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thesis entitled

AERODYNAMIC EVALUATION OF THE CONNECTED DISCOURSE

OF NORMAL-HEARING AND SEVERELY TO PROFOUNDLY

HEARING-IMPAIRED ADULTS

presented by

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has been accepted towards fulfillment
of the requirements for

M.A. degree in Audiology & Speech Sciences

Major professor

Date August 11, 1978

O-7639

AERODYNAMIC EVALUATION OF THE CONNECTED DISCOURSE OF NORMAL-HEARING AND SEVERELY TO PROFOUNDLY HEARING-IMPAIRED ADULTS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Audiology and Speech Sciences

1977

Accepted by the faculty of the Department of Audiology and Speech Sciences, College of Communication Arts, Michigan State University, East Lansing, Michigan.

September 26, 1977

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ABSTRACT

AERODYNAMIC EVALUATION OF THE CONNECTED DISCOURSE OF NORMAL-HEARING AND SEVERELY TO PROFOUNDLY HEARING-IMPAIRED ADULTS

by

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The purpose of this study was to investigate aerodynamic characteristics of connected discourse produced by normal-hearing and severely to profoundly hearing-impaired adults. Eight normal-hearing and eight orally trained hearing-impaired adults participated. Each subject read a total of eighteen sentences. Six sentences were five syllables in length; six sentences were ten syllables in length, and six sentences were fifteen syllables in length. For a spontaneous speech sample, each subject described the activities depicted in a picture of a pet shop scene. All utterances were sensed by a pneumotachograph and recorded by an optical oscillograph. A simultaneous audio recording was made. Inspiratory and expiratory volumes and expiratory time were measured. Three judges assessed the word intelligibility of the hearing-impaired speakers' utterances.

The results indicated that the hearing-impaired subjects displayed greater ranges of inspiratory air

volumes and spontaneous expiratory air volumes and greater expiratory time than the normal hearing subjects. Additionally, in going from contrived to spontaneous utterances, the hearing-impaired subjects varied expiratory air volumes with a systematic change in speech intelligibility. The therapeutic importance of these results was discussed in support of increasing emphasis on aerodynamic controls for developing the speech of the hearing-impaired.

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CHAPTER I

INTRODUCTION

The speech production of hearing-impaired individuals has been a topic reported in the literature for many years. The majority of the literature which has described the speech production of the hearing-impaired has utilized perceptual bases for such descriptions. Perceptual comparisons have been made of the speech of hearing-impaired speakers and normal-hearing speakers rather than judgments of comparisons of objective measures of speech production. By their nature, the perceptual comparisons have been unable to describe on-line dynamics of speech production. Thus, perceptual descriptions of the speech of the hearing-impaired have served to establish the characteristics of the end-product of speech while inferring physiologic occurrences in speech production.

The study by Hudgins and Numbers (1942) was an example of perceptually-based descriptions of the speech of the hearing-impaired. Errors such as (1) failure to produce accurate voiced-voiceless distinctions, (2) final consonant omissions, (3) excessive nasality, (4) vowel prolongations, and (5) abnormal prosodic patterns were established as common in the speech of the hearing-impaired.

Hypernasality (Colton and Cooker, 1968; DiCarlo, 1968), abnormally high pitch and decreased control of loudness (Angelocci, et al., 1964), and decreased rate of speech (Colton and Cooker, 1968; DiCarlo, 1968) were noted perceptually and in acoustic measures of hearing-impaired speakers. Discussions of these descriptions inferred physiologic disturbances. They lacked substantiation by direct measurement of physiologic occurrences in speech production.

In an attempt to document physiologic disturbances in the speech of the hearing-impaired, Hudgins (1934) recorded "air flow rate" as a relative measure. The instrumentation available for his experimentation utilized tracing deflections of the chest wall and stomach wall. The amplitudes of these deflections per second for each syllable provided "air flow rate" or the movement of body walls. This relative measure was coupled with records measured for phrase time and with his own visual analysis. From this, Hudgins qualified a unique set of "speech coordinations of deaf subjects." He noted (1) prolonged vowels, (2) addition of syllables at points where two consonants separate syllables, (3) slow rate of utterance, (4) no distinction between voiced and voiceless stop consonants, and (5) hypernasality. The degree of abnormality was more extensive for prelingually hearing-impaired subjects, and this abnormality increased with increases in degree of hearing loss. Rawlings (1935, 1936) replicated Hudgins' experiment utilizing a 50 syllable paragraph for the speech stimuli as opposed to Hudgins' use of phrases of various lengths. Rawlings' conclusions were similar to those of Hudgins, but he additionally noted that the hearing-impaired sujbects were pausing for breaths more often than normal-hearing subjects and at places other than sentence boundaries. In addition, the time factors of rate of utterance, sentence duration. phonation duration, and interphonation interval were confirmed to be significantly increased in hearing-impaired children (Voelker, 1935; 1938).

Since that time, aerodynamic measurement has been established as one method of directly evaluating physiologic occurrences in speech production. Several aerodynamic parameters have been determined sensitive to certain physiologic occurrences in speech production. One parameter is air flow rate. Air flow rate has been established as a function of expiratory effort and airway resistance. Flow rate events associated with speech are the direct result of structural size and movements beginning with the expiratory forces utilized in generating an air volume as a sound source and occurring at any point of oropharyngeal musculoskeletal valving (VanHattum, 1974). Air flow rates during speech have fluctuated in correspondence to changes in vocal intensity and to selective changes in pitch (Isshiki, 1965; Subtelny, et al., 1966; McGlone, 1967; 1970). Characteristic patterns of air flow rate, in terms of volume velocity, have been observed in speech in association with (1) the presence or absence of voicing, (2) the articulatory gesture produced, and (3) phonetic position of a consonant within a speech segment (Isshiki and Ringel, 1964).

The establishment of air flow rate as a viable measure of aerodynamic functioning in normal speakers is particularly applicable to research with hearing-impaired speakers. Recently, Hutchinson and Smith (1974) investigated three aerodynamic measures in prelingually hearing-impaired young adults. The hearing loss of each subject was poorer than 65 dB HTL (P. T. A.). Four subjects communicated primarily manually. Hutchinson and Smith measured air flow rate, intraoral air pressure, and intraoral air pressure duration. The speech stimuli consisted of 12 monosyllabic words beginning with cognate pairs of stops and fricatives. The hearing-impaired adults produced higher mean intraoral air pressures and greater pressure durations for all consonant classes when compared to previous normative data. While mean air flow rate values did not reveal quantitative differences for any consonant class, the authors noted considerable inter-and intra-subject variability (page 5) in the hearing-impaired. This variability was apparent also in the intraoral air pressure and air pressure duration data. From visual inspection of the data and the aerodynamic recordings three qualitative patterns, specific to the hearing-impaired, were revealed as follows:

Pattern #1--Consonant cognate pairs were produced similarly both quantitatively and qualitatively, resulting in blurred voiced-voiceless distinctions.

Pattern #2--Changes in manner of articulation were evidenced in the use of stops in place of fricatives, a result of the absence of air flow during build-up of intraoral air pressure. These changes occurred less frequently in the substitution of fricatives for stops, a result of the continuation of air flow throughout the duration of the pressure build-up for an initial stop phoneme.

Pattern #3--Inefficient air stream valving was characterized by the presence of high flow rates where low flow rates were expected and, conversely, by the presence of low flow rates where high flow rates were expected.

Gilbert and Dixon (1974) investigated oral and nasal air flows of hearing-impaired subjects during their production of stop consonants in pre-, inter-, and post-vocalic positions. They reported characteristic nasal profiles and ranges of mean peak nasal values falling between mean peak nasal flow rates for normal-hearing and cleft palate speakers established in previous studies. Gilbert and Dixon refer to the cinefluorographic data of McClumpha (1966) to substantiate their results. McClumpha found considerable variation in five hearing-impaired speakers in extent and in duration of velopharyngeal opening during the production of VC syllables. Moll (1960) demonstrated that velopharyngeal valving is affected by phonetic environment and is different for sustained sounds than for valving in connected speech. Bzoch (1965) has indicated that normal speakers tend to break their velopharyngeal seal when their rate of speech is reduced. In their study of perceived nasality in the hearing-impaired, Colton and Cooker (1968) reported that judges declared 5 of 7 speech samples of normal hearing subjects to be hypernasal when uttered in a word-by-word fashion. This further established rate of utterance as a variable contributing to changes in nasality.

Rate of utterance, vowel duration, and phrasing appear critical to physiologic measures of speech production supporting the speculations of Hudgins and others of his time. VanHattum and Worth (1967) found duration of air flow to vary in relationship to voicing and phonetic position in the same manner reported previously for air flow rate. To utilize more information in a single measure, VanHattum and Worth manually integrated air flow records to obtain expelled volumes. The majority of previous data was peak data gathered from syllabic stimuli. VanHattum and Worth (1967) noted that voiceless consonants displayed considerably more expelled air volume than voiced consonants. Manner of articulation appeared to display results similar to those of Isshiki and Ringel (1964). Initial consonants were more variable than final consonants, although they were longer in duration and utilized larger expelled air volumes. The expelled air volumes for individual sounds tended to be less during sentnece production than during the production of single syllables. Duration was generally shorter for the sounds in sentences. Warren and Wood (1969) confirmed the results of VanHattum and Worth with regard to expelled air volumes and their relationshiop to voicing and manner of articulation; they also established significant male-female volume differences.

Thus, aerodynamic measurement has been proven to be a viable quantitative and qualitative gauge of the physiologic dynamics of speech production in normal-hearing and hearing-impaired subjects. Many variables have not been tested in hearing-impaired subjects. Measurement of volume data, accomplished by integrating air flow rate and time, would utilize a combination of sensitive information represented as a single parameter. This single parameter would integrate two variables previously suggested as varying between normal-hearing and hearing-impaired populations. Volume data appear sensitive to voicing and manner of articulation as well as to utterance length and duration. Again, research has suggested inter- and intra-subject group variability related to these factors, although this has not yet been documented in on-line experimentation.

Statement of the Problem

Because aerodynamic measurement has not occurred under varied lengths of utterances and because inspiratory and expiratory air volumes have not been measured in the hearing-impaired, this thesis investigated the following questions:

(1) What volume of air is inspired by normal-hearing and hearing-impaired speakers for utterances of various lengths?

(2) What volume of air is expired by normal-hearing and hearing-impaired speakers for utterances of various lengths?

(3) What is the relationship between inspiratory and expiratory air volumes during the contrived and spontaneous speech of normal-hearing and hearing-impaired speakers?

(4) What is the expiratory time utilized by normal-hearing and hearing-impaired speakers for utterances of various lengths?

(6) What change in speech intelligibility occurs for hearing-impaired speakers going from contrived speech to spontaneous speech?

CHAPTER II

EXPERIMENTAL PROCEDURES

Subjects

Sixteen young adults (four male, twelve female) between the ages of 18 and 30 years comprised two subject groups. The experimental group consisted of two males and six females with bilateral, sensorineural hearing losses (P. T. A. poorer than or equal to 75 dB HTL, re: ANSI, 1969) with onset of loss prior to two years of age (See Appendix A). See Appendix B for individual hearing evaluation results. Middle ear pathology was ruled out by impedance audiometry. Only hearing-impaired individuals who reported oral communication as their primary mode of communication (greater than 50% of expressive communication) comprised the experimental group (See Appendix C). The reports of use of oral communication were verified by persons familiar with the education and training of each hearing-impaired subject. The experimental group also reported no history of acute respiratory disorders. Available clinical records concurred with the subjects' reports.

The control group consisted of two males and six females whose hearing was within normal limits as determined by a pure tone screening test delivered at 20 dB HTL (re: ANSI, 1969) at 500, 1000, 2000, and 4000 Hz. The control subjects had no history of communicative disorders or acute respiratory disorders.

Stimuli

The stimuli consisted of three pairs of syntactically correct active, affirmative, declarative sentences totaling six different sentences (See Appendix D). Two sentences were five syllables in length. Two sentencces were ten syllables in length. Two sentences were fifteen syllables in length. The syllabification of the vocabulary in the sentences was obtained from fifty college students who were presented the stimuli randomized within a pool of fifteen sentences. Each word within the sentences was one or two syllables in length. The sentences were from the Harper and Row Basic Reading Program, All Through the Year (O'Donnell, 1967). All Through the Year was a basic second reader, strand one. The sentences were selected to be within the comprehension of all subjects. Vocabulary Norms for Deaf Children (Silverman-Dresner and Guilfoyle, 1972) has indicated that the vocabulary in the sentence stimuli were within the comprehension of 16 year old hearing-impaired persons. Additionally, a randomized list of the vocabulary which comprised the sentences was given to each subject before the experimentation. The subjects were asked to indicate any words which they did not understand. All subjects claimed to understand the vocabulary.

An additional stimulus item was the "I Wonder" Card W-1 from the Peabody Language Development Kit (Level #2) (1966). This card illustrated children visiting a pet shop. The card was utilized to obtain a spontaneous speech sample for aerodynamic and speech intelligibility analyses.

Instrumentation

The instrumentation utilized in this experiment was similar to the instrumentation utilized by Hutchinson and Ringel (1973) (See Figure 1). The aerodynamic data were obtained using a tightly fitting mask coupled to a pneumotachograph (Hewlett-Packard, custom-made). The pressure drop across the mesh screen of the pneumotachograph was sensed by a Statham PMls differential pressure transducer. This pressure drop has been assumed to be linearly related to the volume velocity from the mouth (Isshiki and Ringel, 1964). The pressure drop was amplified by a Honeywell Accudata 113 Amplifier and recorded on a Honeywell 1508B visicorder oscillograph.

The audio signal was sensed by an Electrovoice 635A microphone placed two inches from the end of the pneumotachograph. This signal was recorded simultaneously on a second channel of the optical oscillograph and on an Ampex 601 tape recorder.

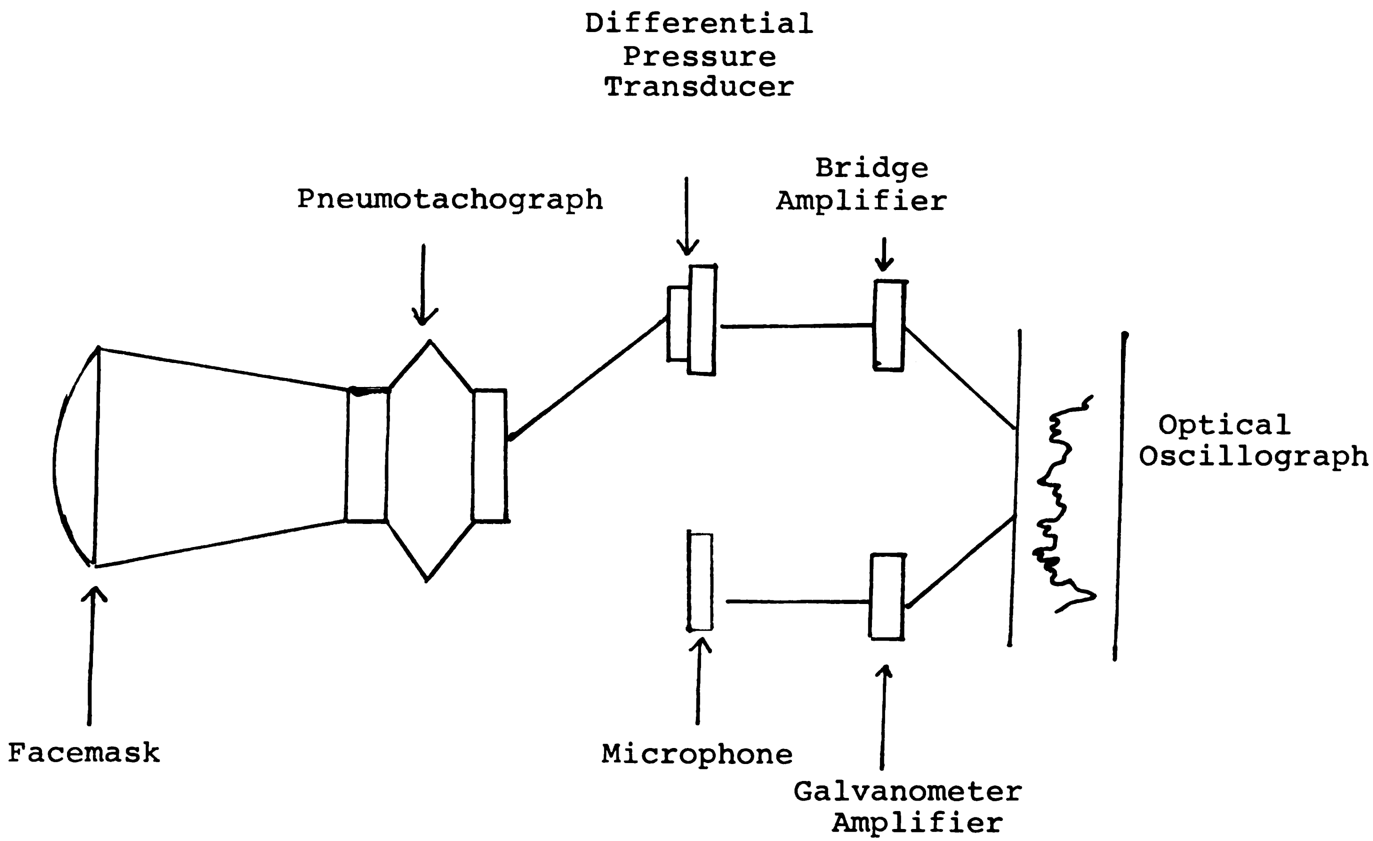


Figure 1.--Schematic representation of instrumental array.

The system was calibrated prior to each subject by directing a constant source of air with a known velocity through a precision bore flowrator glass tube (Fischer and Porter Co., #FP-1/2-27-G-10/27) connected to the pneumotachograph and differential pressure transduction system. The rate of air flow was measured on the flowrator and equated with specific galvanometric deflections. Subjects were run on various days. Recording time was minimal. Normal-hearing subjects utilized up to 93 seconds. Hearing-impiared subjects utilized up to 162 seconds. Repeated calibration and balancing of the recording system were used in order to prepare the equipment to be sensitive to the large range of values which were recorded.

Method

The subjects received written and oral instructions in the experimental procedures (See Appendix E). Each subject completed a case history, indicated his comprehension of the vocabulary which comprised the sentence stimuli, and received a hearing evaluation. At the conclusion of these tasks, the subject proceeded to the recording room for aerodynamic evaluation. The experimenter explained the test procedures and demonstrated the use of the facemask. Prior to the sentence stimuli, the subjects were given three practice sentences corresponding to each pair of test sentences. Prior to the picture stimulus, the subject was given a practice picture. The practice items were used for adjustment to speaking into the facemask. When the subject had practiced and had indicated willingness to proceed, the test items were presented. The presentations of the sentence and picture stimuli were counterbalanced. The six sentences had been typed on individual cards and were presented three times each for a total of eighteen stimulus cards. Sentence order was randomized for each subject.

<u>Analysis of the Data</u>

For each sentence and sentence length mean values and ranges for three dependent variables were calculated from the oscillographic recordings. Those dependent variables were (1) inspiratory air volume, (2) expratory air volume, and (3) time of expiratory air flow. An Ott Compensating Polar Planimeter was utilized for calculating the volume measurements.

By manually circumstracing the recorded deflections and the baseline, the planimeter displayed a dimensionless value for the traced areas. The planimeter measurements were varified by carrying out two tracings beginning in different but symmetrically opposed positions along the perimeter of the area. The mean value of these two measurements was correct because of the automatic compensation of the planimeter utilized. By reversing the direction of the trace, the planimeter value returned to zero proving its accuracy. The verified planimeter measurement was entered into the following forumla (L_2) yielding the air volume within a particular inspiratory or expiratory deflection.

$$AV = \frac{(L_2)(K_2)(L_1)}{K_1}$$

Where AV = the air volume within a particular segment,

L_1 = the arbitrary value for time,

L_2 = the arbitrary value for air flow rate measured on the planimeter

$K_1 = \frac{1 \text{ sec}}{K_1 \text{cm}}$, the time calibration value of the paper,

$K_2 = \frac{K_2 \text{cm}^3/\text{sec}}{1 \text{ cm}}$, the air flow rate calibration value,

L_1 and L_2 were multiplied by 1 cm to bring dimension to their values, as the recording paper is ruled in centimeters.

Thus, the volume value was an integrated function of air flow rate and time, both having been recorded on the oscillograph.

Time of expiratory flow was calculated by measuring the width of an expiration at its baseline and dividing the resultant value by the speed of the recording paper.

Speech intelligibility was judged by three normal-hearing adults who listened in random order to tape recordings of the contrived and spontaneous speech of each subject. The judges had no previous exposure to the hearing-impaired. The judges separately listened to the stimuli from the AMPEX tape recorder via TDH-39 headphones in an IAC booth. The judges adjusted the volume of the recordings and relistened to the recordings as many times as necessary to make a decision. Intelligibility was recorded as the percentage of words correctly identified out of the total word sample. The utilization of word intelligibility was established by John and Howarth (1956) and by Smith (1973).

CHAPTER III

RESULTS

Speech inteeligibility and aerodynamic data indicate substantial quantitative differences between normal-hearing and hearing-impaired subjects. In addition, there are large intersubject differences among hearing-impaired subjects. Separate presentations of these data are in four sections: speech intelligibility, inspiratory data (including number of inspirations and volume), expiratory data, and expiratory time data.

Speech Intelligibility

Table 1 presents the speech intelligibility of the hearing-impaired subjects in mean percentage of words correct in sentence and spontaneous samples. Intelligibility among the sentence samples ranges from 3% (Subject #4) to 100% (Subjects #5, #6, #7, and #8). Mean sentence sample intelligibility for the hearing-impaired subjects is 81%. Intelligibility among the spontaneous samples ranges from 0% (Subject #4) to 100% (Subject #8). The word intelligibility of Subject #2 (50%) is an inflated score in that data could only be collected from four of six sentences because two sentences were entirely unintelligible. An accurate syllable count could not be made. The inclusion of the inflated score also inflates the group mean

TABLE 1.--The number of errors in word intelligibility scored by three judges and the mean percent correct word intelligibility for hearing-impaired subjects.

	SENTENCE			SPONTANEOUS		
subject	words	errors	mean % correct	words	errors	mean % correct
1(male)	53	16 5 6	86	40	18 14 18	58
2(male)	53	13 18 15	71	* 31	18 13 15	50
3(female)	53	2 6 8	90	36	8 12	72
4(female)	53	51 51 51	3	**		0
5(female)	53	0	100	55	2 2 2	96
6(female)	53	0	100	60	2 2 4	96
7(female)	53	0	100	60	25 18 22	64
8(female)	53	0	100	56	0	100
group mean			81			67

*Data collected from 4 of 6 sentences. Two sentences entirely unintelligible.

**Spontaneous sample entirely unintelligible.

spontaneous sample intelligibility of 67%. Still, seven subjects and the subject group mean decrease in speech intelligibility from the sentence samples to the spontaneous samples. The remaining subject (#8) remains 100% intelligible in both speech samples.

Inspiratory Data

While each normal-hearing subject could produce each sentence stimulus after one inspiration, hearing-impaired subjects utilize a greater number of inspirations. Table 2 indicates that hearing-impaired subjects required a range of 0.2 to 1.83 inspirations to produce the five syllable sentence stimulus, a range of 0.5 to 4.50 inspirations to produce the ten syllable sentence stimulus, and a range of 0.5 to 6.00 inspirations to produce the fifteen syllable sentence stimulus.

TABLE 2.--The mean number of inspirations taken by hearing-impaired subjects for each of three sentence lengths.

subject	5-syllable sentence	10-syllable sentence	15-syllable sentence
1(male)	1	2.16	2.16
2(male)	1	2.16	1.66
3(female)	1	1	1.33
4(female)	1.83	4.5	6
5(female)	0.83	1	0.83
6(female)	0.83	1	1
7(female)	1	1	1
8(female)	0.2	0.5	0.5
group mean	0.96	1.67	1.81

Three hearing-impaired subjects (#5, #6, and #8) inspired less than once for each sentence production. Each of these subjects (and subject #7, who inspired once per sentence) is 100% intelligible in the sentence condition. Subject #5 omits two inspirations, the inspiration prior to the 1st stimulus and the inspiration between the 3rd and 4th stimuli. The 3rd and 4th stimuli are 5-syllable stimuli. Subject #6 omits only the inspiration prior to the 1st stimulus. Review of the tracings of subject #8 reveals only 7 inspirations throughout the production of the 18 sentence stimuli. An absence of turbulence over time in the tracings of subjects #5 and #6 indicates that each was holding her breath prior to her initial utterance. Further, subject #5 runs together the production of her 3rd and 4th stimuli without any pause or evidence of held breath.

However, subject #8 inspires for her 1st stimulus and, apparently, randomly thereafter. Additionally, tracings reveal cessation of respiratory activity between each stimulus which is not preceded by an inspiration. Each cessation consists of 0.8 seconds to 1.5 seconds. There is no apparent relationship between the measured inspirations and any other recorded parameter. Expiratory air volumes, length of utterances, expiratory time, and overall time (including interstimulus cessations) vary in relation to the inspirations. Two inspirations occur during the first eleven stimuli, whereas five inspirations occur during the remaining seven stimuli. Because of the uniqueness of the sentence data of subject #8, these data have been excluded from Tables 3 through 6. These data fall well beyond predictions based upon the group mean and standard deviation. The data for subject #8 are presented in Table #7.

The mean inspiratory air volumes (IAV in cc) and their standard deviations for normal-hearing and hearing-impaired subjects are presented in Table 3. The mean values for the normal-hearing subjects range from 100 cc to 916 cc for the five syllable sentence stimuli, 65 cc to 966 cc for the ten syllable sentence stimuli, and 178 cc to 1116 cc for the fifteen syllable sentence stimuli. Mean IAV for the hearing-impaired subjects range from 102 cc to 1318 cc for the five syllable sentence stimuli, 155 cc to 1784 cc for the ten syllable sentence stimuli, and 261 cc to 1489 cc for the fifteen syllable sentence stimuli. Ranges for each sentence stimulus are greater for the hearing-impaired subjects.

The mean overall IAV and their standard deviations for all subjects are presented within Table 4. For normal-hearing subjects in the sentence task inspiratory air volumes per syllable based on 180 total syllables present mean volumes ranging from 11 cc/syllable to 100 cc/syllable with a group mean of 57 cc/syllable. For normal-hearing subjects in the spontaneous task based on a mean of 73 syllable with a mean of 20 cc/syllable. The mean overall IAV of the hearing-impaired subjects range from 17

TABLE 3.--The mean inspiratory air volume and standard deviation (SD) (in cc) for each of three sentence lengths for normal-hearing subjects and hearing-impaired subjects.

normal-hearing subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	916	157	966	137	1116	157
2(male)	783	177	883	227	1083	203
3(female)	366	234	699	183	616	313
4(female)	316	184	558	331	666	189
5(female)	258	110	291	146	233	118
6(female)	533	262	347	161	488	103
7(female)	702	097	828	134	733	082
8(female)	100	053	065	071	178	094
group mean	497	266	580	291	639	323

hearing-impaired subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	275	137	339	136	334	025
2(male)	1318	233	1784	273	1291	384
3(female)	327	072	347	126	374	157
4(female)	669	212	1296	150	1489	256
5(female)	526	321	533	215	931	569
6(female)	249	115	196	125	439	286
7(female)	102	122	155	059	261	179
group mean	495	370	664	580	731	466

TABLE 4.--The mean overall per syllable inspiratory air volume and standard deviation (SD) (in cc), expiratory air volume (in cc), and expiratory time (in sec) for normal-hearing subjects and hearing-impaired subjects.

	SENTENCE						SPONTANEOUS		
normal-hearing subjects	IAV		EAV		ET		IAV	EAV	ET
	mean	SD	mean	SD	mean	SD	mean	mean	mean
1(male)	100	54	177	82	.27	.07	35	43	.24
2(male)	91	54	86	37	.28	.08	27	26	.23
3(female)	60	35	47	17	.30	.08	03	12	.25
4(female)	51	31	37	15	.28	.06	17	07	.23
5(female)	26	23	31	11	.26	.05	10	14	.28
6(female)	45	49	29	19	.27	.08	17	20	.27
7(female)	75	43	80	31	.26	.06	37	47	.21
8(female)	11	10	10	08	.23	.06	13	05	.18
group mean	57	29	62	50	.27	.02	20	22	.24
							(SD) 11	(SD) 13	(SD) .03

	SENTENCE						SPONTANEOUS		
hearing-impaired subjects	IAV		EAV		ET		IAV	EAV	ET
	mean	SD	mean	SD	mean	SD	mean	mean	mean
1(male)	31	23	22	11	.41	.10	101	46	.46
2(male)	146	83	135	56	.50	.10	*130	128	.49
3(female)	35	22	23	18	.54	.14	29	29	.47
4(female)	115	32	128	57	.43	.07			
5(female)	66	51	81	29	.35	.10	31	43	.30
6(female)	30	23	32	32	.34	.09	20	19	.30
7(female)	17	16	12	04	.29	.07	56	37	.33
group mean	63	46	62	49	.41	.08	**61	50	.39
							(SD) 41	(SD) 36	(SD) .08

*Data collected from 4 of 6 sentences.
**Mean data for group excludes subject 4 who was entirely unintelligible spontaneously and for whom the number of syllables uttered could not be determined.

cc/syllable to 146 cc/syllable with a mean of 63 cc/syllable in the sentence task and from 20 cc/syllable to 130 cc/syllable with a mean of 61 cc/syllable in the spontaneous task based on a mean of 60 syllables. Spontaneous data for Subject #4 is not included because unintelligibility prevented the experimenter from securing a more accurate syllable count.

Mean overall IAV ranges are greater for the hearing-impaired groups in each direction. While the mean values for the two groups are only slightly different in the sentence data (6 cc/syllable), the difference in mean values for the spontaneous data is 41 cc/syllable. Normal-hearing subjects decreased their inspiratory air volumes in an average of 65% from sentence to spontaneous speech stimuli, whereas hearing-impaired subjects decreased their inspiratory air volumes an average of 03%.

Expiratory Volume Data

Table 5 presents the mean expiratory air volumes (EAV in cc) and their standard deviation for normal-hearing and hearing-impaired subjects. For the normal-hearing subjects, the mean volumes range from 91 cc to 700 cc for the five syllable sentence stimuli, 127 cc to 1033 cc for the ten syllable stimuli, and 129 cc to 1033 cc for the fifteen syllable stimuli. For the hearing-impaired subjects these volumes range from 81 cc to 925 cc for the five syllable sentence stimuli, 148 cc to 1845 cc for the

TABLE 5.--The mean expiratory air volume and standard deviation (SD) (in cc) for each of three sentence lengths for normal-hearing subjects and hearing-impaired subjects.

normal-hearing subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	675	080	1033	149	950	126
2(male)	700	129	833	113	1033	199
3(female)	333	055	500	168	583	069
4(female)	225	080	408	151	483	107
5(female)	175	046	383	024	358	117
6(female)	268	077	308	102	300	064
7(female)	628	089	861	060	933	085
8(female)	091	054	127	037	129	034
group mean	387	228	557	152	596	317

hearing-impaired subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	130	055	290	079	250	115
2(male)	810	267	1845	404	1400	178
3(female)	243	067	211	061	245	092
4(female)	925	357	1425	087	1497	289
5(female)	573	114	758	177	1013	286
6(female)	368	165	325	033	299	053
7(female)	081	018	148	032	152	046
group mean	447	307	715	620	694	547

ten syllable sentence stimuli, and 152 cc to 1497 cc for the fifteen syllable stimuli.

Syllabic data (Table 4) for normal-hearing subjects indicate mean overall EAV ranging from 10 cc/syllable to 177 cc/syllable in the sentence task with a group mean of 62 cc/syllable and from 5 cc/syllable to 47 cc/syllable with a group mean of 22 cc/syllable in the spontaneous task. Hearing-impaired subjects' data range from 12 cc/syllable to 135 cc/syllable in the sentence task (group mean equals 62 cc/syllable) and from 19 cc/syllable to 128 cc/syllable in the spontaneous task (group mean equals 50 cc/syllable). As previously noted, spontaneous speech data omit data from two of six utterances from hearing-impaired subject #2 and the entire spontaneous sample of hearing-impaired subject #4.

EAV decreased 65% from sentence to spontaneous speech for the normal-hearing subject group and 19% from sentence to spontaneous speech for the hearing-impaired subject group.

Expiratory Time Data

As viewed in Table 6, for normal-hearing subjects the mean expiratory times (ET in sec.) range from 1.55 sec to 2.19 sec for the five syllable sentence stimuli, 2.28 sec to 3.13 sec for ten syllable sentence stimuli, and 3.15 sec to 3.92 sec for the fifteen syllable

TABLE 6.--The mean expiratory time and standard deviation (SD) (in sec) for each of three sentence lengths for normal-hearing subjects and hearing-impaired subjects.

normal-hearing subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	1.78	0.29	2.94	0.31	3.43	0.24
2(male)	1.99	0.22	2.84	0.36	3.81	0.52
3(female)	2.19	0.30	3.13	0.46	3.92	0.36
4(female)	1.82	0.17	2.91	0.21	3.67	0.15
5(female)	1.65	0.15	2.88	0.17	3.41	0.26
6(female)	1.86	0.37	2.83	0.27	3.50	0.15
7(female)	1.75	0.17	2.89	0.15	3.36	0.19
8(female)	1.55	0.17	2.28	0.22	3.15	0.19
group mean	1.82	0.19	2.84	0.23	3.53	0.24

hearing-impaired subjects	5-syllable sentence		10-syllable sentence		15-syllable sentence	
	mean	SD	mean	SD	mean	SD
1(male)	2.25	0.51	4.89	0.84	5.36	0.63
2(male)	3.11	0.32	5.58	0.30	6.40	0.69
3(female)	3.43	0.55	6.18	0.98	7.02	0.65
4(female)	2.38	0.42	4.79	0.22	5.81	0.37
5(female)	2.34	0.45	3.70	0.37	4.68	0.75
6(female)	2.11	0.38	3.77	0.77	4.38	0.29
7(female)	1.75	0.27	3.27	0.54	3.84	0.83
group mean	2.48	0.54	4.60	0.99	5.36	1.05

TABLE 7.--The mean and standard deviation (SD) of data for hearing-impaired subject #8 (female).

5-syllable sentence		10-syllable sentence		15-syllable sentence		sentence data per syllable		spontaneous data per syllable
mean	SD	mean	SD	mean	SD	mean	SD	mean
INSPIRATORY AIR VOLUME								
005	012	036	047	006	009	01	03	09
EXPIRATORY AIR VOLUME								
143	035	190	052	183	043	09	09	09
EXPIRATORY TIME								
1.99	0.22	3.42	0.23	4.56	0.59	.30	.08	.34

sentence stimuli. For the hearing-impaired subjects, these ranges are 1.75 sec to 3.43 sec, 3.27 sec to 6.18 sec, and 3.84 sec to 7.02 sec, respectively.

The mean overall ET and their standard deviations appear in Table 4. For the normal-hearing subject group, these range from .23 sec/syllable to .30 sec/syllable in sentence speech and .18 sec/syllable to .28 sec/syllable in spontaneous speech. Group means are .27 sec/syllable and .24 sec/syllable for sentence and spontaneous speech. For the hearing-impaired subject group, mean overall ET ranges from .29 sec/syllable to .54 sec/syllable in sentence speech and from .30 sec/syllable to .49 sec/syllable in spontaneous speech. Respective group means are .41 sec/syllable and .39 sec/syllable.

Mean expiratory time ranges are increasingly greater for hearing-impaired subjects. Rank order of all normal-hearing and hearing-impaired subjects indicates that hearing-impaired subjects rank 1, 2, 3, 4, 5, 7, 8, 12 in ET utilized for producing the five syllable sentence stimuli, 1 through 8 for the ten syllable sentence stimuli, and 1, 2, 3, 4, 5, 6, 7, 9 for the fifteen syllable sentence stimuli. For the hearing-impaired subjects, increased expiratory time was significant to the 1.0% level in the 5 syllable sentence task and significant to th 0.2% level in the 10 syllable and 15 syllable tasks, and in the overall per syllable sentence and spontaneous data (Wilcoxon Sum of Ranks Test).

CHAPTER IV

DISCUSSION

This experiment documents air stream mismanagement during the connected speech of the hearing-impaired. Mismanagement occurs during inspiratory and expiratory events. The hearing-impaired speakers with poor intelligibility in the sentence condition inspire more frequently than the hearing-impaired speakers with 100% intelligibility and the normal-hearing speakers. Table 8 indicates

Table 8.--The percent correct word intelligibility and the mean number of inspirations for the poor intelligibility hearing-impaired subjects during the sentence condition.

subject	% intelligible	mean number of inspirations 5-syll.	10-syll.	15-syll.
3(female)	90	1	1	1.33
2(male)	86	1	2.16	1.66
1(male)	71	1	2.16	2.16
4(female)	03	1.83	4.5	6

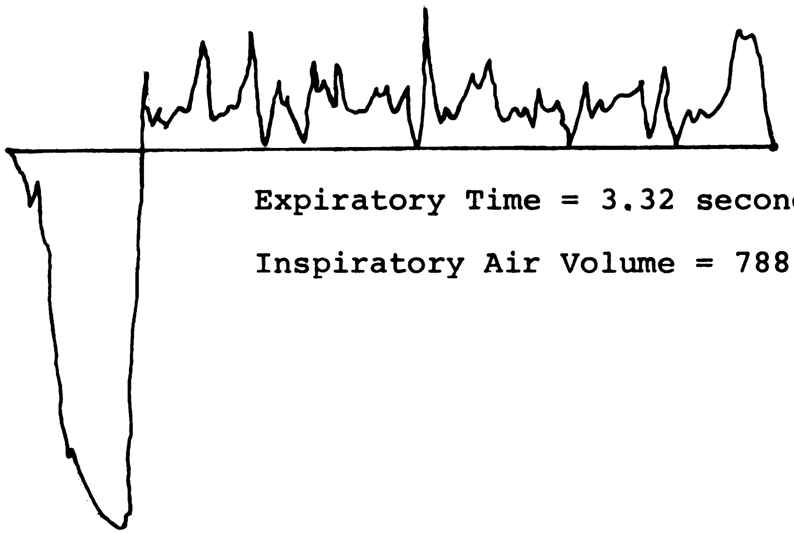
that as intelligibility decreases the number of inspirations increases. These inspirations occur randomly throughout sentence productions. The inspirations do not occur simultaneously with the initiation of noun or verb phrases. The inspirations occur within phrases and within words. In addition to decreasing word intelligibility, random inspirations decrease the listeners' abilities to recognize syntactic patterns within utterances (John and Howarth, 1965).

This mismanagement is ammenable to therapy. John and Howarth (1965) substantiated treatment for relative time factors of syllable length, sentence length, and non-linguistic pauses during connected discourse to the exclusion of articulation emphasis. Repeated imitation of a normal-hearing speaker's rate and rhythm yielded increasing meassage comprehension by increasing word intelligibility and syntactic intelligibility (by 56% and 203%, respectively, in John and Howarth, 1965).

The significantly increased expiratory time utilized by the hearing-impaired speakers is consistent with the early literature (Hudgins, 1934; Rawlings, 1935, 1936; Voelker, 1935, 1938). The hearing-impaired speakers' expiratory time was 52% and 63% greater than that of the normal-hearing speakers in the sentence and spontaneous conditions, respectively. These data coupled with expiratory air volumes similar to normal-hearing speakers yielded decreased air flow rate peak magnitudes. Such decreases are a parameter of blurred consonant production (Hutchinson and Smith, 1974). Figure 2 represents the production of a 15-syllable sentence by normal-hearing subject #7 (female) and by hearing-impaired subject #4 (female). The normal-hearing subject inspired 788 cc of air immediately prior to the intelligible production of the sentence

Figure 2.--Schematic representation of the production of a 15-syllable sentence by (A) normal-hearing subject #7 (female) and by (B) hearing-impaired subject #4 (female). Pattern (A) illustrates on inspiration of 788 cc and expiration of 1060 cc during 3.32 seconds. Pattern (B) illustrates seven random inspirations of 1040 cc and expiration of 1020 cc during 5.94 seconds of expiratory time. Pattern (B) represents completely unintelligible speech by the hearing-impaired subject. The stimulus is, "You know how to stick to things until you find out the answers."

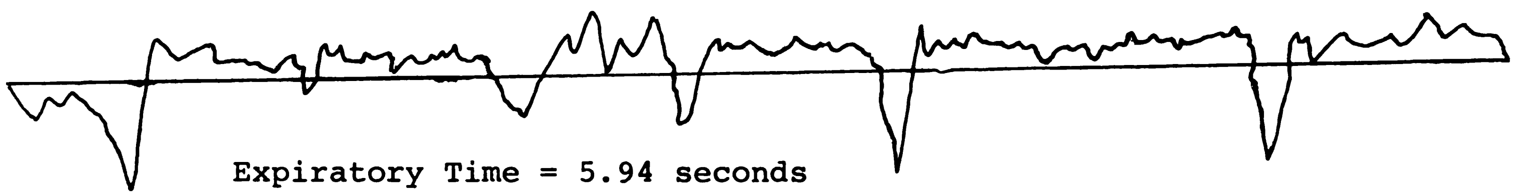
PATTERN (A) Expiratory Air Volume = 1060 cc



Expiratory Time = 3.32 seconds

Inspiratory Air Volume = 788 cc

PATTERN (B) Expiratory Air Volume = 1020 cc



Expiratory Time = 5.94 seconds

Inspiratory Air Volume = 1040 cc

and expired 1060 cc of air in 3.32 seconds. The hearing-impaired subject inspired 1040 cc of air in 7 random inspirations and expired 1020 cc of air in 5.94 seconds throughout a production which was entirely unintelligible. Visual analysis of the two air flow rate (AFR) traces notes a lack of clear peaks in the AFR of the hearing-impaired speaker. That trace denotes air flow turbulence with an absence of clear consonant production. Although expiratory air volumes are similar, the disturbance of time factors and the manner in which the air flow was expired lead to unintelligible speech.

This mismanagement also appears responsive to therapy. Hutchinson and Smith (1974) demonstrated the ability of hearing-impaired adults to condition aerodynamic and concurrent intelligibility changes in monosyllabic stimuli. Their subjects successively approximated optically recorded information from equipment similar to that used in this experiment.

Further research should attempt to increase the length of stimuli practiced in therapy. Perhaps a two-stage treatment program would be effective if based on decreasing expiratory time prior to direct conditioning of air flow. Control for the spontaneity of stimuli should be continued.

The present experiment reveals the occurrence of a distinct aerodynamic event effecting the decreased word intelligibility of hearing-impaired speakers from contrived sentence stimuli to spontaneous stimuli. The group mean intelligibility decreases 14%, whereas individual subjects exhibit a range from no change to -36% (see Table 9). Table 9 was obtained from data presented in Tables 1 and 4.

Table 9.--The change in intelligibility and expiratory air volume (in percentage) for six hearing-impaired subjects.

hearing-impaired subject	intelligibility changes	expiratory air volume change
1(male)	-28%	+209%
3(female)	-18%	+26%
5(female)	-04%	-47%
6(female)	-04%	-41%
7(female)	-36%	+208%
8(female)	0%	-44%

Excluding Subject #2 and Subject #4 because of incomplete data, the six remaining subjects can be reviewed in two groups regarding intelligibility change in the two stimuli conditions. Subjects #7, #1, and #3 decrease their intelligibility 36%, 28%, and 18%, respectively. Subjects #5 and #6 decrease their intelligibility only 4%, while Subject #8 remains 100% intelligible. These changes in intelligibility are consistent with changes in expiratory air volumes. The group of Subjects #7, #1, and #3, while markedly decreasing word intelligibility, increase their EAV by 208%, 109%, and 26%, respectively. Subject #7, who displays the greatest decrease in intelligibility and the greatest increase in EAV, is 100% word intelligible during the production of contrived sentences. During that condition, Subject #7 inspires appropriately. Subject #7, along with Subjects #1 and #3 appear to lose physiologic control when required to speak spontaneously. In the spontaneous condition, these subjects produce 5, 9, and 9 syllables respectively per inspiration. The remaining hearing-impaired subjects and the normal-hearing subjects produce from 10 to 36 syllables per inspiration. Whether the result of ineffective laryngeal or articulatory valving, the changes in EAV are contrary to the performance of the hearing-impaired subjects with highly intelligible spontaneous speech and to the performance of the normal-hearing subjects.

Subjects #5, #6, and #8, with minimal or no decrease in intelligibility, decrease their EAV in the spontaneous condition by 47%, 41%, and 44%. This approaches the 65% decrease (range of 31-81%) which the normal-hearing subjects exhibit. For intelligible spontaneous speech, such information illustrates the necessity to decrease and retain expiratory air volumes from the amount utilized in contrived sentences. We are concerned with the percentage of EAV retained by each subject going from the contrived conditions to the spontaneous condition as opposed to the absolute value of EAV. The retention of EAV by intelligible speakers indicates the recognition and use of a valving adjustment for spontaneous speech. Further research to account for this adjustment is warranted.

The data presented are consistent with other research findings. Forner and Hixon (1977) assessed respiratory events of profoundly hearing-impaired speakers. Their evaluation utilized the apparati for respiration kinematics established by Hixon, Goldman, and Mead (1973). Subjects (young adults) communicated predominantly by manual or total (simultaneous oral and manual) communication and were judged moderately to severely deviant in articulation, rhythm, stress and linguistic phrasing. Data collected during utterances of continuous discourse displayed frequent deviancies in one or more of the following areas: (1) linguistic programming, (2) respiratory adjustments, (3) laryngeal or upper airway adjustments. Similar to the present thesis, Forner and Hixon noted that most of their subjects inspired frequently during nonpunctuated word strings which increased the amount of breaths per minute. Thus, the number of syllables supported per breath was decreased. Forner and Hixon noted tracings which were not accmpanied by vocalization and noted breath haltings which did not involve inspiration. Many subjects expired volumes up to 250 cc during these haltings. This further decreased the available volumes which, as seen in the present thesis, were decreased initially by large volume expenditures. Additionally, the breath haltings involved a phenomenon similar to the cessation of measurable respiratory activity by this thesis' Subject #8. Possibly, this subject retained intelligibility by conserving necessary air volumes.

The support of the Forner and Hixon data for the data of the present thesis is clear. A range of respiratory behaviors is seen during the connected utterances of severely to profoundly hearing-impaired adults. Relationships to speech intelligibility are noted. These relationships need to be expressed in therapeutic programs at the levels of linguistic, respiratory, and laryngeal mechanics. An appropriate component of such programming is the analysis of the communicative behavior of the hearing-impaired in terms of speech intelligibility and aerodynamic functioning. This component, apparently unbiased by minimal variations in extent of hearing loss, establishes initial and continuous evaluation clearly representative of the needs for effective expressive communication.

CHAPTER V

SUMMARY

The purpose of the study was to investigate aerodynamic characteristics of connected discourse produced by normal-hearing and severely-to-profoundly hearing-impaired adults. The results added support for the use of aerodynamic evaluation in speech-disordered populations while providing normative information from normal-hearing and hearing-impaired populations. This is intended to provide a basis for future investigations.

The results established aerodynamic mismanagement during the speech of the hearing-impaired evidenced by increased frequency of inspirations for hearing-impaired subjects with poor speech, increased ranges of inspiratory and expiratory air volumes, and greatly increased expiratory time. The general result of these characteristics was a blurring of aerodynamic peaks necessary for intelligible speech. Further mismanagement was noted in proceeding from contrived to spontaneous stimuli. Hearing-impaired subjects who suffered minimal change in speech intelligibility executed aerodynamic adjustments opposed to those of the normal-hearing and minimal change hearing-impaired subjects.

Previous therapeutic investigations were described and, in conjunction with this study, are supportive of therapeutic emphasis on aerodynamic management. Connected discourse has been seen as an appropriate and reliable stimulus for use in future investigations.

Further investigations should consider the extent of hearing-impairment and the status of respiratory physiology. In this study, speech intelligibility and aerodynamic measures did not vary in relation to hearing loss. For example, hearing-impaired Subject #6 (female) had the poorest pure tone average while exhibiting 100% intelligible speech in the contrived condition and 96% intelligible speech in the spontaneous condition. The status of the subjects' respiratory physiology was not evaluated beyond screening for gross abnormalities. Perhaps further evaluation would explain the lack of respiratory control exhibited by the hearing-impaired subjects of the present investigation.

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LIST OF REFERENCES

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APPENDICES

APPENDIX A

AUDITORY THRESHOLDS FOR PURE TONE AVERAGES

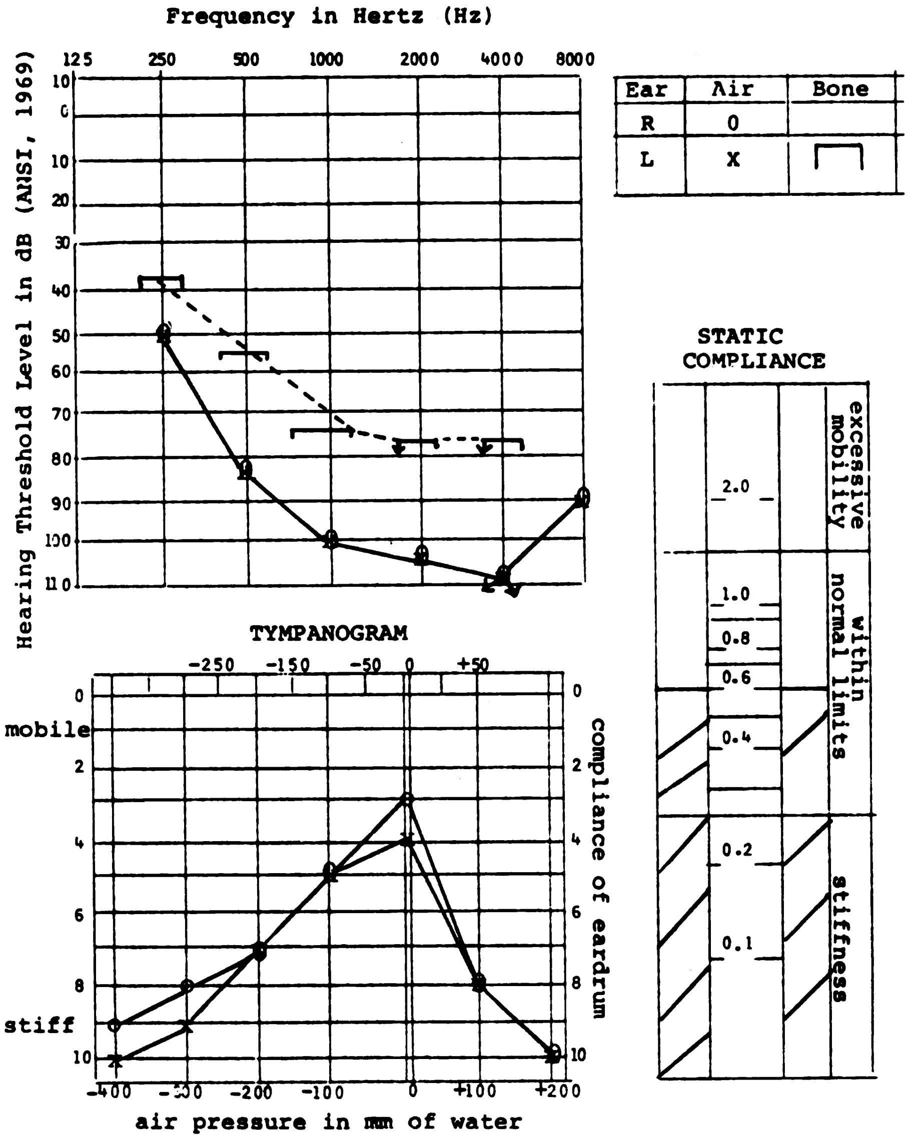
Appendix A.--Air conduction thresholds and pure tone averages for hearing-impaired subjects at 500 Hz, 100 Hz, and 2000 Hz in dB HTL, re: ANSI, 1969.

Subject	Right Ear				Left Ear			
	500 Hz	1000 Hz	2000 Hz	P. T. A.	500 Hz	1000 Hz	2000 Hz	P. T. A.
1(male)	85	100	105	96	85	100	105	96
2(male)	65	95	NR	80	80	95	NR	87
3(female)	80	85	75	80	75	80	75	76
4(female)	85	105	NR	95	NR	105	NR	105
5(female)	70	85	95	83	85	85	90	86
6(female)	100	95	95	96	105	105	100	103
7(female)	85	75	75	78	105	105	105	105
8(female)	55	95	105	85	60	95	105	86

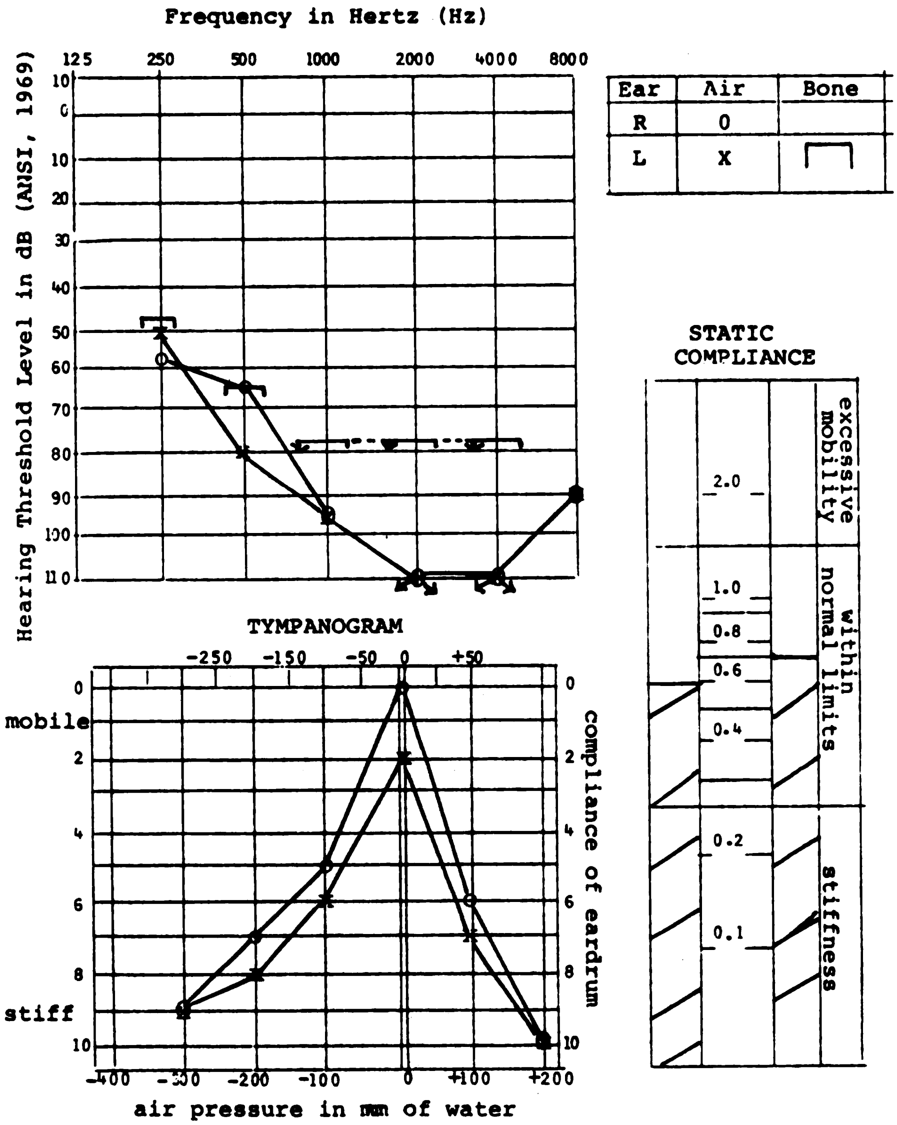
APPENDIX B

RESULTS OF INDIVIDUAL HEARING EVALUATIONS

SUBJECT #1(MALE)



SUBJECT #2(MALE)



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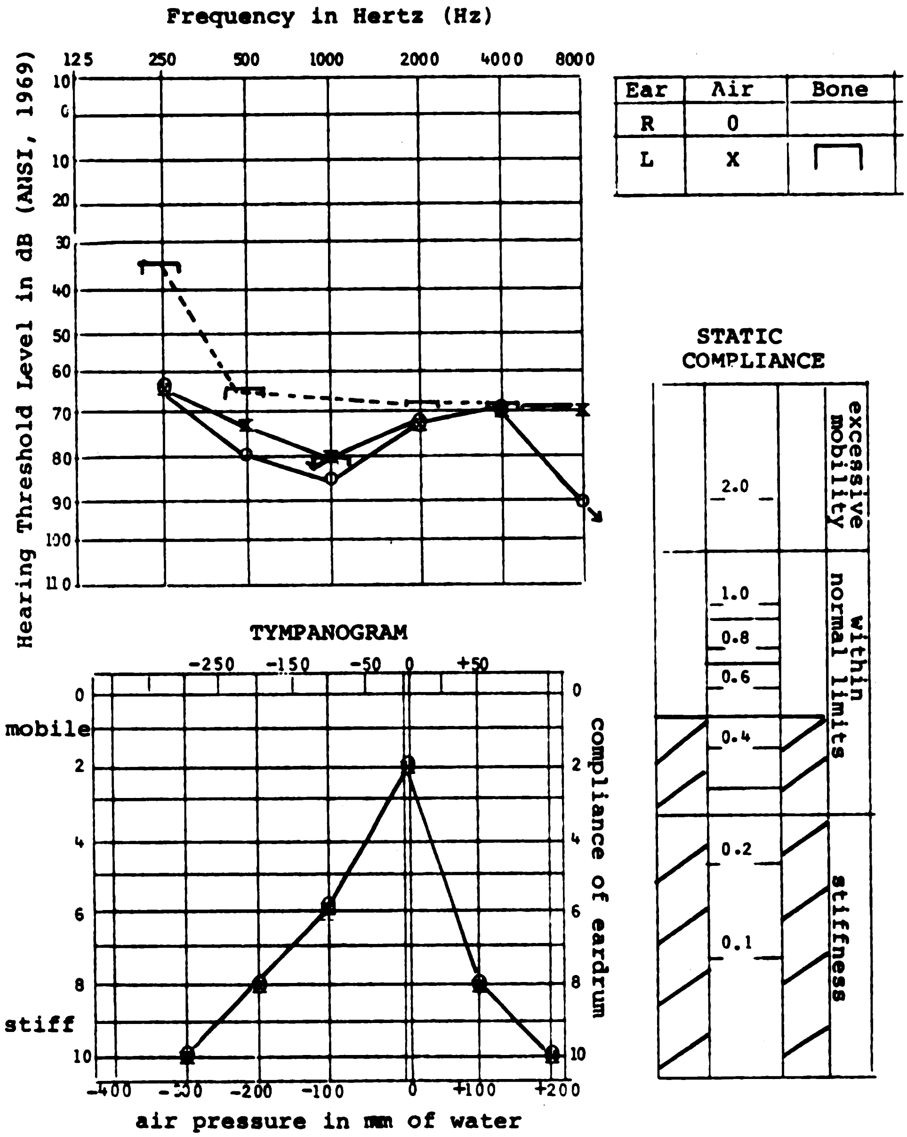

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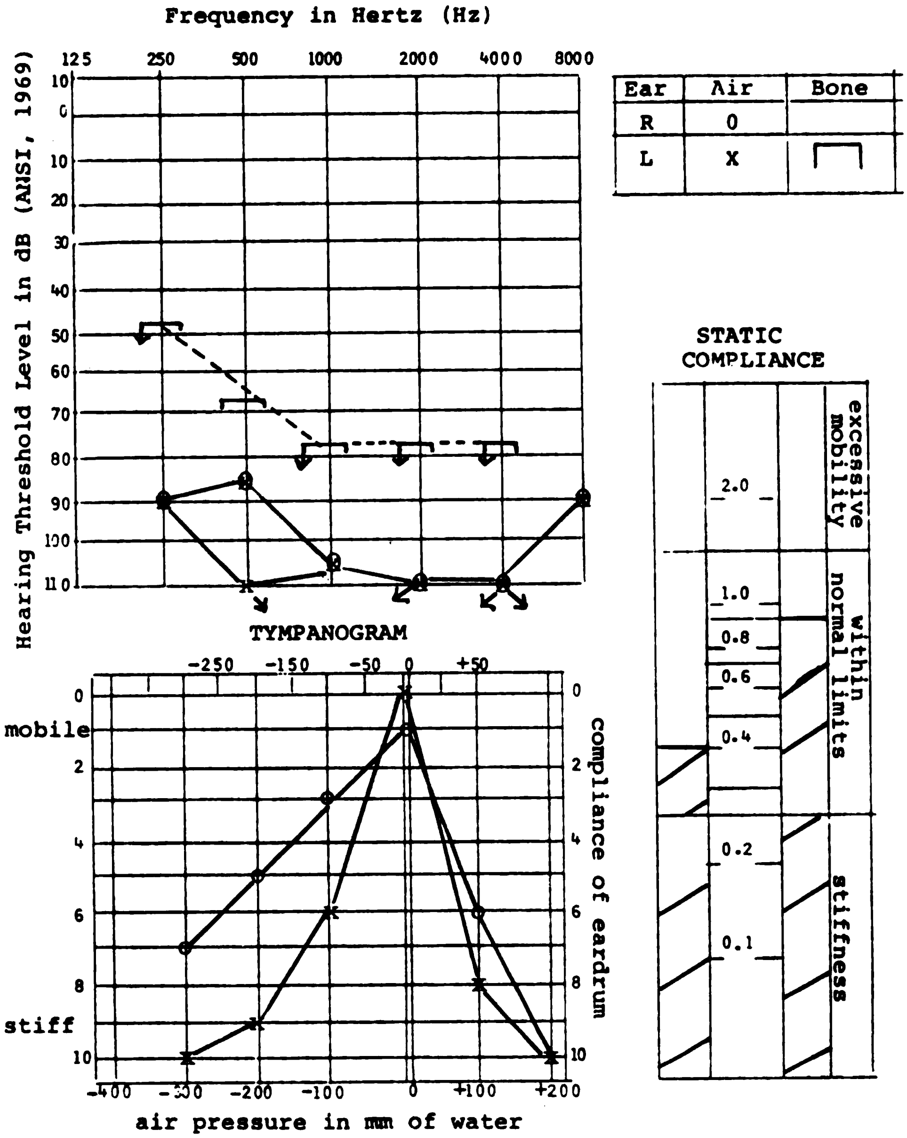

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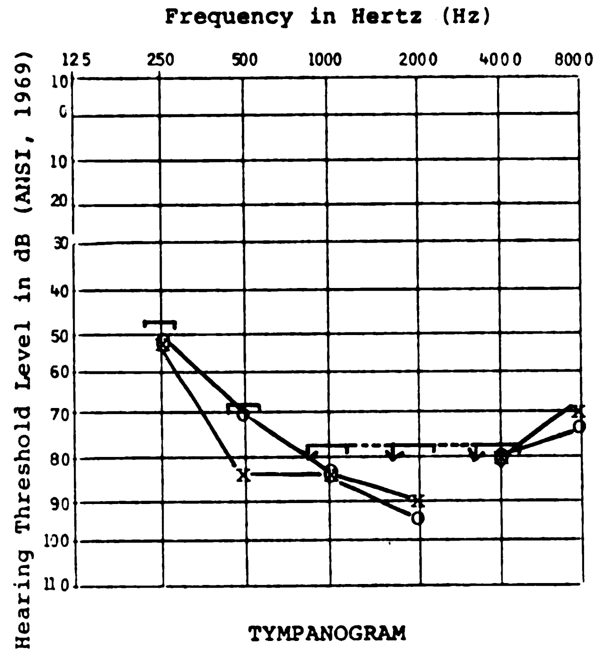
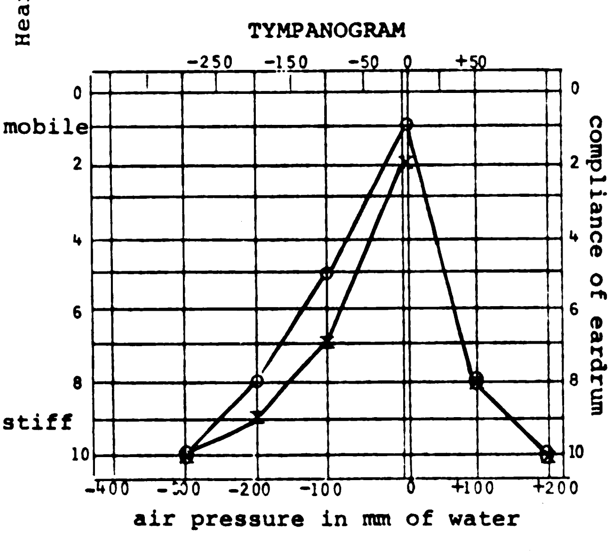
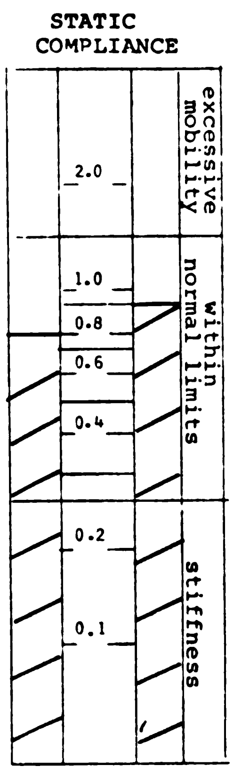
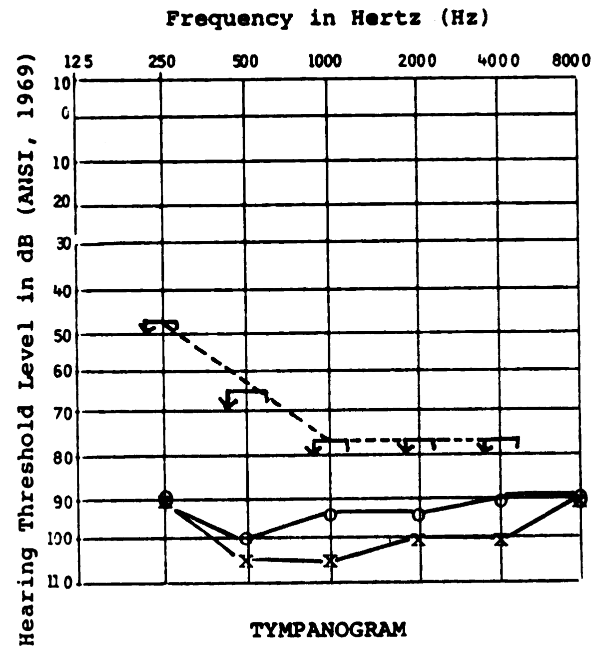


Ear	Air	Bone
R	0	
L	X	⌐¬

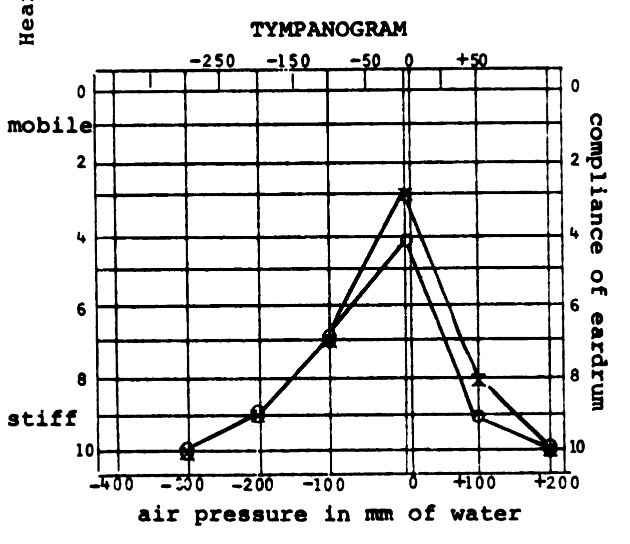


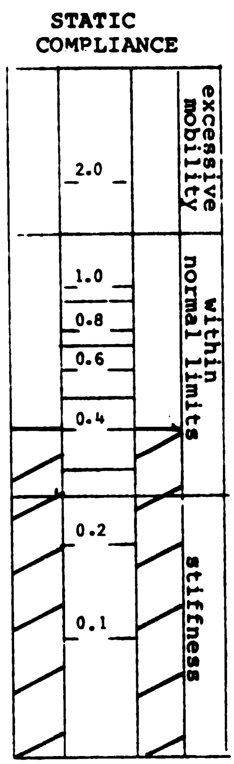


SUBJECT #6 (FEMALE)



Ear	Air	Bone
R	0	
L	X	⊓





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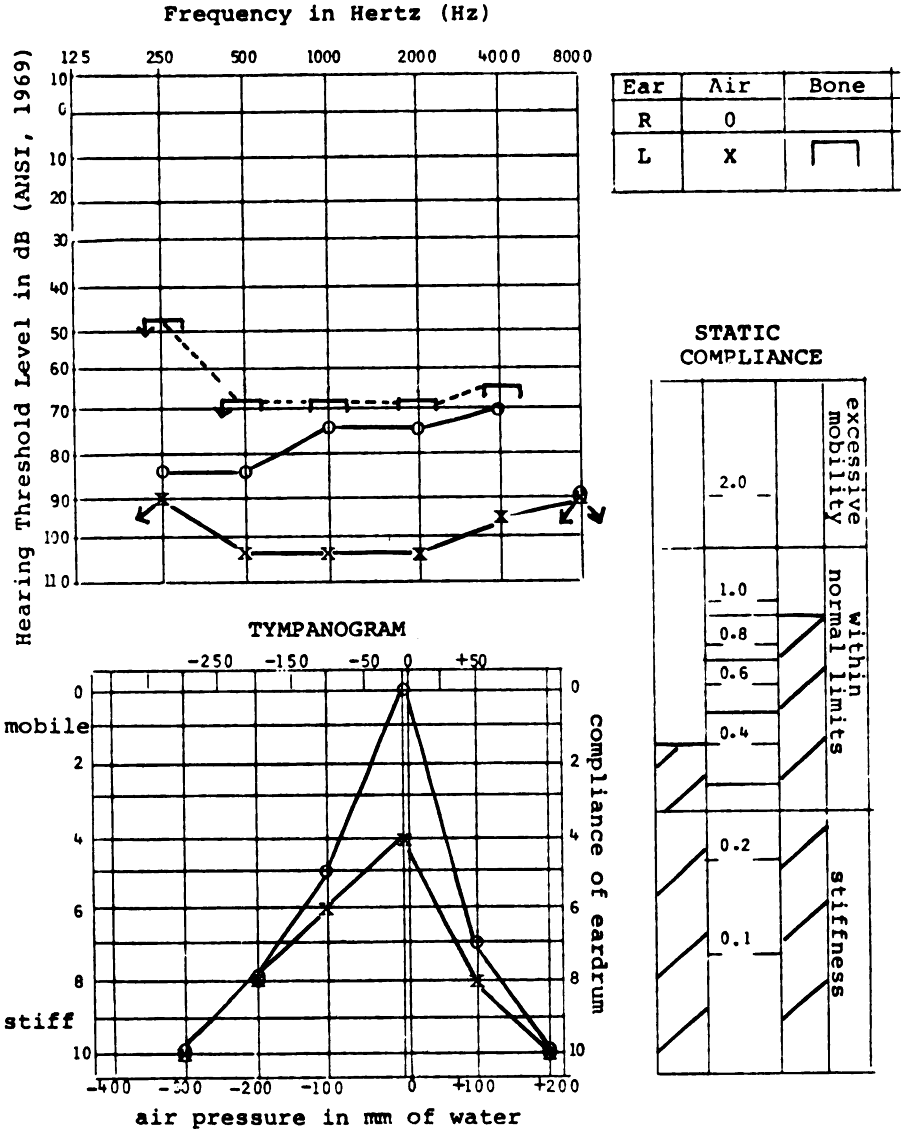
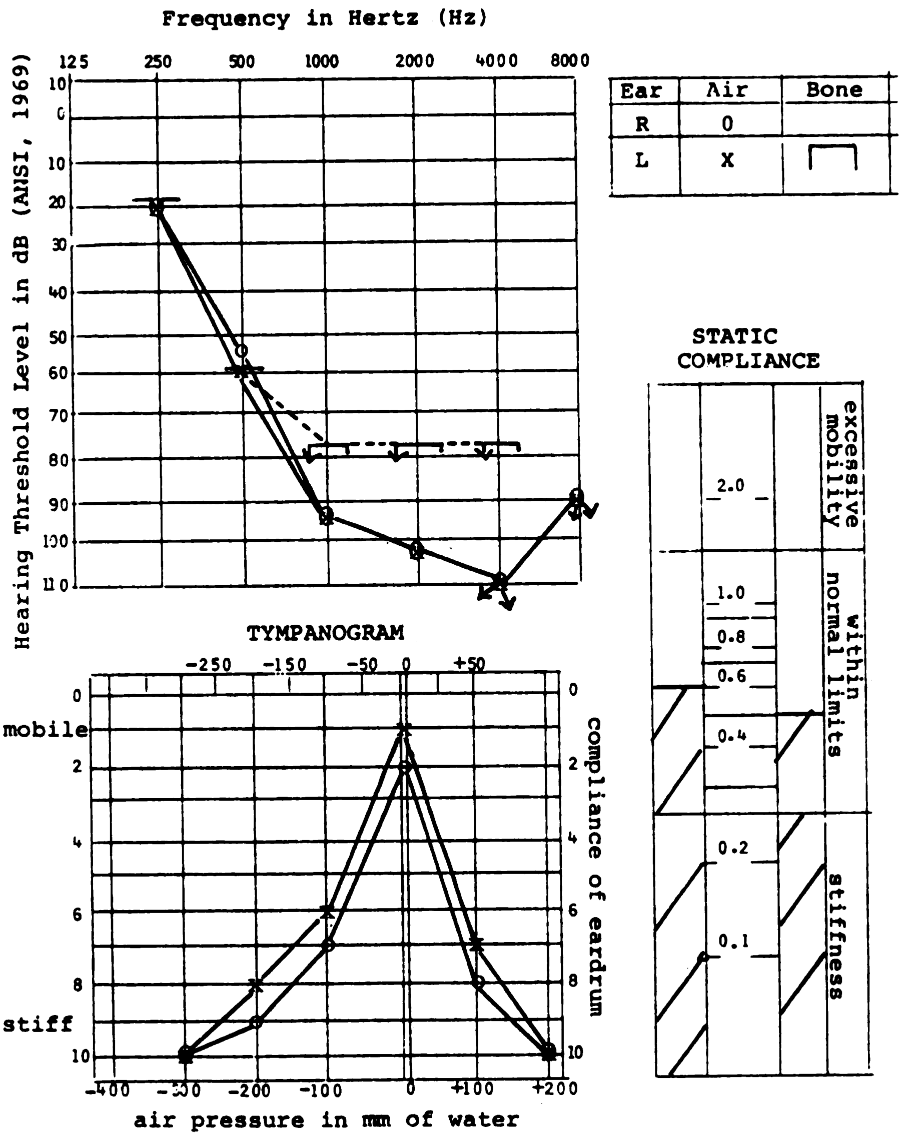


SUBJECT #8 (FEMALE)



Ear	Air	Bone
R	0	
L	X	⊓

APPENDIX C

CASE HISTORY AND RELEASE FORM

Name__________________Birthdate___________Age_____________

Address____________________________________Phone___________

PLEASE FILL IN ALL APPROPRIATE QUESTIONS.

Have you ever had facial surgery or surgery on your ears_______

What kind____

When and where____

What medications do you take now__________________________

Do you have an acute allery (occurs suddenly)_____________

Age of onset of hearing loss______________________________

Cause of hearing loss____________________________________

How has your hearing changed______________________________

Do you wear a hearing aid_________________________________

What kind____

Do you know sign language_________________________________

How often do you sign____________________________________

Do you know fingerspelling________________________________

How often do you fingerspell_____________________________

How often do you write messages in face to face communication____

What percent of your communication is oral as opposed to manual or written____

To what extent was your education oral____________________

manual____

or combined manual____

What was the last school you attended____________________

Where and when have you received speech theraphy________

____

I attest to the truth of the above information and my willingness to participate in this experimentation.

Signature	Witness
Date	Date

APPENDIX D

SENTENCE STIMULI

Practice Sentence Items

We sat on the floor.

I want to wish you a happy birthday.

The two boys worked at the job off and on but not all the time.

Test Sentence Items

Dad went on a trip.

She made a picture.

The ice is too cold to hold in your hands.

That big tree will shade us from the hot sun.

You know how to stick to things until you find out the answers.

Now each person in the office is talking about the dog.

APPENDIX E

INSTRUCTIONS

(1) Please fill out the case history form. I will answer any questions you have.

(2) Read these words. If you do not understand a word, please tell me.

(3) Next, we will go to Room B-5 for a hearing evaluation.

(4) Next, we will go to Room 209-C. You will be seated at the equipment table.

a. Hold the rubber mask to your face, like this (example given).
Make the mask tightly cover your mouth and nose.
Do not let air leak out the sides of the mask.
In front of you is a stack of cards.
Each card has one sentence typed on it.
You will read every sentence into the mask.
When you are ready, I will turn on the machine, and you will begin reading the sentences.
Let's practice.
Read these three sentences. Read as you usually do.
Are you ready to read the other sentences?

b. Hold the rubber mask to your face.
Make the mask tightly cover your mouth and nose.
Do not let air leak out the sides of the mask.
You will look at this picture and hold the mask to your face.

I want you to tell what you see in the picture.
When you are ready, I will turn on the machine,
and you will begin talking about the picture.
Let's practice.
Tell me what you see in this picture. Talk as
you usually do.
Are you ready to tell me about another picture?

(1) Please fill out the case history form. I will answer any questions you have.

(2) Read these words. If you do not understand a word, please tell me.

(3) Next, we will go to Room B-5 for a hearing evaluation.

(4) Next, we will go to Room 209-C. You will be seated at the equipment table.

a. Hold the rubber mask to your face, like this (example given).
   Make the mask tightly cover your mouth and nose.
   Do not let air leak out the sides of the mask.
   You will look at this picture and hold the mask to your face.
   I want you to tell what you see in the picture.
   When you are ready, I will turn on the machine, and you will begin talking about the picture.
   Let's practice.
   Tell me what you see in this picture. Talk as you usually do.
   Are you ready to tell me about another picture?

b. Hold the rubber mask to your face.
   Make the mask tightly cover your mouth and nose.
   Do not let air leak out the sides of the mask.
   In front of you is a stack of cards.
   Each card has one sentence typed on it.

You will read every sentence into the mask.

When you are ready, I will turn on the machine, and you will begin reading the sentences.

Let's practice.

Read these three sentences. Read as you usually do.

Are you ready to read the other sentences?