THE ACOUSTIC AND AERODYNAMIC CHARACTERISTICS OF COMPENSATED ENGLISH CONSONANTS

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ABSTRACT

THE ACOUSTIC AND AERODYNAMIC
CHARACTERISTICS OF COMPENSATED
ENGLISH CONSONANTS

By

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The purpose of this study was to investigate the acoustic and aerodynamic characteristics of compensatory articulation. Following the directions proposed in the literature for compensatory articulation, two subjects participated in two experimental conditions. Each subject read a list of 84 VCV combinations that included all plosives and fricatives appearing in three different vowel contexts (aCa, uCu, iCi). The normal production of the consonant was read five times followed by the compensated consonant. Three judges determined the best production from each group of five. Wide band spectrograms were made of the best production from each group. The acoustic variables that were examined included the closure/constriction duration and the duration of the VC and CV transitions. A second experiment was conducted that included simultaneous recording of intraoral air pressure, air flow rate, and

voicing as each subject read the original list of stimuli saying each VCV combination only one time. A conventional nasal catheter, pneumotachograph, and optical oscillograph system were used to record the data. Quantification of the aerodynamic patterns involved peak amplitude measures for air flow rate and intraoral air pressure as well as the duration of the pressure trace. Distinct aerodynamic patterns were identified and discussed.

The results of the acoustic analysis indicated that in the case of the voiced plosive closure duration, fricative constriction duration, and fricative transition duration, the compensated forms of the consonant exhibited a decrease from the normal production.

The results of the aerodynamic analysis indicated that a general decrease in air flow rate, intraoral air pressure, and duration of pressure was evident for the majority of compensated consonant productions. In addition a number of distinct aerodynamic patterns were evident for speaker DB.

These results are discussed in relation to examining compensatory articulation in various speech disorderd populations. Additional discussion is related to the articulator variability for different phoneme classes during compensatory articulation.

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CHAPTER I

INTRODUCTION

There has been increasing interest in the acoustic and physiologic characteristics of speech and language. This interest has been related to both normal and abnormal functioning of the speech mechanism. For example, it has been suggested that the training of compensatory articulation may be useful for a therapeutic program involving stuttering, cleft palate, or other oral structural deformities (Eisenson 1958, Wells 1971, Bloomer 1971). However to date there is a paucity of research that delineates the acoustic and aerodynamic consequences of such training. The examination of these compensatory movements may reveal therapeutic strategies that can be directed toward specific speech disorders. Before an analysis of the suggested compensations can be initiated, it is necessary to examine the acoustic and physiological phenomena related to normal consonant production.

Acoustic Characteristics of Speech Production

Speech production involves the generation of more or less noisy sounds somewhere within the vocal tract and the selective modification of those sounds by the resonance characteristics of the vocal tract (Minifie 1973). The major resonances produced within the vocal tract are termed formants (Denes and Pinson 1963). When a stop or fricative consonant is combined with a vowel, rapid articulatory movements occur that result in modifications of the formant frequencies. The rapid changes in the vowel formants that occur as the speaker moves his articulators from a vowel to a consonant or a consonant to a vowel, have been termed transitions (Halle, Hughes, and Radley 1957). Minifie (1973) reported that the duration of vocalic transitions are very rapid when they are adjacent to stop sounds because the movements toward and away from stop sound articulations are very rapid. However the vocalic transitions from one vowel sound to another are relatively slow. Many researchers have examined vocalic transitions to determine whether they can serve as cues for perception of consonants. Liberman, Delattre, Gerstman, and Cooper (1956) examined the rate of vocalic transitions and determined that the "direction and extent of the second formant transition enabled listeners to distinguish speech sounds within each of the three classes, voiceless stops, voiced stops, and nasal consonants." Transitions have been examined to determine whether they can serve as cues for the identification of manner of articulation and place of production for consonants. Delattre, Liberman, and Cooper (1955) examined transitional cues of selected stop consonants and concluded that the second formant transition is a cue for three places of articulatory production: bilabial, alveolar, and velar. Examining the acoustic properties of stop consonants, Halle et al. (1957) determined that transitions were influenced by factors such as adjacent vowels, the steady state portion of the vowel, and the feature described as tense-lax (aspiration and degree of plosion). It thus appears that the formant transition is an acoustic variable that is affected by changes within the vocal mechanism.

The duration of consonant closure has been identified as an acoustic variable that is affected by changes within the vocal tract. Sharf (1962) has shown that the closure duration of voiceless stops are typically greater than their voiced cognates. Lisker (1957) examined stop consonants appearing in the intervocalic position and determined that duration of consonant closure served as a cue for distinguishing voiced from voiceless consonants. Rapid changes or modifications of articulatory movements may alter and influence the closure duration of specific consonants. Examination of the consonant closure duration will help to determine the effects of modified articulatory movements.

Aerodynamic Characteristics of Speech Production

The rapid articulatory movements that accompany consonant production are associated with modifications in respiratory dynamics. Fricative production is characterized by the creation of a constriction within the oral cavity that results in a turbulent air flow. The production of a plosive is dependent upon the impounding of air within the vocal tract and then releasing the air in the form of an "explosion." Several physiological variables have been identified as sensitive measures of vocal tract aerodynamics. Isshiki and Ringel (1964) examined the air flow rate of a variety of English consonants. The air flow rate was defined in terms of volume velocity and was measured in cubic centimeters per second. The investigators presented four factors that influenced air flow rate:

1. the opening characteristics of the oral and velopharyngeal stricture.
2. initial pressure within the vocal cavity behind the point of vocal closure.
3. the volume of the cavity in which the pressure is built up.
4. the pulmonary air supply during the period of explosion (p. 241).

The authors determined that volume velocity was related to voicing, manner of articulation, and vowel context. In an attempt to determine the effect of context on air flow rate, Emanuel and Counihan (1970) examined a variety of stop consonants in different vowel environments. The examiners concluded that differences in volume velocities occurred as a result of different vowel environments. Isshiki (1965) attempted to determine whether varying the intensity and pitch would affect the airflow rate of selected speakers.

Isshiki concluded that variations did occur as a function of vocal intensity and this occurred more at high pitch levels than at low pitches. Thus the research to date suggests that the measurement of air flow rate appears to be a sensitive measure of changes in respiratory dynamics.

One of the determinants of the rate of air flow is the air pressure that is impounded behind a stricture within the vocal tract (Isshiki and Ringel 1964, Subtelny, Worth, and Sakuda 1966). Examination of consonant production has been conducted to determine the intraoral air pressure characteristics that accompany consonant production and the variables such as phonetic context and manner of production that are associated with the modification of that pressure. Subtelny et al. (1966) and Arkebauer, Hixon, and Hardy (1967) examined the intraoral air pressure associated with a variety of English consonants. The manner of production appeared to be the significant variable in determining the intraoral air pressure. The voiceless consonants tended to have greater peak amplitudes and longer durations of intraoral air pressure than their voiced cognates. The plosive group was characterized by the highest intraoral air pressure, whereas the fricatives exhibited the longest durations. Additional variations occurred as a result of phonetic context, subject grouping by age and sex, and increased vocal intensity. Malecot (1968) examined the intraoral air pressure of selected consonants as a function of position and stressing. He concluded that consonants occurring before a stressed vowel or in the initial position demonstrated higher intraoral air pressures. In addition he concluded that the duration of pressure values increased as a function of a stressed vowel.

The measurement of air flow rate and intraoral air pressure appears to reflect the modifications that occur in respiratory dynamics. It appears that both measures would be sensitive to modifications that might occur in the production of compensated speech forms.

Compensated Forms of Articulation

A number of investigators have suggested the idea of teaching a compensated form of articulation as a result of structural and functional deficits. Bloomer (1971) has stated that the oral mechanism is capable of many compensatory movements. He explained that when a speech pathologist is confronted with an oral structural deviation, it is his ". . . responsibility for determining to what extent adaptation is not merely possible but feasible" (p. 735). A number of therapeutic approaches directed toward stuttering advocated the teaching of compensatory movements in the form of "loose contacts." As Eisenson (1958) reports:

> Some therapists teach the stutterer new patterns of articulation that call for less articulatory tension, for less "sticking" on some sounds that most of us employ in our speaking. Perhaps what these therapists are helping their cases to accomplish is a manner of articulation that does not require a firm motor set (p. 263).

Van Riper (1958) proposed that the stutterer should "fill much of his speech with voluntary loose movements of the tongue, jaw, and lips." In addition, as part of the stutterers approach to "fluent nonabnormal stuttering," Van Riper suggested the use of loose contacts.

Wells (1971) has proposed the teaching of light contacts for alveolar sounds in the remediation of cleft palate speech. Van Hattum (1974) has suggested the following approach to speech therapy with cleft palate clients:

> Action of the articulators should be precise and rapid as possible . . . . Loose articulatory contacts similar to those advocated in some stuttering activities may result in relaxing closure or stricture, thus reducing the amount of air forced through the nasal cavity and lowering the air need, so that there is less likelihood of excessive air use. The articulators are kept in motion, and words are easier to produce (p. 329).

Shelton, Hahn, and Morris (1968) explained that a person demonstrating veolpharyngeal inadequacy cannot be expected to have the necessary air flow associated with accurate fricative and plosive production. The authors proposed the teaching of a light, quick, constriction for the production of fricatives. It is explained that any prolongation of a fricative will increase the amount of nasal emissions. When teaching the production of plosives, the authors suggested the use of light, quick, articulatory contacts. They explained:

> Sustained tense contacts may cause enough breath to escape through the nasal passages that the result is an undesirable facial grimace which comes about from an attempt to prevent nasal escape of air (pp. 251-252).

The preceding recommendations reveal the fact that compensatory articulation is related to the aerodynamic mechanism. Any articulatory modifications that occur will directly affect the aerodynamic characteristics of the phonemes produced.

Statement of the Problem

Whereas various authors have suggested the teaching of a compensated form of articulation for various speech disorders (Bloomer 1971, Van Hattum 1974, Van Riper 1958), a lack of empirical data exists to support the training of the compensatory movements. Thus it appears necessary to examine the specific variables that will reflect the acoustic and aerodynamic changes that might occur during the production of compensated articulation. Acoustic variables that will reflect these changes include the duration of the closure or constriction phase of the plosive and fricative consonants and the duration of the VC and CV formant transitions. Aerodynamic measures that will indicate changes in the respiratory dynamics include the volume velocity and the intraoral air pressure. In summary the purpose of this investigation was to examine two acoustic and three aerodynamic characteristics of a variety of compensated English consonants. The following specific questions were asked:

1. Will the proposed compensations exhibit the same consonant closure or constriction duration and the same VC and CV transition durations as a normal production of the consonant?

2. Will the proposed compensations exhibit the same air flow rate, intraoral air pressure, and duration of intraoral air pressure as a normal production of the same consonant?

CHAPTER II

PROCEDURES

Experiment I

Subjects

The subjects of the present study were two adult males with a mean age of twenty-eight (28) years. Each subject was a trained speech scientist and speaker of the General American Dialect. As reported in a health questionnaire (Appendix A), each subject was reported to be in good physical health with no apparent physical disorders.

Speech Stimuli

The speech stimuli consisted of fourteen (14) consonants (p,t,k,b,d,g,s,z,f,v,θ,ð,ʃ,ʒ) appearing in the intervocalic position of a monosyllabic unit (VCV). The vowels that preceeded and succeeded each consonant include /i,a,u/, representing the range of tongue positions. A vowel-consonant-vowel (VCV) combination was constructed where the initial and final vowel remained the same (e.g., /ipi/, /ata/). The list of stimuli (Table 1) represented eighty-four (84) VCV combinations, whereby a normal production of the consonant was followed by the compensated form of the same consonant. The order of presentation for each

TABLE 1.--The list of speech stimuli representing normal and compensated consonant productions.

1.	apa	*22.	iθi	43.	ugu	*64.	idi
*2.	apa	23.	udu	*44.	ugu	65.	ata
3.	ibi	*24.	udu	45.	aza	*66.	ata
*4.	ibi	25.	uθu	*46.	aza	67.	uʒu
5.	aba	*26.	uθu	47.	ufu	*68.	uʒu
*6	aba	27.	aʃa	*48.	ufu	69.	ivi
7.	iti	*28.	aʃa	49.	ifi	*70.	ivi
*8.	iti	29.	iki	*50.	ifi	71.	izi
9.	uzu	*30.	iki	51.	isi	*72.	izi
*10.	uzu	31.	uʃu	*52.	isi	73.	ipi
11.	uku	*32.	uʃu	53.	upu	*74.	ipi
*12.	uku	33.	utu	*54.	upu	75.	afa
13.	ada	*34.	utu	55.	igi	*76.	afa
*14.	ada	35.	aða	*56.	igi	77.	aka
15.	usu	*36.	aða	57.	iði	*78.	aka
*16.	usu	37.	uðu	*58.	iði	79.	uvu
17.	ubu	*38.	uðu	59.	iʒi	*80.	uvu
*18.	ubu	39.	asa	*60.	iʒi	81.	aθa
19.	aga	*40.	asa	61.	aʒa	*82.	aθa
*20.	aga	41.	iʃi	*62.	aʒa	83.	ava
21.	iθi	*42.	iʃi	63.	idi	*84.	ava

*Compensated production.

normal compensated pair was determined by a random selection procedure.

Test Environment

The recording of the acoustic signal was accomplished using a high quality reel to reel tape recorder (Ampex 6440B) and a stationary microphone (Electrovoice 635A) located within a double walled prefabricated booth (I.A.C. series 1600). Each subject was able to monitor the intensity of each production by observing a VU meter (Calectro DI-930) located within the booth. External monitoring of the acoustic signal was facilitated by amplifying the acoustic signal (Ampex 440B) through an external speaker (Ampex AA620).

Method

The subject was seated within an I.A.C. booth, ten centimeters from a stationary microphone. Each subject was presented with a list of eighty-four (84) VCV combinations (normal/compensated) listed in a random order. Verbal instructions for the production of the compensated articulations were constructed according to the recommendations of previous investigators (Shelton et al. 1968, Wells 1971, Van Hattum 1974). The instructions were as follows:

1. For the plosive compensations you should approximate the place of production of the normal phoneme, but you should have a lighter lip or tongue contact and a more rapid closure.

2. For the production of the fricative you should attempt a more rapid constriction with less frication.

3. For the production of alveolar sounds you should attempt to make a type of flapping movement with your tongue to and away from the place of production.

4. For the production of velar sounds you should attempt to have a less firm attack and more aspiration.

Each subject was instructed to say the normal VCV combination and compensated VCV combination five times. The subject was also asked to speak in a monotone with equal stress on each syllable. The speaker was advised to monitor his productions on a VU meter to attempt to maintain consistency of productions.

Two judges, the author, a non-participating subject, and the speaker himself determined the acceptability of each production. This determination was made on a score sheet (Appendix B) where each production was rated on a three-point scale, representing good, better and best production. Final acceptance of one production was determined by the highest average score of the five productions.

Analysis

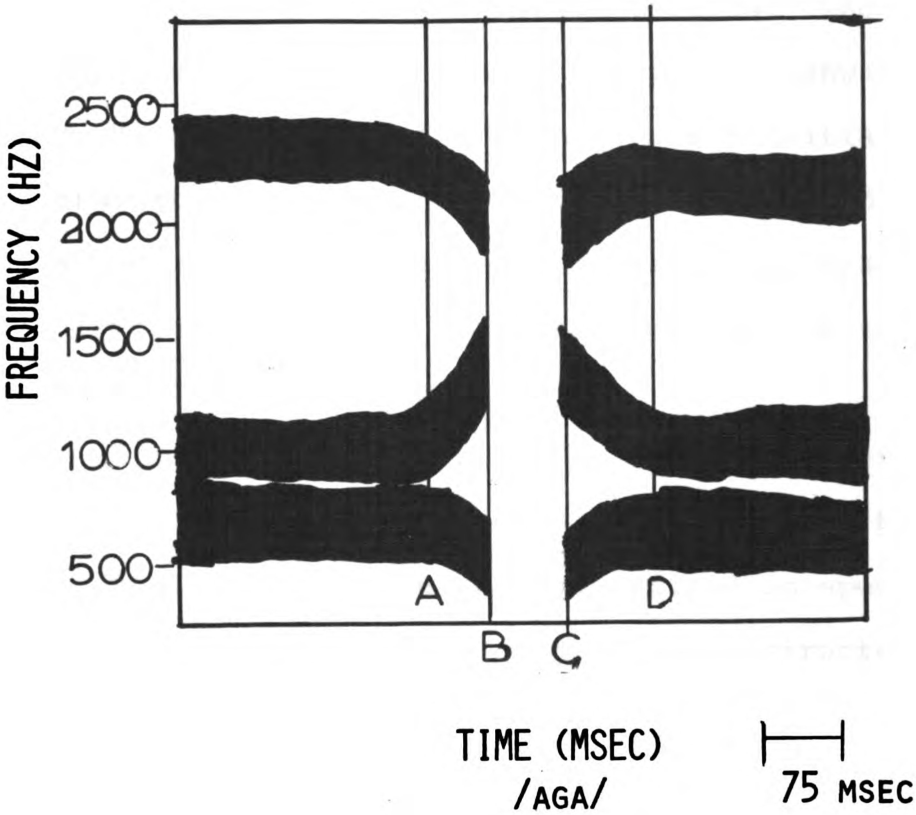
Wide band spectrograms were made of each production to provide the means for measuring the acoustic variables of VC and CV transition rate and the constriction or closure duration of each consonant.

After evaluating the possible methods of transition measurement, it was determined that the duration of the transition would best reflect the articulatory dynamics occurring during normal and compensated consonant production. The duration of the formant transitions were measured for both the VC and CV segments. As indicated in Figure 1, the initial measurement of the VC segment began at the point where rapid frequency changes began to occur in the structure of the first formant. If the first formant did not reveal a distinct point for measurement, determination of the point of change was made from the second and third formants (Figure 1). This rule was adopted for all transition duration measurements. The terminal measurement of the VC segment concluded at the downward frequency shift of the first formant and the beginning of the consonant closure. The initial measurement of the CV segment began at the point of an initial spike for a voiceless plosive or at the point of a rapid frequency shift in the first formant for the remainder of the consonants. The terminal measurement was made at the point where the frequency began to stabilize in the first formant. Vertical lines were drawn at each point of measurement to facilitate the analysis of the results. The procedures described by Öhman (1966) were used:

> An extrapolation rule was adopted that stated that the formant was assumed to move into the stop gap without a change in slope from the nearest observable value in the vowel (p. 152).

Figure 1a.--Schematic representation of spectrographic analysis where determination of values are made from the first formant. The first formant exhibits a distinct transition as indicated at point a-b. The points b-c represent the closure duration of the consonant and the point c-d indicates the final transition duration.

Figure 1b.--Schematic representation of spectrographic analysis where determination of values are made from the second formant. Because the initial formant appears straight, the second formant is examined to determine the point of transition. Point a-b represents the direction of the initial transition, point b-c closure duration, and point c-d the final transition.


FREQUENCY (HZ)
2500
2000
1500
1000
500
A
B
C
D
TIME (MSEC)
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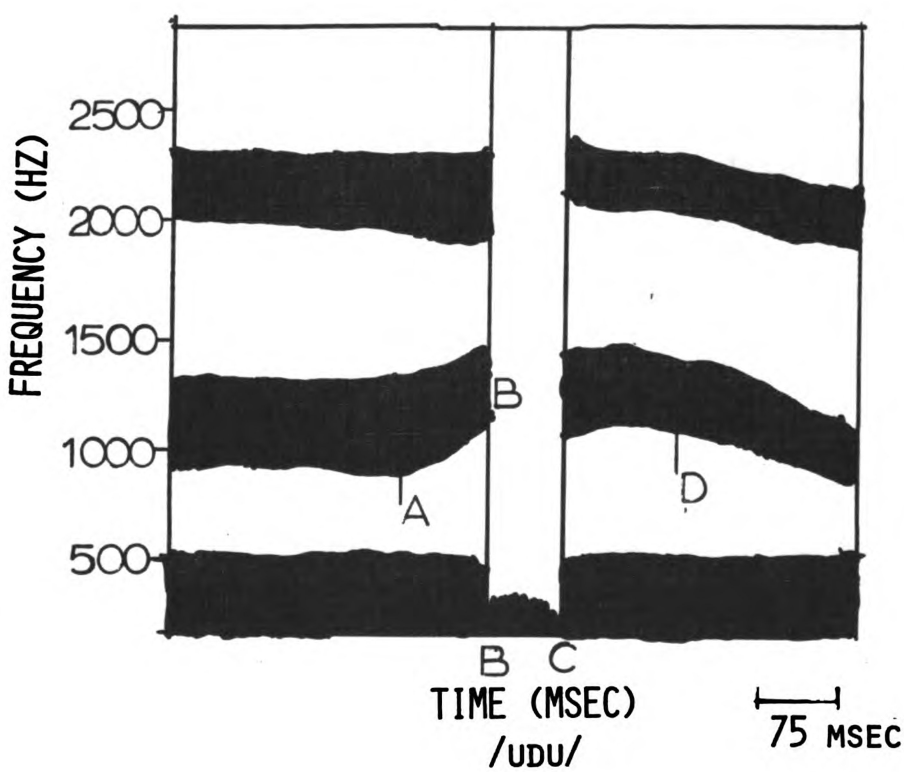
75 MSEC


FREQUENCY (HZ)
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C
D
TIME (MSEC)
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75 MSEC

The duration of the constriction or closure duration was measured by drawing a vertical line at the initiation of closure as indicated by the downward frequency shift of the first formant for the initial vowel. The termination of the constriction or closure duration was marked by a spike for the voiceless plosives or a rapid frequency shift in the first formant for the remainder of the consonants.

A reliability check was performed on every fifth spectrogram. These measurements were performed by a Ph.D. student in Speech Science who was trained in spectrographic analysis. In addition, the student was instructed by the experimenter following the procedures previously presented. The reported reliability values for closure/constriction duration were a mean value of 14.6, standard deviation 5.99, and range 4-29. Original results reported were a mean value of 14.4, standard deviation of 6.02, and range of 5-28. The reliability measurements for transition durations were a mean value of 8.6, standard deviation of 3.42, and range of 3-22. The original measurements were a mean value of 11.4, standard deviation of 2.79, and range of 7-23. The table of these values is presented in Appendix C.

All of the duration measurements were based on the formula: 31.8 cm equals 2.4 seconds, or 1 mm equals 7.5 msec.

Experiment II

Subjects

The subjects used in this experiment were the same as those used in Experiment I.

Speech Stimuli

The speech stimuli were the same as reported in Experiment I.

Test Environment

The procedure used was similar to those described by Hutchinson (1973). A catheter (#12 French) was utilized to obtain measurements of intraoral air pressure. The catheter was inserted through the nasal passage until it was visible in the oropharynx as determined by the experimenter. The opening of the catheter was perpendicular to the air flow to prevent spuriously high air pressure readings that can occur when the air flow directly impinges on the orifice of the tube (Hardy 1965). The catheter was attached to a pressure transducer (Statham 131TC). The signal from the transducer was amplified (Accudata 113 Bridge Amplifier) and recorded on one channel of an optical oscillograph (Visicorder 1508B). Prior to the initiation of the experiment, a static calibration was accomplished using a U-tube water manometer. The procedure enabled the experimenter to correlate a known pressure with a given galvanometer deflection on the optical oscillograph.

The air flow data were obtained using a tight fitting face mask (CI-6, large) coupled to a pneumotachograph (Hewlitt-Packard custom made). The pneumotachograph houses a screen that provides a resistance to the air flow. As stated by Isshiki and Ringel (1964), "the principle of measuring a flow rate is based on the fact that the pressure drop across a resistance (mesh screen), which is caused by an air stream, varies linearly with flow rate under certain conditions." In the present investigation the pressure drop was sensed by a differential pressure transducer (Statham, PM 15), amplified (Honeywell Accudata 113 Bridge Amplifier), and recorded on a second channel of the optical oscillograph. Calibration of the flow rate system was achieved by directing a constant source of air with a known velocity through a 55 cm glass tube (to reduce the turbulence from the air source) connected to the pneumotachograph and differential pressure transducer system. The rate of air flow was measured by a velometer (Alnor) and equated with specific galvanometer deflections.

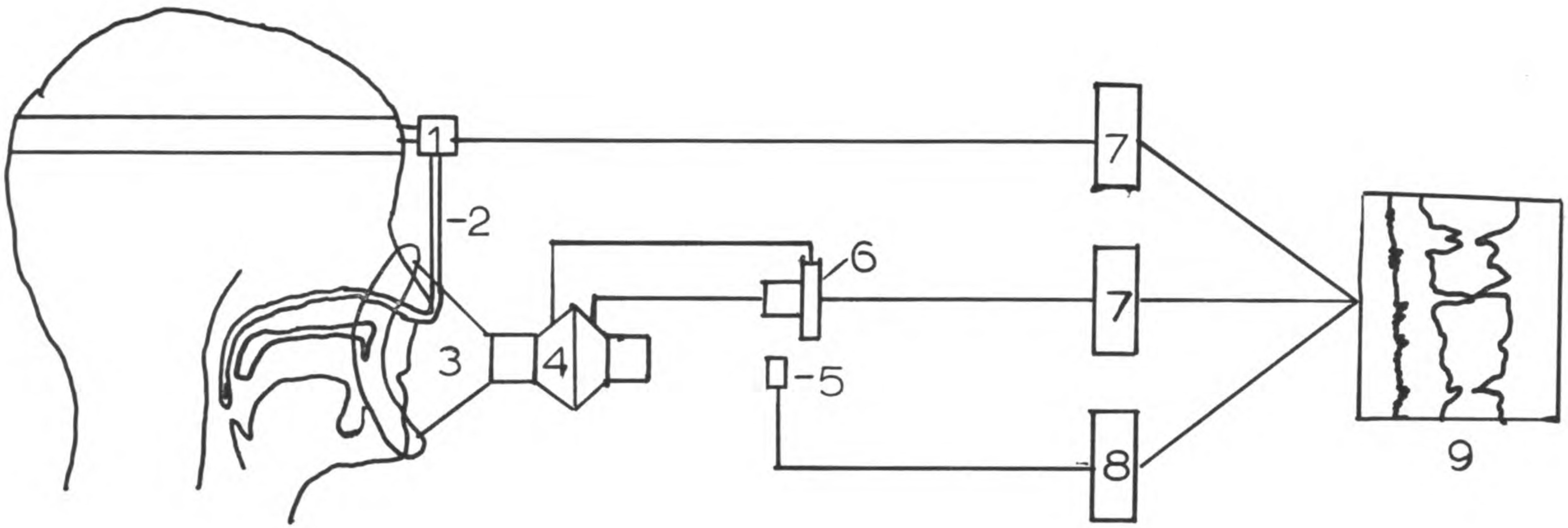
To obtain an audio signal, a high quality microphone (Electrovoice 635A) was placed near the end of the pneumotachograph. The signal was amplified (Ampex 601) and recorded on a third channel of the optical oscillograph. Simultaneous audio recording was achieved using a high quality tape recorder (Ampex 601) and microphone (Electrovoice 635A). A schematic representation of the instrumental array is presented in Figure 2. In addition Figure 3 presents a pictorial display of the subject and aerodynamic sensing equipment.

Method

The subject was seated in the testing room where he received the same list of stimuli (Table 1) as described in the preceding experiment. The instructions for the compensatory productions of the consonants remained the same except that the subject was asked to state only one normal and one compensated production. As previously reported, each subject had a nasal catheter inserted through the nasal passage to facilitate the measurement of intraoral air pressure. In addition, each subject was asked to manually place the face mask coupled to the pneumotachograph tightly around his mouth to facillitate the measurement of air flow rate. The participating subject, non-participating subject, and the author served as judges for each production. A one hundred percent agreement criterion was established for the acceptance of each production. Each subject was required to produce verbally each list of productions three times. These trials occurred on two separate days for both speakers.

Analysis

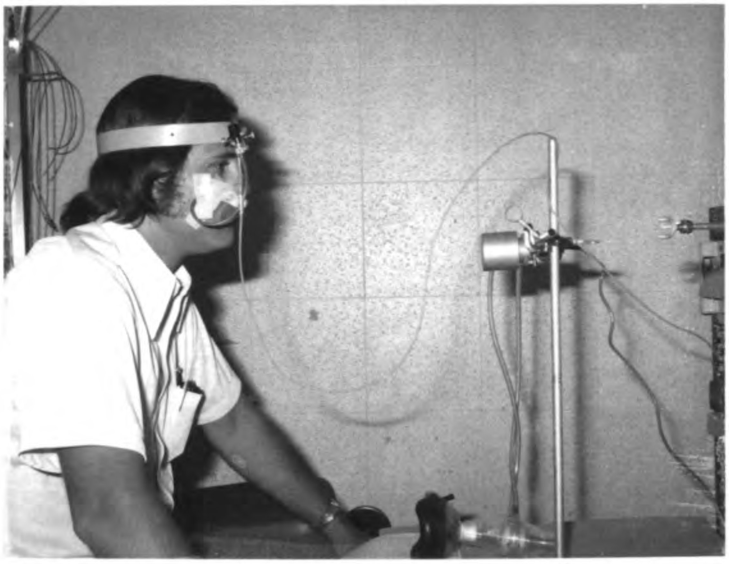
Before the measurements of the intraoral air pressure and air flow rate were made, the audio recordings were played back and each production was identified to insure accuracy.

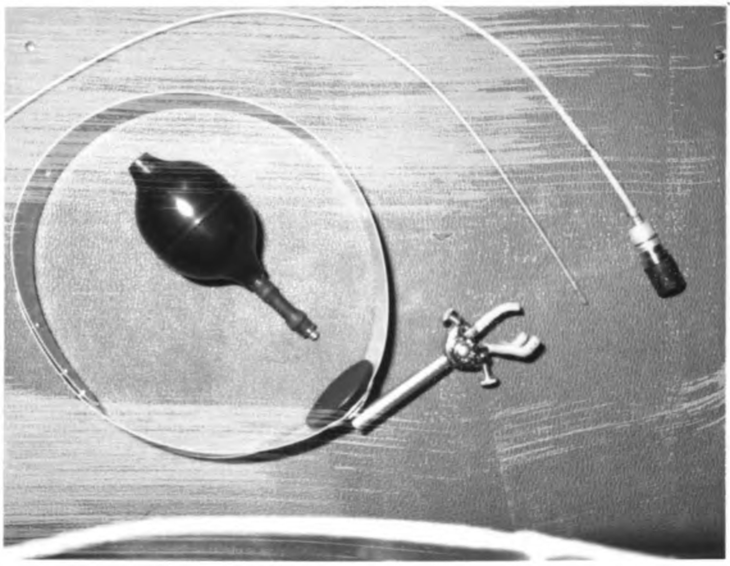


1. PRESSURE TRANSDUCER
2. CATHETER
3. FACE MASK
4. PNEUMOTACHOGRAPH
5. MICROPHONE
6. PRESSURE TRANSDUCER
7. BRIDGE AMPLIFIER
8. GALVONOMETER AMPLIFIER
9. OPTICAL OSCILLOGRAPH

Figure 2.--Instrumental array used for recording the aerodynamic data.

Figure 3.--Pictorial representation of speaker DB and equipment used for aerodynamic measurement.





The normal and compensatory articulatory productions were examined both quantitatively and qualitatively. The peak intraoral air pressures and air flow rates were examined for all of the consonants produced. Measurements were made from an established baseline to the point of greatest excursion for the intraoral air pressure and to the point of greatest excursion following the release of the consonant for the air flow rate. For many of the consonants examined, this peak air flow rate was not the point of greatest excursion. During the production of many of the compensated consonants, the point of greatest excursion from the baseline occurred prior to the release of the consonant. As a result, consistent measurements of the air flow peaks were made following the consonant release.

The duration of the intraoral air pressure was measured from the point where the pressure curve began to rise from the base pressure and then terminated at the point where the pressure curve joined the vowel trace at the baseline. These measurement procedures are similar to those reported by Subtelny et al. (1966) and Malécot (1968).

The quantitative data were collected for three trials for each subject. The data reported reflects the means of the three experimental trials.

The qualitative analysis consisted of a search for distinct new aerodynamic patterns that occurred as a result of the compensatory articulations.

CHAPTER III

RESULTS

The results of the present investigation will be presented in two sections. The first section will deal with the acoustic analysis of normal and compensated consonant productions followed by an evaluation of the aerodynamic experimentation. A third section of this chapter will attempt to integrate the measurements of the first two sections in an effort to examine the interrelationships that may exist between the acoustic and aerodynamic characteristics as they relate to compensatory articulation.

Acoustic Analysis

Plosive Closure Duration

The duration of the plosive closures are presented in Table 2.

TABLE 2.--Mean plosive closure duration (in msec.) for speakers JH and DB.

	JH			DB	
	Normal	Compensated		Normal	Compensated
aCa	108	75	aCa	79	82
uCu	102	107	uCu	84	116
iCi	120	103	iCi	76	119
Means	110	95		80	105

An examination of the means for this table indicated that the closure duration of the compensated plosives decreased for JH while for DB, the duration of closure for the compensated plosives increased. A further breakdown of this category as exhibited in Table 2, revealed a number of inconsistencies within the voiceless plosive class, thus minimizing the drawing of any significant trends from the results associated with this class of phonemes.

TABLE 3.--The mean plosive closure durations (in msec) and ranges across the voiced-voiceless (V-VL) distinction.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
JH								
aCa	116	101-131	86	56-128	99	98-101	64	23- 86
uCu	103	86-124	115	60-173	80	86-113	100	34-161
iCi	118	105-128	115	45-180	123	113-135	91	49-120
DB								
aCa	103	71-101	115	53-135	71	60- 83	63	41- 94
uCa	91	71-113	165	109-218	76	68- 86	66	45-101
iCa	83	60-105	190	173-218	70	45- 90	48	34- 68

Examination of the closure duration of the normal and compensated voiced plosives revealed that eighty-three percent (83%) of these plosives decreased in duration during the compensated production of the consonant. It was only within the voiced /uCu/ contest for speaker JH, that the compensated plosive production increased in duration.

Fricative Constriction Duration

The fricative constriction durations for the normal and compensated fricative productions are presented in Table 4.

TABLE 4.--Mean fricative constriction durations (in msec) for speakers JH and DB.

	JH			DB	
	Normal	Compensated		Normal	Compensated
aCa	148	125	aCa	106	83
uCu	155	131	uCu	115	94
iCi	136	109	iCi	88	88
Means	146	122		103	88

Examination of the values presented for both speakers indicated that the compensated form of the fricative productions decreased or remained the same in duration within the three vowel contexts. When the fricative constriction durations were further broken down according to the voiced-voiceless distinction (Table 5), it can be seen that ninety-three percent (93%) of the compensated productions decreased in duration. Only one context, /iCi/ for a single speaker, showed no change between the normal and compensated production.

TABLE 5.--Mean fricative constriction durations and ranges (in msec) for both speakers JH and DB.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
JH								
aCa	160	150-173	127	105-146	135	127-150	124	86-180
uCu	183	165-210	154	109-173	126	113-135	109	53-150
iCi	188	169-203	158	130-169	84	71- 94	60	38- 83
DB								
aCa	144	116-128	112	94-124	68	64- 75	54	45- 75
uCu	159	190-210	132	53-154	70	45-113	55	38- 71
iCi	118	60-165	120	94-158	56	53- 75	56	34- 94

Plosive Transition Duration

The initial and final plosive transition durations are shown in Table 6.

TABLE 6.--Initial and final plosive transition durations.

	JH				DB			
	initial		final		initial		final	
	norm	comp.	norm	comp.	norm	comp.	norm	comp.
aCa	81	81	91	95	94	74	108	89
uCu	74	98	132	112	89	74	109	132
iCi	69	71	121	97	71	74	101	100
Mean	75	83	115	101	84	74	106	107

Examination of the results for the normal and compensated productions revealed inconsistencies that prevented the drawing of any significant conclusions. A further analysis of the plosive transitions according to the voiced-voiceless distinction can be found in Table 7. The results presented in Table 7 further support the inconsistencies reported for the plosive transitions. Because only fifty-eight percent (58%) of the initial and final transitions increased in duration from the normal to compensated productions, it was not possible to draw any significant conclusions.

TABLE 7.--Initial and final plosive transition durations (in msec) voiced-voiceless distinctions.

	initial			final			mean
	aCa	uCu	iCi	aCa	uCu	iCi	
JH							
VLN	78	74	69	96	181	163	110
VLC	75	91	76	85	143	116	98
VDN	85	74	70	86	83	80	80
VDC	86	104	66	105	75	78	85
DB							
VLN	86	65	81	114	105	115	94
VLC	79	83	71	105	138	120	96
VDN	101	113	60	103	113	88	96
VDC	70	65	76	74	125	81	81

VLN = voiceless normal
VLC = voiceless compensated
VDN = voiced normal
VDC = voiced compensated

Fricative Transition Duration

As viewed in Table 8, the mean compensated duration values for the fricative transitions decreased for both speakers in the voiced and voiceless categories.

TABLE 8.--Initial and final fricative transition durations (in msec): voiced-voiceless distinction.

	initial			final			mean
	aCa	uCu	iCi	aCa	uCu	iCi	
JH							
VLN	90	98	98	72	102	87	91
VLC	95	72	68	90	75	79	80
VDN	89	105	83	85	96	98	93
VDC	88	99	107	82	86	83	91
DB							
VLN	77	63	61	88	83	109	80
VLC	72	53	59	83	91	66	71
VDN	58	89	68	72	82	95	77
VDC	53	70	55	72	68	68	65

It must be noted however that for JH a number of instances occurred where the compensated transition duration exceeded the normal production of the consonant. In addition, in one context, speaker DB exhibited an increase in the transition duration during the production of the voiceless fricatives appearing in the /u/ context.

Summary of the Acoustic Analysis

In summarizing the previously reported data, the fricative results appeared to be more consistent between speakers than the plosive results. The results presented in the previous experiment indicated that in the case of voiced plosive closure duration, fricative constriction duration, the fricative transition duration, and compensated forms of the consonants exhibited a decrease from the normal production.

Aerodynamic Analysis

The presentation of these date will be in four sections. These sections will include: the quantitative analysis of air flow rate, the quantitative analysis of intraoral air pressure, the qualitative characteristics of air flow rate and intraoral air pressure during the compensatory productions, and, finally, the durational measurement of the intraoral air pressure.

Plosive Air Flow Rate

The mean air flow rates for voiced and voiceless plosives are presented in Table 9. In the voiceless plosive category, both speakers exhibited a lower air flow rate for the compensated production when compared to the normal production of the consonant. It can also be noted that the voiced plosives exhibited a decrement in air flow during the production of the compensatory consonants. Although the air flow rates obtained in this study were higher than those previously reported in the literature, the normal productions followed the same pattern as in

TABLE 9.--The mean plosive air flow rates (in cc/sec) and range of values for both speakers.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
JH								
aCa	2169	1666-2446	606	168-1712	632	240- 963	192	43- 382
uCu	2192	1269-2461	904	260-1682	751	459-1177	329	183- 566
iCi	1852	596-2446	482	275- 780	557	397- 657	226	168- 795
DB								
aCa	2224	1980-2400	1235	431-1896	516	296- 795	516	46- 996
uCu	2041	1590-2446	887	275-1942	841	431-1269	841	108- 612
iCi	1965	1387-2416	430	135- 876	743	611- 889	743	40-1758

previous studies, whereby, the voiced plosives exhibited a lower air flow rate than their voiceless cognates.

Fricative Air Flow Rate

The fricative air flow data is presented in Table 10.

TABLE 10.--The fricative air flow rate (in cc/sec) and range of values for speaker JH and DB.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
JH								
aCa	1062	612-1773	1099	168-1620	620	275- 840	380	214-1207
uCu	1158	657-1544	1271	573-1788	745	489- 948	552	76-1193
iCi	997	627-1559	1010	214-1223	611	344- 826	360	275- 519
DB								
aCa	1411	1037-1941	1301	81-2447	751	275-1253	631	81-2128
uCu	1490	1978-1987	837	229-1712	1020	581-1482	399	153-1100
iCi	1308	963-1636	1040	121-1437	982	672-1559	592	306-1040

The decrement in air flow rate that was previously reported in the compensated plosive productions is also evident in the compensated fricative productions of speaker DB. However, JH has demonstrated some variability between the production of the normal and compensated consonants. Specifically, within the voiceless class of fricatives, JH has exhibited an increase in the air flow rate during the compensated productions. In addition, although not represented by this table of mean values, speaker DB also exhibited a number of increased air flow rates for compensated productions of /asa, aθa, ava, usu, iθi/. For both speakers the voiced fricative class of phonemes appeared to be more stable with a majority of the voiced fricatives compensations exhibiting a decrement in air flow rate.

Plosive Intraoral Air Pressure

The mean plosive intraoral air pressure data for both speakers are presented in Table 11. A decrement in the intraoral air pressure was exhibited by both speakers during the production of all voiced and voiceless productions of the compensated plosives. The normative results presented in Table 11 are similar to those reported by Malécot (1968).

Fricative Intraoral Air Pressure

As in the case of the plosive intraoral air pressures, the fricative intraoral air pressures as produced by both speakers exhibited a decrease in value during the production

TABLE 11.--The mean plosive intraoral air pressures (in cm/ H_2O) and range of values for both speakers JH and DB.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
<u>JH</u>								
aCa	8.9	4.2-10.1	5.1	3.5-6.6	5.6	3.2-8.0	2.6	1.2-3.4
uCu	9.1	6.8-10.2	5.5	3.0-7.5	7.1	4.0-8.5	3.2	.4-5.0
iCi	8.8	6.8-10.3	4.7	2.0-6.1	5.9	4.5-7.0	2.7	1.0-4.4
<u>DB</u>								
aCa	8.5	6.5- 9.8	2.4	.7-5.5	4.5	2.7-5.4	.7	.3-1.4
uCu	9.6	7.6-11.0	1.4	.3-2.6	5.4	4.1-7.2	1.3	.5-2.9
iCi	9.5	8.6-10.3	1.4	.2-2.6	5.6	2.8-6.4	1.7	.4-3.2

of the compensated productions of the consonants. Consistent with previous reported investigations (Subtelny <u>et al</u>. 1966, Arkebauer <u>et al</u>. 1967), the voiced fricatives all displayed lower intraoral air pressures when compared with their voiceless cognates. The peak fricative pressures are reported in Table 12.

<u>Distinct Aerodynamic Patterns</u>

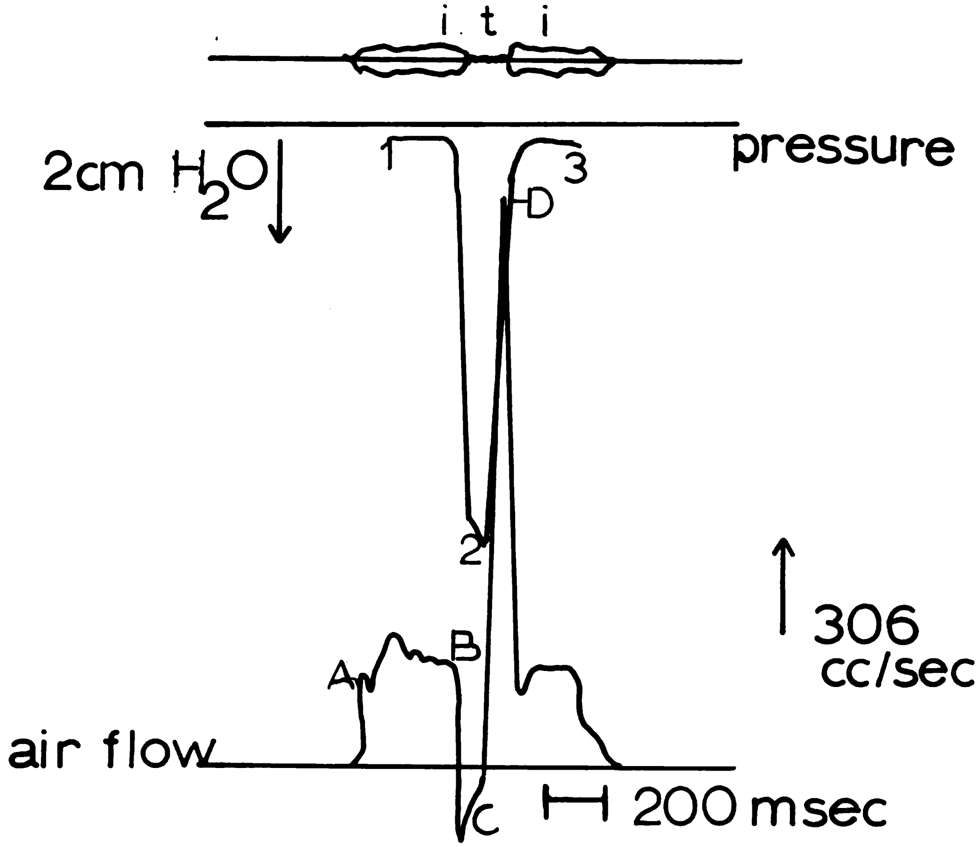
A number of distinct aerodynamic patterns were revealed from the oscillographic traces. As presented in Figure 4, this pattern occurs in a majority of compensated productions produced by speaker JH. In this type of production, the air flow pattern of the normal production was characterized by a relatively low continuous air flow occurring during the production of the vowel (point a-b).

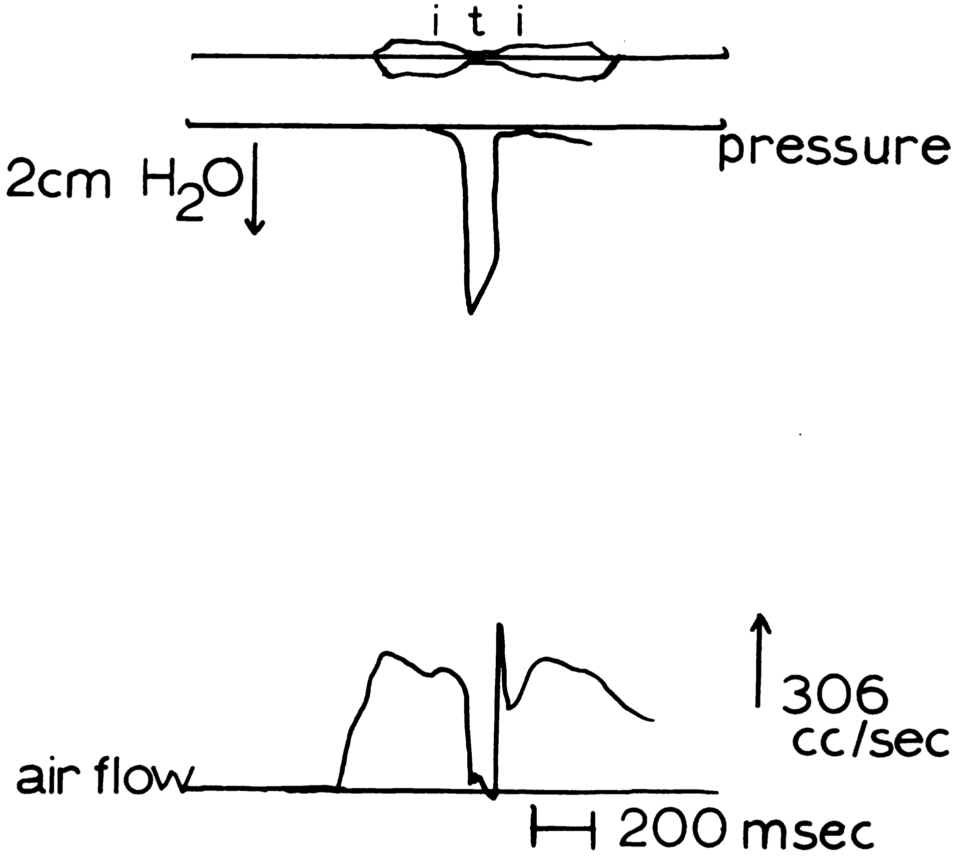
TABLE 12.--Mean fricative intraoral air pressures (in cm/H_2O) and range of values for both speakers JH and DB.

	VL				V			
	norm	range	comp.	range	norm	range	comp.	range
JH								
aca	6.7	3.7- 8.4	3.1	.1-5.4	4.3	1.6- 7.3	1.7	.4-3.9
ucu	7.6	4.5- 8.8	3.1	.6-4.6	5.5	3.1- 7.0	2.6	1.1-3.9
ici	7.4	4.1-10.0	3.6	.6-4.7	5.6	3.9- 7.6	2.1	1.1-3.8
DB								
aca	8.8	6.0-10.9	1.6	.5-2.5	6.1	2.1- 8.6	1.7	.2-8.6
ucu	9.2	7.9-10.6	1.3	.2-3.5	7.6	2.9-11.3	1.6	.8-2.6
ici	9.6	8.2-10.6	1.2	.5-2.2	7.6	5.9- 9.2	2.1	.3-5.5

Following the vowel the air flow drops off rapidly (b-c) while the intraoral air pressure is impounded and elevated (1-2). Following the release of the closure (2-3), the air flow rate increases rapidly (c-d) and then returns quickly to the baseline for the production of the final vowel. The compensated form of the consonant appears to demonstrate the same configuration as reported for the normal production although it is evident that the compensated production displayed a marked decrease in both the air flow rate and intraoral air pressure. This aerodynamic pattern is a graphic representation of the quantitative differences previously reported for the normal and compensated production.

Figure 4.--Schematic representation of quantitative differences between the normal and compensated consonants. The top trace represents the acoustic envelope; the second, intraoral air pressure; and the bottom air flow rate. Baselines are drawn through the traces. (Hereafter similar figures will follow the same organization.)


i t i
pressure
2cm H_2O
1
2
3
D
A
B
C
306
cc/sec
air flow
200 msec


i t i
pressure
2cm H_2O
306
cc/sec
air flow
200 msec

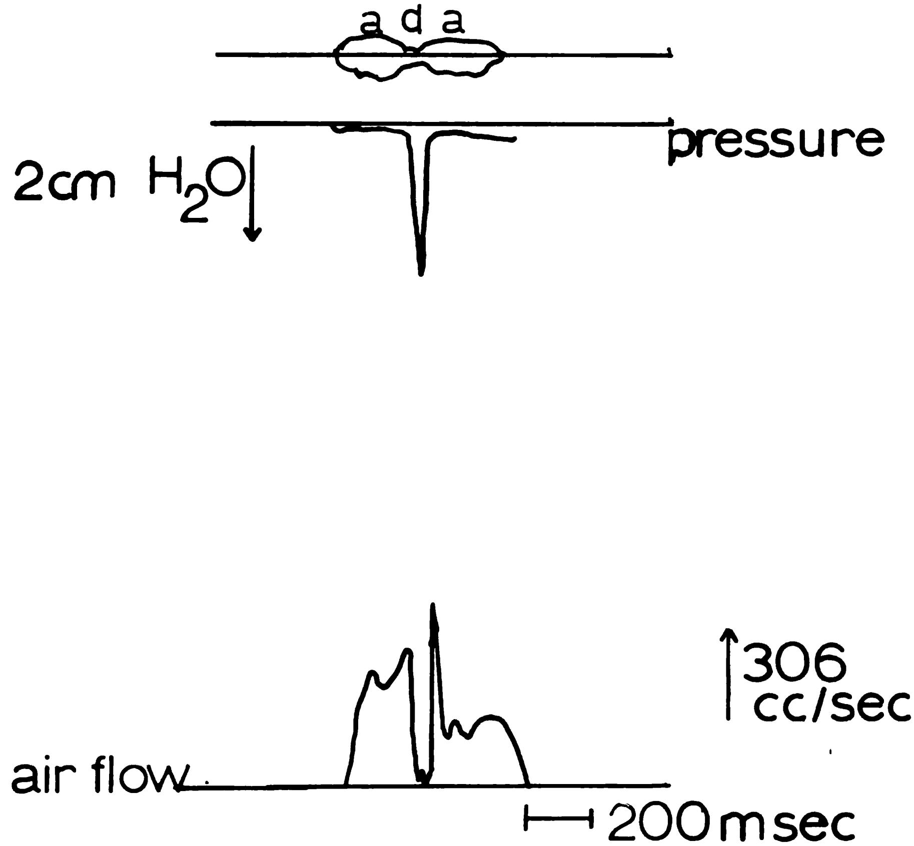
A number of qualitative aerodynamic patterns were displayed by speaker DB. In the compensated production displayed in Figure 5, DB has produced the consonant on an inhalatory pattern. Examination of the air flow trace reveals an increased air flow rate prior to consonant release (point a). This exhalation of air is followed by an inhalation (b), and the production of the consonant. In this type of production there was a minimal rise in intraoral air pressure from the initiation to termination of the consonant.

A second distinct qualitative aerodynamic pattern is exhibited in Figure 6. This pattern was characterized by a rapid increase in air flow rate and intraoral air pressure at the initiation of the compensated consonant. These initial peaks quickly return to the baselines. The air flow pattern reveals an inhalatory pattern that is represented by the valley occurring below the baseline. While this inhalatory production is occurring, the intraoral air pressure remains minimal for about 100 msec. until the initiation of the vowel.

A third qualitative aerodynamic pattern occurred for many of the compensated fricative productions for DB. As seen in Figure 7, the normal production of many fricatives are characterized by dual air flow peaks and a large intraoral air pressure peak. The compensated productions are characterized by an increase in the initial air flow peak (a)

Figure 5a.--Schematic representation of the normal production of /ada/ by speaker DB.

Figure 5b.--Schematic representation of the inhalatory pattern exhibited by DB during the production of the compensated /ada/. In this production there is minimal intraoral air pressure.


a d a
pressure
2cm H_2O
306 cc/sec
air flow
200 msec

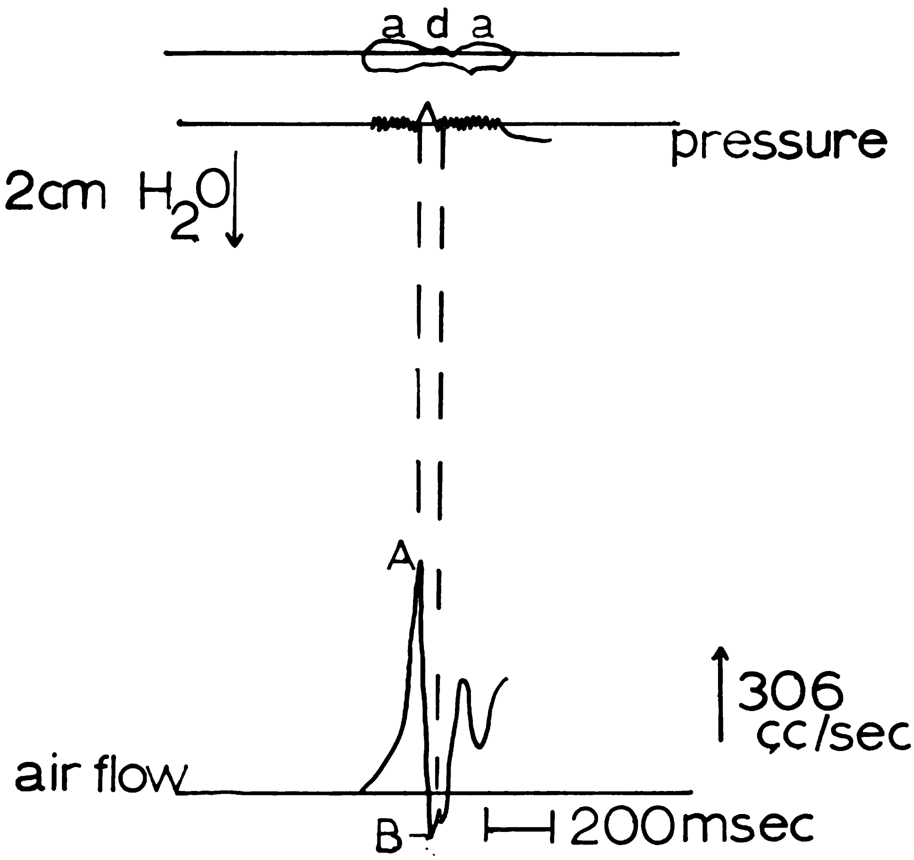

a d a
pressure
2cm H_2O
A
306 cc/sec
air flow
B
200 msec

Figure 6a.--Schematic representation of the normal production of /upu/ by DB.

Figure 6b.--Schematic representation of a second inhalatory pattern produced by speaker DB. During this production the intraoral air pressure rises and falls rapidly and remains minimal for about 100 msec.

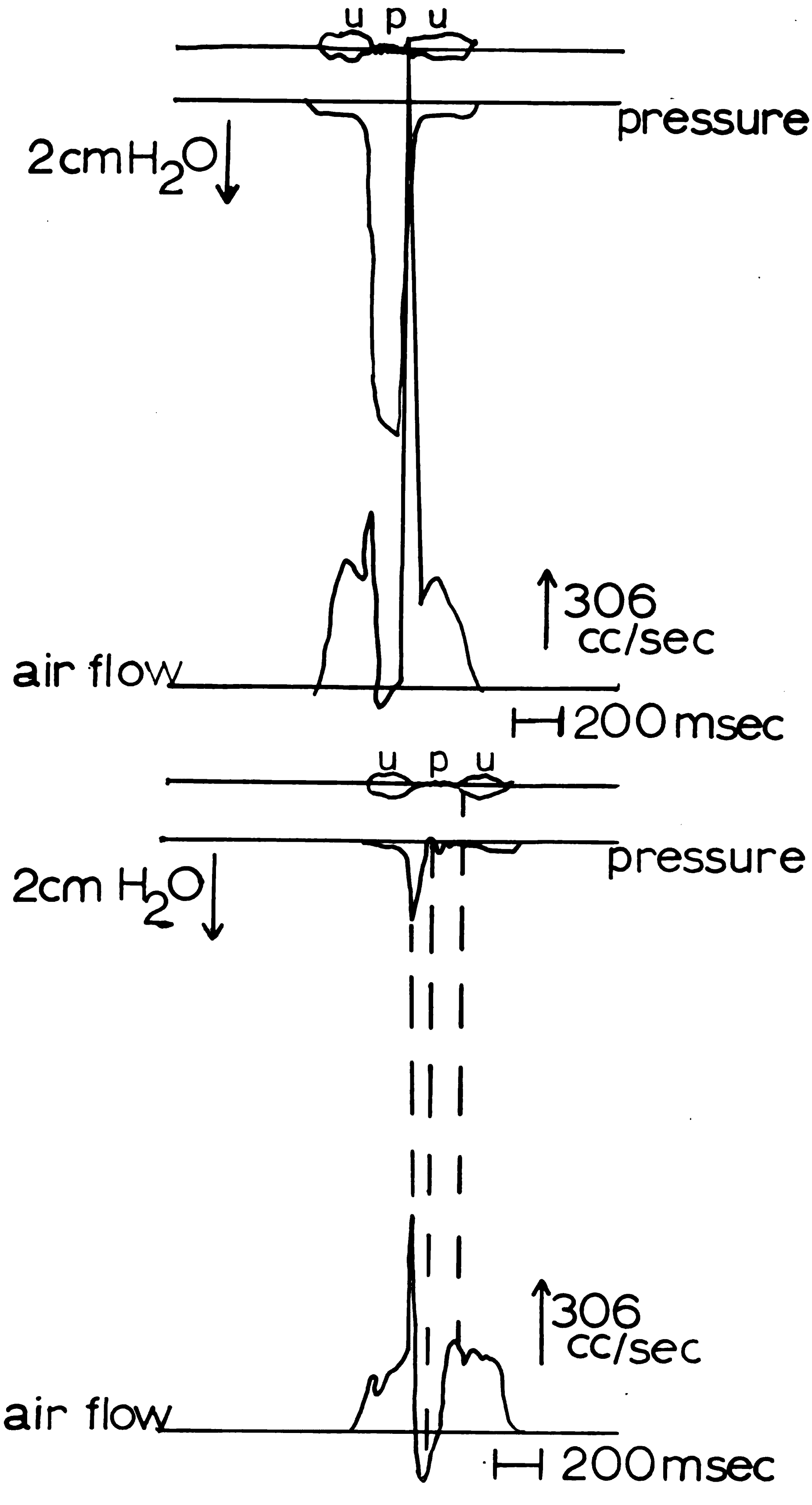
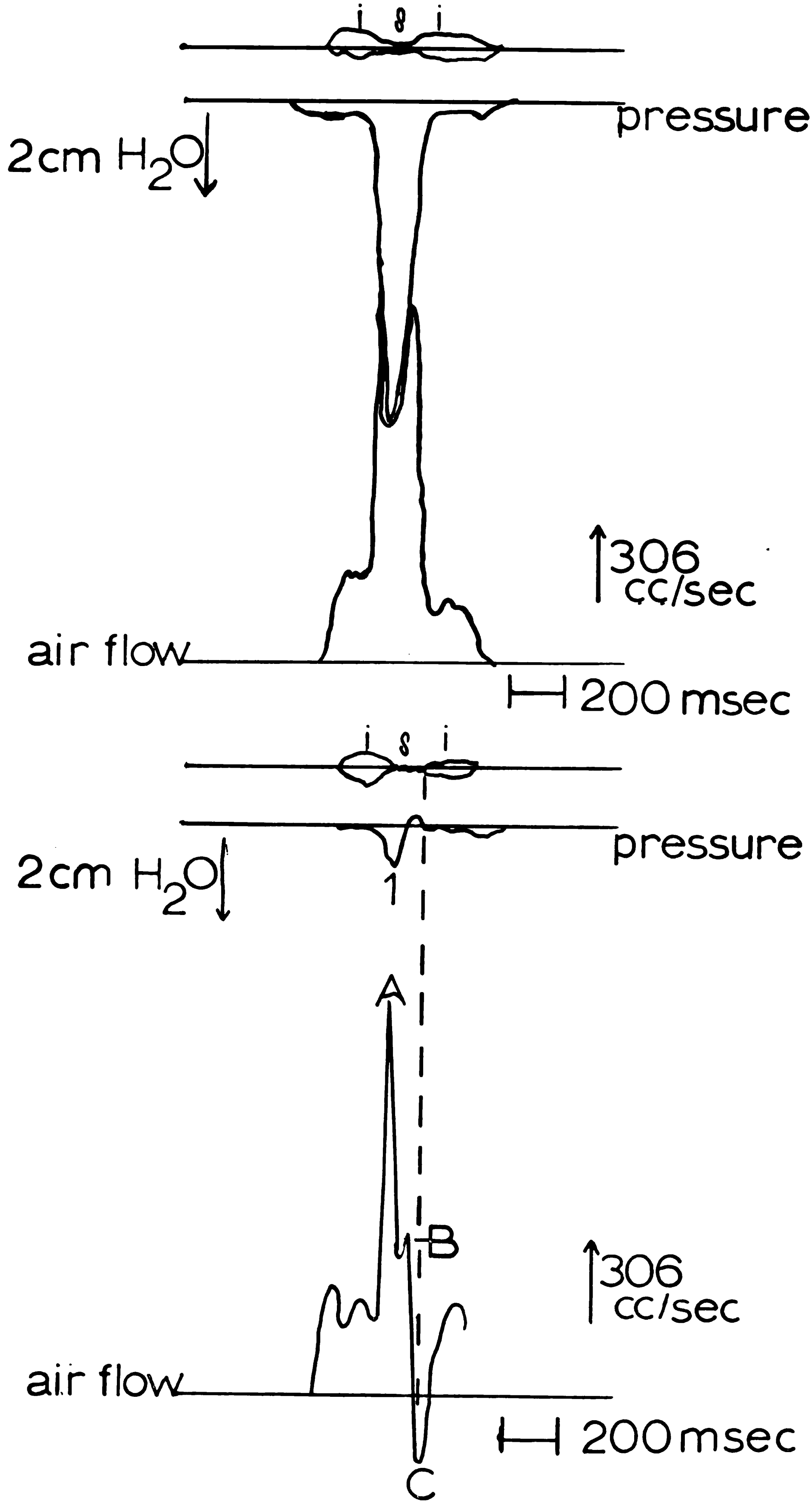

u p u
pressure
2cm H_2O
306 cc/sec
air flow
200 msec
u p u
pressure
2cm H_2O
306 cc/sec
air flow
200 msec

Figure 7a.--Schematic representation of the normal production of /iʃi/ by speaker DB.

Figure 7b.--Schematic representation of /iʃi/ compensated for speaker DB. This pattern is representative of many of the compensated fricative productions.



i
i
pressure
2cm H_2O
306 cc/sec
air flow
200 msec
i
i
pressure
2cm H_2O
1
A
B
306 cc/sec
air flow
200 msec
C

and a decrease in the second peak (b). In addition, while DB has increased the initial air flow peak he has produced the consonant with a decrease in intraoral air pressure (l). Following the decreased second peak, DB produced an inhalatory pattern (c) for the termination of the consonant and initiation of the vowel.

Intraoral Air Pressure Duration

The results of the analysis of intraoral air pressure duration for plosives and fricatives are presented in Table 13.

TABLE 13.--Intraoral air pressure durations of plosives and fricatives (in msec) for speakers JH and DB.

	JH		DB	
	normal	compensated	normal	compensated
Plosives				
aCa	160	148	190	147
uCu	179	154	208	140
iCi	167	148	210	138
means	168	150	202	142
Fricatives				
aCa	187	143	175	150
uCu	214	159	202	138
iCi	216	148	203	126
means	206	150	193	126

The results for the normative productions are similar to those reported by Hutchinson (1973) and Malécot (1968). The results appeared to indicate that for all compensated productions, the duration of the intraoral air pressure decreased. It must be noted, however, that for a number of compensated productions in which the inhalatory aerodynamic configuration appeared, it was impossible to obtain any distinct duration measurements.

Summary of the Aerodynamic Analysis

Upon completion of the aerodynamic analysis, it is possible to draw a number of conclusions regarding the normal and compensated productions of plosives and fricatives.

1. The airflow rate for compensated plosives decreased in all productions.

2. The majority of the voiced fricative compensations exhibited a decrement in air flow rate.

3. Intraoral air pressure decreased for fricative and plosives in all compensated productions.

4. A number of distinct aerodynamic patterns occurred for both speakers upon examination of the oscillographic aerodynamic traces.

5. Intraoral air pressure durations decreased for both speakers in all plosive and fricative compensations.

Integration of Acoustic and Aerodynamic Characteristics

To the extent that comparison is possible this section will attempt to bring together some relative information provided by the acoustic and aerodynamic investigation of compensatory articulation. It is evident from the results obtained, that compensatory articulation, whether measured acoustically or aerodynamically, decreased in the time required to produce the consonants. In only one instance for one speaker did the duration of the compensated productions increase. A second point worth noting was the fact that although the fricative compensations produced the more stable results during the acoustic experimentation, they appeared to be more variable than the plosive productions during the aerodynamic analysis. This variability may be related to the specific characteristics examined for each consonant, or possibly some physiological factor was put into play during the acoustic experimentation, or finally either acoustic or aerodynamic measurement was a better tool for examining compensated consonant production.

CHAPTER IV

DISCUSSION

The results of Experiment 1 generally supported the hypothesis that the degree of closure/constriction of the compensated consonants decreased in duration when compared with the normal production of the consonants. In addition, the data reported for the fricative transition durations further supported the contention that the compensatory articulations decreased in duration when compared with the normal production.

Compensatory Articulation and Closure/Constriction Duration

The majority of the closure/constriction durations decreased during the production of the compensated consonants. The voiceless plosives appeared to be the only class of consonants that exhibited an increase in duration of closure during the compensated productions. The data reported for the increased closure durations revealed that speaker DB produced the compensatory voiceless plosives in 165 and 190 msec in the /u/ and /i/ context respectively.

The normal production of the voiceless plosives average 100 msec in duration as reported in Table 3.

However, if the voiceless fricative constriction durations are examined, it is evident that the results reported for the increased plosive durations were similar in duration to the fricative productions. This fact is supported by an examination of the aerodynamic patterns for many of the compensated plosives produced by DB. The compensated consonant is characterized by the initiation of air flow rate and consonant production prior to the release of intraoral air pressure. This pattern is typically found in the production of normal fricatives. It appears that DB has produced a modified plosive that is similar to a fricative in duration. In this case the aerodynamic measurements helped to confirm the acoustic data.

The fricatives within this closure/constriction classification were the more consistent group of phonemes when the normal and compensated productions were examined. Only one context /uCu/ evidenced an increase in duration during the compensated productions.

Compensatory Articulation and Transition Duration

The initial and final transition durations were examined to provide an indication of the modifications that occurred in the vocal mechanism during the production of the normal and compensated consonants. The fricative data appeared to exhibit an eighty-three percent (83%) decrease in duration for initial transitions and a ninety-two percent (92%) decrease in duration for final transitions when comparing the normal and compensated productions. The plosives, however, provided inconsistent results between the normal and compensated productions. Because only fifty-eight percent (58%) of the initial and final transition durations decreased during the production of the compensated consonants, no significant patterns could be drawn.

As indicated in the previous section, the fricatives appeared to be the more consistent group of phonemes when comparing the normal and compensated consonant productions. Perhaps a reason for the variability that occurred within the plosive group came as a result of various attempts by both speakers to produce acceptable compensations within the framework of the instructions presented and still maintain an acceptable plosive.

The results of Experiment 2 indicated that a general decrease in air flow rate, intraoral air pressure, and duration of intraoral air pressure was evident in the majority of compensatory articulations when compared with the normal production.

Compensatory Articulation and Air Flow Rate

When comparing the normal production of the plosives to the compensated form, it was evident that the peak air flow rate decreased in all productions of the compensated plosives. The normative data reported is higher than those previously reported in the literature (Isshiki and Ringel 1964, Hutchinson 1973). However, a possible explanation may be the fact that both speakers have had considerable training in public address and this may account for increased physiological intensity that would result in increased volume velocity. It should be noted that the voiced production of the plosives were of smaller air flow values than the voiceless plosives, thus supporting previous investigations (Isshiki and Ringel 1964).

As previously reported, a majority of the voiced fricatives appeared to exhibit a decrease in peak air flow rate. Although DB exhibited a decrease in peak air flow rate for the voiceless compensated fricatives, JH exhibited an increase of all voiceless fricative compensations. The possibility exists that the laryngeal mechanisms helps to direct and control the air flow during the production of the voiced phonemes. During the production of the voiceless fricatives, the increase in air flow rate was related to manner of production. A normal production of a fricative requires a constriction within the vocal tract, resulting in a turbulent air flow. When the compensations were produced it is possible that the rapid articulatory movements and rapid constrictions yielded a constriction that was more relaxed than the normal productionof the consonant. During this production JH attempted to increase his volume velocity in order to produce the same amount of turbulent air flow to produce an acceptable consonant.

Compensatory Articulation and Intraoral Air Pressure: Peak and Duration

The peak intraoral air pressures reported for the plosives and fricatives examined, exhibited a decrease in value from the normal to the compensated production. In addition, the duration of the consonant pressures decreased from the normal to compensated production. This decrement in duration was reflective of both speakers following the instructions for more rapid closure/constriction durations during the production of the compensated consonants. The decrease in duration was in general agreement with the reported duration of the acoustic analysis.

Compensatory Articulation and Qualitative Observations

Examination of the oscillograph traces for the consonants produced, provided some indication of how the compensated productions differed from the normal productions. Although both speakers exhibited a decreased air flow rate and intraoral air pressure for a majority of the compensated productions, the nature of the compensatory movements appeared quite different. It appeared that JH produced many of the compensatory articulations in similar manner as the normal production. This is supported by the high frequency of occurrence of the pattern exhibited in Figure 4.

Speaker DB on the other hand modified his method of production as evidenced by the occurrence of the inhalatory patterns. The evidence reported points to the fact that the human vocal tract is capable of many types of articulatory compensations that can yield decreased air flow rate and intraoral air pressure. However, the question arises as to whether or not unwanted articulatory compensations may be produced as a result of recommended articulatory postures. Although speaker DB was able to produce the necessary compensatory movements, one cannot rule out the possibility that the inhalation type production may be an unwanted compensatory movement. Perhaps a direct training procedure for a length of time may be sufficient to teach adequate methods of compensatory movements.

General Discussion

As previously reported, various investigators have suggested the use of light articulatory contacts and rapid lip and jaw movements as a method of decreasing the intraoral air pressure and air flow rate during consonant production. This proposed decrement in aerodynamic variables arises from the fact that a person who exhibits velopharyngeal inadequacy will usually have trouble impounding the necessary oral air pressure required for plosives or have difficulty maintaining adequate air flow for the production of fricatives. By decreasing these aerodynamic variables, investigators such as Shelton et al. (1968) and Van Hattum (1974) have indicated that adequate consonant production can be accomplished. As indicated in the present investigation, an individual has the ability to decrease the intraoral air pressure and air flow rate provided he has been instructed as to how to produce the compensatory articulations, and he is capable of relatively normal articulatory movements. These facts would indicate the need to examine the teaching of compensatory movements to individuals demonstrating velopharyngeal inadequacy. In addition the amount of articulatory training should be examined to determine the effects of intense articulatory training upon compensatory movements. As noted previously a short instruction period for the production of compensatory articulation may result in unwanted compensations such as exhibited by speaker DB in the inhalatory productions.

Examination of the consonant data throughout the present investigation indicated that the fricatives displayed the more consistent results during the compensated productions when compared to the plosive productions. The place of production appeared to be the significant factor affecting this variability. During the production of a compensatory plosive, the speaker is not able to vary his place of production beyond a limited range. A bilabial stop can only be produced at the juncture of the lips. Any modification of this place of production will result in a distorted consonant. The fricatives, however, appeared to have displayed a wider variability of articulator placement during the compensatory articulations and they still were able to exhibit more consistent results. This hypothesis suggests the possibility of examining lip, jaw, and tongue movements during the normal and compensated articulations to examine the extent that variability is possible for both fricatives and plosives.

Although it appears that light contacts will be effective as a therapeutic approach to cleft palate speech, the need exists to examine whether the perception of the compensated consonants will remain the same as the perception of the normal consonant. From the data presented relating to fricative production, the possibility exists that perception of the fricative compensations will be more accurate as a result of their wider range articulatory placement. This investigation should confirm the consistency of the fricative results.

The use of "loose contacts" have also been suggested as a therapeutic tool in the remediation of stuttering (Van Riper 1958). In a later publication Van Riper (1971) has suggested three requirements that are necessary for initiation of a stuttering tremor. These include "(1) a localized area of hypertension, (2) a postural fixation of the muscle groups involved, a posture different from that normally used for the sound, and (3) a sudden ballistic movement, or surge of tension or pressure." The omission of any one of the three factors seems to prevent tremor. The present investigation has revealed that an individual is capable of reducing both intraoral air pressure and air flow rate using compensated consonants. This would lead us to believe that a stutterer could reduce the "ballistic movement" and subsequently reduce or remove the tremor behavior if he was taught a form of compensatory articulation. Examination of compensatory articulation in stutterers should provide the results.

CHAPTER V

SUMMARY

The purpose of this investigation was to examine the acoustic and aerodynamic characteristics of compensated English consonants. The results provided normative data from which further investigation of compensated consonants can be initiated.

It was determined from the acoustic experimentation that the voiced plosive closure duration, fricative constriction duration, and fricative transition duration, all decreased from the normal to compensated production of the consonants. In addition it appeared that the fricative results appeared to be more consistent between speakers than the plosive results.

The results of the aerodynamic analysis indicated that the compensated productions of the consonants exhibited a general decrease in value for air flow rate, intraoral air pressure, and duration of the pressure measurement. Qualitative differences were also evident between speakers upon examination of the oscillographic configurations.

The effects of compensatory productions were discussed and compared with the normal productions of the consonants. Practical applications were discussed and consideration for future research presented. These included the need to examine compensatory articulation in those individuals with velopharyngeal insufficiency and stutterers. The period of training was also presented as a factor to be examined. The variability of place of production was offered as an explanation for consistency within phoneme classes and finally, the perception of compensatory consonants was offered to document the variability of production and consistency of results.

LIST OF REFERENCES

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Arkebauer, H. J., Hixon, T. J., and Hardy, J. C. Peak intraoral air pressure during speech. J. Speech Hearing Res., 10 (1967).

Bloomer, H. Speech defects associated with dental malocclusions and related abnormalities; in Travis, Handbook of Speech Pathology and Audiology. New York: Appleton-Century-Crofts (1971).

Delattre, P. C., Liberman, A. M., and Cooper. F. S. Acoustic loci and transitional cues for consonants. J. Acoustical Society of America, 27, 765-773 (1955).

Denes, P. B., and Pinson, E. N. The Speech Chain. New York: Anchor Press, Doubleday (1973).

Eisenson, J. A perseverative theory of stuttering; in Eisenson, Stuttering A Symposium. New York: Harper and Row (1958).

Emanuel, F. W., and Counihan, D. T. Some characteristics of oral and nasal air flow during plosive consonant production. Cleft Palate J., 7, 249-260 (1970).

Halle, M., Hughes, G. W., and Radley J., P.A. Acoustic properties of stop consonants. J. Acoustical Society of America, 29, 107-116 (1957).

Hardy, J. C. Air flow and air pressure studies; in communicative problems in cleft palate. ASHA reports, number 5 (1965).

Hutchinson, J. M. The effect of oral sensory deprivation on stuttering behavior. Ph.D. dissertation, Purdue University (1973).

Isshiki, N. Vocal intensity and air flow rate. Folia Phoniatrica, 17, 92-104 (1965).

Isshiki, N., and Ringel, R. L. Air flow during the production of selected consonants. J. Speech Hearing Res., 7, 233-244 (1964).

Liberman, Delattre, Gerstman, and Cooper. Tempo of frequency change as a cue for distinguishing classes of speech sounds. J. of Experimental Psychology, 27, 765-768 (1955).

Lisker, L. Closure duration and the intervocal voiced-voiceless distinction in English. Language, 33, 42-49 (1957).

Malécot, A. The force of articulation of American stops and fricatives as a function of position. Phonetica, 18, 95-102 (1968).

Minifie, F. D. Speech acoustics; in Minifie, Hixon and Williams, Normal Aspects of Speech, Hearing, and Language. New Jersey: Prentice Hall Inc. (1973).

Öhman, S. E. G. Coarticulation in VCV utterances: spectrographic measurements. J. Acoustical Society of America, 39, 151-168 (1966).

Sharf, D. J. Duration of post stress intervocalic stops preceeding vowels. Language and Speech, 5, 26-30 (1962).

Shelton, Hahn, and Morris. Diagnosis and therapy; in Spriestersbach and Sherman, Cleft Palate and Communication. New York: Academic Press (1968).

Subtelny, J. D., Worth, J. H., and Sakuda, M. Intraoral air pressure and rate of flow during speech. J. Speech Hearing Res., 9, 498-518 (1966).

Wells, C. Cleft Palate and Its Associated Disorders. New York: McGraw-Hill (1971).

Van Hattum, R. J. Communicative therapy for problems associated with cleft palate; in Dickson, Communication Disorders. Glenview, Illinois: Scott, Foresman and Co. (1974).

Van Riper, C. Experiment in stuttering therapy; in Eisenson, Stuttering A Symposium. New York: Harper and Row (1958).

Van Riper, C. The Nature of Stuttering. New Jersey: Prentice Hall, Inc. (1971).

APPENDICES

APPENDIX A

HEALTH QUESTIONNAIRE

Name____

Date of Birth____________________Chronological Age_____

Sex________

Have you had your hearing tested within the last year?_____

Any known hearing loss at the present time? If yes, to what extent?

____

____

Do you ever experience any difficulty when speaking? To what extent?

____

____

Do you demonstrate any known articulation errors?

____

____

What is the nature of your general health?

____

____

Please describe any physical limitations you might have that effect your speech production.

____

____

____

____

APPENDIX B

SCORE SHEET

APPENDIX B.--Score Sheet.

1.	apa	123	123	123	123	123	43.	ugu	123	123	123	123	123
*2.	apa	123	123	123	123	123	*44.	ugu	123	123	123	123	123
3.	ibi	123	123	123	123	123	45.	aza	123	123	123	123	123
*4.	ibi	123	123	123	123	123	*46.	aza	123	123	123	123	123
5.	aba	123	123	123	123	123	47.	ufu	123	123	123	123	123
*6.	aba	123	123	123	123	123	*48.	ufu	123	123	123	123	123
7.	iti	123	123	123	123	123	49.	ifi	123	123	123	123	123
*8.	iti	123	123	123	123	123	*50.	ifi	123	123	123	123	123
9.	uzu	123	123	123	123	123	51.	isi	123	123	123	123	123
*10.	uzu	123	123	123	123	123	*52.	isi	123	123	123	123	123
11.	uku	123	123	123	123	123	53.	upu	123	123	123	123	123
*12.	uku	123	123	123	123	123	*54.	upu	123	123	123	123	123
13.	ada	123	123	123	123	123	55.	igi	123	123	123	123	123
*14.	ada	123	123	123	123	123	*56.	igi	123	123	123	123	123
15.	usu	123	123	123	123	123	57.	iði	123	123	123	123	123
*16.	usu	123	123	123	123	123	*58.	iði	123	123	123	123	123
17.	ubu	123	123	123	123	123	59.	iʒi	123	123	123	123	123
*18.	ubu	123	123	123	123	123	*60.	iʒi	123	123	123	123	123
19.	aga	123	123	123	123	123	61.	aʒa	123	123	123	123	123
*20.	aga	123	123	123	123	123	*62.	aʒa	123	123	123	123	123
21.	iθi	123	123	123	123	123	63.	idi	123	123	123	123	123
*22.	iθi	123	123	123	123	123	*64.	idi	123	123	123	123	123
23.	udu	123	123	123	123	123	65.	ata	123	123	123	123	123
*24.	udu	123	123	123	123	123	*66.	ata	123	123	123	123	123
25.	uθu	123	123	123	123	123	67.	uʒu	123	123	123	123	123
*26.	uθu	123	123	123	123	123	*68.	uʒu	123	123	123	123	123
27.	aʃa	123	123	123	123	123	69.	ivi	123	123	123	123	123
*28.	aʃa	123	123	123	123	123	*70.	ivi	123	123	123	123	123
29.	iki	123	123	123	123	123	71.	izi	123	123	123	123	123
*30.	iki	123	123	123	123	123	*72.	izi	123	123	123	123	123
31.	uʃu	123	123	123	123	123	73.	ipi	123	123	123	123	123
*32.	uʃu	123	123	123	123	123	*74.	ipi	123	123	123	123	123
33.	utu	123	123	123	123	123	75.	afa	123	123	123	123	123
*34.	utu	123	123	123	123	123	*76.	afa	123	123	123	123	123
35.	aða	123	123	123	123	123	77.	aka	123	123	123	123	123
*36.	aða	123	123	123	123	123	*78.	aka	123	123	123	123	123
37.	uðu	123	123	123	123	123	79.	uvu	123	123	123	123	123
*38.	uðu	123	123	123	123	123	*80.	uvu	123	123	123	123	123
39.	asa	123	123	123	123	123	81.	aθa	123	123	123	123	123
*40.	asa	123	123	123	123	123	*82.	aθa	123	123	123	123	123
41.	iʃi	123	123	123	123	123	83.	ava	123	123	123	123	123
*42.	iʃi	123	123	123	123	123	*84.	ava	123	123	123	123	123

* = Compensated Production

APPENDIX C

SPECTROGRAM RELIABILITY

APPENDIX C.--Spectrogram Reliability (1 mm - 7.5 sec.)

	Closure Duration (in mm)		Transition Duration (in mm)			
			Initial		Final	
	JM	HS	JM	HS	JM	HS
JH Production						
afa-n	21	20	7	10	8	7
ugu-n	16	14	8	11	8	11
aba-n	14	13	7	9	7	9
aza-n	12	17	14	15	11	13
wθw-n	24	22	12	14	13	15
uvu-n	20	20	7	10	6	8
utu-n	15	13	14	10	10	22
usu-n	27	28	12	13	5	14
igi-n	16	18	9	8	7	9
udu-c	4	5	10	12	8	15
aga-c	10	11	15	12	12	16
uzu-c	17	7	12	23	10	17
ivi-c	9	6	13	12	10	12
ifi-c	21	21	8	11	8	8
izi-c	14	10	14	15	11	11
iki-c	25	24	6	12	6	12
ata-c	10	10	8	12	13	13
usu-c	15	14	9	9	13	12
utu-c	16	16	13	13	5	18
DB						
ifi-c	18	17	7	5	7	11
uzu-c	7	9	7	8	3	8
usu-n	29	28	5	7	11	15
izi-c	6	5	12	8	5	13
ivi-c	8	8	6	6	10	13
aba-n	9	11	11	7	5	10
uθu-n	18	18	7	7	4	13
ifi-c	16	17	5	7	5	7
aza-n	8	10	8	7	10	9
asa-c	15	16	7	9	4	10
aða-n	8	9	9	9	7	9
afa-n	16	17	7	11	5	10
ata-n	9	12	10	14	13	19
iki-c	22	23	7	11	22	19
aga-c	12	13	5	9	10	13
aθa-n	16	16	4	11	4	9
uvu-c	6	10	7	9	6	9

APPENDIX C.--Continued.

	Closure Duration (in mm)		Transition Duration (in mm)			
			Initial		Final	
	JM	HS	JM	HS	JM	HS
DB (Cont.)						
afa-n	16	17	9	11	15	10
igi-n	10	10	4	11	5	18
aba-n	11	11	5	7	4	10
ata-n	16	12	7	14	17	19

	JM	HS	JM	HS
Range	4-29	5-28	3-22	7-23
Mean	14.6	14.4	8.6	11.4
S.D.	5.99	6.02	3.42	3.79

APPENDIX D

RAW DATA: JH

APPENDIX D.--Raw Data: JH

	Acoustic			Aerodynamic								
	Closure/ Constriction (in msec)	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
		Initial	Final	Trial 1	2	3	Trial 1	2	3	Trial 1	2	3
apa	131	86	94	1896	2048	1880	8.4	8.3	7.9	220	230	210
apa	128	75	112	413	168	236	5.6	5.3	6.6	180	160	190
ata	116	64	71	2293	2446	2446	8.3	10.2	9.4	180	220	200
ata	75	86	98	1131	1712	963	5.3	5.1	6.4	180	160	160
aka	101	83	124	1666	2446	2400	8.5	9.5	4.2	230	250	240
aka	56	64	45	199	245	397	4.9	3.5	4.0	180	220	220
aba	101	68	68	240	366	413	3.2	4.0	3.8	160	120	140
aba	86	56	64	184	-	168	1.2	2.9	1.9	140	90	80
ada	98	98	83	841	871	963	6.4	6.4	6.7	200	150	80
ada	23	113	135	76	46	168	1.8	2.3	2.6	140	90	90
aga	98	90	109	260	703	627	5.3	8.0	6.7	160	160	150
aga	83	90	116	260	275	382	3.4	2.5	3.0	160	100	110
afa	150	71	49	612	1055	932	5.6	6.5	8.4	200	220	190
afa	143	105	71	168	566	1314	2.4	1.6	3.8	120	150	120
asa	161	104	90	887	1146	917	6.5	8	7.4	210	210	220
asa	105	68	90	612	1161	1314	1.5	4.2	5.4	150	150	180
aʃa	173	94	101	1147	1620	1773	3.9	7.9	7.8	240	180	220
aʃa	146	98	109	1131	1330	1620	.1	3.5	4.3	260	190	180
aθa	158	90	49	948	856	948	6.5	4.0	3.7	200	220	220
aθa	113	109	90	1070	1207	917	2.4	2.9	1.9	120	160	160
ava	131	90	68	275	459	413	3.1	2.3	1.6	160	200	180
ava	90	75	49	-	366	397	-	.4	.8	-	140	130
aza	131	109	94	474	764	825	4.5	7.3	7.3	180	160	160
aza	180	64	71	290	504	428	.8	2.8	3.9	100	120	100
aʒa	150	86	128	826	840	825	5.8	6.2	5.5	100	180	180
aʒa	139	75	75	321	428	382	2.1	1.3	2.1	140	160	160
aða	127	71	131	505	581	520	2.5	2.3	2.8	150	140	130
aða	86	139	94	214	321	352	.4	1.5	.5	110	-	90

APPENDIX D.--Continued.

	Acoustic			Aerodynamic								
	Closure/ Constriction (in msec)	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
		Initial	Final	Trial 1	2	2	Trial 1	2	3	Trial 1	2	3
upu	124	94	158	1544	2400	2461	6.8	9.7	10.2	260	240	280
upu	173	120	71	260	749	795	3.4	6.2	5.2	200	130	170
utu	98	75	161	2125	2110	2416	6.3	8.5	9.4	250	220	220
utu	113	94	131	474	1682	1452	3.0	5.9	7.5	190	160	120
uku	86	53	225	1269	2278	2170	8.1	9.6	9.9	280	250	260
uku	60	60	225	352	413	352	5.6	4.3	6.0	300	160	150
ubu	86	53	68	642	856	1024	6.8	7	8.1	140	170	160
ubu	105	101	45	245	474	290	5.0	3.5	3.5	150	100	100
udu	113	90	101	726	1177	1100	4.0	7.7	7.9	190	160	130
udu	34	90	108	275	474	566	.4	3.1	3.2	120	60	50
ugu	105	79	79	459	673	826	6.3	8.0	8.5	180	190	200
ugu	161	120	94	245	183	336	3.9	2.8	4.3	140	100	120
ufu	191	71	83	657	856	795	7.5	7.6	8.3	280	230	240
ufu	69	56	64	573	902	1085	1.1	3.4	4.2	160	180	180
usu	210	94	105	933	1238	1269	8.1	8.6	8.8	240	220	240
usu	173	86	105	696	1773	1147	3.9	4.5	3.6	220	180	200
uʃu	169	120	113	1055	1253	1406	4.5	7.3	8.2	240	220	220
uʃu	165	94	86	963	1483	1697	.7	3.6	4.6	220	190	200
uθu	165	105	109	1284	1544	1391	5.3	7.9	7.0	260	210	200
uθu	109	53	45	688	1498	1788	.6	.8	4.0	160	150	150
uvu	128	71	60	489	871	703	5.0	3.1	3.3	180	240	210
uvu	150	68	94	199	245	397	1.7	2.4	1.1	120	140	160
uzu	131	158	158	642	718	677	5.7	6.7	7.2	220	210	200
uzu	53	169	128	76	596	642	2.5	3.2	3.8	130	120	140
uʒu	135	64	71	657	933	856	6.0	5.6	7.0	220	200	200
uʒu	146	86	68	382	795	1193	2.8	3.9	3.0	180	140	160
uðu	113	128	94	612	948	841	4.9	5.3	6.4	150	150	160
uðu	86	75	56	307	642	489	1.7	2.2	2.8	120	130	100

APPENDIX D.--Continued.

	Acoustic			Aerodynamic								
	Closure/ Constriction (in msec)	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
		Initial	Final	Trial 1	2	3	Trial 1	2	3	Trial 1	2	3
ipi	105	75	150	1758	2446	2446	8.1	7.1	9	250	230	220
ipi	120	60	49	352	275	275	3.4	6.1	5	140	130	140
iti	120	64	210	1162	1911	2247	7.1	9.1	9.7	240	210	220
iti	45	83	210	573	566	780	2.0	4.3	5.7	190	130	150
iki	128	68	128	596	1208	1315	6.8	9.6	10.3	360	270	270
iki	180	86	90	413	581	520	2.2	5.2	6.0	180	240	190
ibi	113	83	101	459	535	397	4.5	5.2	4.9	160	130	120
ibi	105	68	86	229	214	168	2.2	2.9	1.7	110	80	70
idi	120	71	75	657	612	795	7.3	6.7	6.0	190	190	160
idi	49	67	75	275	657	397	2.8	4.4	3.6	80	80	80
igi	135	56	64	459	489	612	5.2	7.0	6.3	210	190	200
igi	120	64	71	229	260	459	1.0	2.6	3.2	180	160	160
ifi	188	116	75	627	795	840	5.7	7.5	7.2	240	220	230
ifi	158	83	60	214	1055	917	.6	4.0	2.6	150	140	140
isi	203	90	86	719	948	1040	7.2	10	9.4	260	240	220
isi	158	83	79	283	1085	825	1.7	4.7	5.2	240	190	200
iʃi	169	75	109	1254	1559	1559	5.9	6.8	4.1	230	240	230
iʃi	150	60	68	948	1147	1223	2.2	3.8	4.1	160	180	220
iθi	191	109	79	963	825	871	5.4	8.0	7.0	190	220	220
iθi	160	49	109	841	1131	1009	1.5	3.7	3.3	140	140	160
ivi	94	75	86	344	581	444	4.5	4.5	5.1	160	220	190
ivi	45	90	86	-	367	351	-	1.1	1.7	-	120	100
izi	71	83	105	474	810	611	7.2	7.6	6.4	220	240	200
izi	83	131	86	277	519	428	2.9	3.1	3.8	110	120	150
iʒi	79	86	90	535	810	826	5.4	5.2	6.7	220	220	200
iʒi	75	113	83	276	382	367	2.2	1.4	2.6	160	170	180
iði	94	90	109	459	734	703	3.9	5.9	5.1	150	270	180
iði	38	94	75	290	382	321	1.4	1.8	2.2	100	100	70

APPENDIX E

RAW DATA: DB

APPENDIX E.--Raw Data: DB.

	Acoustic			Aerodynamic								
	Closure/ Constriction (in msec)	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
		Initial	Final	Trial 1	2	3	Trial 1	2	3	Trial 1	2	3
apa	101	49	53	2400	2400	1980	6.5	6.9	8.7	210	300	160
apa	135	45	41	795	459	660	.7	5.5	2.7	200	0	170
ata	86	101	139	2064	2293	2183	8.4	8.5	9.4	160	160	160
ata	53	90	113	1896	1406	431	2.1	.9	1.5	120	140	80
aka	71	109	150	2400	2140	2155	9.8	8.7	9.5	230	220	170
aka	116	101	161	1895	1727	1845	2.5	3.5	1.8	180	190	200
aba	83	53	75	795	489	538	3.3	3.7	4.7	150	150	120
aba	53	64	45	46	153	256	.7	.5	1.4	80	120	120
ada	60	90	109	550	581	458	2.7	3.4	3.8	80	100	100
ada	41	79	83	367	275	996	.3	.4	1.2	-	-	5
aga	71	161	124	459	474	296	5.3	5.4	4.8	130	150	140
aga	94	68	94	61	76	-	.5	.6	1.0	-	-	-
afa	128	83	71	1070	1085	1400	6.0	10.9	10.0	200	190	180
afa	124	64	90	183	-	81	2.3	2.3	.8	170	170	160
asa	150	83	120	1116	1406	1037	9.3	7.5	9.1	200	200	220
asa	116	64	71	2446	2446	849	1.3	1.0	2.3	120	120	120
aʃa	184	64	94	1865	1941	1630	10.0	8.5	10.3	220	230	210
aʃa	94	71	94	489	764	40	1.2	2.5	1.2	130	140	120
aθa	116	79	68	1529	1636	1212	7.0	7.7	9.2	190	220	200
aθa	113	90	75	2247	673	1751	2.4	1.8	.5	130	-	150
ava	64	38	34	550	382	767	2.6	5.3	6.9	140	130	160
ava	60	41	45	1452	489	1037	2.1	1.9	.5	140	180	140
aza	75	53	68	1085	917	822	6.5	8.2	7.8	170	150	120
aza	45	60	79	321	214	81	1.1	.8	1.2	100	-	140
aʒa	71	75	120	1146	1253	1104	9.0	7.9	8.6	200	160	140
aʒa	75	68	105	1009	367	458	3.2	3.5	2.3	130	110	90
aða	64	68	68	596	275	552	4.4	2.1	3.9	140	120	110
aða	38	45	60	336	275	2128	.2	.9	2.5	120	-	100

APPENDIX E.--Continued.

	Acoustic			Aerodynamic								
	Closure/ Constriction	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
				Trial			Trial			Trial		
		Initial	Final	1	2	3	1	2	3	1	2	3
upu	90	64	94	1758	2369	2209	7.6	8.0	11.0	200	220	200
upu	109	60	71	489	352	310	.3	2.0	.7	200	180	170
utu	113	75	116	2140	2446	2155	10.4	10.2	9.8	200	220	220
utu	218	98	101	1712	1942	377	1.6	1.8	.5	180	190	160
uku	71	56	105	1789	1590	2088	9.2	9.4	9.2	230	240	170
uku	169	90	244	275	627	-	1.1	2.3	2.6	170	180	180
ubu	68	184	131	1207	993	431	4.1	5.1	3.5	160	160	150
ubu	101	83	131	443	612	108	1	1	.5	140	100	110
udu	86	64	94	1269	795	862	7.2	5.6	5.5	140	100	110
udu	45	49	150	190	-	417	2.1	2.9	1.1	140	120	60
ugu	75	90	113	612	810	593	5.9	6.7	5.4	170	170	160
ugu	53	64	94	352	306	-	1.2	1.5	.5	110	110	130
ufu	120	83	90	1819	1315	1226	8.1	8.8	9.2	230	230	230
ufu	154	53	90	856	443	229	.9	.9	.5	160	150	170
usu	210	53	109	1238	1376	1078	8.4	8.6	9.9	210	240	220
usu	53	49	90	1406	1712	821	1.0	1.1	.8	160	170	160
uʃu	173	53	45	1987	1682	1643	7.9	9.3	9.1	250	230	240
uʃu	168	60	86	1375	1116	754	3.5	2.0	1.5	170	220	170
uθu	135	64	86	1575	1544	1482	10.7	8.6	10.6	200	180	190
uθu	154	53	98	367	397	562	2.1	.2	1.1	130	140	110
uvu	71	53	53	902	780	889	6.9	7.7	6.8	180	190	230
uvu	71	64	64	153	306	404	1.8	2.6	1.3	150	90	120
uzu	113	128	71	1299	1131	1064	11.3	9.2	8.0	230	210	230
uzu	68	75	53	443	428	660	1.7	2.2	2.4	100	80	120
uʒu	45	105	120	1330	1177	1482	8.4	9.1	9.0	200	170	160
uʒu	45	86	79	1100	581	391	.8	1.1	1.3	-	-	-
uðu	53	71	83	581	887	1347	2.9	5.0	7.0	120	140	130
uðu	38	56	79	321	306	767	1.3	.9	2.0	100	100	100

APPENDIX E.--Continued.

	Acoustic			Aerodynamic								
	Closure/ Constriction (in msec)	Transition Duration (in msec)		Air Flow Rate (cc/sec)			Intraoral Air Pressure (cm/H_2O)			Duration of Pressure (in msec)		
		Initial	Final	Trial 1	2	3	Trial 1	2	3	Trial 1	2	3
ipi	105	90	109	2156	2156	2155	9.4	9.5	10	200	210	-
ipi	180	75	128	382	245	876	1.4	1.6	1.5	120	140	160
iti	60	83	113	2416	2339	1764	9.2	9.2	8.6	190	180	220
iti	218	56	90	642	673	821	.2	.8	1.7	160	150	170
iki	83	71	124	1421	1896	1387	9.2	9.9	10.3	200	200	180
iki	173	83	143	506	152	135	2.4	2.6	.8	160	140	-
ibi	90	49	71	719	611	808	5.4	2.8	5.1	140	130	140
ibi	34	56	64	276	275	40	.5	.4	3.2	130	-	120
idi	45	49	56	810	764	889	6.0	6.1	6.3	160	160	100
idi	41	90	71	1177	1758	418	2.0	1.4	.9	180	160	100
igi	75	83	135	688	764	633	6.4	6.3	6.0	180	140	140
igi	68	83	109	138	229	391	2.6	1.5	3.0	130	140	190
ifi	109	53	83	1636	1177	1428	9.2	10.3	10.6	210	220	-
ifi	128	53	53	1284	1437	121	1	1	.5	160	160	180
isi	165	75	90	1636	1177	1091	11.3	8.9	10.6	280	260	240
isi	101	64	68	550	734	714	1	1.4	2.0	140	160	160
iʃi	139	45	98	1238	1040	1427	9.3	8.2	8.2	270	290	240
iʃi	94	64	49	871	612	916	1.1	1.2	2.2	150	130	110
iθi	60	71	169	1406	963	1482	9.6	9.6	9.2	230	240	210
iθi	158	56	97	1330	1345	1336	.7	.5	1.7	100	100	130
ivi	75	75	75	1146	780	781	8.3	6.1	8.5	140	140	160
ivi	57	45	94	336	673	458	1.9	1.6	.5	110	140	120
izi	53	86	116	1040	826	1010	7.3	8.2	9.2	210	240	180
izi	94	56	86	596	397	808	2.4	4.0	5.5	80	90	90
iʒi	49	56	79	1559	1528	1010	6.1	10	9.2	220	200	190
iʒi	34	60	98	764	840	754	2	.8	4.7	12	-	100
iði	49	56	109	672	688	740	5.9	6.1	6.6	100	140	120
iði	41	60	63	306	459	-	.3	.6	1.1	-	-	100