

Most investigators have studied the timing of articulatory gestures of normal adult speakers. However acoustic analyses of temporal factors in several groups of deviant speakers including apraxics (Hamre, 1977), hearing impaired (Angelocci, Kopp and Holbrook, 1964; Raphael, 1972; Monsen, 1974, 1976), and stutterers (Stromsta, 1965; Agnello, 1975) have been performed. Velocity of transitions, voice onset time, and duration of different subsegments have been frequently investigated in these

acoustic studies. In each of these groups, significant deviations from normal temporal patterns have been reported.

In addition to the above studies, some recent investigators have examined the timing of movement patterns in articulatory defective children (Faircloth and Faircloth, 1970; Dalston, 1974; Kuehn and Tomblin, 1974; Chaney and Menyuk, 1975). These investigators reported differences in the timing of articulatory gestures in articulatory defective children from that reported on normal speaking adults (Öhman, 1966; Daniloﬀ and Moll, 1968; Carney and Moll, 1971; Dalston, 1974). When results obtained on children are compared to results reported for adults, there is the possibility of confounding the effects of durational differences due to groups (articulatory defective and normal speakers) with the effects of durational differences due to age (adults and children).

Investigations of temporal factors in the speech of normal adults exhibiting articulation disorders have not been reported in the literature. Such studies may eliminate confounding of the effects of age with those of group. Significant differences between groups would be attributable to the effect of the articulatory disorder. Since physiological movement patterns of articulators can be inferred from acoustic analyses and since these acoustic studies have provided an understanding of normal articulation in adults, it seems logical to assume that acoustic data may be used to describe the speech of articulatory defective adults. The present study is designed to investigate specific durational characteristics of phonemically

accurate productions of adult speakers with articulatory defects and adult speakers with normal articulation.

II. REVIEW OF THE LITERATURE

Temporal Characteristics of Normal Speaking Adults and Children

The durational aspects of articulatory production patterns have been investigated in controlled phonetic environments. Systematic analyses of temporal characteristics of subsegments within an utterance have provided information on both static and dynamic properties of speech production. These properties are important because they may reflect patterns of organization of neuromotor control for speech articulation (Lindblom, 1963; Kozhevnikov and Chistovich, 1965; Liberman et al., 1967; Öhman, 1967). The temporal patterning relations between nonadjacent sounds seems to require present timing which implies predominantly central rather than peripheral control of timing. Conceivably the various motor commands are issued on the basis of a rhythmic pattern which underlies the temporal structure of speech (Martin, 1972).

Effect of vowel environment on consonant duration. In an investigation of the effects of vowel environment on the duration of consonants, Schwartz (1969) reported that in adult speech, fricatives in the environment of /a-i/ and /i-i/ were significantly longer than those in the environment of /a-a/ and /i-a/. Schwartz suggested that the shorter durations before /a/ may represent an earlier release of

the consonant constriction. He posited that the earlier release may be an anticipatory response to the greater spatial distance which must be covered by articulators when proceeding from a fricative to /a/ than when proceeding from a fricative to /i/. In terms of neurological commands to the speech musculature, Schwartz hypothesized that during the production of /s/ or /ʃ/, a scanning mechanism looks ahead and considers the relative magnitudes of articulatory adjustments required for the transition from the fricative to the vowel and uses this information to time the arrival of the neural commands which initiate the movement away from the constriction. Di Simoni (1974a) studied developmental changes in the duration of consonants in controlled vowel environments. The children produced vowel + consonant + vowel (VCV) sequences ending in /a/ and in /i/. None of the differences was significant whereas in the Schwartz (1969) study on adults, differences were significant. Di Simoni also reported that the individual subject variability of consonant duration decreased with an increase in age. In reference to the forward scan described by Schwartz, Di Simoni reported that if such a mechanism is active in children, it is not yet functioning in the manner assumed for adults. He postulated two explanations for his results: (1) by age nine, the system has not yet developed to the level of operating efficiency assumed for adults; and (2) since children have smaller orofacial structures and thus smaller spatial differences between vowels than adults, the expected differences between vowels would not be as great.

Effect of length of utterance on consonant duration. Malmberg (1944), Jones (1944), Lindblom (1968), and Schwartz (1969) reported that in adult speakers, both consonant and vowel durations decrease as overall length of an utterance is increased. Schwartz interpreted this as evidence indicating that a speaker scans ahead to appraise the length of an utterance and uses this information to determine the amount of time he may devote to the articulation of individual sounds. Di Simoni (1974b) studied consonant closure durations in utterances of increasing length in three, six, and nine year old children. The durations of the consonants were examined in the initial syllable of the following utterances: (1) /ipi/; (2) /ipi/ saw /ipi/; (3) /ipi/ saw /ipi/ with /ipi/. Although the average durations of the consonant /p/ decreased with age as did variation in the subjects' productions, an increase in utterance length resulted in a significant decrease in duration only in the six and nine year old groups and not in the three year old group.

Di Simoni (1974c) also investigated the durations of vowels in both voiced and voiceless plosive environments in children ages three, six and nine years. The greatest change in durations of vowels in both voiced and voiceless plosive environments was observed between the three and six year levels. With respect to voiced versus voiceless environments, Di Simoni's results were in agreement with those of House and Fairbanks (1953), Peterson and Lehiste (1960) and Zlatin and Koenigsknecht (1976), who reported that in adult English speakers, vowels in voiceless consonant environments are shorter in duration than those in voiced environments.

Allen (1970) and Lehiste (1971) reported that the overall duration of a speech segment remains relatively constant while the subsegments vary in a compensatory manner to maintain the constancy of the duration of the total segment during repeated productions of the segment. This behavior is called temporal compensation and can be identified by a lower relative variance in a segment relative to the relative variance of its parts (Allen, 1970). Allen posited that every individual has a speech "timing mechanism." This mechanism has an inherent level of accuracy which may be expressed as a constant of proportionality between durational variability of the subsegments and mean segment duration. Although he suggested that the determination of this constant of proportionality would make it possible to define temporal groupings of speech production units, he did not discuss the specific methodology for determining the temporal groupings. Di Simoni (1974d) investigated the temporal compensation in children ages three, six and nine years of age in order to identify a developmental pattern. Although all mean durations and standard deviations tended to decrease with age, the phenomenon of temporal compensation was not demonstrated in any of the age groups. The children in this study had larger relative variances at all age levels than adult subjects in similar studies (Allen, 1970; Lehiste, 1971). Di Simoni concurred with Allen's (1970) contention that an individual with large relative variance measures probably has less "inherent accuracy" in timing and may be unable to execute neurologic commands with adequate precision.

It is apparent from studies reviewed thus far, that there seems to be a developmental pattern in which control of duration improves rapidly

during childhood. The motor timing for speech seems to develop along a continuum which spans approximately the first twelve years of life (Eguchi and Hirsh, 1969; Di Simoni, 1974).

Effect of duration on sound discrimination. Liberman et al. (1954) investigated temporal acoustic characteristics as cues to the differentiation among classes of speech sounds. They reported that although cues are added by the temporal characteristics of the third formant transitions, the second formant transition is nearly sufficient to identify stops and nasals. They experimentally separated the characteristics of rate of transition in cycles per second per millisecond (cps/ms) and duration of the transition in milliseconds (ms) and concluded that duration rather than rate of change is the controlling cue in distinguishing stop consonant from semivowel from vowel of changing color. They posited that duration is the most important dimension for the discrimination and identification of individual speech sounds. That adults use timing information to distinguish among sounds within a given class was reported by Tiffany (1953), Stevens (1959), Bennet (1968), and Powell and Tosi (1970). Dalston (1974) hypothesized that if temporal acoustic cues are used to distinguish perceptually among phonemes, significant differences should exist in spectrographic measurements of subsegment durations of individual phonemes within a class. He further hypothesized that measures of specific temporal characteristics which do not result in a significant difference in duration among phonemes within the same class are not used to perceptually distinguish among phonemes. The purpose of his investigation was to determine by acoustic analysis,

which subsegments of an utterance showed significant durational differences among phonemes. The utterances were composed of correct productions of the sonorants /w/, /r/, and /l/ by adults and children in word initial position in the contexts of /i/, /a/, and /u/. He measured: (1) duration of the steady state of each of the first three sonorant formants; (2) duration of the transition of each of the first three sonorant formants; and (3) rate of the transition of each of the first three sonorant formants. Steady state duration (of both first and second formants) was significantly different for both children and adults between the /l/ and the other two sonorants. Formant one transition duration and rate were characterized by a shorter transition duration for /l/ production and a more rapid transition rate than were /w/ and /r/ productions. Second formant transition duration was significantly shorter than those of /w/ and /r/ in the adults but not in the children. The variable of second formant transition rate was significantly slower for the /r/ than for the /w/ and /l/ productions of child subjects but was not different for adults. The third formant transition duration and transition rate consistently differentiated /r/ from /w/ and /l/ in the productions of all subjects. Dalston concluded that the sounds investigated are distinguishable on the basis of the specific temporal acoustic characteristics measured.

Öhman (1966) studied vowel steady states and formant transitions spectrographically in vowel + stop consonant + vowel (VCV) sequences produced by Swedish, Russian, and American adults. The VCV sequences analyzed were various combinations of voiced stop consonants /b/, /d/,

/g/, with the vowels /i/, /u/, /ø/, /a/, /y/, /ɛ/, /o/. In all sequences he observed two simultaneous articulatory gestures: (1) a vowel-to-vowel diphthongal movement; and (2) an independent consonant gesture superimposed upon the diphthongal movement. In order to determine the influence of the intervocalic consonant upon the pre- and postconsonantal vowel, he examined both the steady state and the transitional portion of vowels. Öhman observed only a slight influence of the consonant on the steady state portions of vowel formant frequencies. This influence was obvious in both the initial and final vowels in the sequence. When the transitional portions were analyzed, traces of the final vowel were observable in the transition from the initial vowel to the consonant. Thus, he posited that motion toward the final vowel starts simultaneously with the onset of the stop consonant gesture. The production of the consonant involves concomitant articulatory adjustments partially anticipating the configuration of the succeeding vowel. He hypothesized that neural commands for the consonant and following vowel must be active simultaneously. However, certain components of the final vowel instruction are probably inhibited during the initial vowel. Öhman suggested that some components of the postconsonantal vowel are active at the onset of the consonant closure in certain VCV sequences, but there is no conclusive evidence as to whether or not further neural instructions are added for the vowel during or at the offset of the consonant gesture. He stated that judging from x-ray motion pictures of the VCV sequence /ydu/, the /d/ could not be properly articulated if the posterior portion of the tongue assumed the /u/ position too

early because the tongue tip would apparently be unable to reach the alveolar ridge. Thus, the completion of the motion in the direction of the final vowel must be delayed until the offset of the consonant.

Öhman emphasized the absence of a uniqueness of transitional frequency ranges of the vowel second formant transitions into and away from the respective stop consonant productions. That is, the frequencies over which the different second formant transitions (posited by Delattre et al. (1955) to be the most important cue for the perception of stop consonants) occurred were similar regardless of whether the intervocalic consonant was /b/, /d/, or /g/. Öhman hypothesized that second formant vowel transition frequency is less important for the perception of stops than the duration of the transition into and out of the stop. He concluded that the perception of an intervocalic stop must be based upon an auditory analysis of the temporal characteristics as well as the frequency characteristics of the entire VCV pattern.

From the above review of literature, it is evident that information about the nature of timing of movements for various articulatory gestures has been obtained through an analysis of the acoustic signal, and that durational characteristics are important perceptual cues for distinctions among phonemes. The temporal characteristics most often reported to be important to distinctions in the production and perception of phonemes are duration of transition and duration of the steady state of vowels. In addition to the investigations reviewed, other researchers (Lashley, 1951; Martin, 1972; Michon, 1974) have suggested that timing may be the most critical factor in skilled motor performance, including movement patterns required for speech articulation.

Temporal Characteristics of Articulation Cases

Timing of nonspeech behaviors. Several investigators (Karlin, Youtz and Kennedy, 1940; Major, 1940; Bilito, 1941; Mase, 1946; Fairbanks and Spriestersbach, 1950; Maxwell, 1953; Dickson, 1962) have attempted to determine if differences exist for measures of timing proficiency between the motor behavior of normal speakers and speakers with articulation disorders. Previous investigators have studied motor behaviors other than speech, such as speed of tapping (Major, 1940; Maxwell, 1953) and speed of placing a pellet in a bottle (Maxwell, 1953). The results of these types of investigations have been contradictory. Some investigators have reported significant differences between good and poor articulation groups while others have reported no differences between the two groups of speakers. Discrepancies in results may be accounted for in part by differences in methods of test administration, differences in the methods of subject selection, differences in ages of subjects, lack of control of related variables, and inappropriate statistical tests. It seems logical to assume that if differences in timing of motor behaviors do exist between normal speakers and articulatory defectives, that these differences would be observable in the movement patterns during speech. Only a few such investigations of differences have been reported in the literature.

Temporal characteristics of speech. Faircloth and Faircloth (1970) studied acoustic characteristics of connected speech and isolated words produced by a child with an articulatory disorder. The purpose of the

investigation was to determine if spectrographic information provided by single word productions differed in durational values of certain temporal characteristics from the same words produced in connected speech. The subsegments measured were vowel duration, and consonant implosive and release phase durations. The subject was an eleven year old male with a severe articulation disorder who had received no formal speech training. A tape recording was made of the subject's spontaneous conversation. Twenty-five misarticulated words were randomly selected from his utterance. These twenty-five words were then produced in isolation and tape recorded. The connected speech and single word productions were analyzed acoustically and compared. Several differences were observed. Vowel and consonant durations were significantly reduced in the connected speech samples. Difficulty in differentiating between the implosive and release phases of stop consonants in the connected speech samples was reported, however, there was no difficulty in differentiating between the two phases in isolated word productions. Because they could not distinguish between the implosive and release phases of the consonants in the connected speech condition, durational values for these characteristics could not be compared between conditions.

Kuehn and Tomblin (1974) studied movement patterns of specific "flesh points" of the tongue and lips during perceptually correct productions of children with moderate to severe articulation disorders. Three males, ranging in age from eight to eleven years who had been diagnosed as having impaired articulation, served as subjects. The subjects were filmed using cineradiography while producing the

consonants /z/, /b/, /g/, and /l/ in symmetric and asymmetric vowel + consonant + vowel (VCV) sequences with the vowels /i/, /a/, and /u/.

The structures monitored were the surface of the tongue dorsum, the tongue blade, the tongue tip, and the lower lip. Measures of articulatory velocity and distance moved were determined for transitional movements.

All productions analyzed were judged as phonemically accurate. Three time points were sampled during each asymmetric VCV production: (1) the steady state of the preconsonantal vowel; (2) the first frame of lip closure for /b/; and (3) the steady state of the postconsonantal vowel.

Tongue position assumed for the preconsonantal vowel and at the moment of bilabial stop closure were virtually identical which was interpreted as an indication that the tongue had not yet begun movement toward the final vowel at the time of consonant closure. These results are not consistent with the articulatory dynamics of normal adult speakers as inferred from acoustic data of Öhman (1966) and cinefluorographic data of Daniloff and Moll (1968) and Carney and Moll (1971). These investigators reported that articulatory movements toward the second vowel, in utterances similar to those used in the Kuehn and Tomblin investigation, coincide in time with movements toward the consonantal closure. In the children studied by Kuehn and Tomblin, anticipatory gestures of the final vowel occurred later in time relative to consonant production than would have been predicted on the basis of normal adult behavior. This seems to imply an extended duration of the steady state portion of the first vowel. The postconsonantal tongue position did appear to be influenced by the preconsonantal vowel as would be predicted by

Öhman's (1966) data. Articulatory velocity and displacement measurements were also obtained on the same subjects. For a given distance moved, the associated velocity of movement was not disproportionately slow compared to normal adult behavior. Since there were no similar data for normal speaking children on any of the temporal characteristics observed in this study, it is uncertain whether they are unique to the child with an articulation disorder.

It is evident from the above review of the literature that differences in duration of various temporal characteristics of articulatory movement patterns do exist between articulatory defective children and normal speaking adults. One possible reason for these findings is that comparisons have been made across age groups. If, as many investigators (Eguchi and Hirsh, 1969; Di Simoni, 1974; Dalston, 1975) have posited, there is a developmental hierarchy of durational control, then comparisons between normal adult speakers and articulatory defective children may not be appropriate. There are no reports in the literature of investigations of temporal characteristics in phonemically accurate productions in the speech of adult articulatory defectives so that comparisons can be made with normal speaking adults without the confounding of effects of age and developmental differences with the effects of the articulatory disorder. An investigation of this type may provide useful information about articulatory movement patterns in the speaker with a mature (though possibly aberrant) speech production system. This information should prove useful for both research and clinical purposes.

According to Shoup and Pfeifer (1976), temporal acoustic characteristics such as VOT, vowel formant steady state and transition, and consonant duration are useful cues in distinguishing among place of production of stop consonants in VCV context. These time varying patterns of articulatory positioning and movement are assumed to be lawful in the productions of adult speakers with normal articulation. Since many errors of adult articulatory cases are perceived as errors of place of production, it is the goal of the present investigation to determine if during phonemically accurate productions, the same lawful temporal patterns exist in the speech of adult articulatory defectives as in adults with normal speech.

III. PURPOSE OF THE STUDY

The purpose of this study was to investigate the differences between durational characteristics of phonemically accurate productions of vowel + stop consonant + vowel (V_1CV_2) sequences in adult speakers with articulatory defects and adult speakers with normal articulation. Specifically the following questions were asked:

1. Does the duration of the steady state of the preconsonantal vowel (SSV_1) in a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?
2. Does the duration of the second formant transition of the preconsonantal vowel (TV_1) in a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?

3. Does the duration of the stop consonant (CD) in a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?

4. Does the duration of the second formant transition of the postconsonantal vowel (TV_2) in a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?

5. Does the duration of the steady state of the postconsonantal vowel (SSV_2) in a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?

6. Does the total disyllable duration (TDD) of a V_1CV_2 sequence differ significantly between groups of normal adult speakers and articulatory defective adult speakers?

CHAPTER II

METHODS AND PROCEDURES

I. METHODS

Subjects

Ten articulatory defective adults and ten adults with normal articulation matched for age, race, and sex participated as subjects for this study. For the purposes of this research, "adult" was defined as sixteen years of age or older (although none of the actual participants was less than 18 years of age). The group of normal articulating adults was matched for age within three years of the articulatory defective adults. The mean ages of the normal speakers and articulatory defective speakers were 31-9 years and 31-5 years respectively. No subject with an obvious dialectal difference was included. Subjects were selected on the basis of the following criteria:

1. No significant deviation in the structure or function of the oral mechanism as determined by an oral peripheral examination;
2. No voice or fluency disorder as judged by the investigator;
3. Hearing within normal limits as evidenced by passing a pure tone air conduction screening test at 25 dB (ANSI) at octave intervals between 500 Hz and 8000 Hz;
4. No history of neurologic damage or symptoms of neurologic damage as evidenced by normal diadochokinetic rates (both automatic and

voluntary) and a score of at least 97 on the Isolated Volitional Oral Movements (IVOM) test (adapted from Yoss and Darley, 1974);

5. Appropriate grade placement for chronologic age or completion of high school;

6. Sufficient errors produced by each articulatory defective speaker to place him at least one standard deviation below the mean score for an eight year old child on the Templin-Darley Tests of Articulation; no articulatory errors produced by the normal speakers at the time of the study and a negative history of speech disorders. (See Table A-1 of Appendix A for individual subjects' data.)

Stimuli

The voiceless stop consonants /p/ and /k/ were combined with the vowels /a/, /i/, and /u/ to form eighteen vowel + stop consonant + vowel (V_1CV_2) sequences (six symmetric and twelve asymmetric). The V_1CV_2 sequences were embedded in the phrase, "Say the word V_1CV_2 please." (The list of stimuli are contained in Appendix B.)

The two stop consonants were chosen because their manner of production provides more definitive identification of phone boundaries than any other category of consonants. The production of a stop consonant can be subdivided into two phases: (1) closure/pressure build-up, represented spectrographically as a gap of spectral energy; and (2) release phase represented spectrographically as a burst of spectral energy (Klatt, 1975). These two phases represent respectively, the initiation and termination of a stop consonant. The voiceless consonants were selected to eliminate instances of prevoicing which

can occur when a voiced stop is preceded by another voiced sound. Use of the voiceless stops has been reported to increase the accuracy with which acoustic measurements are made (Klatt, 1975; Metz, Conture, and Carouso, 1978). The bilabial place feature was selected because it represents the least amount of interference with the vowel-to-vowel diphthongal movement (Öhman, 1966). That is, the tongue is not used as a primary articulator for the production of bilabial plosives. The velar place feature was chosen because it provides a contrasting amount of interference with the vowel-to-vowel diphthongal movement upon which a consonant is superimposed.

The specific vowels were selected as representative of the articulatory extremes of the vowel diagram. Their spectral properties are reportedly the most stable of all of the vowels (Liberman, 1977).

The sequence of V_1CV_2 was chosen because when a stop is adjacent to a vowel, the movement to/from the closure results in "rapid" changes in the formant frequencies. These changes in vowel formant frequency are called transitions and the duration of these transitions comprises one of the measures of interest in this investigation. The V_1CV_2 sequence provides two transitions per sequence.

Recording System

The Bruel and Kjaer (B&K) microphone amplifier (Model #2603) was calibrated to 124 dB SPL (re: 0.0002 dy/cm^2) using a B&K pistonphone (Model #4220) attached to a B&K condensor microphone (Model #4133). The Electro Voice microphone (Model #RE 20) was connected to the Shure microphone mixer (Model #M 67) and placed parallel to the condensor

microphone. The microphones were situated six inches from a Grason Stadler loudspeaker (Model #162-4). A Grason Stadler noise generator (Model #433C) was used to generate broadband white noise through the loudspeaker and attenuated to 75 dB on the microphone amplifier. After the noise was adjusted to 75 dB, the VU meters of the microphone mixer and the Ampex tape recorder (Model AG #440B), to which it was connected, were adjusted to -5 dB. Thirty seconds of noise was recorded for subsequent adjustment to -5 VU during playback. Instrumentation for calibration is shown in Figure 1.

II. PROCEDURES

Recording of Subjects

Each subject was seated in an Industrial Acoustics Company (IAC) sound treated booth (Model #1403-ACT). A constant mouth-to-microphone distance of six inches was maintained. The subjects were given a set of instructions which were read by the experimenter (see Appendix A). The subjects were not informed about the specific purpose of the investigation prior to the experimental session. They were instructed to read the written stimuli five times each in a conversational manner. The stimuli were presented to them one sentence at a time on individual index cards. Appropriate intensity levels were established by instructing the subjects to say the phrase "Today is month, date, 1979" as many times as necessary to establish appropriate intensity levels for recording. A training procedure consisted of the subjects' reading of the list of V_1CV_2 sequences to be embedded into the experimental

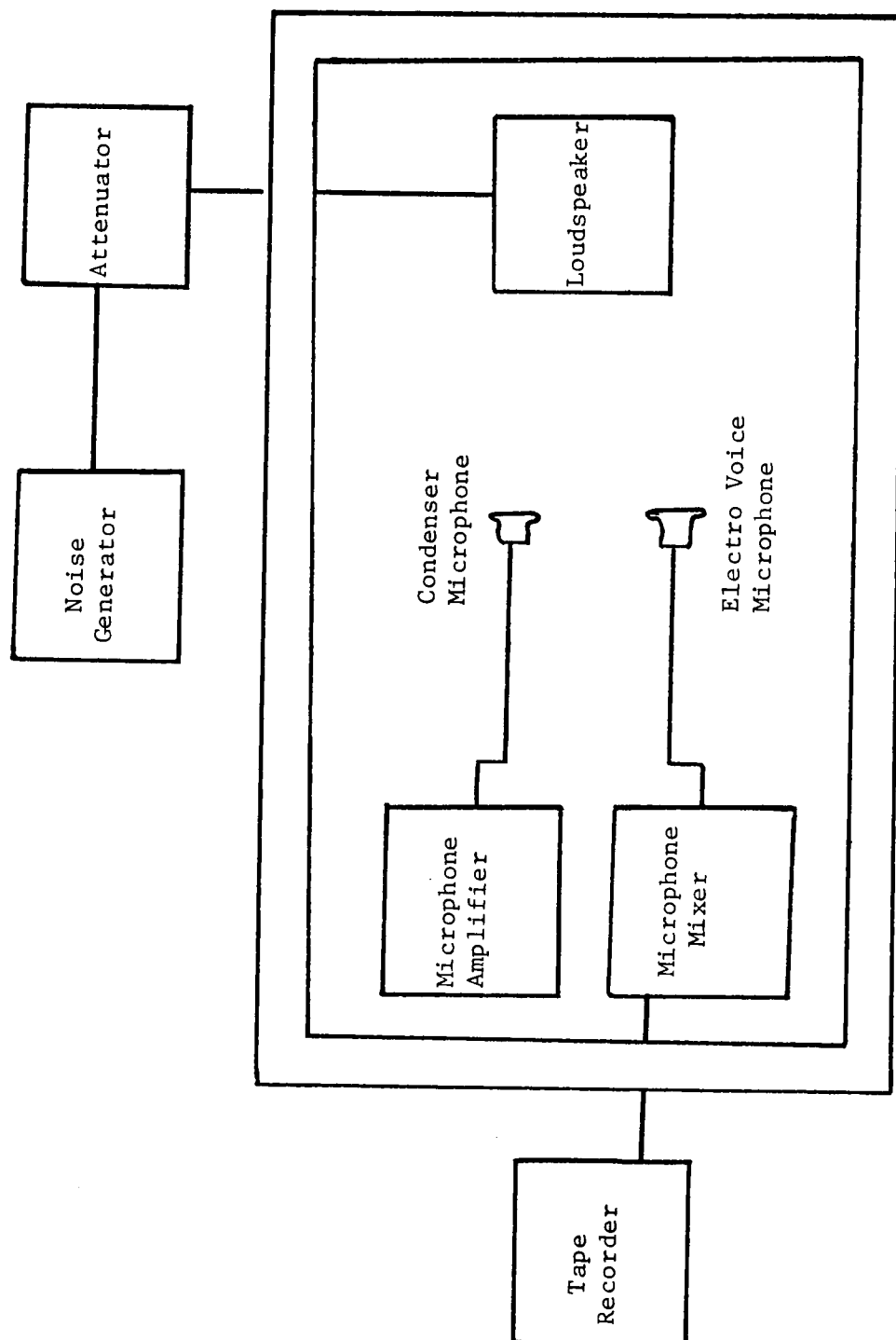


Figure 1. Instrumentation for the calibration of the recording system.

sentences (see Appendix B). The list was practiced until the subject was able to complete the list twice with no errors. The third production of each group of five productions of each sentence was used for the analysis. Instantaneous judgments of appropriateness of loudness, conversational manner and phonemic accuracy were made as the stimuli were read. The subjects were asked to produce five more repetitions of the same stimulus if any judgment of inacceptability was made. Instrumentation for recording of subjects' responses is shown in Figure 2.

Judgment of Phonemic Accuracy

The third production by each subject was dubbed from the original tapes using a Sony tape recorder (Model #TC-65). A four second silent interval was inserted between each sample. A panel of three certified speech-language pathologists phonetically transcribed each V₁CV₂ sequence from the dubbed tape. There was 100% listener agreement in transcription and all transcriptions represented the appropriate V₁CV₂ sequence.

Spectrographic Analysis

A total of 360 broadband spectrograms (18 V₁CV₂ sequences × 20 subjects) were analyzed on the Voice Identification Unit (700 series) using a high frequency shaping circuit and linear expand mode set at 0 - 4 K Hz. The unit was calibrated according to the manufacturer's specifications before and after each subject's responses were analyzed.

The following durational measures were obtained from the spectrograms:

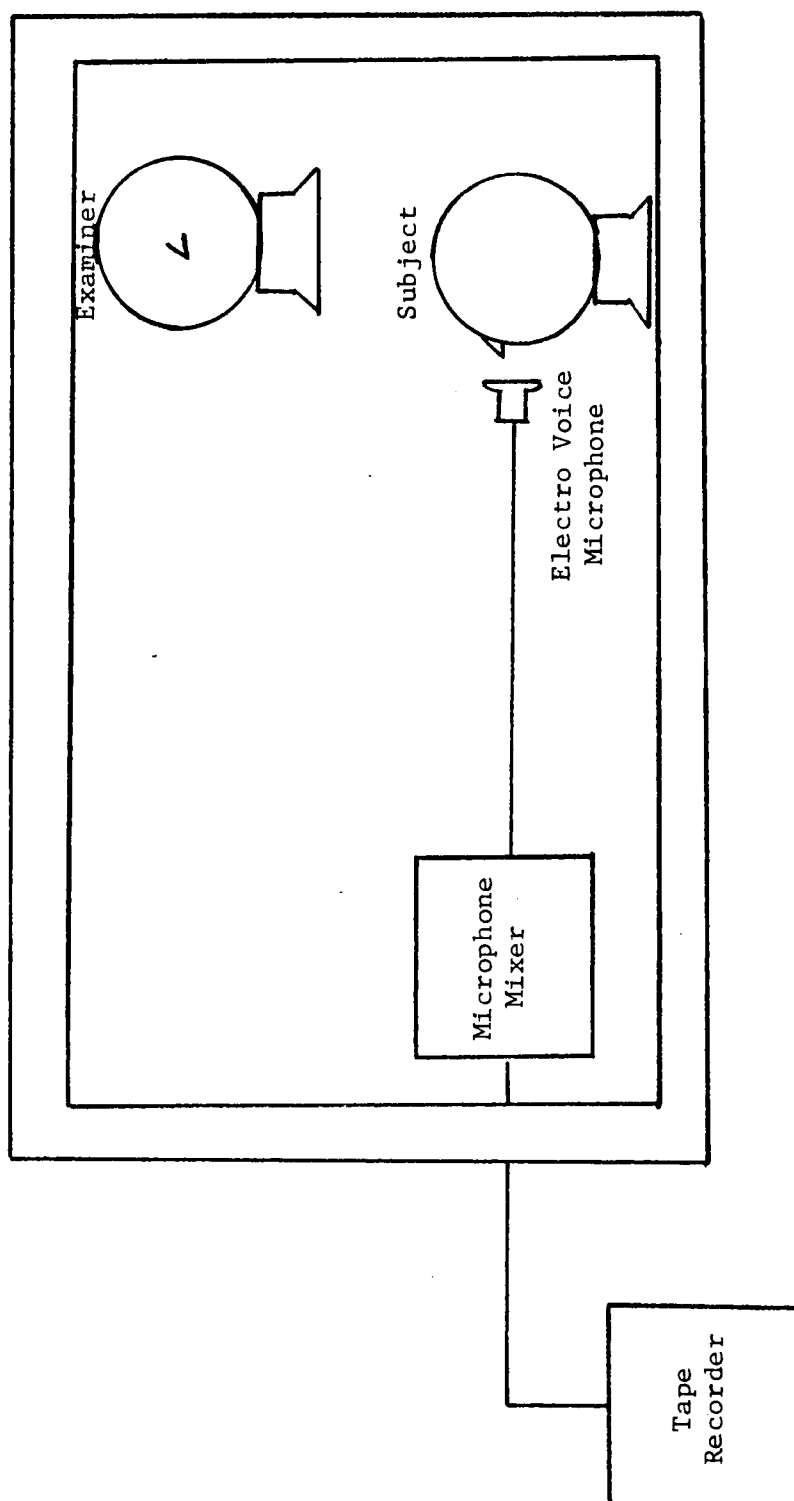


Figure 2. Instrumentation for recording test stimuli.

1. Steady state portion of V_1 defined as that portion of the vowel during which the rate of frequency change of the second formant is at a minimum (see interval A of Figure 3);

2. Preconsonantal transition defined as that portion of V_1 after the steady state portion during which the greatest frequency shift occurs (see interval B of Figure 3);

3. Consonant duration measured from the last vertical striation of the preconsonantal vowel to the first vertical striation of the postconsonantal vowel (see interval C of Figure 3);

4. Postconsonantal transition defined as that portion of V_2 , prior to its steady state, during which the greatest frequency shift occurs (see interval D of Figure 3);

5. Steady state portion of V_2 defined as that portion of the vowel after the postconsonantal transition during which the rate of frequency change of the second formant is at a minimum (see interval E of Figure 3);

6. Disyllable duration measured from the first vertical striation of the preconsonantal vowel steady state to the last vertical striation of the postconsonantal vowel steady state (see interval F of Figure 3).

All measurements were made at or in the area of the second formant.

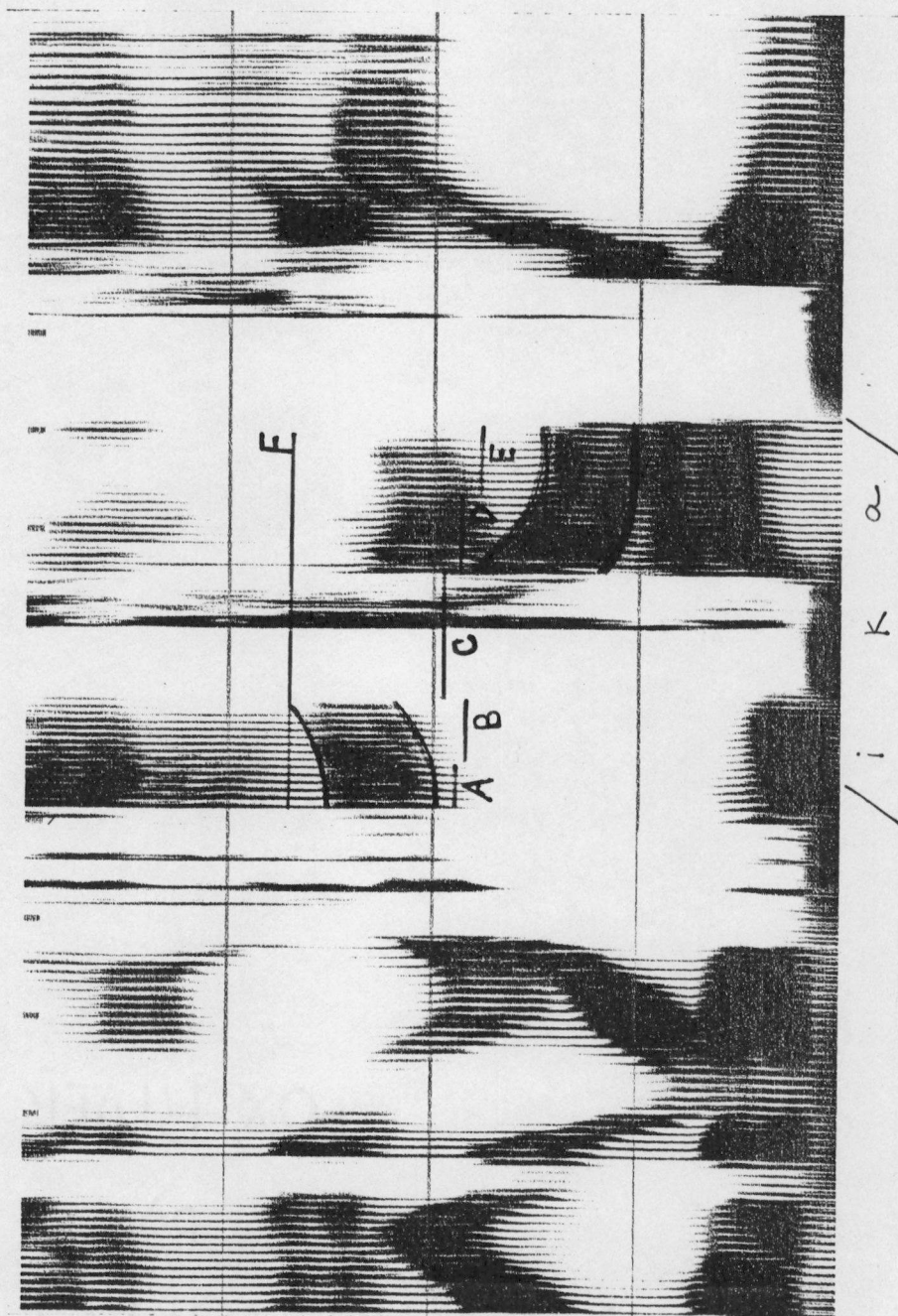


Figure 3. Sample spectrogram indicating points at which the six durational measures were obtained.

CHAPTER III

RESULTS

Two groups (normal and articulatory defective) of adult speakers consisting of ten subjects each, produced 18 vowel + stop consonant + vowel (V_1CV_2) sequences. The V_1CV_2 sequences consisted of the voiceless stop plosives /p/ and /k/ combined with the vowels /a/, /i/, and /u/ to form 6 symmetric and 12 asymmetric V_1CV_2 sequences. The V_1CV_2 sequences were embedded in the phrase, "Say the word V_1CV_2 please." Durational analyses of the following subsegments were performed:

1. Steady state of the preconsonantal vowel (SSV₁);
2. Transition of the preconsonantal vowel (TV₁);
3. Consonant duration (CD);
4. Transition of the postconsonantal vowel (TV₂);
5. Steady state of the postconsonantal vowel (SSV₂);
6. Total disyllable duration (TDD).

The criterion measure was the duration in milliseconds (ms) of each of these subsegments of the V_1CV_2 sequence.

I. RELIABILITY

Two subjects from each group performed the experimental task a second time within two weeks. A standard error for each durational measure from the analysis of spectrograms obtained during the first and second experimental sessions was computed using the formula

S. E. = $\sqrt{\frac{\sum (X_1 - X_2)^2}{2N}}$. The following were the standard errors

in milliseconds (ms) for each of the six measures of duration:

1. $SSV_1 = 4.92$ ms;
2. $TV_1 = 2.46$ ms;
3. $CD = 1.01$ ms;
4. $TV_2 = 0.38$ ms
5. $SSV_2 = 2.13$ ms;
6. $TDD = 3.37$ ms.

These values are comparable to those reported in similar experiments (Gay, 1978).

II. DURATION MEASURES

Duration of Steady State of Preconsonantal Vowel (SSV_1)

For the measure of SSV_1 , the 360 obtained observations ranged from 15.80 ms to 158.00 ms in the normal group with a mean of 61.33 ms. For the articulatory defective speakers, the range was from 39.50 ms to 418.00 ms with a mean of 99.28 ms. The individual subjects' data are presented in Table C-1 of Appendix C.

For this measure and the five subsequent measures, three factor analyses of variance with repeated measures on two factors (Winer, 1971) were used to evaluate durational differences between the two groups of speakers, among the nine vowel contexts and between the two consonants. In the analysis of variance for SSV_1 (see Table 1), there was no significant interaction among groups, vowel contexts, and consonants, between groups and vowel contexts, between groups and consonants, or between vowel contexts and consonants. The absence of significant

Table 1. Summary of analysis of variance for evaluating differences between groups, among vowel contexts, and between consonants, for mean duration of the steady state of the preconsonantal vowel.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>	19			
Groups (G)	1	129563.20	11.14	.003
Error (b)	18	11632.09		
<u>Within Speakers</u>	340			
Vowel Contexts (V)	8	13944.32	12.54	.0009
Consonants (C)	1	4138.173	3.72	NS
GV	8	3671.70	2.71	NS
GC	1	1267.31	0.93	NS
VC	8	1111.87	0.82	NS
GVC	8	1357.03	1.00	NS
Error (w)	306	1355.55		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

interaction indicates that the trends over vowel contexts and the trends over consonants followed the same patterns in both groups of speakers. Figures 4 and 5 display these trends for each group separately. Figure 4 represents the mean durations for each of the nine vowel contexts for the two groups of speakers for both consonants combined. The trends for all three symmetric vowel contexts ($V_1 = V_2$) and five of the six asymmetric vowel contexts ($V_1 \neq V_2$) were the same for both groups of speakers. In Figure 5, which demonstrates the mean durations of SSV_1 for each group for each consonant summed across vowel contexts, the magnitude of the difference in mean duration of SSV_1 between the two consonants may be seen to be slightly larger in the articulatory defective speakers than in the normal speakers. The difference, however, was not statistically significant.

The difference in mean duration of SSV_1 between the two groups of speakers was significant at the 0.003 level. The duration of SSV_1 was significantly longer in the group of articulatory defective speakers than in the group of normal speakers. These differences are presented in Figures 4 and 5. The longer mean duration of SSV_1 for the articulatory defective group was observed for every V_1CV_2 sequence in this study.

The difference among vowel contexts was significant at the 0.0009 level. This was expected since the three vowels used have different durations. Lehiste and Peterson (1960) reported that the intrinsic durations of the particular vowels used in this investigation increase in duration from /i/ to /u/ to /a/. As seen in Figure 6, the mean

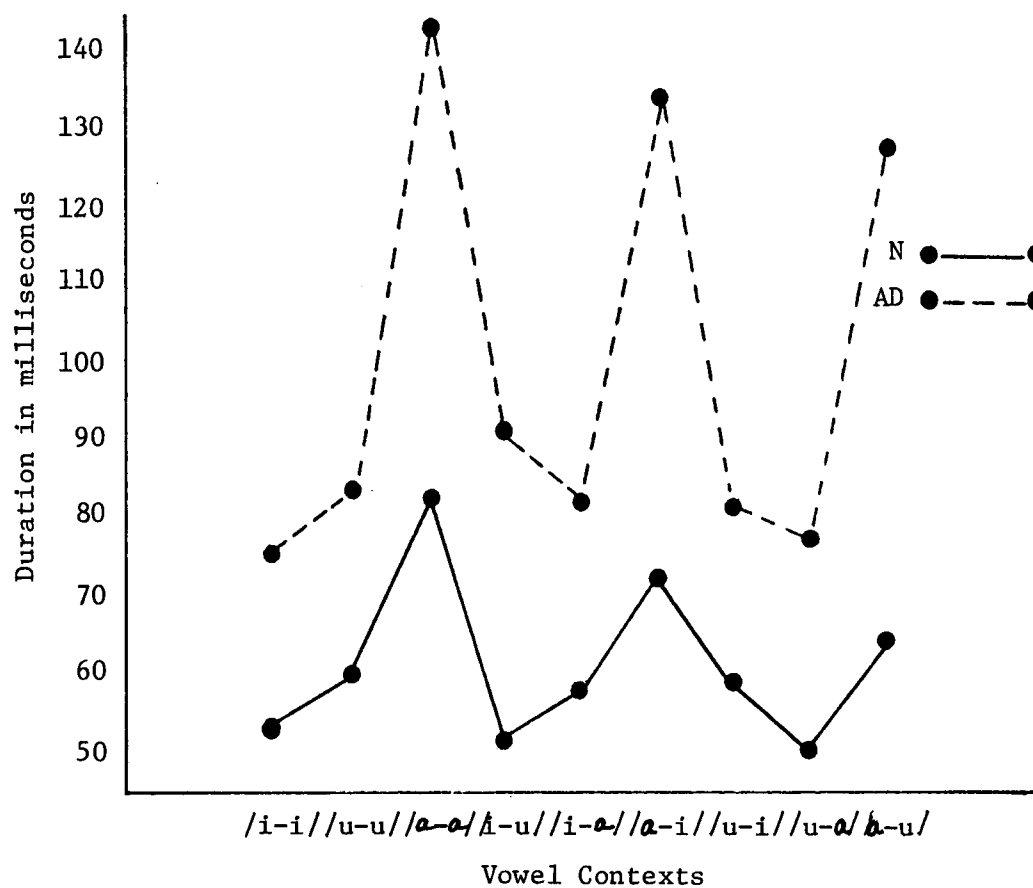


Figure 4. Mean duration of SSV₁ in the nine different vowel contexts in each group of speakers with vowel context summed across consonants.

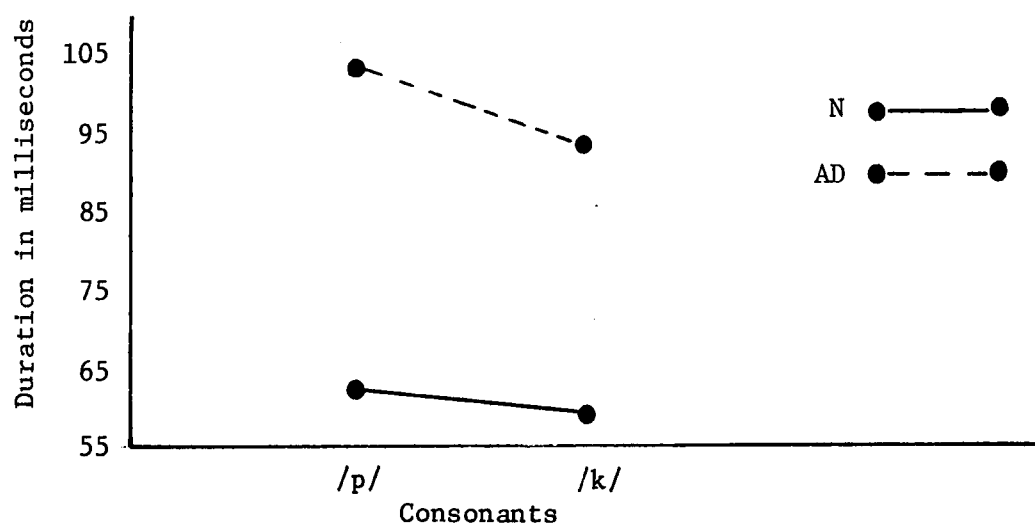


Figure 5. Mean duration of SSV₁ for each group for each consonant summed across vowel context.

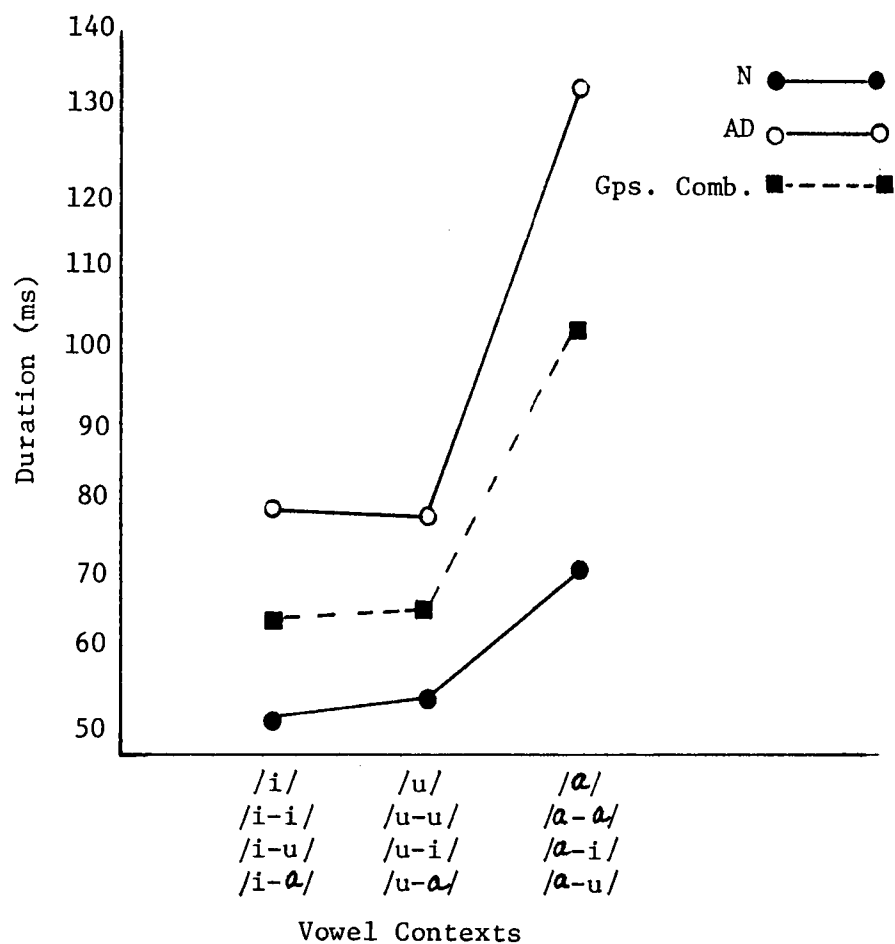


Figure 6. Mean duration of SSV₁ for all syllables beginning with /i/, /u/, /a/ for each group and groups combined.

durations of SSV_1 for all vowel contexts beginning with /i/ were shorter than those beginning with /u/ which were shorter than those beginning with /a/ for both groups of speakers. The Newman-Keuls multiple comparison test statistic was used to determine which ordered pairs were significantly different. The pairwise comparisons among the nine vowel contexts summed for both groups and the two consonants are arranged in Table 2 in order of the increasing magnitude of SSV_1 duration. Though not significantly different from one another, the three vowel contexts beginning with the vowel /a/ had significantly longer SSV_1 durations than vowel contexts beginning with /i/ or /u/. None of the vowel contexts beginning with /i/ or /u/ had a significantly different SSV_1 duration from any of the other vowel contexts beginning with /i/ or /u/.

The difference between the two consonants /p/ and /k/ was not significant. This indicates that the two stop plosives, selected for this study did not appear to have a differential effect on the duration of SSV_1 for either group.

Duration of Transition of Preconsonantal Vowel (TV_1)

The 360 obtained observations of duration of TV_1 ranged from 0.00 ms to 146.15 ms in the normal speakers with a mean of 55.94 ms. For the articulatory defective speakers, the range was from 0.00 ms to 237.00 ms with a mean of 62.34 ms. Individual subject measurements are presented in Table C-2 of Appendix C. The occurrence of 0.00 ms values for TV_1 in some subjects in each group indicates that no obvious frequency shift occurred after the steady state portion of V_1 during

Table 2. Comparisons among the ordered pairs of mean steady state of vowel one (SSV₁) durations for the nine vowel contexts summed across groups and consonants.

Ordered Vowel Contexts	Ordered Vowel Contexts**								
	/i-i/ ms	/u-a/ ms	/i-a/ ms	/u-i/ ms	/i-u/ ms	/u-u/ ms	/a-u/ ms	/a-i/ ms	/a-a/ ms
i-i	0.00	0.01	3.95	6.62	7.41	8.00	31.01*	39.79*	48.98*
u-a		0.00	3.85	6.52	6.31	7.90	31.90*	39.91*	48.88*
i-a			0.00	2.67	3.46	4.05	28.05*	35.85*	45.03*
u-i				0.00	0.79	1.38	25.38*	33.17*	42.36*
i-u					0.00	0.59	24.59*	32.38*	41.57*
u-u						0.00	24.00*	37.79*	40.98*
a-u							0.00	7.01	16.98
a-i								0.00	9.19
a-a									0.00

*Indicates significance ($\alpha = 0.05$).

**Vowel contexts arranged according to the increasing order of the mean SSV₁ durations.

the production of some of the stimuli. In these stimuli, it can be assumed that the total transition occurred across the intervocalic consonant. The 0.00 ms TV_1 was observed approximately twice as often in the articulatory defective speakers as in the normal speakers (27 and 13 times respectively). In the normal speakers, it occurred 7 times when the following consonant was /p/ and 6 times when the following consonant was /k/. In the articulatory defective speakers, it was observed 18 times when the following consonant was /p/ and 9 times when the following consonant was /k/. During production of the bilabial consonant /p/, the tongue is free to move into position for the postconsonantal vowel during the production of the intervocalic consonant, therefore, the transition often occurs during consonant production. Since the tongue position of /k/ is greatly influenced by the forwardness or backwardness of the tongue position of the surrounding vowels (Klatt, 1975), the total transition often occurs across the consonant. The 0.00 ms TV_1 occurs in both the symmetric and asymmetric vowel contexts.

An analysis of variance was used to evaluate differences in TV_1 duration between the two groups of speakers, among the nine vowel contexts, and between the two consonants (see Table 3). There was no significant interaction among groups, vowel contexts, and consonants, between groups and vowel contexts, between groups and consonants, or between vowel contexts and consonants. The trends in the duration of TV_1 over vowel contexts and the trends over consonants were similar for both groups. There was no significant difference in duration of TV_1 between groups, among vowel contexts, or between consonants, thus it

Table 3. Summary of analysis of variance for evaluating differences between groups, among vowel contexts and between consonants, for mean durational differences of transition of the preconsonantal vowel.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>	19			
Groups (G)	1	3695.37	0.50	NS
Error (b)	18	7367.45		
<u>Within Speakers</u>	340			
Vowel Contexts (V)	8	864.03	0.93	NS
Consonants (C)	1	50.10	.05	NS
GV	8	1606.58	1.08	NS
GC	1	117.19	0.08	NS
VC	8	930.47	0.70	NS
GVC	8	1488.65	1.13	NS
Error (w)	306	1321.60		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

can be assumed that the two groups cannot be differentiated on the basis of duration of TV_1 .

Consonant Duration (CD)

For the measurement of consonant duration (CD), the 360 obtained measurements ranged from 94.80 ms to 197.00 ms for the normal speakers with a mean of 145.27 ms. The range for the articulatory defective group was from 110.60 ms to 339.70 ms with a mean of 195.92 ms. The individual subject observations are presented in Table C-3 of Appendix C.

Analysis of variance was used to evaluate differences in CD between the two groups of speakers, among the nine vowel contexts and between consonants (see Table 4). There was no significant interaction among groups, vowel contexts, and consonants, between groups and vowel contexts, between groups and consonants, or between vowel contexts and consonants, therefore, it may be assumed that trends over vowel contexts and consonants were the same for both groups of speakers. This similarity in trends for both groups is graphically presented in Figures 7 and 8. Figure 7 presents the mean durations of the consonants for each group for each of the nine vowel contexts averaged for the two consonants. Inspection of this graph reveals that consonant durations varied similarly in both groups in all symmetric vowel contexts and in five of the six asymmetric vowel contexts. Figure 8 reveals that the articulatory defective speakers showed a greater magnitude of difference between the two consonants than did the normal speakers, but trends for both groups were similar.

Table 4. Summary of analysis of variance for evaluating differences between groups, among vowel contexts and between consonants with reference to mean consonant duration.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>	19			
Groups (G)	1	230867.77	18.20	.0005
Error (b)	18	12683.33		
<u>Within Speakers</u>	340			
Vowel Contexts (V)	8	3016.36	22.69	.0001
Consonants (C)	1	8314.57	62.56	.0001
GV	8	1451.04	2.34	NS
GC	1	1631.15	2.63	NS
VC	8	132.91	0.16	NS
GVC	8	620.80	0.73	NS
Error (w)	306	846.59		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

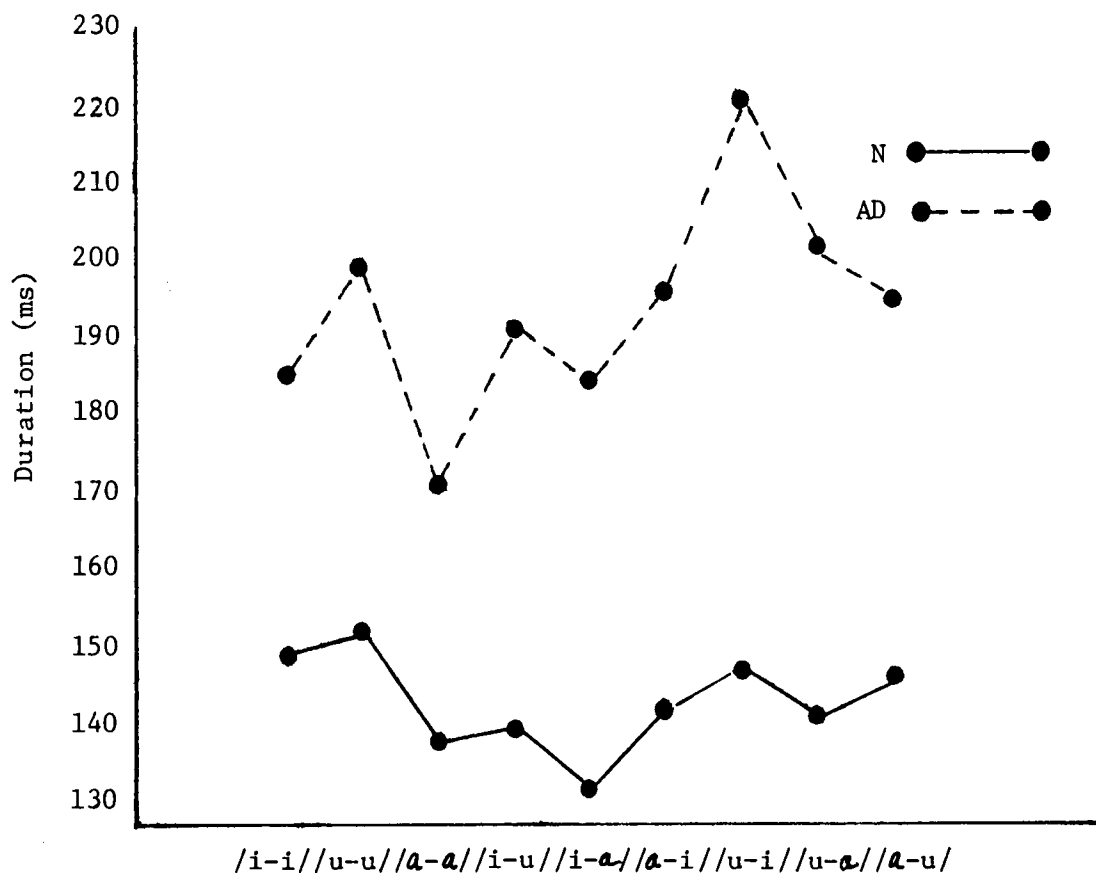


Figure 7. Mean duration of consonant in the nine vowel contexts in normal and articulatory defective speakers with vowel contexts summed across consonants.

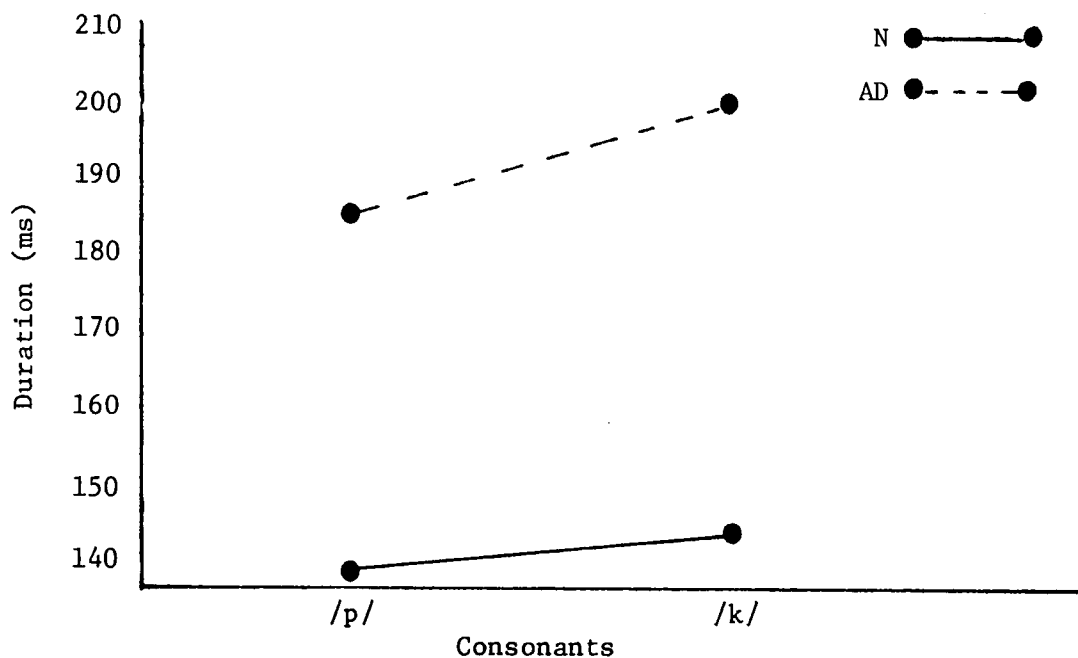


Figure 8. Mean durations for each consonant for each group summed across vowel contexts.

The mean CD in the normal speakers was 145.27 ms and in the articulatory defective speakers was 195.92 ms. This group difference of 50.65 ms was significant at the 0.0005 level.

The differences in CD among the vowel contexts was significant at the 0.0001 level. Multiple comparisons using the Tukey test statistic were performed to assess differences among the vowel contexts. The pairwise comparisons among the nine vowel contexts averaged for both groups and the two consonants are arranged in order of increasing CD duration from left to right and top to bottom in Table 5. For all pairs of conditions marked by an asterisk, the difference between the two consonant durations was significant ($\alpha = 0.05$). The results indicate that the longest consonant duration in the vowel context /u-i/ was significantly longer than the two shortest consonant durations in the vowel contexts /a-a/ and /i-a/. The second longest consonant duration in the vowel context /u-u/ was significantly different from the shortest consonant duration which occurred in the /a-a/ vowel context. The two longest consonant durations in the vowel contexts /u-i/ and /u-u/ were not significantly different from one another.

The mean difference in duration between the two consonants was significant at the 0.0001 level. Specifically the duration of /k/ is significantly longer than the /p/ for both groups, regardless of vowel context. The magnitude of difference between the two consonants was 9.91 ms. This result agrees with the data reported by Klatt (1975) who stated that /k/ was significantly longer than /p/ in all contexts studied and the research findings of Barry and Kuenzel (1975) who

Table 5. Comparisons among the ordered pairs of mean consonant durations (CD) for the nine vowel contexts summed across groups and consonants.

Ordered Vowel Contexts	Ordered Vowel Contexts**								
	/a-a/	/i-a/	/i-u/	/i-i/	/a-i/	/a-u/	/u-a/	/u-u/	/u-i/
	157.01 ms	160.66 ms	166.59 ms	169.75 ms	171.23 ms	172.52 ms	173.70 ms	177.95 ms	185.95 ms
a-a	0.00	3.66	9.58	12.74	14.22	15.51	16.69	19.94	28.94*
i-a		0.00	5.92	9.08	10.56	11.85	12.33	17.28	25.28*
i-u			0.00	3.16	4.64	5.93	7.11	11.36	19.36
i-i				0.00	1.48	2.77	3.95	8.20	16.20
a-i					0.00	1.29	2.47	6.72	14.72
a-u						0.00	1.18	5.43	13.43
u-a							0.00	4.25	12.25
u-u								0.00	8.00
u-i									0.00

*Indicates significance ($\alpha = 0.05$).

**Vowel contexts arranged according to the increasing order of the mean CD.

reported that the closure phase of /k/ was significantly longer than the closure phase of /p/.

Duration of Transition of Postconsonantal
Vowel (TV₂)

The 360 obtained measures of TV₂ duration ranged from 0.00 ms to 150.00 ms in the normal speakers with a mean of 58.99 ms. The articulatory defective group ranged from 0.00 ms to 197.50 ms with a mean of 93.68 ms. The measures for individual subjects are contained in Table C-4 of Appendix C.

Analysis of variance was used to evaluate durational differences in TV₂ between the two groups of speakers, among the nine vowel contexts and between the two consonants. The results of the analysis are presented in Table 6. The interactions among groups, vowel contexts, and consonants, between groups and vowel contexts, and between groups and consonants were not significant at the 0.05 level. There was a significant interaction between vowel contexts and consonants. This interaction for each group separately is displayed in Figure 9. Although the interaction between groups and vowel contexts was not significant at the 0.05 level, graphical representation reveals obvious reversal in the trends over vowel contexts for the two groups of speakers. The F-value for the interaction between groups and vowel contexts approached significance. Because of the significant vowel context by consonant interaction and the nearly significant group by vowel context interaction, tests among vowel contexts and between consonants were not appropriate. Since the differences between groups were significant, the Newman-Keuls

Table 6. Summary of analysis of variance for evaluating differences between groups, among vowel contexts, and between consonants with reference to mean duration of transition of the postconsonantal vowel.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>	19			
Groups (G)	1	108331.66	36.12	.0001
Error (b)	18	2999.36		
<u>Within Speakers</u>	340			
Vowel Contexts (V)	8	2217.12	0.46	NS
Consonants (C)	1	7.32	0.01	NS
GV	8	4599.42	3.15	NS (0.06)
GC	1	2774.17	1.90	NS
VC	8	4857.95	3.13	.002
GVC	8	1460.05	0.94	NS
Error	306	1551.31		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

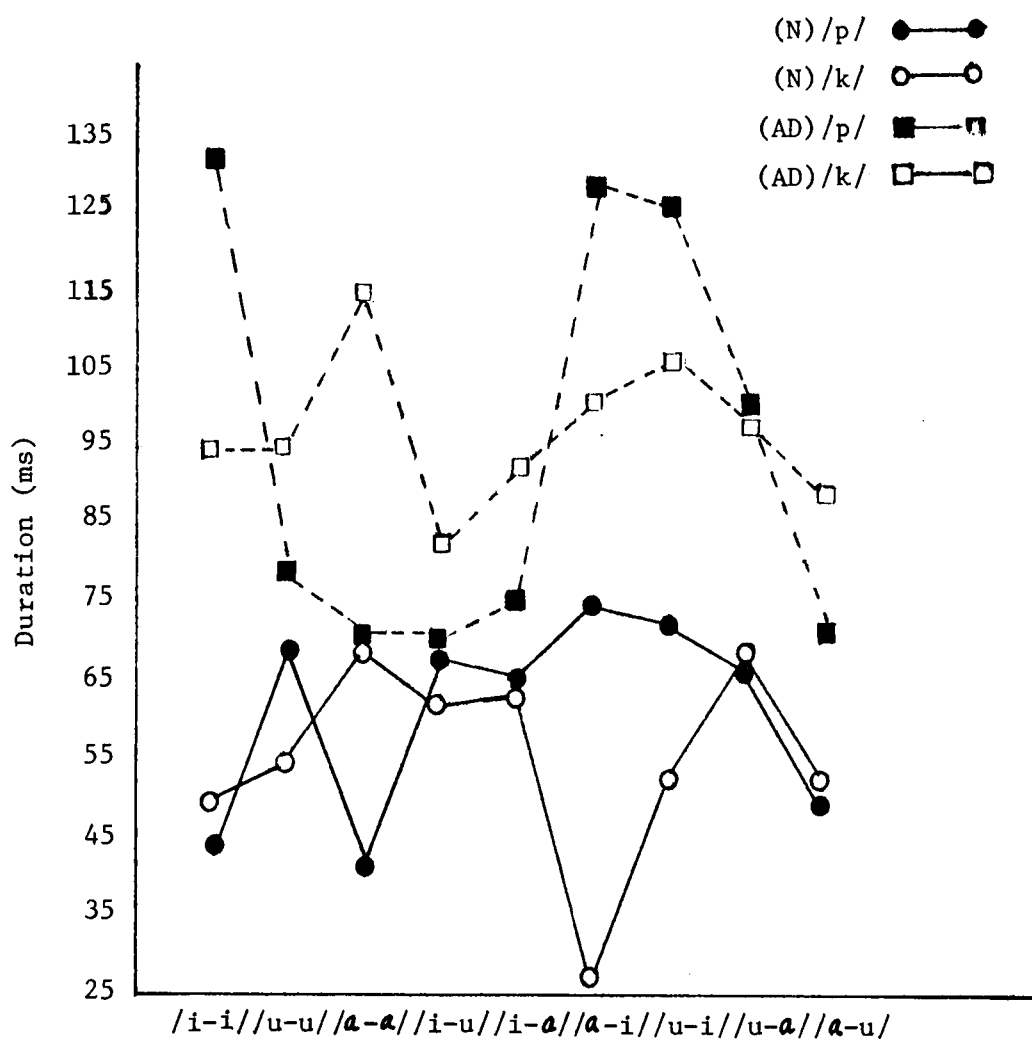


Figure 9. Mean TV₂ durations for each of the two consonants in each vowel context for each group.

multiple comparison test statistic was used, for each group separately, to determine which vowel contexts were significantly different ($\alpha = 0.05$) when each of the two consonants separately were in the intervocalic position (see Tables 7-10). The results of the multiple comparisons indicated that in the normal speakers, there were no significant differences in TV₂ duration between vowel contexts when the /p/ was the intervocalic consonant nor when the /k/ was the intervocalic consonant. In the articulatory defective speakers, the three longest TV₂ durations when /p/ was the intervocalic consonant occurred in the vowel contexts /upi/, /api/, and /ipi/. The TV₂ durations in these three contexts were not significantly different from one another but all three were significantly different from the TV₂ durations in the other six vowel contexts (/upa/, /ipu/, /apa/, /apu/, /ipa/, and /upu/). In the articulatory defective group, when /k/ was the intervocalic consonant, there were no significant differences in TV₂ duration among vowel contexts. Considering the results for the articulatory defective speakers, the six shortest TV₂ durations were associated with syllables in which the bilabial intervocalic consonant /p/ was followed by a back vowel (/u/ or /a/). The three longest TV₂ durations were associated with syllables in which the bilabial intervocalic consonant /p/ was followed by a front vowel (/i/). The /i/ had a relatively short duration compared with /u/ and /a/ and the consonant /p/ had a slightly shorter duration than /k/ as evidenced by measurement of intervocalic consonant duration. Thus it appears that in the articulatory defective speakers, the longer TV₂ durations occur with the shorter consonant in the intervocalic

Table 7. Comparisons among the ordered pairs of mean durations of the transition of the postconsonantal vowel for normal speakers when /p/ is the intervocalic consonant.

Ordered Disyllables Containing /p/ in Intervocalic Position**									
Ordered Disyllables	/a pa/	/ipi/	bpu/	/ipa/	/upa/	/ipu/	/upu/	/upi/	/api/
	41.48 ms	44.64 ms	49.77 ms	66.36 ms	66.36 ms	68.73 ms	69.52 ms	72.68 ms	75.05 ms
a pa	0.00	3.15	8.29	24.88	24.88	27.25	28.04	31.20	33.57
ipi		0.00	5.13	21.72	21.72	24.09	24.88	28.04	30.41
a pu			0.00	16.59	16.59	18.96	19.75	22.91	25.28
ipa				0.00	0.00	2.37	3.16	6.32	8.69
upa					0.00	2.37	3.16	6.32	8.69
ipu						0.00	0.79	3.95	6.32
upu							0.00	3.16	5.53
upi								0.00	2.37
api									0.00

*Indicates significance. None of the comparisons are significant ($\alpha = 0.05$).

**Disyllables arranged according to the increasing order of the mean TV₂ duration.

Table 8. Comparisons among the ordered pairs of mean durations of the transition of the postconsonantal vowel for articulatory defective speakers when /p/ is the intervocalic consonant.

Ordered Disyllables Containing /p/ in Intervocalic Position**									
Ordered Disyllables	/upa/ 61.62 ms	/ipu/ 69.13 ms	/apa/ 70.71 ms	/apu/ 71.10 ms	/aip/ 76.63 ms	/upu/ 79.00 ms	/upi/ 126.40 ms	/api/ 129.56 ms	/ipi/ 132.72 ms
upa	0.00	7.51	9.09	9.48	15.01	17.38	64.78*	67.94*	71.10*
ipu		0.00	1.58	1.97	7.50	9.87	57.27*	60.45*	63.59*
apa			0.00	0.39	5.92	8.29	55.69*	58.85*	62.01*
apu				0.00	5.53	7.90	55.30*	58.46*	61.62*
ipa					0.00	2.37	49.77*	52.93*	56.09*
upu						0.00	47.40*	50.56*	53.72*
upi							0.00	3.16	6.32
api								0.00	3.16
ipi									0.00

*Indicates significance ($\alpha = 0.05$).

**Disyllables arranged according to the increasing order of the mean TV₂ durations.

Table 9. Comparisons among the ordered pairs of mean durations of the transition of the postconsonantal vowel for normal speakers when /k/ is the intervocalic consonant.

Ordered Disyllables	Ordered Disyllables Containing /k/ in Intervocalic Position**									
	/a-ki/ 27.65 ms	/a-ku/ 52.14 ms	/iki/ 52.93 ms	/uki/ 53.33 ms	/uku/ 54.90 ms	/ika/ 63.20 ms	/iku/ 65.18 ms	/uka/ 68.34 ms	/aka/ 69.52 ms	
a-ki	0.00	24.49	25.28	25.68	27.25	35.55	37.62	40.69	41.87	
a-ku		0.00	0.79	1.19	2.76	11.06	13.04	16.20	17.38	
iki			0.00	0.40	1.97	10.27	12.25	15.41	16.66	
uki				0.00	1.57	9.87	11.85	15.01	16.19	
uku					0.00	8.30	10.28	13.44	14.62	
ika						0.00	1.98	5.14	6.32	
iku							0.00	3.16	4.34	
uka								0.00	1.18	
aka									0.00	

*Indicates significance. None of the pairwise comparisons is significant.

**Disyllables arranged according to the increasing order of the mean TV₂ durations.

Table 10. Comparisons among the ordered pairs of mean durations of the transition of the postconsonantal vowel for articulatory defective speakers when /k/ is the intervocalic consonant.

Ordered Disyllables	Ordered Disyllables Containing /k/ in Intervocalic Position**									
	/iku/ 82.16 ms	iku/ 84.53 ms	/ika/ 88.88 ms	/iki/ 94.41 ms	/uku/ 95.20 ms	/uka/ 100.33 ms	/aki/ 101.52 ms	/uki/ 106.65 ms	/aka/ 115.74 ms	
iku	0.00	2.37	6.72	12.25	13.04	18.17	19.36	24.99	33.58	
aku		0.00	4.35	9.88	10.67	15.80	16.99	22.12	31.13	
ika			0.00	5.52	6.32	11.45	12.64	17.77	26.86	
iki				0.00	0.79	5.92	7.11	12.24	21.33	
uku					0.00	5.13	6.32	11.45	20.54	
uka						0.00	1.32	6.32	15.41	
aki							0.00	4.48	14.22	
uki								0.00	9.09	
aka									0.00	

*Indicates significance. None of the pairwise comparisons is significant.

**Disyllables arranged according to the increasing order of the mean TV₂ durations.

position and the shortest vowel in the postconsonantal position. The duration of a transition depends to some extent on how far the tongue must move in order to achieve the position for the following sound. The /k/ phoneme is known to assume a more forward or backward tongue placement as a result of surrounding sounds (Klatt, 1975). It can therefore be assumed that the lack of significant differences in both groups for TV₂ durations when /k/ was in the intervocalic position can be attributed to smaller differences in distance of tongue movement between the /k/ and the following vowel.

As previously mentioned, the mean duration of TV₂ was significantly longer (0.0001 level) in the articulatory defective group than in the group of normal speakers. The mean TV₂ duration in the normal speakers was 58.98 ms and in the articulatory defective speakers, it was 93.68.

Duration of Steady State of Postconsonantal Vowel (SSV₂)

For the measure of SSV₂, the 360 obtained observations ranged from 11.85 ms to 177.75 ms with a mean of 64.25 ms in the normal speakers. In the group of articulatory defective speakers, the range was from 15.80 ms to 339.70 ms with a mean of 87.38 ms.

Analysis of variance was used to evaluate durational differences between the two groups of speakers, among the nine vowel contexts and between the two consonants (see Table 11). There were no significant interactions except the group by consonant interaction. The trends for the nine vowel contexts for both groups are displayed in Figure 10. One trend reversal in the duration of SSV₂ existed in the vowel context

Table 11. Summary of analysis of variance for evaluating differences between groups, among vowel contexts, and between consonants with reference to the steady state of the postconsonantal vowel.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>	19			
Groups (G)	1	48147.41	5.35	.03
Error (b)	18	9003.37		
<u>Within Speakers</u>	340			
Vowel Contexts (V)	8	18219.51	10.38	.001
Consonant (C)	1	12638.03	7.20	.02
GV	1	1485.30	1.87	NS
GC	1	8698.57	10.97	.01
VC	8	1755.57	1.08	NS
GVC	8	792.68	0.49	NS
Error	306	1621.75		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

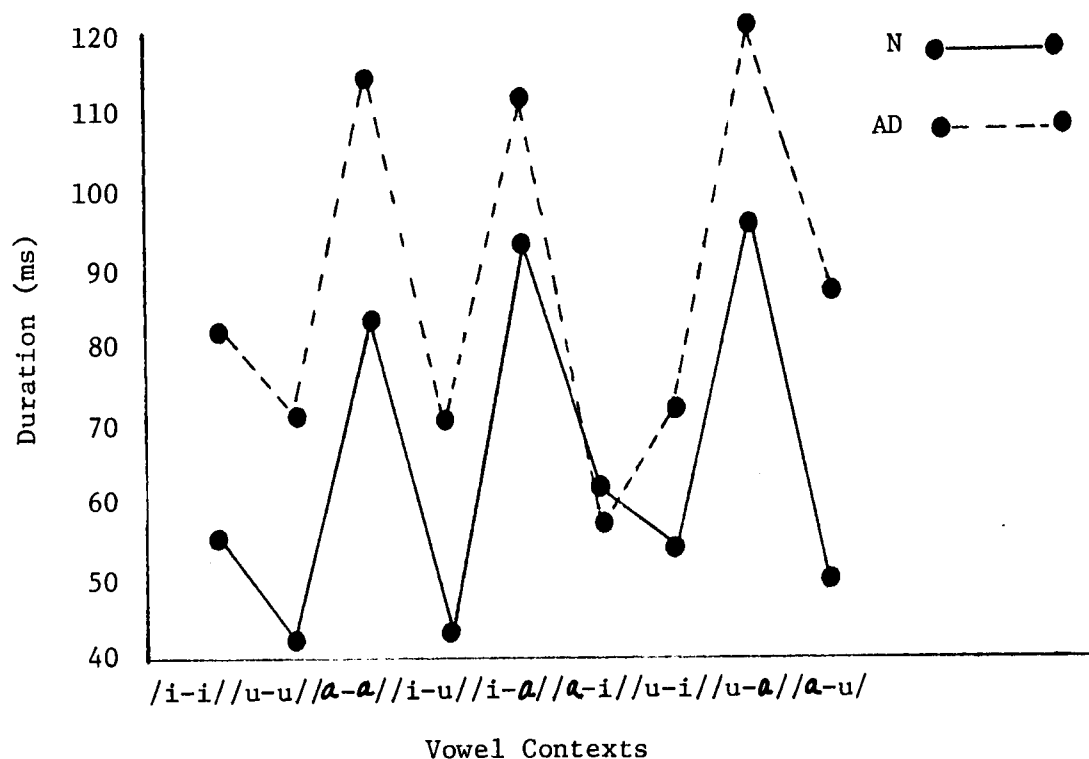


Figure 10. Mean duration of SSV₂ in the nine vowel contexts summed across consonants.

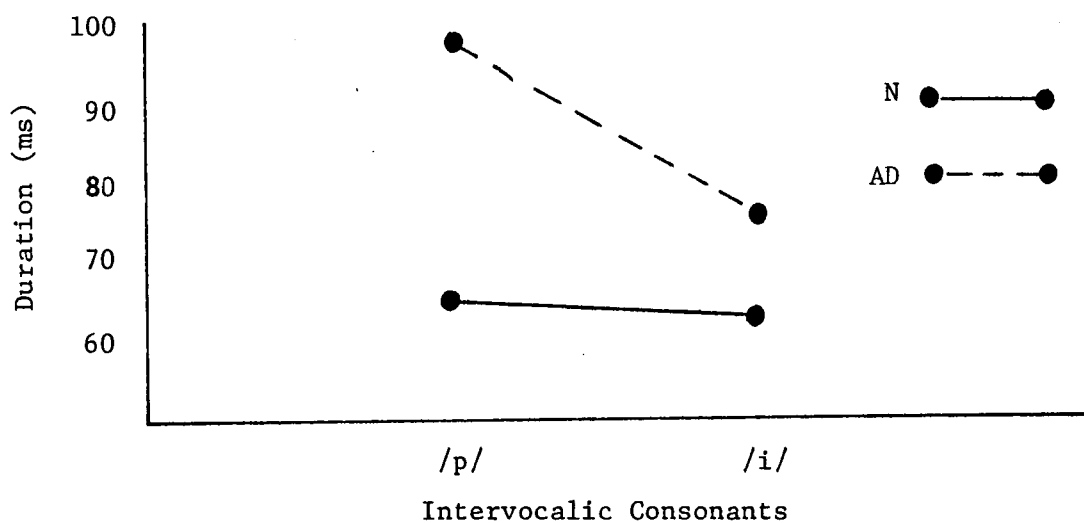


Figure 11. Mean duration for SSV₂ for each group for the two consonants summed across vowel contexts.

/u-i/ indicating the presence of some interaction between group and vowel context, however, the difference was not statistically significant.

The nonparallel lines of Figure 11 illustrate the group by consonant interaction. The Tukey test statistic was used to determine which pairs of consonants were significantly different. The significant pairwise comparisons for the two consonants are presented in Table 12. The consonant /p/ in the articulatory defective group was associated with a significantly longer SSV₂ than the /k/ in that same group and also it was significantly longer than both the /p/ and /k/ in the normal speakers. The /p/ and /k/ in the normal speakers were not significantly different from one another. Despite the difference in trends between the two groups, the mean difference in duration of SSV₂ between consonants was significant at the 0.02 level. The mean duration of SSV₂ when preceded by /p/ was 81.74 ms and was significantly longer than the mean duration when preceded by /k/ (69.89 ms).

The difference between the two groups of speakers was significant at the 0.03 level. The mean duration of SSV₂ was significantly longer in the articulatory defective group than in the group of normal speakers. The SSV₂ durations in every context were longer in the articulatory defective speakers than in the normal speakers. The mean SSV₂ duration in the normal speakers was 64.25 ms and in the articulatory defective group, it was 87.38 ms.

The differences among vowel contexts was significant at the 0.001 level. This was expected since the three vowels have different intrinsic durations (Lehiste and Peterson, 1960). The SSV₂ durations for all

Table 12. Comparisons among the ordered pairs of mean durations of the steady state of the postconsonantal vowel for normal and articulatory defective speakers for each consonant separately summed across vowel contexts.

Group	Ordered Consonants**			
	N	N	AD	AD
Ordered Consonants	/k/ 63.24 ms	/p/ 65.26 ms	/k/ 76.54 ms	/p/ 98.22 ms
(N) /k/	0.00	2.02	13.30	34.98*
(N) /p/		0.00	11.28	32.96*
(AD) /k/			0.00	21.68*
(AD) /p/				0.00

*Indicates significance.

**Consonants arranged according to the increasing order of the mean SSV₂ durations.

vowel contexts ending with /i/ were averaged, those ending in /u/ were averaged and those ending in /a/ were averaged, summed across consonants, and are presented in Figure 12. The Newman-Keuls multiple comparison test statistic was used to determine which ordered pairs were significantly different. The pairwise comparisons among the nine vowel contexts summed for both groups and the two consonants are arranged in Table 13 in order of the increasing magnitude of SSV₂ duration. Though not significantly different from one another, the three vowel contexts beginning with the vowel /a/ had significantly longer SSV₂ durations than vowel contexts beginning with /i/ or /u/. None of the vowel contexts beginning with /i/ or /u/ had a significantly different SSV₂ duration from any of the other vowel contexts beginning with /i/ or /u/.

Total Disyllable Duration (TDD)

For the measure of TDD, the 360 obtained observations ranged from 264.65 ms to 493.75 ms in the group of normal speakers with a mean of 385.52 ms. The range for the articulatory defective speakers was from 347.60 ms to 1082.30 ms with a mean of 537.57 ms. The individual subject measures are presented in Table C-6 of Appendix C.

An analysis of variance was used to evaluate the durational differences between the two groups of speakers, among the nine vowel contexts and between the two consonants (see Table 14). There was no significant interaction among groups, vowel contexts and consonants, between groups and vowel contexts, between groups and consonants, or between vowel contexts and consonants. The absence of significant interaction indicated that the trends over vowel contexts and the

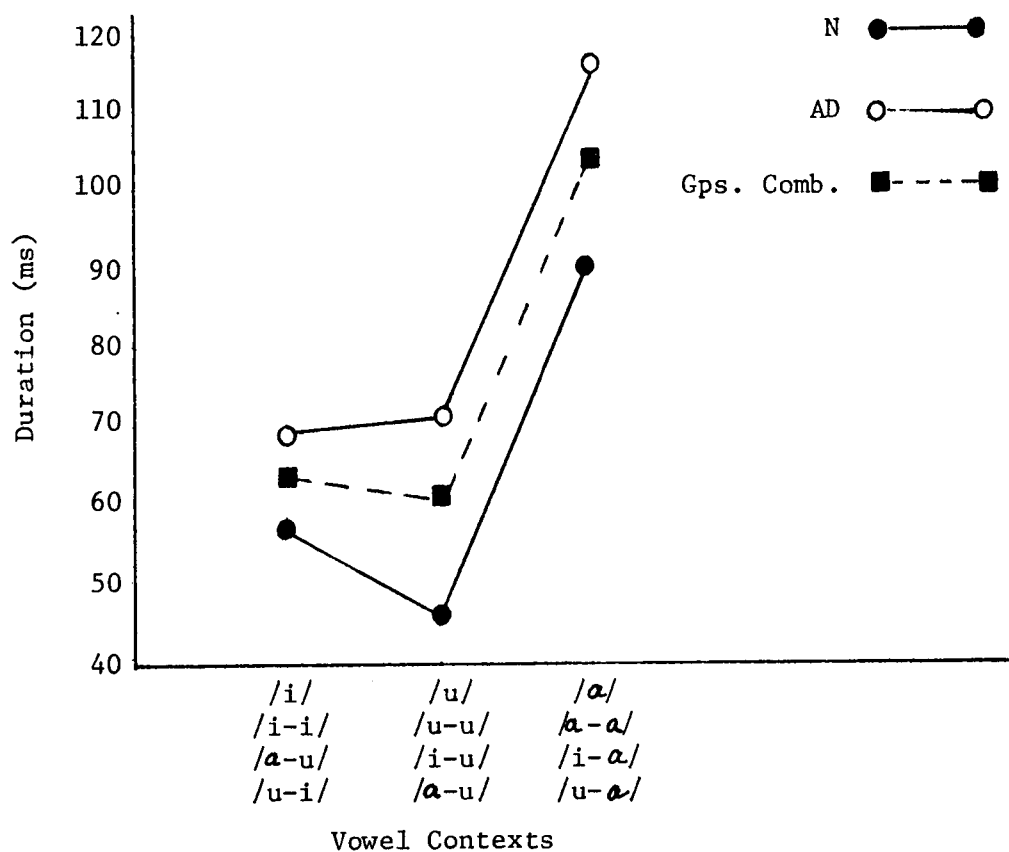


Figure 12. Mean duration of SSV₂ of all syllables ending with each of the three vowels averaged across consonants for each group of speakers and all speakers combined.

Table 13. Comparisons among the ordered pairs of mean steady state of vowel two (SSV₂) durations for the nine vowel contexts summed across groups and consonants.

Ordered Vowel Contexts	Ordered Vowel Contexts**								
	/i-u/ 56.68 ms	/u-u/ 57.18 ms	/a-i/ 58.26 ms	/u-i/ 62.61 ms	/a-u/ 68.14 ms	/i-i/ 69.03 ms	/a-a/ 98.95 ms	/i-a/ 103.10 ms	/u-a/ 108.43 ms
i-u	0.00	0.50	1.58	5.93	11.46	12.35	42.27*	46.42*	51.75*
u-u		0.00	1.08	5.43	10.96	11.85	41.77*	45.92*	51.25*
a-i			0.00	4.35	9.88	10.77	40.69*	44.84*	50.17*
u-i				0.00	5.53	6.42	36.34*	40.49*	45.82*
a-u					0.00	0.89	30.81*	34.96*	40.29*
i-i						0.00	29.92*	34.07*	39.40*
a-a							0.00	4.15	9.48
i-a								0.00	5.33
u-a									0.00

*Indicates significance ($\alpha = 0.05$).

**Vowel contexts arranged according to the increasing order of the mean SSV₂ durations.

Table 14. Summary of analysis of variance for evaluating differences between groups, among vowel contexts, and between consonants with reference to mean disyllable duration.

Source	<u>df</u>	<u>MS</u>	<u>F</u> *	<u>p</u> **
<u>Between Speakers</u>				
Group (G)	1	2080811.85	28.07	.0001
Error (b)	18	74140.94		
<u>Within Speakers</u>				
Vowel Contexts (V)	8	19316.91	29.23	.0001
Consonants (C)	1	9452.04	14.30	.005
GV	8	2830.53	0.80	NS
GC	1	1327.30	0.40	NS
VC	8	660.81	0.19	NS
GVC	8	3277.61	0.93	NS
Error (w)	306	3526.42		
Total	359			

*F ratios: MSG/MSE_b ; $MSV/MSVC$; $MSC/MSVC$; $MSGV/MSGVC$; $MSGC/MSGVC$; $MSVC/MSE_w$; $MSGVC/MSE_w$.

**Point in the F-distribution.

trends over consonants for the two groups of speakers were similar. In Figures 13 and 14, these trends are presented for each group separately. Figure 13 presents mean TDD in the nine vowel contexts summed across consonants. The articulatory defective speakers had longer TDDs than the normal speakers. In Figure 14, the mean TDD is presented for each group for each consonant summed across vowel contexts and again it can be seen that the TDDs were longer in the group of articulatory defective speakers.

The mean difference in TDD between the two groups of speakers was significant at the 0.0001 level. The TDD mean of 537.57 ms in the articulatory defective speakers was significantly longer than the mean of 385.52 ms in the normal speakers.

The differences in duration of TDD among the nine vowel contexts was significant at the 0.0001 level. This significance was expected since the three vowels used in the investigation have different intrinsic durations (Lehiste and Peterson, 1960). Figure 13 which contains the mean TDD for each group separately and for the two groups combined presents the effect of each of the vowel contexts on TDD. Inspection of this figure reveals that the three symmetric vowel contexts followed the order of increasing duration from /i/ to /u/ to /a/ reported by Lehiste and Peterson (1960) in the group of normal speakers but the order in the group of articulatory defective speakers was from /u/ to /i/ to /a/. These differences were not significant and may be due to individual subject variation.

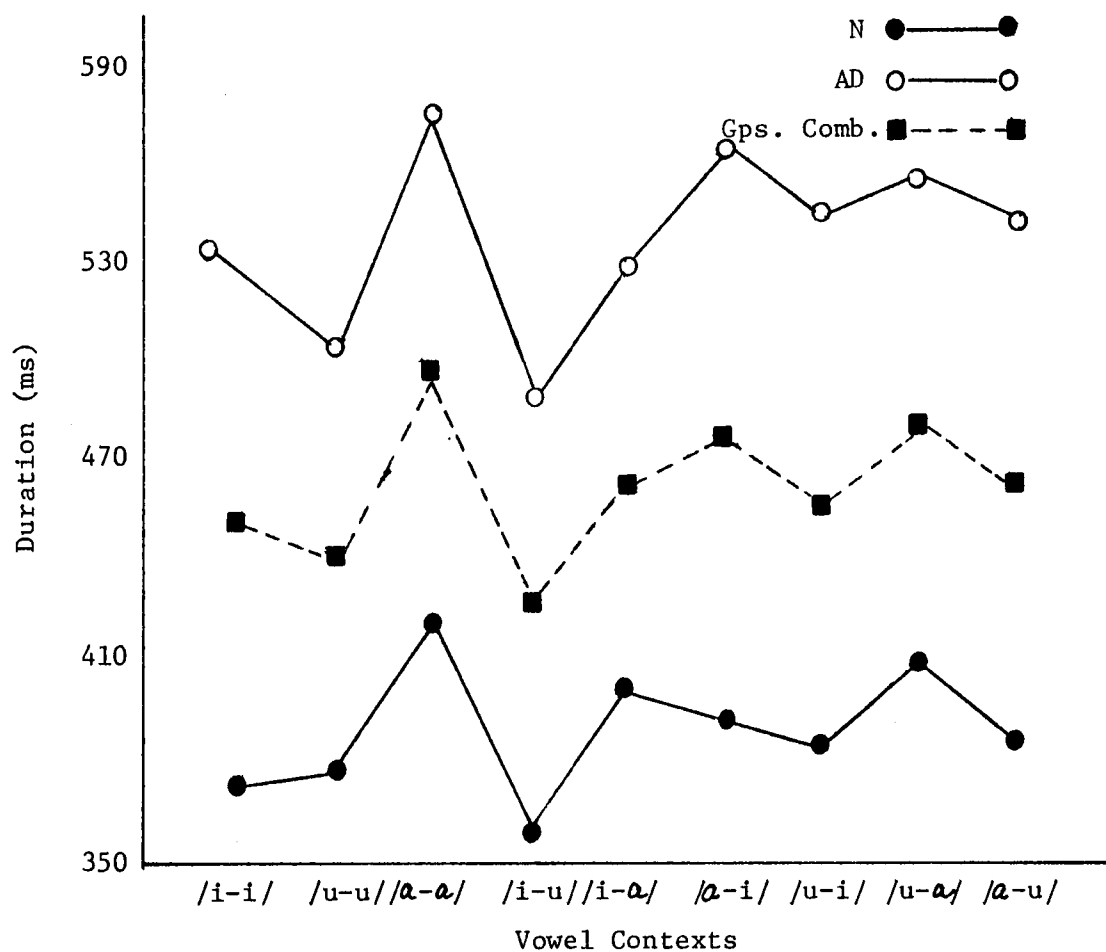


Figure 13. Mean TDD for each of the vowel contexts summed across consonants for each group separately and for groups combined.

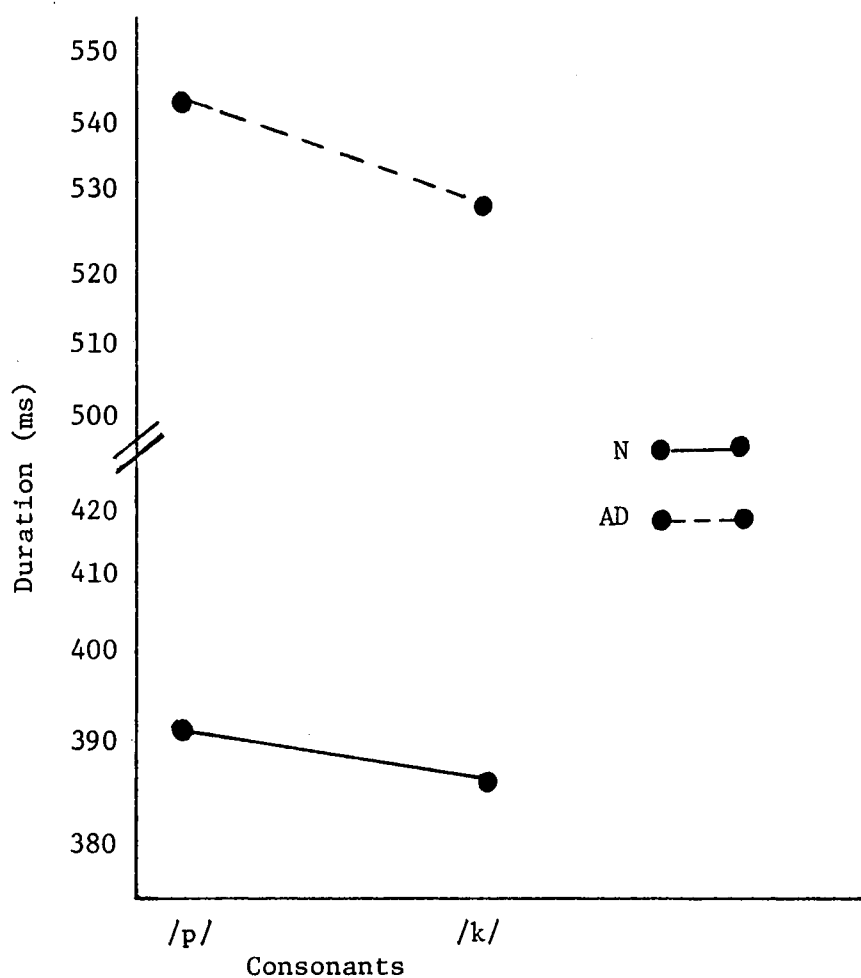


Figure 14. Mean TDD for each group for each of the two consonants summed across vowel contexts.

The mean differences in TDD between the two consonants was significant at the 0.005 level. The mean TDD of 466.67 ms when the /p/ was in the intervocalic position was significantly longer than the mean TDD of 456.42 ms when the /k/ was in the intervocalic position.

III. INDIVIDUAL SUBJECT VARIATION

All of the analyses performed were comparisons of means. The means for the articulatory defective speakers were significantly longer than those of the normal speakers on all measures except the transition of vowel one (TV₁). There were, however, considerable individual subject variations. Subjects #2, #10, and #12 (normal speakers) had longer SSV₁ durations than those of subjects #6 and #17 (articulatory defective speakers). This durational measure was significantly different between groups. Subjects #14, #16, #18, and #19 (normal speakers) had longer TV₁ durations than subjects #6, #8, #9, and #11 (articulatory defective speakers). This measure was not significantly different between groups of speakers. The mean consonant durations (CD) of subjects #5 and #16 (normal speakers) were slightly longer than those of subjects #9 and #15 (articulatory defective speakers). This measure was significantly different between groups. For the measure of TV₂, all normal speakers had durations which were shorter than all TV₂ durations in the articulatory defective speakers. There was a significant difference between groups on this duration measure. For the measure of SSV₂, subjects #2, #4, and #18 (normal speakers) had durations as long or longer than subjects #3, #9, and #15 (articulatory defective speakers). This

duration measure was significantly different between groups. For the measure of TDD, all normal speakers had durations shorter than all TDD durations in the articulatory defective speakers. These individual differences can be seen in Tables C-1 - C-7 of Appendix C. No subject in the articulatory defective group was consistently shorter on all six durational measures than any subject in the normal speakers group.

Two of the ten articulatory defective speakers (#9 and #15) had mean subsegment durations which were very close to the means exhibited by the normal speakers. Both of these subjects scored 130 on the Templin-Darley Tests of Articulation. This score is the highest achieved by any of the subjects in the group of articulatory defective speakers. Both, however, achieved scores at the lower end of the continuum on the Isolated Volitional Oral Movements test (100 and 102 respectively). Subject #9 scored the highest on the measure of diadochokinetic rate of any subject in either group and subject #15 scored in the middle range of values when both groups were considered together. These two subjects exhibited durational values more similar to those of the normal subjects and with the exception of the Isolated Volitional Oral Movements score, they achieved test results similar to the normal articulating subjects. In the normal group, subject #2 exhibited test scores commensurate with all of the normal subjects, but his durational values were more similar to those of the articulatory defective subjects.

In general, two of the articulatory defective subjects exhibited consistently short durational values relative to the other subjects in that group and performed similarly to the normal speakers. Both subjects

scored exactly one standard deviation below the norm for an eight year old child on the Templin-Darley Tests of Articulation while seven of the other eight articulatory defective subjects scored considerably lower. It may be that these two subjects had spurious results on the articulation test and did not, in fact, satisfy the criteria for inclusion in the study. All of the test results for subject #2 (normal) were well within the normal range, however, durational values were more similar to the articulatory defective than the normal speakers in this investigation.

IV. SUMMARY OF RESULTS

The major results of this study are graphically summarized in Figure 15 and are as follows:

1. The duration of the steady state of the preconsonantal vowel (SSV_1) was significantly longer in the articulatory defective speakers than in the normal speakers;
2. The duration of the second formant transition of the preconsonantal vowel (TV_1) was not significantly different in the group of normal speakers and the group of articulatory defective speakers;
3. The duration of the intervocalic consonant (CD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers;
4. The duration of the second formant transition of the postconsonantal vowel (TV_2) was significantly longer in the articulatory defective speakers than in the normal speakers;

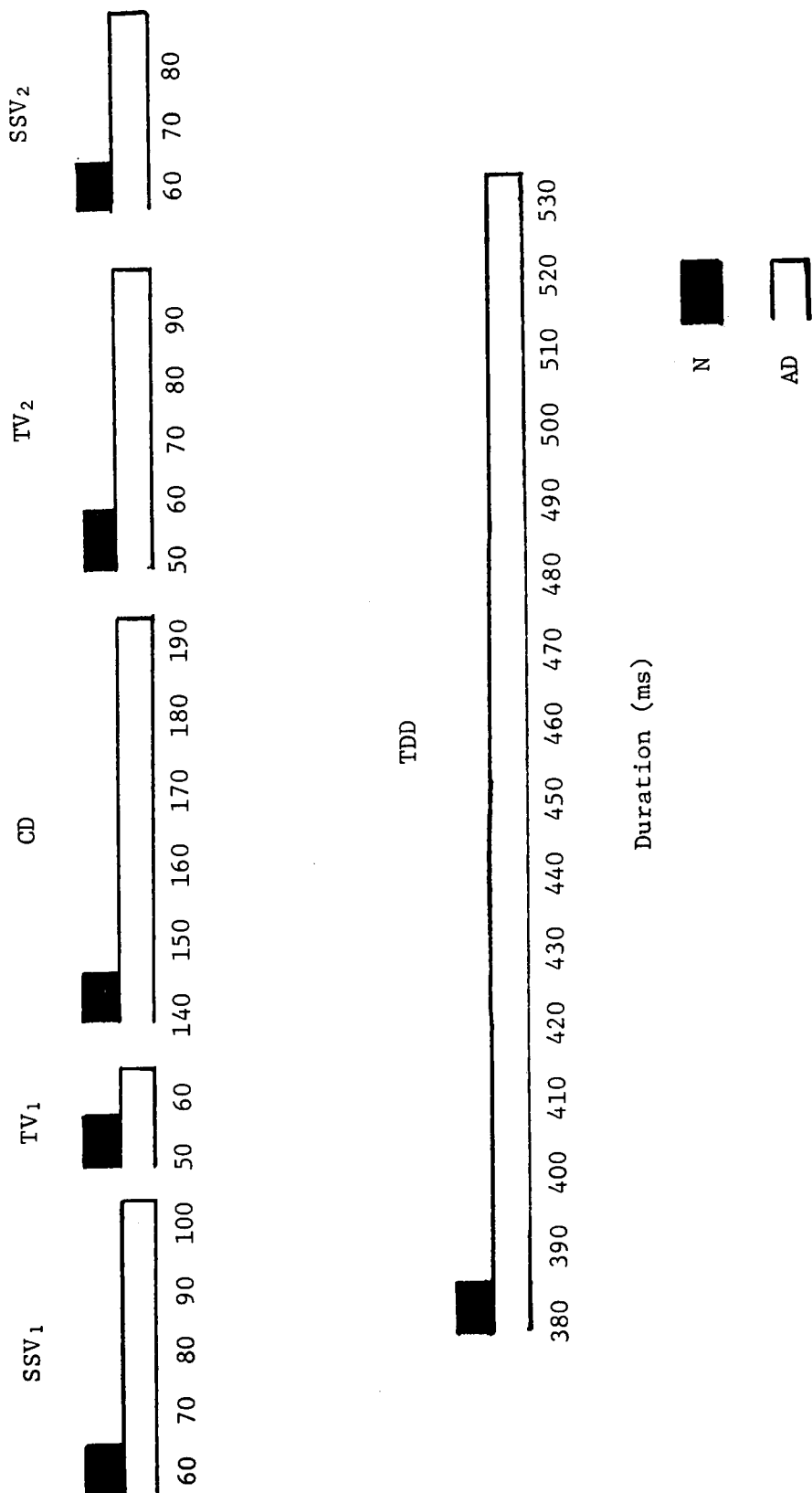


Figure 15. Mean duration of steady state of the preconsonantal vowel (SSV₁), transition of the preconsonantal vowel (TV₁), consonant duration (CD), transition of the postconsonantal vowel (TV₂), steady state of the postconsonantal vowel (SSV₂), and total disyllable duration.

5. The duration of the steady state of the postconsonantal vowel (SSV₂) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers;

6. The total disyllable duration (TDD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers;

7. Two subjects in the articulatory defective group exhibited durational values similar to those exhibited by speakers in the group of normal speakers. One subject in the group of normal speakers exhibited durational values similar to those obtained by the articulatory defective speakers.

In general, the group of articulatory defective speakers had significantly longer durations of all subsegments measured in the V₁CV₂ sequence with the exception of transition of the preconsonantal vowel (TV₁) for which there was no significant difference between groups of speakers.

CHAPTER IV

DISCUSSION

Differences between Groups in Mean Duration of Steady State of the Preconsonantal Vowel (SSV₁) and Transition of the Preconsonantal Vowel (TV₁)

The total mean duration for the two subsegments, SSV₁ and TV₁ combined in the group of normal speakers was 117.27 ms and in the articulatory defective speakers, it was 161.62 ms. The mean duration of SSV₁ for the normal speakers was 61.33 ms, therefore, when only these two subsegments (SSV₁ + TV₁ = duration of preconsonantal vowel) were considered, the proportion of time spent in SSV₁ was 52%. The mean duration of SSV₁ for the articulatory defective speakers was 99.28 ms, therefore, the proportion of time spent in the steady state portion of the first vowel was 62%. The mean duration of TV₁ for the group of normal speakers was 55.94 ms, therefore, the proportion of time spent in TV₁ was 48%. The mean duration of TV₁ in the group of articulatory defective speakers was 62.34 ms which was 38% of the total duration of the preconsonantal vowel.

The mean duration of SSV₁ was significantly longer in the group of articulatory defective speakers than in the normal speakers, however, mean duration of TV₁ was not. This finding is consistent for every V₁CV₂ sequence used in this study. By comparing these results with findings reported by Öhman (1966) and Kuehn and Tomblin (1974), it appears that the normal speakers in this study behaved in a manner similar to the normal adult speakers in the study by Öhman and that

the articulatory defective adults behaved in a manner similar to the articulatory defective children in the study by Kuehn and Tomblin. Öhman reported that in normal speaking adults, articulatory movements toward the second vowel in a V_1CV_2 utterance coincide in time with movements toward the consonantal closure. The 0.00 ms TV_1 duration values (indicating no movement of the tongue toward the postconsonantal vowel prior to consonant closure) occurred twice as frequently in the articulatory defective speakers as in the normal speakers in this study (27 and 13 times respectively). The larger number of 0.00 ms TV_1 durations and the presence of more very short TV_1 durations in the articulatory defective speakers indicates that transitions into the postconsonantal vowel began later in time during the production of the V_1CV_2 sequences. Consequently there was a significant delay in onset of movement toward the final vowel in the articulatory defective speakers.

The observed behavior in the group of articulatory defective speakers was contrary to articulatory dynamics of normal adult speakers as inferred from the acoustic data of Öhman (1966). Öhman suggested that during closure for a bilabial stop consonant, in an asymmetric vowel context, the tongue position should be intermediate between that for the pre- and postconsonantal vowel. Kuehn and Tomblin's data revealed that in the articulatory defective children in their study, the tongue did not assume the intermediate position until later in time. Their subjects delayed movement toward the final vowel until after consonant closure. Kuehn and Tomblin interpreted this result as a delay

in anticipatory coarticulation. These researchers also measured velocity of tongue movement as a function of the corresponding displacement and reported the measures for the articulatory defective children to be equivalent to patterns in normal adult speakers. Although no measurement of displacement can be made from the present data, it can be inferred that velocity (as reflected by TV_1 durations) was not significantly different in the articulatory defective speakers and the normal speakers.

Öhman's (1966) data provide evidence that the stop-consonant gestures are superimposed on a context-dependent vowel substrate which is present during all of the consonantal gesture. A V_1CV_2 utterance cannot be regarded as a linear sequence of three successive gestures since traces of the final vowel are observable already in the transition from the initial vowel to the consonant. Öhman hypothesized that the production of vowels and consonants involves activity in three overlapping sets or channels of muscles which have separate neural representations in the motor network of the brain. Articulatory impulses may be transmitted over all three channels independently and simultaneously. The response of the tongue is then a summation of response to each of the components of the articulatory command. If the timing of the instructions (articulatory commands) over the apical and dorsal channels (responsible for stop consonant production) are asynchronous with the channel responding to vowel instructions, then perhaps the muscles responding to vowel information are not free to anticipate a following vowel. According to Öhman, some components of the vowel are active at the onset of the consonant closure in certain V_1CV_2 sequences, but

there is no conclusive evidence of whether or not further vowel instruction components are added on during or at the offset of the consonant gesture. Judging from cineradiography, he hypothesized that there are some contextual situations (back vowel + lingua-alveolar stop consonant + back vowel) in which the motion in the direction of the final vowel must await the offset of the consonant before it can be completed. That is, the consonant gesture overrides the vowel gesture if the latter is antagonistic to the former. If the timing of instructions along the apical and dorsal channels for articulatory defective speakers is asynchronous with timing for the vowel gestures, perhaps the consonant cannot override the vowel gesture, resulting in articulatory errors due to malposition of the tongue during consonant production. In the present study, correct productions were analyzed but evidence indicates that it may have taken longer for the consonant gesture to override the vowel gesture causing a delay in onset of the consonant production. Perhaps the channels are not synchronized, therefore, summation of signals from the independent generators takes longer, thus resulting in delay in achieving steady state of the subsequent vowel (as evidenced by significantly longer TV_2 duration).

Kent, Carney, and Severeid (1974) suggested that the strategy of motor control assumes that a string of phonetic segments is translated into a pattern of transition instructions some of which are coincident. If the coincident nature of these instructions is interrupted by a delay in summation of signals along one channel (as proposed by Öhman), the relative timing of events will be affected. The cause of such a delay

is at present unknown, however there has been speculation that it may be the result of impairment of sensory processing and in particular of proprioceptive input with an ensuing failure to program, organize and implement coordinated movements (Lost, 1972). Most motor activity, in relation to speech, becomes automatic, however, proprioceptive feedback may exercise a monitoring function. A prolonged interruption of proprioceptive feedback or lack of development of normal proprioceptive feedback may lead to difficulty in motor speech programming. It may take longer for proprioceptive signals to summate which could result in delay in initiation of subsequent or coincident movements.

Differences between Groups in Mean Duration of the Consonant (CD)

The mean consonant duration (CD) for articulatory defective speakers was significantly longer than that for the normal speakers. The mean CD in the normal speakers was 145.27 ms and in the articulatory defective speakers was 195.92 ms.

Monsen (1972) reported that duration of the preconsonantal vowel transition provided clues not only to its own identity, but to the identity of the following consonant. He stated that if these cues are contravened by an opposing gesture (such as the superimposition of a consonant upon a vowel gesture), the listener may perceive the consonant incorrectly even though the normal spectral properties of the consonant are present. If in the case of the articulatory defective speakers in the present study, redundant cues were missing because of the short TV₁ durations, the cues may be added at a point later in time which would

result in the increased duration of the consonant, causing perception of a correct consonant. An alternative explanation may be that increased duration per se rather than the addition of the cues at a later point in time increased the perception of a correct consonant.

Martin (1972) stated that speech sounds may have a "temporal locus" rather than a "static locus" with each succeeding sound dependent upon the "temporal locus" of those preceding. In the data from the present study, the mean TV_1 duration in the articulatory defective group was short relative to the SSV_1 duration. The second element in the sequence (TV_1) was not related to the first (SSV_1) element with the same proportional magnitude as that exhibited by the normal speakers. The third element (CD) in the sequence was longer in the articulatory defective speakers and again not related to the first two elements with the same proportional magnitude as that exhibited by the normal speakers. However, the extended duration of the consonant may have been compensatory in nature to allow additional cues for perception of the correct consonant.

If as Öhman (1966) suggested, the vowel-to-vowel articulatory gesture is the basic unit of speech production, and if there is a delay in the movement toward V_2 in articulatory defective subjects (evidenced by extended SSV_1 duration) but the rate of movement is normal (evidenced by no significant extension of TV_1 duration), then spatial or temporal targets of the succeeding vowel will take relatively longer to achieve (as evidenced by extended duration of the intervocalic consonant and TV_2 duration). Cues omitted during TV_1 must be added during consonant

duration and duration of TV₂ in order to provide the listener with all necessary cues for perception of the correct consonant. Conceivably, when the cues are not added by extending the duration of the intervocalic consonant and transition into the succeeding vowel, an error in consonant production is perceived. There may be a threshold of durational acceptability for perception of correct consonant element, which if patterned aberrantly results in perception of consonant error even though the source of the aberrant timing initiated with the preconsonantal vowel.

Differences between Groups in Mean Duration
of Transition of the Postconsonantal Vowel (TV₂)

The mean duration of transition of the postconsonantal vowel was significantly longer in the articulatory defective speakers than in the normal speakers. There was significant interaction between vowel contexts and consonants and there was interaction between groups and vowel contexts which approaches significance. Results of post hoc testing indicate that none of the differences in TV₂ durations among vowel contexts was significant regardless of the intervocalic consonant (/p/ or /k/) in the normal speakers. For the articulatory defective speakers, none of the differences in TV₂ durations among vowel contexts was significant when /k/ was the intervocalic consonant, but there were significant differences when /p/ was the intervocalic consonant. The three significantly longer TV₂ durations all were transitions from the prevocalic consonants /a/, /u/, and /i/ into the front vowel /i/. The consonant /p/ had a shorter duration than /k/ and the vowel /i/ had a

short duration relative to the other two vowels used in this study (/a/ and /u/), thus the longest TV₂ durations were associated with the relatively shortest consonant and vowel. In two cases, /~~a~~pi/ and /upi/, movement occurred from a back to a front vowel position with no intervening intervocalic tongue movement. If there was any tongue movement in the case of /ipi/, it was in the front of the oral cavity. There are two conflicting views on which types of articulatory coordinations are more difficult in terms of motor planning. Some researchers have suggested that articulatory motor coordinations from one sound to another involving movement in the same area of the oral cavity are more difficult than those requiring movement from a more distant area because they require more precision of movement. If true, lack of appropriate proprioceptive feedback as posited by Lost (1972) could account for this difficulty in precision of movement and be reflected in longer TV₂ durations shown by articulatory defective speakers. Other researchers have suggested that articulatory movements from one area to a more distant area are the most difficult because of the spatial distance which must be covered in a finite amount of time. The articulatory defective subjects in this study exhibited extended TV₂ durations in the case of back-to-front movement as well as front-to-front movement. This reflects more time taken in moving from SSV₁ to SSV₂ despite the fact that with /p/ as the intervocalic consonant, there is no antagonistic consonant gesture superimposed upon the vowel-to-vowel movement which may cause a delay in the addition of certain components of the final vowel (as posited by Öhman, 1966). There should be no further neural

instructions added at the offset of the consonant gesture since the consonant gesture was not antagonistic. This result indicates that the timing irregularity seen in delay in initiation of TV_1 , which is the beginning of the movement into the postconsonantal vowel and the relatively short TV_1 durations of these articulatory defective speakers may be viewed as displacement of the movement until after consonant production. This may reflect temporal asynchrony between channels as suggested by Öhman, and also of maintenance of integrity of the movement pattern itself. That is, no portion of the movement patterns are sacrificed to obtain temporal regularity; rather, normal temporal patterning is sacrificed to obtain normal integrity of the movement pattern.

Differences between Groups in Mean Steady State
of the Postconsonantal Vowel (SSV_2)

The mean steady state of the postconsonantal vowel (SSV_2) for the articulatory defective speakers was significantly longer than that for the normal speakers. This finding is consistent for every V_1CV_2 sequence used in this study. The probability level associated with this result was 0.03 compared with a probability of 0.003 associated with the mean difference between groups for SSV_1 . These two subsegments are not analogous since the SSV_2 in this sequence preceded the consonant blend composed of the stop consonant /p/ and the sonorant /l/ in the word "please." "Please" was the last word in the stimulus sentence "Say the word V_1CV_2 please." Influence of a phonetic segment upon preceding segments has been shown to exist across word boundaries (Moll and

Daniloff, 1971) as well as phoneme boundaries (Öhman, 1966), thus it may be assumed that the magnitude of the delay in anticipation (as evidenced by extended duration of SSV₂) of the postconsonantal vowel in the articulatory defective subjects is similar to that of SSV₁. The effect of extended duration of SSV₂ was present in the articulatory defective speakers, but the magnitude of difference between groups in duration of steady state was not as great for SSV₂ as for SSV₁. It is possible that the use of an unfamiliar semantic component (the nonsense syllable V₁CV₂) caused a more extreme delay in anticipation of the postconsonantal vowel than would have existed if the V₁CV₂ sequence under analysis had comprised a familiar word. If such an effect did occur, it should have been present in both groups of speakers unless the articulatory defective speakers were more susceptible to a disruption in timing of automatic articulatory movements in the presence of an unfamiliar semantic event than were the normal speakers. The influence of the unfamiliar semantic component could be determined by a replication of the investigation using a familiar word in place of the nonsense V₁CV₂ sequence.

Differences between Groups in Total Disyllable Duration (TDD)

The mean total disyllable duration (TDD) was significantly longer (0.0001 level) in the articulatory defective speakers than in the normal speakers. This finding was consistent for every sequence used in this investigation. The proportion of time spent in each of the subsegments for each of the groups is displayed in Table 15. Inspection of this

Table 15. Proportion of time spent, relative to total disyllable duration (TDD), on each subsegment for each group of speakers.

Subsegment	Group	Proportion relative to TDD
SSV ₁	Normal	61.33 ms/385.52 ms = 0.16
	Articulatory Defective	99.28 ms/537.57 ms = 0.18
TV ₁	Normal	55.95 ms/385.52 ms = 0.15
	Articulatory Defective	62.34 ms/537.57 ms = 0.12
CD	Normal	145.27 ms/385.52 ms = 0.30
	Articulatory Defective	195.92 ms/537.57 ms = 0.36
TV ₂	Normal	58.99 ms/385.52 ms = 0.15
	Articulatory Defective	93.68 ms/537.57 ms = 0.17
SSV ₂	Normal	64.25 ms/385.52 ms = 0.17
	Articulatory Defective	87.38 ms/537.57 ms = 0.16

table reveals that when each subsegment is considered individually, the articulatory defective speakers spent a greater proportion of time relative to total disyllable duration in SSV₁, CD, and TV₂ than did the normal speakers. The differences are, however, quite small. If the mean TV₁ duration had been significantly longer in the articulatory defective speakers than in the normal speakers, this finding could have been interpreted as a generalized reduction in speed of articulatory movements for that group. The lack of significant differences between groups for the measure of TV₁ duration indicates that speed of articulatory movement is similar in both groups. The adult articulatory defective speakers in this investigation exhibited aberrant timing patterns similar to those reported by Kuehn and Tomblin (1974) for children with defective articulation. The subjects in the study by Kuehn and Tomblin ranged in age from eight to eleven years. The development of adult patterns of duration control seems to develop during the first twelve years of life. Since there was no control group of children with normal articulation for comparison of their results, it was not possible to determine whether the results occurred because the development of timing control was not yet complete or because of the articulation disorder. Consequently, Kuehn and Tomblin proposed the following two explanations for their findings:

1. Perhaps these children were restricted in their capacity to scan ahead or plan for upcoming positioning required; or
2. Perhaps these children may not have had sufficient production trials to achieve the response integration found in adults.

The latter hypothesis is based upon the assumption that anticipatory coarticulation is a result of an overlearning process in which units of speech containing smaller elements of speech become integrated wholes through repeated productions. The adult articulatory defective speakers in the present study did not exhibit the same temporal response integration exhibited by the normal speakers, yet it could be assumed that they had experienced sufficient production trials. The data on transition velocity of the preconsonantal vowel in both studies indicate, that the articulatory defective subjects do not move their articulators disproportionately slower than normal adult speakers. The subjects seemed to be able to produce articulatory movements of appropriate speed and range, but appeared to delay the initiation of movements. This may indicate an involvement in the planning and/or integration of articulatory movements. However, at the present time it is unknown whether speakers with articulatory difficulty are unable to move the articulators with sufficient speed or whether they move them more slowly to ensure accuracy of production.

Individual Subject Variation

Two articulatory defective subjects exhibited durational values which were similar to those obtained by the normal speakers. One normal speaker exhibited durational values which were similar to those obtained by the articulatory defective subjects. With these exceptions, analysis of group differences revealed that the articulatory defective speakers had significantly longer durations of all subsegments measured in the

V₁CV₂ with the exception of transition of the preconsonantal vowel for which there was no significant difference between groups of speakers.

From the results of this study it was determined that further research is needed to more thoroughly investigate the durational characteristics of speech. Specifically, the following areas warrant study:

1. Durational characteristics in other phonemic sequences produced by normal and articulatory defective adult speakers should be identified. Several types of phonemic sequences should be studied, such as sequences of different length, and sequences composed of different classes of vowels and consonants.

2. Durational characteristics during the speech development period in both normal speaking and articulatory defective children should be further explored. If there are consistent differences between the two groups of children, perhaps durational measures similar to those in this research may be used to differentiate among children who will and will not require clinical intervention.

3. Additional data are needed to identify the effect of imposed rate of production on the durational characteristics during speech production of both normal and articulatory defective adults and children.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the differences between durational characteristics of phonemically accurate productions of vowel + stop consonant + vowel (V_1CV_2) sequences in adult speakers with articulatory defects and adult speakers with normal articulation. Durational measurements on the following subsegments were obtained: steady state of the preconsonantal vowel; transition of the preconsonantal vowel; consonant; transition of the postconsonantal vowel; steady state of the postconsonantal vowel; and total disyllable.

Ten adults with articulation errors sufficient to place them one standard deviation below the mean score for an eight year old child on the Templin-Darley Tests of Articulation comprised the experimental group. Ten adults with no articulation errors and no history of articulation errors comprised the control group. All subjects met the following criteria: no significant deviation in the structure or function of the oral mechanism; normal hearing; normal voice and fluency; normal intelligence; and negative history of neurologic damage or symptoms. The stimuli used in this investigation were eighteen vowel + stop consonant + vowel sequences embedded in the phrase, "Say the word V_1CV_2 please." The subjects read each of the stimuli five times. These responses were tape recorded and later analyzed on the Voice Identification Unit. All durational measurements made from the broadband spectrograms were obtained at the second formant. The

duration measurements were used to infer timing of articulatory movements during the subsegments of the V_1CV_2 sequence.

The major findings of the investigation were as follows:

1. The duration of the steady state of the preconsonantal vowel (SSV_1) was significantly longer in the articulatory defective speakers than in the normal speakers.

2. The duration of the transition of the preconsonantal vowel (TV_1) was not significantly different in the group of normal speakers and the group of articulatory defective speakers.

3. The duration of the intervocalic consonant (CD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.

4. The duration of the transition of the postconsonantal vowel (TV_2) was significantly longer in the articulatory defective speakers than in the normal speakers.

5. The duration of the steady state of the postconsonantal vowel (SSV_2) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.

6. The total disyllable duration (TDD) was significantly longer in the group of articulatory defective speakers than in the group of normal speakers.

7. Two subjects in the articulatory defective group exhibited durational values similar to those exhibited by speakers in the group of normal speakers. One subject in the group of normal speakers exhibited durational values similar to those obtained by the articulatory defective speakers.

8. Future research is needed to: (a) investigate the consistency of these results in other phonemic sequences; (b) investigate the consistency of these results in groups of normal speaking and articulatory defective children; and (c) investigate the consistency of these results under imposed rate conditions.

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APPENDICES

APPENDIX A

Table A-1. Age, sex, and test scores for each individual subject.

Subject No.	Group	Age	Sex	Artic. test score	IVOM score	Diado. rate combined syl.
1	artic.	25-6	F	127	102	1.46
3	artic.	24-4	F	91	103	1.53
6	artic.	22-1	M	108	101	1.53
8	artic.	55-0	M	130	104	1.73
9	artic.	18-0	F	130	100	1.86
11	artic.	25-6	F	129	104	1.60
13	artic.	44-9	F	129	104	1.20
15	artic.	22-4	M	130	102	1.46
17	artic.	43-5	M	90	100	1.06
20	artic.	32-9	F	109	102	1.06
2	normal	21-0	M	141	104	1.73
4	normal	22-5	M	141	104	1.66
5	normal	26-10	F	141	104	1.80
7	normal	22-8	F	141	104	1.80
10	normal	55-11	M	141	104	1.80
12	normal	24-6	F	141	104	1.73
14	normal	46-4	F	141	104	1.73
16	normal	21-2	F	141	104	1.80
18	normal	46-0	M	141	104	1.73
19	normal	33-5	F	141	104	1.80

APPENDIX B

INSTRUCTIONS TO THE SUBJECT

As a subject in this study, you will be given eighteen short sentences to read. The sentences are all the same except for one word which will differ in each sentence. I would like you to read each sentence five times in a normal conversational manner. The sentences are typed on index cards and will be handed to you one at a time. Are there any questions. Before we begin the actual experiment, I am going to ask you to say "Today is month the day, 1979" several times so that I can adjust the volume of your voice coming through the microphone. I will then give you a list of practice words to read into the microphone. When you have practiced enough and are ready, we will begin the experiment. You are free to quit at any time during the procedure and are under no obligation to continue. In order to leave the room, simply press down on this handle (demonstrate). This session will last approximately thirty minutes.

STIMULUS SENTENCES USED IN RECORDING PROCEDURE

1. Say the word epee please.
2. Say the word ekee please.
3. Say the word ōopō please.
4. Say the word ōocō please.
5. Say the word ahpah please.
6. Say the word ahkah please.
7. Say the word epō please.
8. Say the word ecō please.
9. Say the word epah please.
10. Say the word ekah please.
11. Say the word ahpee please.
12. Say the word ahkee please.
13. Say the word ōopee please.
14. Say the word ōokee please.
15. Say the word ōopah please.
16. Say the word ōokah please.
17. Say the word ahpō please.
18. Say the word ahcō please.

PRACTICE MATERIAL USED PRIOR TO RECORDING

"e" as in the word "he"

"oo" as in the word "coo"

"ah" as in the word "shot"

For example, a baby will cōō when he is happy.

It is spelled with an "o" but pronoun-ed as an "ah"

These are the practice words which appear in the sentences:

1. epee
2. ekee
3. ōōpōō
4. ōōcōō
5. ahpah
6. ahkah
7. epōō
8. ecōō
9. epah
10. ekah
11. ahpee
12. ahkee
13. ōōpee
14. ōōkee
15. ōōpah
16. ōōkah
17. ahpōō
18. ahcōō

APPENDIX C

Table C-1. Measurement (in ms) of individual subjects' steady state of preconsonantal vowel (SSV₁) durations.

Syllables

Sub.*	/ipi/	/iki/	/upu/	/uku/	/əpə/	/əkə/	/ipu/	/iku/	/ipə/	/ikə/	/əpi/	/əki/	/upi/	/uki/	/upə/	/ukə/	/əpu/	/əku/
2	102.70	63.20	47.40	79.00	110.60	79.00	79.00	114.55	110.60	71.10	102.70	86.90	94.80	63.20	55.30	43.45	110.60	55.30
4	67.15	47.40	39.50	23.70	47.40	79.00	23.70	94.80	71.10	51.35	94.80	39.50	79.00	118.50	86.90	94.80	63.20	86.90
5	63.20	134.30	102.70	71.10	71.10	86.90	55.30	23.70	94.80	82.95	86.90	79.00	47.40	55.30	39.50	31.60	63.20	39.50
7	39.50	31.60	43.45	43.45	55.30	86.90	118.50	47.40	55.30	23.70	63.20	79.00	71.10	79.00	43.45	55.30	47.40	63.20
10	82.95	47.40	79.00	63.20	158.00	118.50	39.50	47.40	86.90	47.40	126.40	63.20	55.30	15.80	47.40	31.60	146.15	39.50
12	63.20	55.30	118.50	47.40	75.05	102.70	59.25	71.10	67.15	55.30	51.35	79.00	35.55	79.00	79.00	47.40	126.40	86.90
14	23.70	31.60	63.20	63.20	106.65	126.40	31.60	55.30	23.70	47.40	31.60	47.40	31.60	31.60	47.40	47.40	39.50	31.60
16	35.55	39.50	35.55	39.50	51.35	102.70	31.60	31.60	27.65	39.50	82.95	55.30	63.20	23.70	39.50	31.60	63.20	79.00
18	36.60	47.40	55.30	79.00	39.50	63.20	23.70	47.40	63.20	47.40	126.40	94.80	55.30	47.40	71.10	47.40	39.50	23.70
19	23.70	15.80	39.50	63.20	23.70	71.10	15.80	23.70	23.70	79.00	23.70	39.50	39.50	102.70	55.30	31.60	39.50	39.50
1	55.30	90.85	158.00	75.05	63.20	102.70	106.65	122.45	110.60	31.60	31.60	134.30	181.70	82.95	94.80	63.20	181.70	86.90
3	63.20	71.10	71.10	39.50	79.00	126.40	47.40	63.20	39.50	63.20	39.50	47.40	79.00	63.20	75.05	79.00	47.40	134.30
6	39.50	55.30	55.30	55.30	118.50	55.30	23.70	47.40	47.40	55.30	94.80	86.90	55.30	39.50	47.40	55.30	118.50	142.20
8	110.60	118.50	118.50	189.60	418.70	221.10	146.15	134.30	181.70	158.00	260.70	71.10	110.60	205.40	47.40	181.70	181.70	189.60
9	126.40	94.80	47.40	94.80	126.40	126.40	130.35	71.10	79.00	47.40	102.70	134.30	79.00	130.35	79.00	31.60	118.50	82.95
11	102.70	75.05	189.60	51.35	244.90	142.20	130.35	55.30	150.10	86.90	189.60	154.05	31.60	110.60	118.50	150.10	237.00	118.50
13	39.50	79.00	90.85	110.60	221.20	209.35	71.10	63.20	79.00	86.90	205.40	197.50	71.10	39.50	39.50	39.50	47.40	51.35
15	39.50	59.25	94.80	39.50	39.50	134.30	39.50	79.00	110.60	79.00	142.20	165.90	86.90	94.80	79.00	94.80	150.10	47.40
17	63.20	39.50	23.70	39.50	31.60	39.50	55.30	39.50	23.70	15.80	79.00	134.30	63.20	79.00	79.00	39.50	213.30	55.30
20	150.10	39.50	39.50	98.75	189.60	173.80	197.50	102.70	47.40	79.00	150.10	189.60	86.90	79.00	86.90	39.50	146.15	213.30

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

Table C-2. Measurement (in ms) of individual subjects' transition of prenasal vowel (TV₁) durations.

Sub.*	Syllables																			
	/ipt/	/lki/	/upu/	/uku/	/apu/	/aku/	/ipu/	/iku/	/ipa/	/ika/	/api/	/aki/	/upi/	/uki/	/upa/	/uka/	/apu/	/aku/		
2	15.80	86.90	55.30	27.65	15.80	63.20	31.60	23.70	0.00	31.60	23.70	55.30	23.70	39.50	47.40	39.50	27.65	79.00		
4	0.00	39.50	39.50	90.85	71.10	47.40	102.70	0.00	7.90	0.00	0.00	47.40	0.00	0.00	31.60	31.60	110.60	35.55		
5	55.30	63.20	47.40	86.90	63.20	47.40	31.60	75.05	39.50	0.00	71.10	71.10	43.45	39.50	79.00	71.10	55.30	94.80		
7	71.10	31.60	43.45	47.40	23.70	23.70	0.00	47.40	51.35	39.50	71.10	23.70	15.80	31.60	47.40	23.70	51.35	43.45		
10	39.50	31.60	55.30	47.40	39.50	71.10	15.80	55.30	47.40	15.80	19.75	86.90	86.90	31.60	47.40	51.35	31.60	0.00		
12	77.90	63.20	47.40	0.00	23.70	11.85	39.50	98.75	23.70	79.00	39.50	110.60	23.70	31.60	27.65	43.45	0.00	31.60		
14	126.40	71.10	47.40	47.40	55.30	31.60	102.70	63.20	102.70	63.20	118.50	94.80	94.80	94.80	71.10	71.10	118.50	102.70		
16	102.70	79.00	67.15	51.35	35.55	63.20	102.70	71.10	71.10	82.95	86.90	102.70	63.20	98.75	55.30	59.25	86.90	55.30		
18	86.90	55.30	55.30	39.50	118.50	79.00	94.80	55.30	47.40	63.20	0.00	31.60	35.55	47.40	47.40	43.45	138.25	146.15		
19	86.90	118.50	63.20	63.20	126.40	94.80	94.80	102.70	71.10	79.00	118.50	39.50	79.00	31.60	39.50	94.80	122.45	102.70		
1	79.00	55.30	23.70	86.90	106.65	94.80	0.00	31.60	0.00	79.00	150.10	59.25	0.00	55.30	55.30	71.10	0.00	86.90		
3	90.85	23.70	55.30	63.20	71.10	71.10	71.10	39.50	63.20	39.50	158.00	102.70	31.60	31.60	63.20	47.40	94.80	15.80		
6	15.80	43.45	55.30	55.30	0.00	31.60	110.60	47.40	15.80	31.60	71.10	39.50	47.40	0.00	55.30	39.50	0.00	23.70		
8	0.00	71.10	0.00	15.80	79.00	39.50	0.00	86.90	71.10	47.40	55.30	63.20	118.50	47.40	79.00	79.00	0.00	79.00		
9	15.80	31.60	79.00	63.20	15.80	0.00	0.00	71.10	31.60	51.35	86.90	0.00	47.40	0.00	39.50	55.30	47.40	55.30		
11	31.60	94.80	0.00	47.40	23.70	86.90	0.00	138.25	0.00	47.40	63.20	55.30	150.10	0.00	0.00	31.60	0.00	63.20		
13	94.80	79.00	55.30	31.60	0.00	0.00	79.00	98.75	79.00	102.70	0.00	0.00	102.70	31.60	94.80	102.70	126.40	63.20		
15	134.30	90.85	55.30	110.60	126.40	55.30	102.70	63.20	67.15	63.20	67.15	63.20	39.50	19.75	39.50	31.60	43.45	142.20		
17	142.20	110.60	185.65	118.50	79.00	94.80	86.90	150.10	213.30	94.80	39.50	55.30	63.20	63.20	71.10	63.20	0.00	126.40		
20	75.05	165.90	181.70	0.00	55.30	79.00	43.45	47.40	158.00	110.60	63.20	15.80	110.60	150.10	237.00	142.20	63.20	0.00		

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

Table C-3. Measurement (in ms) of individual subjects' consonant durations (CD).

		Syllables															
Sub.*	/ip/	/ik/	/up/	/uk/	/ep/	/ek/	/ipu/	/iku/	/ipe/	/ike/	/epi/	/eki/	/upi/	/uki/	/upo/	/upe/	/oku/
2	134.30	118.50	126.40	142.20	110.60	114.55	130.35	94.80	110.60	134.30	118.50	102.70	134.30	134.30	122.45	126.40	126.40
4	158.00	158.00	158.00	158.00	134.30	158.00	158.00	142.20	138.25	134.30	134.30	173.80	158.00	169.85	150.10	138.25	185.65
5	177.75	173.80	197.50	197.50	197.50	173.80	158.00	126.40	158.00	165.90	173.80	197.50	142.20	158.00	201.45	173.80	189.60
7	134.30	158.00	150.10	158.00	150.10	173.80	150.10	158.00	154.05	142.20	134.30	158.00	138.25	197.50	165.90	197.50	154.05
10	158.00	150.10	134.30	142.20	106.65	126.40	142.20	138.25	130.35	102.70	134.30	126.40	134.30	130.35	102.70	150.10	94.80
12	118.50	134.30	146.15	126.40	110.60	118.50	134.30	110.60	102.70	118.50	110.60	142.20	102.70	134.30	118.50	126.40	134.30
14	110.60	142.20	110.60	142.20	150.10	142.20	126.40	142.20	126.40	142.20	118.50	134.30	134.30	146.15	118.50	118.50	142.20
16	197.50	181.70	173.80	173.80	158.00	169.85	158.00	142.20	165.90	142.20	189.60	173.80	158.00	197.50	154.05	150.10	158.00
18	126.40	158.00	142.20	142.20	102.70	142.20	142.20	158.00	118.50	138.25	130.35	142.20	130.35	142.20	142.20	118.50	150.10
19	165.90	181.70	173.80	189.60	130.35	134.30	142.20	146.15	142.20	126.40	142.20	158.00	181.70	158.00	150.10	150.10	165.90
1	177.75	193.55	205.40	201.45	189.60	181.70	197.50	213.30	173.80	213.30	185.65	185.65	205.40	173.80	237.00	213.30	205.40
3	173.80	165.90	201.45	197.50	134.30	142.20	213.30	189.60	197.50	158.00	237.00	173.80	181.70	229.10	158.00	197.50	154.05
6	158.00	173.80	229.10	197.50	158.00	193.55	110.60	197.50	181.70	142.20	181.70	165.90	189.60	197.50	248.85	197.50	173.80
8	189.60	189.60	300.20	197.50	268.60	244.90	244.90	252.80	213.30	260.70	225.15	268.60	237.00	229.10	221.20	300.20	284.40
9	158.00	150.10	126.40	134.30	158.00	118.50	134.30	173.80	126.40	122.45	308.10	165.90	150.10	339.70	102.70	110.60	201.45
11	197.50	229.10	213.30	276.50	173.80	193.55	237.00	213.30	237.00	213.30	197.50	217.25	244.90	237.00	221.20	205.40	237.00
13	173.80	173.80	165.90	244.90	165.90	158.00	150.10	165.90	158.00	158.00	158.00	189.60	402.90	213.30	205.40	197.50	205.40
15	158.00	165.90	161.95	150.10	122.45	130.35	150.10	142.20	165.90	150.10	130.35	158.00	134.30	134.30	118.50	134.30	142.20
17	181.70	229.10	197.50	197.50	102.70	165.90	118.50	197.50	150.10	221.20	142.20	189.60	165.90	300.00	173.80	300.20	205.40
20	229.10	284.40	158.00	276.50	221.20	252.80	229.10	331.80	221.20	268.60	237.00	237.00	252.80	237.00	244.90	284.40	197.50

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

Table C-4. Measurement (in ms) of individual subjects' transition of postconsonantal vowel (TV₂).

Sub.*	Syllables																			
	/lpi/	/lki/	/upu/	/uku/	/apu/	/aku/	/ipu/	/iku/	/lpa/	/lka/	/api/	/aki/	/upi/	/uki/	/upa/	/uka/	/apu/	/aku/		
2	19.75	63.20	102.70	134.30	31.60	47.40	79.00	59.25	110.60	0.00	94.80	0.00	67.15	94.80	23.70	71.10	31.60	79.00		
4	79.00	79.00	110.60	90.85	55.30	146.15	110.60	71.10	0.00	150.00	134.30	63.20	63.20	0.00	71.10	79.00	0.00	0.00		
5	0.00	55.30	0.00	0.00	79.00	0.00	63.20	94.80	79.00	39.50	39.50	0.00	55.30	63.20	71.10	63.20	47.40	110.60		
7	39.50	47.40	55.30	0.00	0.00	86.90	86.90	63.20	63.20	0.00	55.30	23.70	55.30	102.70	39.50	63.20	63.20	39.50		
10	55.30	0.00	55.30	0.00	114.55	79.00	39.50	102.70	86.90	55.30	47.40	0.00	63.20	0.00	39.50	79.00	79.00	0.00		
12	39.50	47.40	142.20	79.00	39.50	86.90	39.50	51.35	79.00	110.60	71.10	39.50	86.90	23.70	71.10	55.30	71.10	47.40		
14	102.70	63.20	63.20	79.00	47.40	55.30	94.80	63.20	55.30	31.60	63.20	71.10	118.50	82.95	110.60	47.40	71.10	71.10		
16	71.10	79.00	55.30	79.00	47.40	86.90	71.10	94.80	118.50	106.65	94.80	23.70	79.00	79.00	79.00	102.70	55.30	71.10		
18	39.50	23.70	31.60	0.00	0.00	55.30	63.20	0.00	39.50	86.90	110.60	55.30	55.30	39.50	39.50	43.45	31.60	31.60		
19	0.00	71.10	79.00	86.90	0.00	51.35	39.50	31.60	31.60	71.10	39.50	0.00	82.95	47.40	118.50	79.00	47.40	71.10		
1	79.00	43.45	86.90	67.15	31.60	47.40	110.60	86.90	63.20	63.20	150.10	94.80	110.60	134.30	55.30	63.20	55.30	118.50		
3	173.80	31.60	23.70	47.40	134.30	173.80	31.60	94.80	173.80	39.50	102.70	86.90	39.50	23.70	23.70	118.50	94.80	0.00		
6	134.30	79.00	79.00	102.70	0.00	134.30	55.30	71.10	197.50	118.50	158.00	134.30	134.30	165.90	150.10	150.10	86.90	142.20		
8	165.90	118.50	134.30	134.30	71.10	106.65	142.20	79.00	31.60	47.40	126.40	165.90	142.20	126.40	55.30	102.70	79.00	134.30		
9	165.90	31.60	79.00	86.90	55.30	110.60	102.70	23.70	31.60	63.20	150.10	71.10	197.50	134.30	47.40	63.20	43.45	86.90		
11	47.40	102.70	94.80	63.20	181.70	71.10	43.45	110.60	94.80	94.80	71.10	86.90	142.20	47.40	47.40	31.60	63.20	39.50		
13	158.00	142.20	71.10	71.10	31.60	142.20	79.00	94.80	142.20	146.15	94.80	94.80	142.20	126.40	47.40	47.40	47.40	102.70		
15	39.50	102.70	86.90	102.70	122.45	142.20	79.00	86.90	0.00	118.50	71.10	79.00	86.90	71.10	71.10	134.30	98.75	86.90		
17	181.70	134.30	134.30	102.70	47.40	118.50	0.00	173.80	0.00	134.30	165.90	98.75	126.40	79.00	0.00	110.60	71.10	0.00		
20	181.70	158.00	0.00	173.80	31.60	110.60	47.40	0.00	31.60	63.20	205.40	102.70	142.20	158.00	118.50	181.70	71.10	134.30		

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

Table C-5. Measurement (in ms) of individual subjects' steady state of postconsonantal vowel (SSV₂) durations.

Syllables															
Sub.*	/ipi/	/iki/	/upu/	/uku/	/apo/	/aka/	/ipu/	/iku/	/ipa/	/ika/	/api/	/aki/	/upi/	/uki/	/upa/
2	110.60	663.20	15.80	23.70	110.60	39.50	79.00	31.60	94.80	181.70	31.60	86.90	47.40	39.50	165.90
4	47.40	47.40	15.80	15.80	94.80	63.20	39.50	71.10	177.75	43.45	39.50	118.50	110.60	142.20	134.30
5	63.20	86.90	71.10	102.70	39.50	94.80	5.35	15.80	94.80	86.90	79.00	118.50	51.35	47.40	79.00
7	71.10	47.40	51.35	71.10	150.10	0.00	15.80	31.60	47.40	126.40	55.30	63.20	55.30	23.70	94.80
10	39.50	63.20	47.40	55.30	23.70	134.30	31.60	19.75	102.70	114.55	63.20	71.10	39.50	102.70	126.40
12	55.30	11.85	15.80	11.85	94.80	15.80	47.40	15.80	39.50	27.65	27.65	63.20	39.50	59.25	67.15
14	39.50	15.80	39.50	11.85	118.50	79.00	47.40	31.60	102.70	110.60	31.60	23.70	23.70	15.80	39.50
16	31.60	23.70	39.50	19.75	79.00	79.00	39.50	118.50	35.55	86.90	31.60	94.80	35.55	39.50	82.95
18	79.00	71.10	102.70	94.80	150.10	106.65	55.30	71.10	110.60	71.10	31.60	39.50	63.20	67.15	134.30
19	94.80	43.45	23.70	23.70	118.50	75.05	23.70	23.70	134.30	79.00	47.40	102.70	23.70	47.40	31.60
1	86.90	79.00	47.40	55.30	142.20	126.40	47.40	23.70	110.60	106.65	39.50	59.25	71.10	47.40	118.50
3	55.30	79.00	90.85	39.50	63.20	23.70	94.80	31.60	35.55	94.80	55.30	15.80	79.00	31.60	146.15
6	94.80	126.40	39.50	55.30	244.90	79.00	126.40	63.20	39.50	79.00	47.40	71.10	55.30	63.20	94.80
8	126.40	94.80	71.10	47.40	244.90	150.10	71.10	79.00	134.30	197.50	142.20	31.60	150.10	79.00	173.80
9	15.80	39.50	39.50	35.55	79.00	15.80	55.30	71.10	126.40	98.75	79.00	15.80	55.30	31.60	110.60
11	126.40	39.50	55.30	118.50	71.10	134.30	102.70	23.70	94.80	110.60	47.40	47.40	39.50	134.30	158.00
13	59.25	118.50	55.30	71.10	118.50	39.50	47.40	39.50	71.10	55.30	39.50	47.40	79.00	47.40	134.30
15	213.30	23.70	43.45	15.80	31.60	31.60	55.30	31.60	165.90	31.60	102.70	63.20	55.30	23.70	79.00
17	63.20	118.50	102.70	189.60	205.40	205.40	197.50	31.60	339.70	118.50	71.10	39.50	102.70	165.90	213.30
20	31.60	63.20	229.10	31.60	181.70	102.70	71.10	142.20	86.90	158.00	23.70	71.10	63.20	55.30	142.20

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

Table C-6. Measurement (in ms) of individual subjects' total disyllable durations (TDD).

Sub.*	Syllables														
	/tɪl/	/iki/	/upu/	/uku/	/epɔ/	/akɔ/	/ipu/	/iku/	/ipɔ/	/ika/	/api/	/aki/	/upi/	/uki/	/upa/
2	383.15	395.00	347.60	406.85	379.20	343.65	398.95	323.90	426.60	418.70	371.30	331.80	367.35	371.30	414.75
4	351.55	371.30	410.80	379.20	402.90	493.75	434.50	379.20	430.55	379.20	402.90	442.40	410.80	430.55	474.00
5	359.45	513.50	418.70	458.20	450.30	402.90	359.45	335.75	466.10	375.25	450.30	466.10	339.70	363.40	470.05
7	355.50	316.00	343.65	319.95	379.20	371.30	371.30	347.60	371.30	331.80	379.20	347.60	335.75	434.50	391.05
10	375.25	292.30	371.30	308.10	442.40	529.30	268.60	363.40	454.25	335.75	391.05	347.60	379.20	280.45	363.40
12	284.40	312.05	470.05	264.65	343.65	335.75	319.95	347.60	312.05	391.05	300.20	434.50	288.35	327.85	363.40
14	402.90	323.90	323.90	343.65	477.95	434.50	402.90	355.50	410.80	395.00	363.40	371.30	402.90	371.30	363.40
16	438.45	402.90	371.30	363.40	371.30	501.65	402.90	351.55	418.70	458.20	485.85	450.30	398.95	438.45	410.80
18	363.40	355.50	387.10	355.50	410.80	446.35	379.20	331.80	379.20	406.85	398.95	363.40	339.70	343.65	434.50
19	371.30	430.55	379.20	426.60	398.95	426.60	316.00	327.85	402.90	434.50	371.30	339.70	406.85	387.10	395.00
1	477.95	481.90	521.40	485.85	537.20	553.00	462.15	477.95	458.20	493.75	536.95	529.30	497.70	493.75	560.90
3	556.95	371.30	442.40	387.10	481.90	537.20	458.20	418.70	509.55	395.00	592.50	426.60	410.80	379.20	466.10
6	442.40	477.95	458.20	454.25	521.40	493.75	410.80	426.60	481.90	426.60	553.00	497.70	481.90	466.10	596.45
8	592.50	592.50	624.10	584.60	1082.30	762.35	687.30	635.95	584.60	734.70	707.05	790.00	718.90	592.50	734.70
9	481.90	347.60	371.30	414.75	434.50	371.30	422.65	410.80	395.00	383.15	726.80	387.10	529.30	632.00	379.20
11	505.60	541.15	553.00	556.95	695.20	628.05	513.50	541.15	576.70	553.00	568.80	560.90	608.30	529.30	545.10
13	525.35	592.50	438.45	529.30	537.20	549.05	410.80	462.15	529.30	549.05	497.70	529.30	797.90	458.20	521.40
15	584.60	442.40	442.40	418.70	442.40	493.75	426.60	402.90	509.55	442.40	513.50	529.30	402.90	343.65	387.10
17	632.00	632.00	643.85	647.80	466.10	553.00	458.20	592.50	726.80	584.60	497.70	517.45	521.40	687.30	537.20
20	659.65	711.00	608.30	580.65	679.40	718.90	588.55	624.10	545.10	679.40	679.40	616.20	655.70	679.40	829.50

*The first ten subjects listed are normal speakers and the last ten are articulatory defective speakers.

VITA

Marcia Ohle Burns was born in New Orleans, Louisiana on January 27, 1946. She was graduated from Woodlawn High School in 1963. The following September, she entered Louisiana State University, and in June, 1967, she received a Bachelor of Science degree in Speech Therapy and Audiology.

Following two years of employment as a public school speech therapist, she enrolled in the Master of Arts program in Speech Pathology at Louisiana State University. She received the degree of Master of Arts in Speech Pathology in August, 1970.

After six years of employment as instructor and assistant professor at Columbia College in Columbia, South Carolina, she enrolled in the doctoral program in Speech and Hearing Science at The University of Tennessee, Knoxville, Tennessee, in June, 1976. She received the degree of Doctor of Philosophy in Speech and Hearing Science in December, 1979.