

AERODYNAMIC PARAMETERS OF
HEARING-IMPAIRED CHILDREN
FOR SELECTED CONSONANT PRODUCTION

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ABSTRACT

AERODYNAMIC PARAMETERS OF HEARING-IMPAIRED CHILDREN FOR SELECTED CONSONANT PRODUCTION

By

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Relatively few research efforts have been directed toward identifying the differences that occur in the speech of hearing-impaired children. Substantial insight can be gained from direct physiological monitoring of speech production using aerodynamic techniques. This type of investigation allows identification of specific patterns of speech production, and consequently has potential therapeutic implications. The purpose of the present investigation was to evaluate the aerodynamic parameters of selected consonant production in hearing-impaired children.

The subjects included ten children with severe-to-profound, bilateral, sensori-neural hearing losses and ten children with normal hearing. Their task was to produce five pairs of monosyllabic words initiated by cognate pairs of stop and fricative consonants. Each child repeated the task three times.

The aerodynamic parameters analyzed were:

(1) peak intraoral air pressure; (2) peak air flow rate;

and (3) duration of intraoral air pressure. Intraoral air pressure data were obtained using an endoral method, that is, a catheter tube was placed in the anterior oral cavity. The catheter was attached to a pressure transducer and finally to one channel of an optical oscillograph. Air flow data were obtained using a tightly fitting face mask coupled to a pneumotachograph. These data were recorded on a second channel of the optical oscillograph. The audio signal was simultaneously recorded on a third channel of the oscillograph.

In addition to quantitative analyses of the three aerodynamic parameters, a qualitative evaluation of unique or unusual aerodynamic tracings was undertaken.

Quantitative analyses of the data revealed that the experimental group, as compared to the control group, had: (1) greater average intraoral air pressure peaks; (2) lower average air flow rates for voiceless consonants; (3) higher average air flow rates for voiced consonants; (4) greater average duration of intraoral air pressure. Further, the experimental group exhibited greater inter- and intrasubject variability than the control group.

Both the experimental group and the control group failed to exhibit a clear stop consonant voiced-voiceless distinction for intraoral air pressure peak and duration

values. Among the normal-hearing children, the fricative consonant voiced-voiceless distinction was apparent in all aerodynamic parameters under study. The hearing-impaired children exhibited mean values for peak pressure, pressure duration, and air flow rate for the fricative consonants which indicated indistinct voiced-voiceless contrasts.

Qualitative analyses of the data revealed four unusual patterns which appeared to be characteristic of the speech of the hearing-impaired children in this study. These patterns were: (1) indistinct voiced-voiceless contrasts; (2) change in manner of consonant production; (3) inefficient air stream valving; and (4) reduced intraoral air pressure durations.

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By

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CHAPTER I

INTRODUCTION

Speech production in the hearing-impaired has been a topic of clinical concern for many years. However, relatively few research efforts have been directed toward identifying the deviations that occur in the speech of this population. The earliest scientific investigations were primarily perceptual comparisons of the speech of hearing-impaired subjects and normal hearing subjects. From these early investigations, it was determined that hearing-impaired subjects often failed to exhibit a clear voiced-voiceless contrast. There was frequent omission of final consonants, misarticulation of consonant blends, addition of extra syllable elements, vowel and diphthong prolongations, distortions, substitutions, and excessive nasality (Hudgins, 1934; Hudgins and Numbers, 1942). Distorted prosodic patterns were also found to be characteristic of the speech of the hearing-impaired (Hudgins, 1934; Hudgins and Numbers, 1942; Stark and Levitt, 1974).

While perceptual studies yield valuable information, additional insight can be gained from acoustic analyses, which permit direct measurement of fundamental frequency,

amplitude, formant patterns and duration characteristics. A limited number of studies have used spectrographic techniques to document speech deviations in the hearing-impaired. For example, Boone (1966, 1971) revealed that, although there are no significant differences in the fundamental frequency of the pre-adolescent hearing-impaired (age 7-8 years) as compared to a normal hearing population, post-adolescent hearing-impaired males (age 17-18 years) exhibited fundamental frequencies which averaged 54 Hz higher than normal hearing subjects. Similarly, Angelocci, Kopp, and Holbrook (1964) found that hearing-impaired children aged 11-14 years, when compared to normal-hearing subjects, exhibited higher mean fundamental frequencies for all vowels, greater mean ranges of fundamental frequencies and amplitudes, and smaller mean ranges of the first three formant frequencies. Angelocci et al. also found a consistent depression in frequency of the second formant, which they interpreted as evidence of inappropriate tongue carriage. This was consistent with the cineflurographic observation of Boone (1966), that hearing-impaired subjects often employed a retracted tongue position. Prolongation of vowels and frequent, inappropriate pauses were also observed in the cineflurographic and acoustic studies (Boone, 1966). These various articulatory disturbances were thought to be related to the analytic approach used

for teaching speech to hearing-impaired children. Mastery of isolated phonemes is stressed in such habilitation techniques and carry-over into contextual speech may not be properly achieved (Boone, 1971).

Whereas the analysis of acoustic characteristics have added to the understanding of speech production in hearing-impaired populations, it must be recognized that such research strategies were limited by the lack of on-line physiological information. Accordingly, speculations regarding events occurring within the speech system were somewhat hazardous. Although cinefluorographic procedures permit direct observation of vocal tract dynamics, ionizing radiation danger considerably reduced the sample of speech available for study. Therefore, substantial insight can be gained from direct physiological monitoring of speech production. However, to date only a scattered number of investigations have sought to evaluate physiological functioning. Perhaps the earliest study using aerodynamic procedures was that of Hudgins (1934), who made kymographic recordings and tracings of air pressure ". . . just outside the mouth . . ." (p. 3) and air flow rates to determine the volume of air used per phrase and rate of a syllable utterance. He compared the speech of 62 hearing-impaired subjects to a control group of 25 normal-hearing subjects. All subjects repeated phrases of varied syllable length.

The hearing impaired subjects exhibited ". . . slow and labored speech . . ." which was associated with ". . . high chest pressure . . ." (p. 45) and the release of excessive amounts of air flow.

Recently more sophisticated procedures have been used to describe the distorted speech patterns of hearing-impaired adults. Hutchinson and Smith (1974) studied seven adult subjects with severe-to-profound, bilateral, sensorineural hearing losses with onset prior to two years of age. The subjects were asked to repeat 12 monosyllabic words initiated by cognate pairs of stops and fricatives. Intraoral air pressure and air flow rate measurements were obtained. Results indicated that mean intraoral air pressure was higher and mean intraoral air pressure duration was longer for all consonant classes. The usual differences between voiced and voiceless consonants were observed, but the differences were less distinct for the hearing-impaired subjects. Hutchinson and Smith also observed qualitative differences such as blurring of the voiced-voiceless distinctions in consonant cognates and changes in manner of articulation, which were consistent with earlier perceptual and acoustic studies. In addition, the authors reported ". . . inefficient air stream valving . . ." (p. 9) characterized by the presence of high volume flows, where low flow rates would be expected and low volume flows where high flow

rates would be expected. Although Hutchinson and Smith found no significant differences in air flow rates between the two populations, a study by Gilbert and Dixon (1974) did reveal some significant air flow rate abnormalities for hearing-impaired adults on oral/nasal air flow rate measurements and spectrographic recordings. Results indicated indistinct voiced-voiceless contrasts with relation to oral air flow, as well as sporadic air flow and rapid fluctuations of oral air flow associated with voiced stop plosives. Further, the appearance of inappropriate nasal air flow and lack of continuous voicing in CVC syllables (voiced stop plosives in the consonant positions) were consistent with the results of other studies.

Such precise aerodynamic data greatly increase our knowledge of the specific physiological differences among the hearing-impaired, and consequently has therapeutic potential. Hutchinson and Smith (1974) utilized the findings of their study in an experimental training procedure. Normal intraoral air pressure and voice tracings for the cognates /p/ and /b/ were photographed from oscilloscopic tracings to serve as target models. Two hearing-impaired subjects were then asked to produce /p/ and /b/ which were subsequently displayed on the oscilloscope. Explanations of the deviations in peak pressure and voice onset time were presented as well as instructions for operating the

storage oscilloscope. The subjects were then asked to modify their productions in an effort to copy the target models. After a ten-minute period both subjects were successful in producing the aerodynamic characteristics essential for the voiced-voiceless distinction. The results indicate promise for use of aerodynamic procedures as a clinical feedback tool in modifying articulatory aberrations during speech production of hearing-impaired persons.

Most investigators agree that early intervention with hearing-impaired children will facilitate articulatory training (Davis and Silverman, 1970; Oyer, 1966). Nevertheless, no research efforts have emerged to document the nature of the physiological deviations of the speech production of hearing-impaired children. Therefore, the purpose of the present investigation is to evaluate the aerodynamic parameters of selected consonant productions in hearing-impaired children.

CHAPTER II

EXPERIMENTAL PROCEDURES

Ten normal-hearing and 10 hearing-impaired children produced five pairs of words initiated by stop and fricative consonant cognates. Each of the subjects underwent an orientation period immediately prior to the experimental session.

Subjects

The subjects of the present study were 20 children free of physical handicaps, subdivided into experimental and control groups, from English-speaking, non-bilingual homes. The experimental group was composed of 10 children who exhibited a severe-to-profound, bilateral, sensori-neural hearing loss (characterized by at least a 70 dB loss in the better ear for an average of the speech frequencies), with onset prior to two years of age. Two of the children in this group were enrolled in a special total communication classroom, five were enrolled in a special oral communication classroom, and three attended regular classrooms. These children ranged in age from eight years and one month

to ten years and nine months, with a mean age of nine years and six months. The control group was composed of 10 normal-hearing children, whose ages ranged from eight years and three months to ten years and nine months, with a mean age of nine years and five months.

Speech Stimuli

Speech stimuli consisted of five monosyllabic word pairs, initiated by stop and fricative consonant cognates, represented by both pictured objects and/or a printed word. The stimulus items were pea/bee, pig/big, pool/boot, face/vase, and feet/"v",¹ and were words which all the children had been exposed to previously in the school setting. Each subject named the pictured object three times. The stimulus items were presented in random order and the subject's task was to say the word which was pictured.

All subjects participated in an orientation period immediately prior to the experimental session. The orientation period included familiarization with both the speech stimuli and the aerodynamic measure equipment. The speech stimuli were presented prior to the experiment to insure that each hearing-impaired child was able to approximate verbalization of every word (based on visually correct

¹The orthographic "v" was used in lieu of the nonsense word "veet".

phonetic placement, not necessarily correct articulation, as determined by an experienced speech clinician), and that each normal-hearing child was free of articulatory errors associated with the specific stimulus items.

Instrumentation

A catheter (#12, French) was utilized in an endoral method to obtain measurements of intraoral air pressure. The catheter was positioned in the oral cavity such that the orifice was perpendicular to the air flow thus preventing erroneously high air pressure readings that could occur when air directly impinged at the opening of the tube (Hardy, 1965). The catheter was attached to a pressure transducer (Statham 131 TC). The signal from the transducer was amplified (Accudata 113 Bridge Amplifier) and recorded on one channel of an optical oscillograph (Visacorder 1508 B). Prior to each experimental session, a static calibration was completed using a U-tube water manometer, which permitted the experimenter to correlate a known pressure with a given galvanometer deflection on the optical oscillograph.

The air flow data were obtained using a large tightly fitting face mask coupled to a pneumotachograph (Hewlett-Packard, custom made). The pneumotachograph housed a screen that provided a resistance to air flow. The mesh screen was heated with a small electrical current

(1.5 v) to prevent moisture condensation which would alter the response characteristic of pneumotachograph. 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." 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 air flow rate system was accomplished using a flowrater meter (Fisher and Porter, 10A1027A).

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, tape recorder) and simultaneously recorded on a third channel of the optical oscillograph and the tape recorder (Ampex 601) (see Appendix A).

Data Analysis

Oscillograph tracings were analyzed with reference to three aerodynamic parameters: (1) peak air flow rate; (2) peak intraoral air pressure; and (3) duration of the intraoral air pressure. Measurements were determined from an established baseline to the point of greatest excursion

for peak intraoral air pressure (see points A to B on Figure 1) and to the point of greatest excursion following the release of the consonant for the peak air flow rate (see points C to D on Figure 1).

Duration of the pressure pulse was obtained by measuring the distance from onset of the pulse to offset. The onset was established as the point of departure from the zero pressure baseline and the offset was judged to be the point where the pressure trace returned to the baseline, or the steady-state portion of the subsequent vowel (see points E to F on Figure 1). In addition, the experimenter examined the aerodynamic traces for unique or unusual qualitative patterns.

A measurement of intra-subject reliability resulted in a correlation of .99 for IOAP, .99 for AFR, and .99 for duration (see Appendix B).

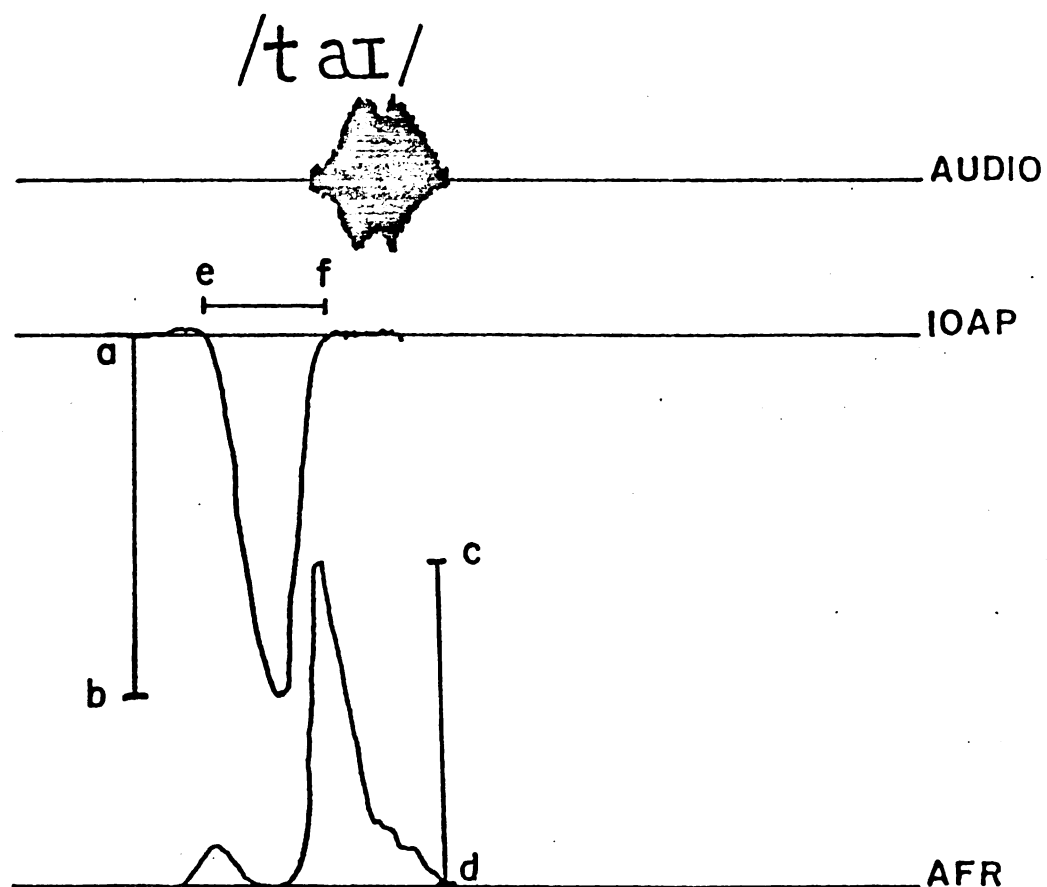


Figure 1. Schematic drawing of aerodynamic tracing.

CHAPTER III

RESULTS

The results of this study will be presented in two major sections. Quantitative analysis, with reference to intraoral air pressure, air flow rate, and intraoral air pressure duration will be discussed in the first section. Qualitative differences in aerodynamic patterns which characterized the speech of the hearing-impaired children used in the present study will be discussed in the second section.

Quantitative Analysis

Intraoral Air Pressure

Table 1 presents the mean intraoral air pressure values of the normal-hearing children used in the present study, compared to the mean data on normal-hearing children in the study by Arkebauer et al. (1967). The mean values measured in the present study were higher than those found by Arkebauer et al. for all consonant classes. Except for the voiced-stop, however, the mean values of the previous study were contained within ± 1 standard deviation of the mean values of the present study. In addition, although

Table 1. Comparative mean IOAP values (in cm H₂O) for four consonant classes produced by normal-hearing children in the present study and an earlier study (Arkebauer et al., 1967)

Investigator	Voiceless Stops	Voiced Stops	Voiceless Fricatives	Voiced Fricatives
Arkebauer, Hixon, and Hardy (1967)	6.69	3.14	5.56	3.15
Kornhauser (1975)	8.18	7.92	7.79	4.92

the expected pressure differences between the voiced and voiceless stop consonants were maintained by the normal-hearing subjects, the difference was relatively small.

The results for intraoral air pressure by consonant class are depicted in Figure 2 (data are found in Appendix C). For all consonant classes, except voiceless fricatives, the hearing-impaired subjects exhibited greater average intraoral air pressure. Further, the typical pressure differences observed between voiced and voiceless cognates in earlier studies for normal subjects (Arkebauer et al., 1967; Hutchinson, 1973) were not observed in the mean values for the hearing-impaired children.

Five of the 10 hearing-impaired subjects and 7 of the 10 normal-hearing subjects exhibited higher intraoral air pressure values for the voiceless-stop than for the voiced-stop consonant productions (see Table 2). For the fricative class of consonants, 5 of the 10 hearing-impaired children exhibited higher intraoral air pressure values for the voiceless consonant than for the voiced consonant, whereas all 10 of the normal-hearing subjects demonstrated higher intraoral air pressure for the voiceless consonant.

A high degree of variability was observed among the hearing-impaired subjects as compared to the normal-hearing subjects. In all instances, the standard deviations for the

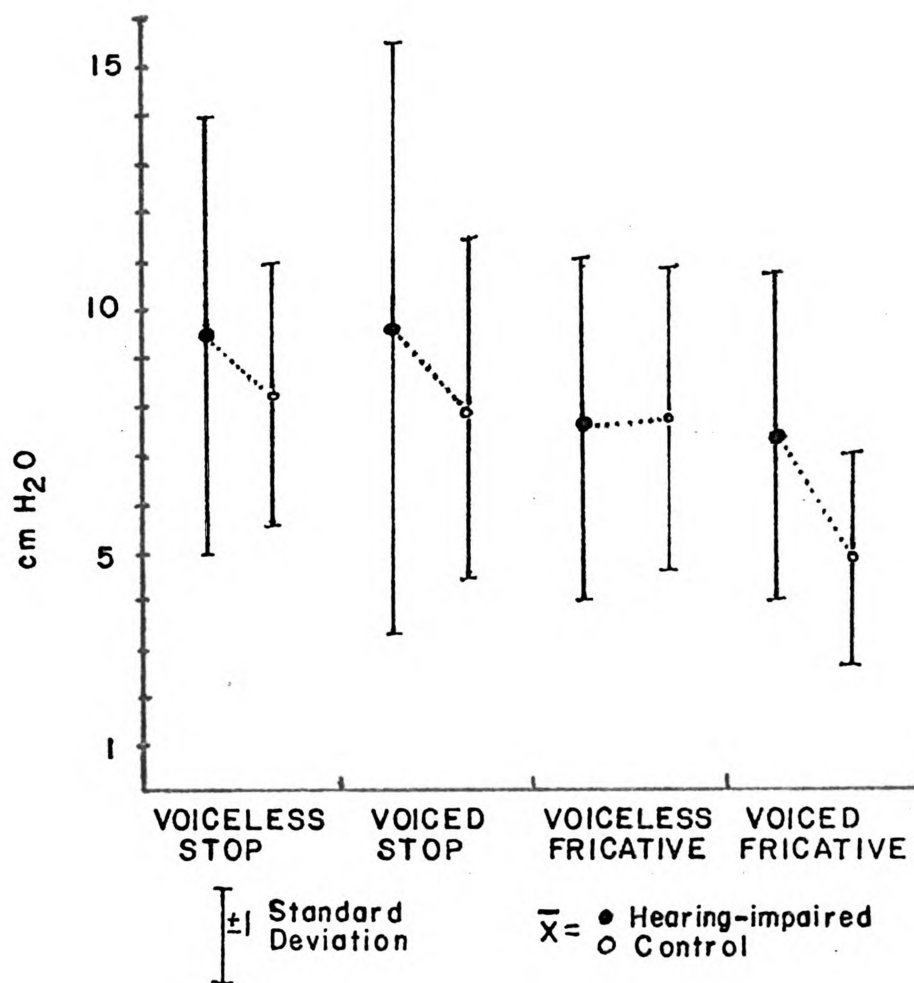


Figure 2. Mean and standard deviation 10 AP values by consonant class for hearing-impaired and normal-hearing children.

Table 2. IOAP peak mean values for each subject (in cm H₂O)

Experimental Subjects	/p/	/b/	/f/	/v/
E ₁	6.52	6.77	3.53	5.31
E ₂	13.85	12.57	8.49	10.26
E ₃	3.19	4.69	5.51	5.08
E ₄	9.70	7.81	6.32	3.96
E ₅	7.37	11.30	7.68	8.89
E ₆	8.23	2.72	8.26	2.58
E ₇	16.27	17.67	14.60	11.20
E ₈	10.83	13.61	8.99	11.75
E ₉	9.36	8.96	9.08	8.98
E ₁₀	11.40	9.49	6.61	6.78
Control Subjects	/p/	/b/	/f/	/v/
S	6.11	4.61	5.36	3.23
S	8.47	9.46	7.83	5.94
S	10.17	8.81	7.24	4.64
S	6.43	5.74	5.73	3.12
S	7.36	6.62	7.17	2.60
S	7.61	6.22	6.62	5.15
S	11.21	14.94	11.67	6.55
S	10.17	9.94	11.95	6.99
S	7.27	7.85	6.37	5.21
S	6.27	5.83	7.73	5.48

experimental group were extremely large, and, except in the case of the voiced-fricative, encompassed the range of ± 1 standard deviation for the control group.

The experimental group also exhibited considerable intrasubject variability between the three productions of the same word. Examination of Figure 3 revealed a 14.4 cm H₂O difference between Trial 1 and Trial 3. In addition, the pressure duration differed by 230 milliseconds between Trial 2 and Trial 3.

Air Flow Rate

The results for air flow rate measurements are presented in Figure 4 (data are found in Appendix C). In general, it can be observed that the experimental group exhibited lower mean air flow rates for voiceless consonants and higher mean air flow rates for voiced consonants as compared to the control group.

Although all of the hearing-impaired subjects maintained the commonly observed differences in air flow rate between the voiced and voiceless stops, only 3 of the 10 hearing-impaired subjects maintained the air flow difference between voiced and voiceless fricatives (data can be found in Table 3). All of the normal-hearing subjects maintained this air flow difference for both the stop consonants and the fricative consonants.

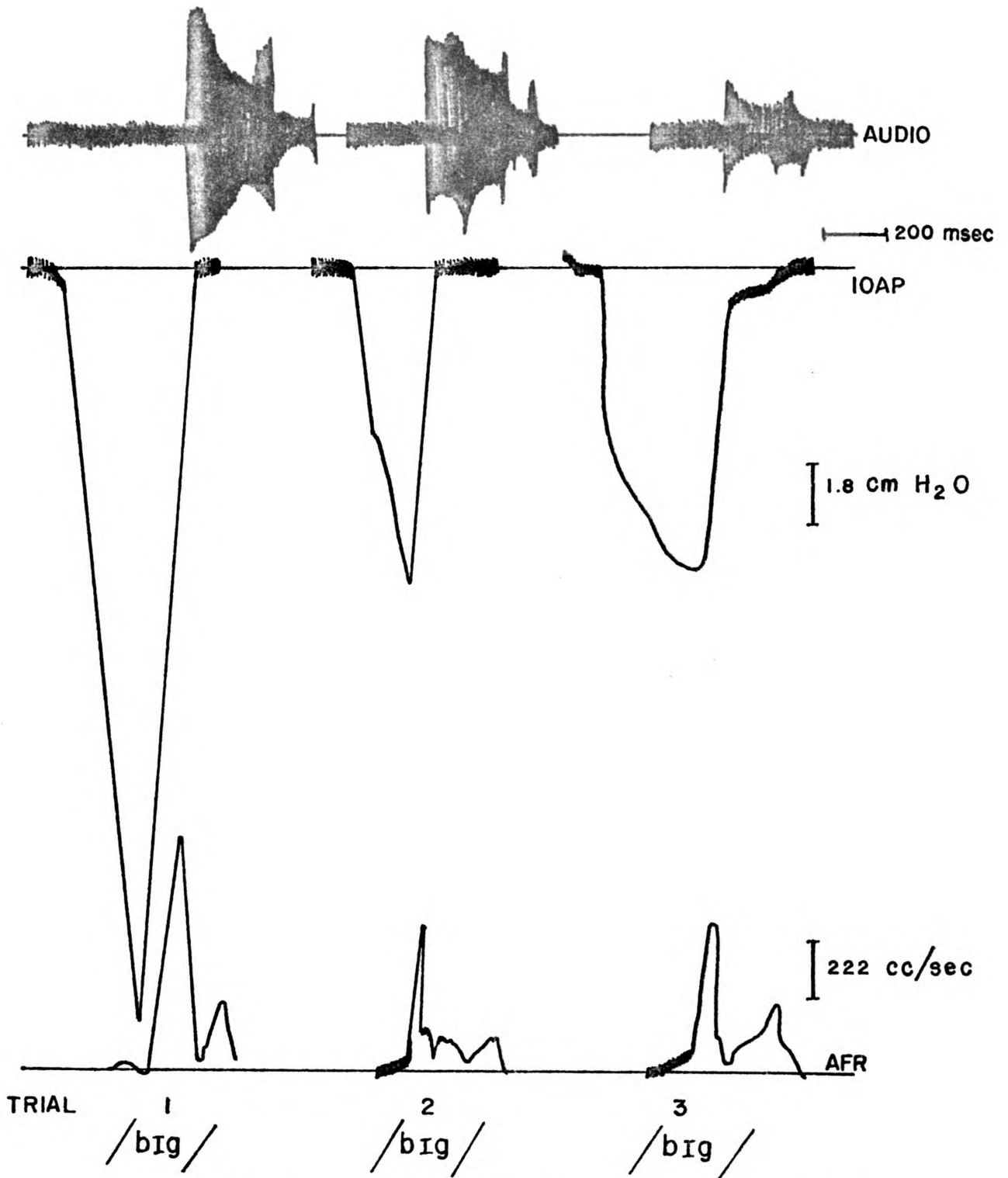


Figure 3. Three productions of /big/ by hearing-impaired Subject 5, demonstrating intrasubject variability.

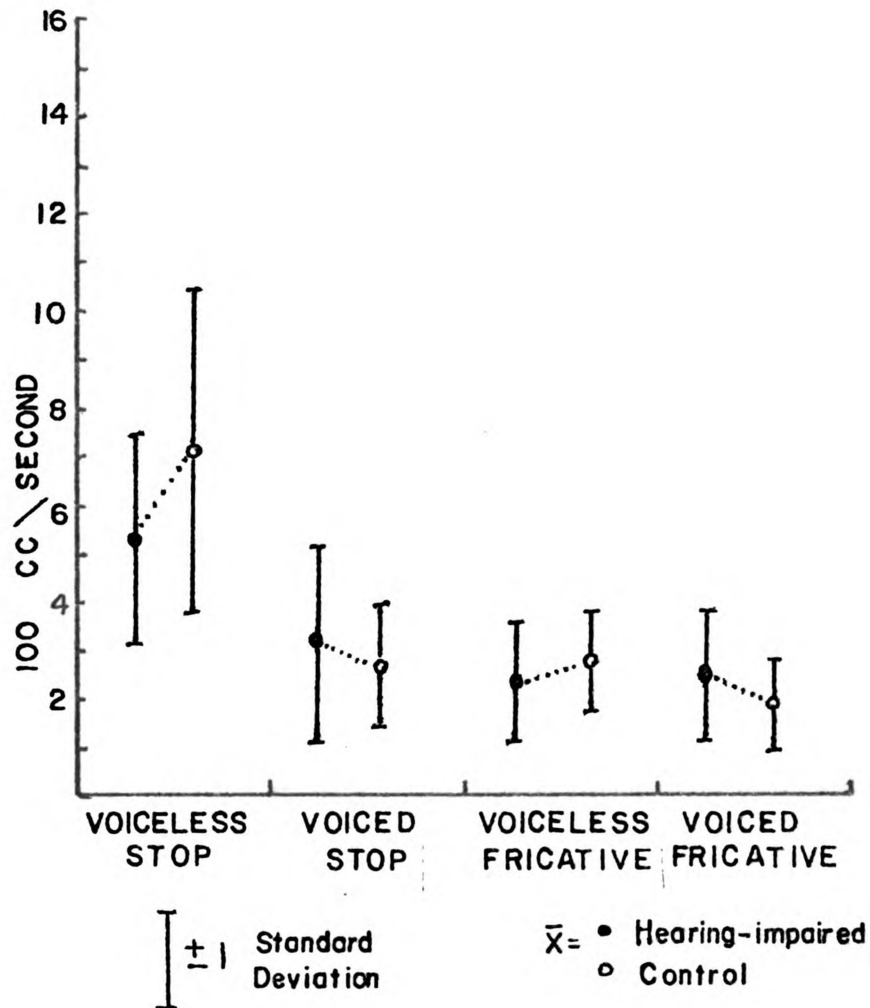


Figure 4. Mean and standard deviation AFR values by consonant class for hearing-impaired and normal-hearing children.

Table 3. AFR mean values for each subject (in cc/sec)

Experimental Subjects	/p/	/b/	/f/	/v/
E ₁	620.5	291.1	234.8	227.7
E ₂	487.2	464.3	351.3	383.3
E ₃	228.5	129.9	113.2	132.8
E ₄	454.5	444.8	464.5	355.8
E ₅	752.4	451.8	328.7	337.0
E ₆	426.4	127.7	193.9	201.3
E ₇	419.2	403.3	289.0	312.0
E ₈	516.9	230.5	175.5	204.8
E ₉	569.9	324.2	264.5	254.2
E ₁₀	686.6	306.4	153.5	153.6
Control Subjects	/p/	/b/	/f/	/v/
S ₁	376.5	212.9	345.4	289.8
S ₂	736.4	248.5	316.3	157.3
S ₃	808.2	258.8	413.8	171.0
S ₄	554.0	226.9	222.3	135.0
S ₅	233.3	133.1	169.6	91.4
S ₆	732.6	392.9	342.4	273.7
S ₇	1328.4	405.2	281.9	194.8
S ₈	1068.7	348.5	333.2	256.3
S ₉	848.1	314.0	304.1	207.1
S ₁₀	495.0	222.1	201.2	129.0

Except in the case of the voiceless-stop consonants, the hearing-impaired subjects evidenced greater intersubject air flow rate variability than the normal-hearing subjects (see Figure 4). Intrasubject variability, exemplified in Figure 5, was also observed among the experimental group. An average difference of 237 cc/second was found between Trials 1, 2, and 3. In Trials 1 and 2 the voiceless-fricative /f/ was produced in a stop manner, while the /f/ in Trial 3 preserved its fricative characteristics.

Intraoral Air Pressure Duration

The results of the total intraoral air pressure durations can be found in Figure 6 (see Appendix C for raw data). The mean duration values for the hearing-impaired subjects were higher in every consonant class than for the normal-hearing subjects. Previous normative data for adults (Prosek and House, 1975) indicated that mean duration values for the voiceless consonants were higher than for the voiced consonants. The normal-hearing children in the present study exhibited the expected duration difference for the fricative consonants. Production of the stop consonants by the control subjects also revealed this expected duration difference, although the difference observed was small (7 milliseconds). Similarly, the hearing-impaired subjects produced the stop consonants with the typical, but very

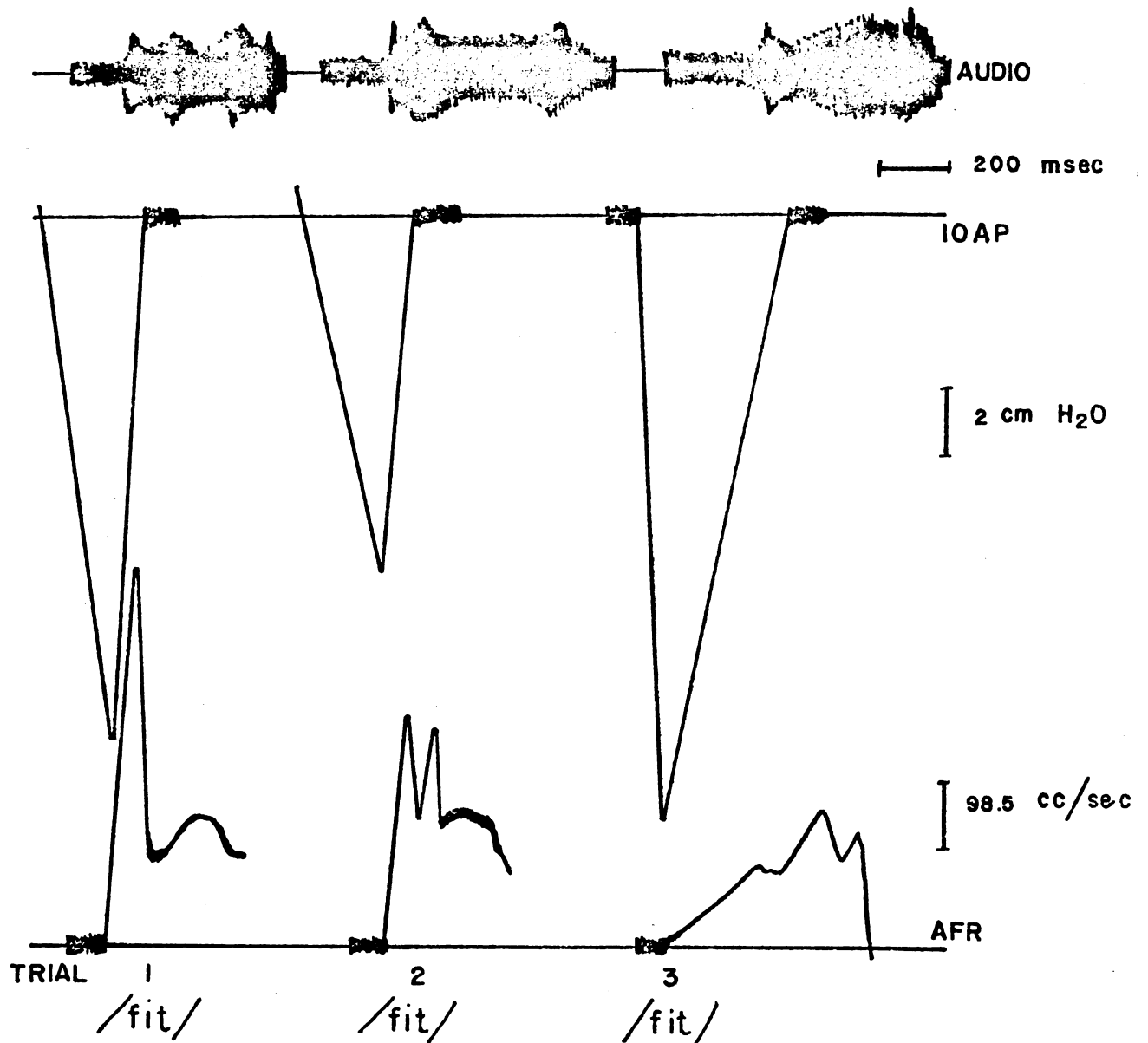


Figure 5. Three productions of /fit/ by hearing-impaired Subject 7, demonstrating intrasubject variability.

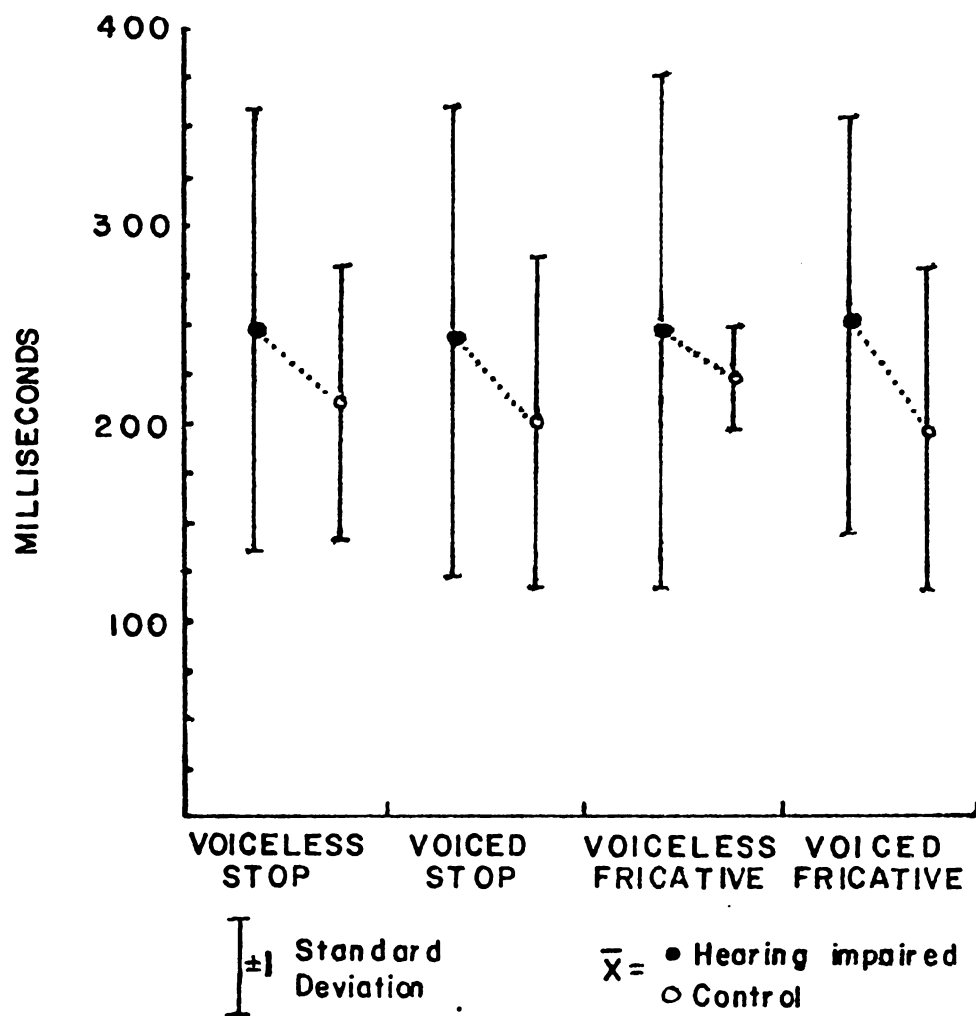


Figure 6. Mean and standard deviation IOAP total duration values by consonant class for hearing-impaired and normal-hearing children.

slight duration difference (3 milliseconds). However, the duration values for the voiceless fricative consonants produced by the hearing-impaired subjects were slightly lower than for the voiced-fricative consonants, which was a reversal of the expected pattern.

The hearing-impaired subjects exhibited a high degree of variability for the measurement of intraoral air pressure duration. The ranges of ± 1 standard deviation for the experimental group were much wider for both the stop consonants and the fricative consonants than for the control group. The range of ± 1 standard deviation for both the voiceless-stops and voiceless-fricatives produced by the hearing-impaired subjects encompassed the range of ± 1 standard deviation for both the voiceless-stops and voiceless-fricatives produced by the normal-hearing subjects. Such was not the case, however, for the voiced consonants.

Similar mean duration differences were observed in the onset time of intraoral air pressure (see Figure 7) (see Appendix C for data). For all consonant classes the experimental group exhibited higher mean durations than the control group. The range of ± 1 standard deviation shows greater variability among the hearing-impaired subjects than among the normal-hearing subjects.

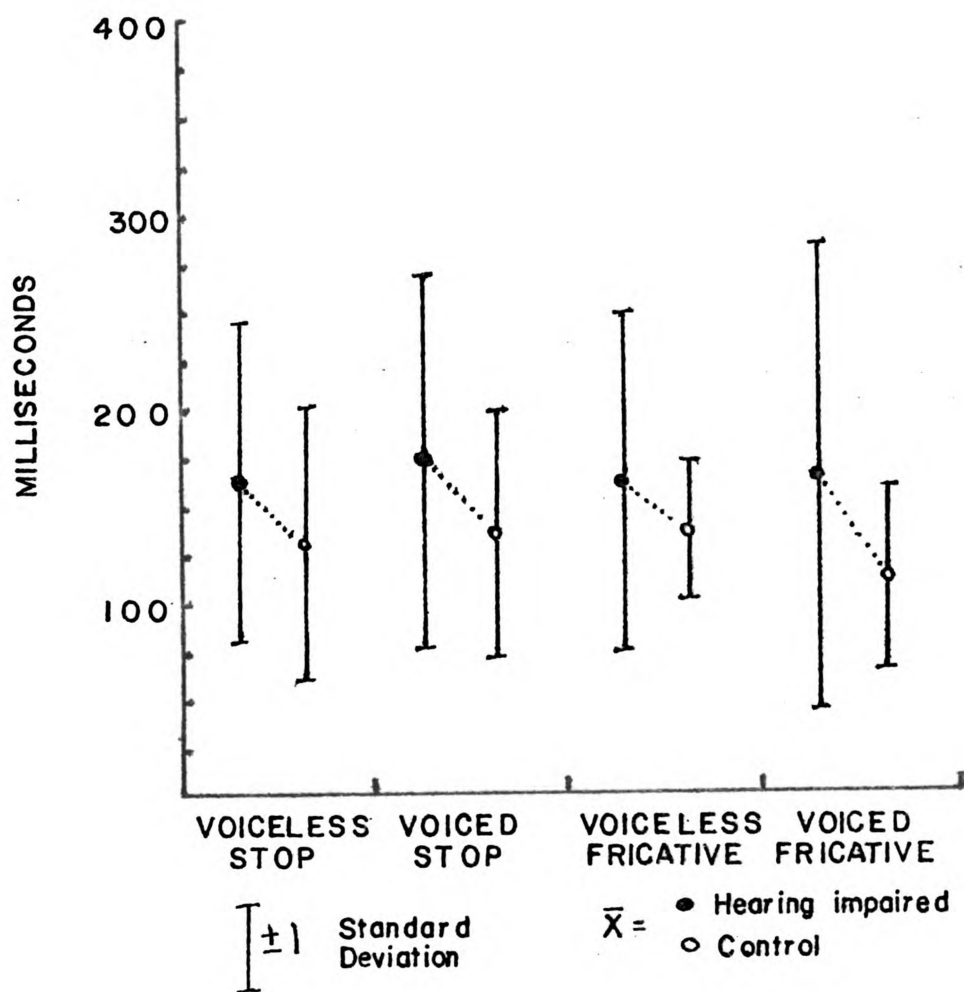


Figure 7. Mean and standard deviation IOAP onset duration values by consonant class for hearing-impaired and normal-hearing children.

Figure 8 contains the mean results of the offset duration of intraoral air pressure. The mean values for the hearing-impaired group were somewhat higher than for the normal-hearing group. The ranges of ± 1 standard deviation among the hearing-impaired subjects was larger and, in fact, encompassed the ranges of ± 1 standard deviation among the control subjects for all consonant classes except the voiced-stop consonants.

Qualitative Analysis

Visual inspection of the aerodynamic tracings revealed four unusual patterns which seemed to be characteristic of the speech of the hearing-impaired children used in this study.

Indistinct Voiced-Voiceless Contrasts

Several of the hearing-impaired subjects failed to produce consonant cognates with the appropriate differences in intraoral air pressure and/or air flow rates. In examining Figure 9, the similarity between Subject 1's production of /ves/ and /fes/ is apparent. The intraoral air pressure peaks were almost identical, the intraoral air pressure duration for each word shows only a 30 msec difference, and the air flow rates are only 50 cc/sec different. Also the onset of voicing, shown by the dotted

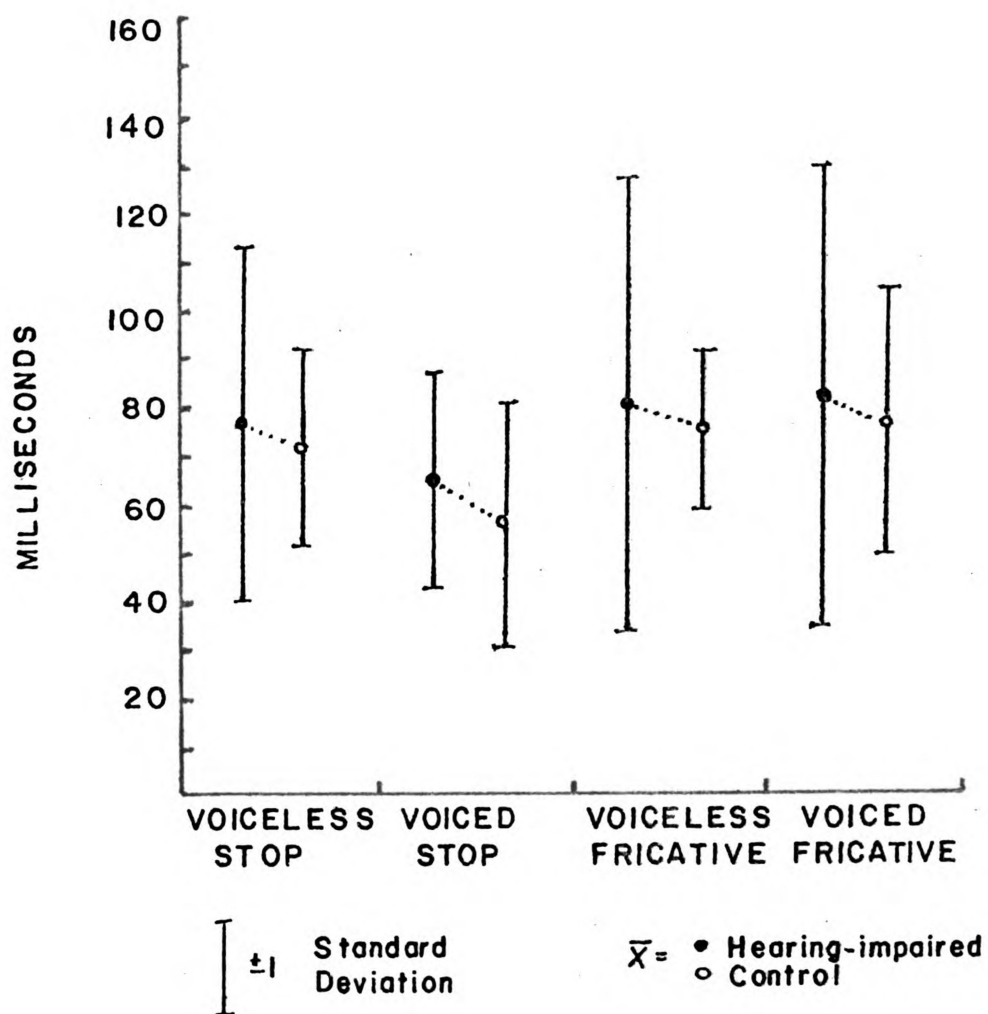


Figure 8. Mean and standard deviation IOAP offset duration values by consonant class for hearing-impaired and normal-hearing children.

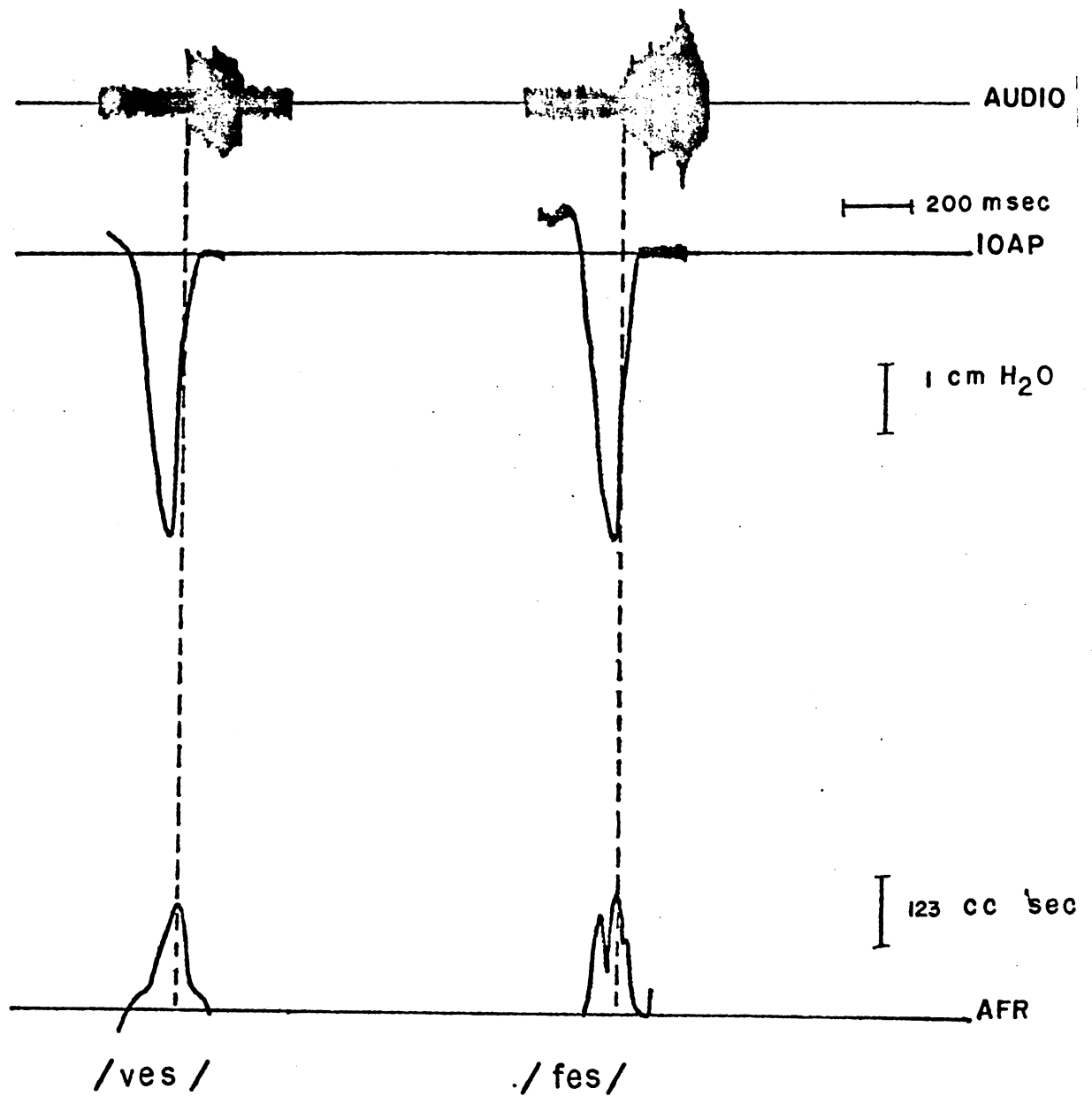


Figure 9. Two productions by Subject 1 demonstrating indistinct voiced-voiceless contrasts.

line, began just after the release of the peak pressure in both words.

Change in Manner of Production

One common change in manner of production was the substitution of a stop for a fricative. As seen in Figure 10, Subject 2 produced the voiceless-fricative /f/ in a stop manner. No air flow was observed during the pressure build-up for the consonant, and the release of air for the fricative production did not occur until after the pressure release. A similar pattern was observed in Subject 3's production of /fit/. Interestingly, no air was released during the pressure build-up, although the pressure duration of 640 msec was unusually long. This pattern, a stop substituted for a fricative, was observed in 48 percent of the possible cases of fricative consonant production in the experimental group. Six of the 10 hearing-impaired children exhibited this pattern.

A less frequently observed pattern was the substitution of a fricative for a stop (see Figure 11). An example was the production of /pul/ by Subject 3. Throughout the pressure build-up, there was a simultaneous air flow which is characteristic of fricative production. This also was seen in Subject 4's production of /pig/. Three of the hearing-impaired children exhibited this pattern, which

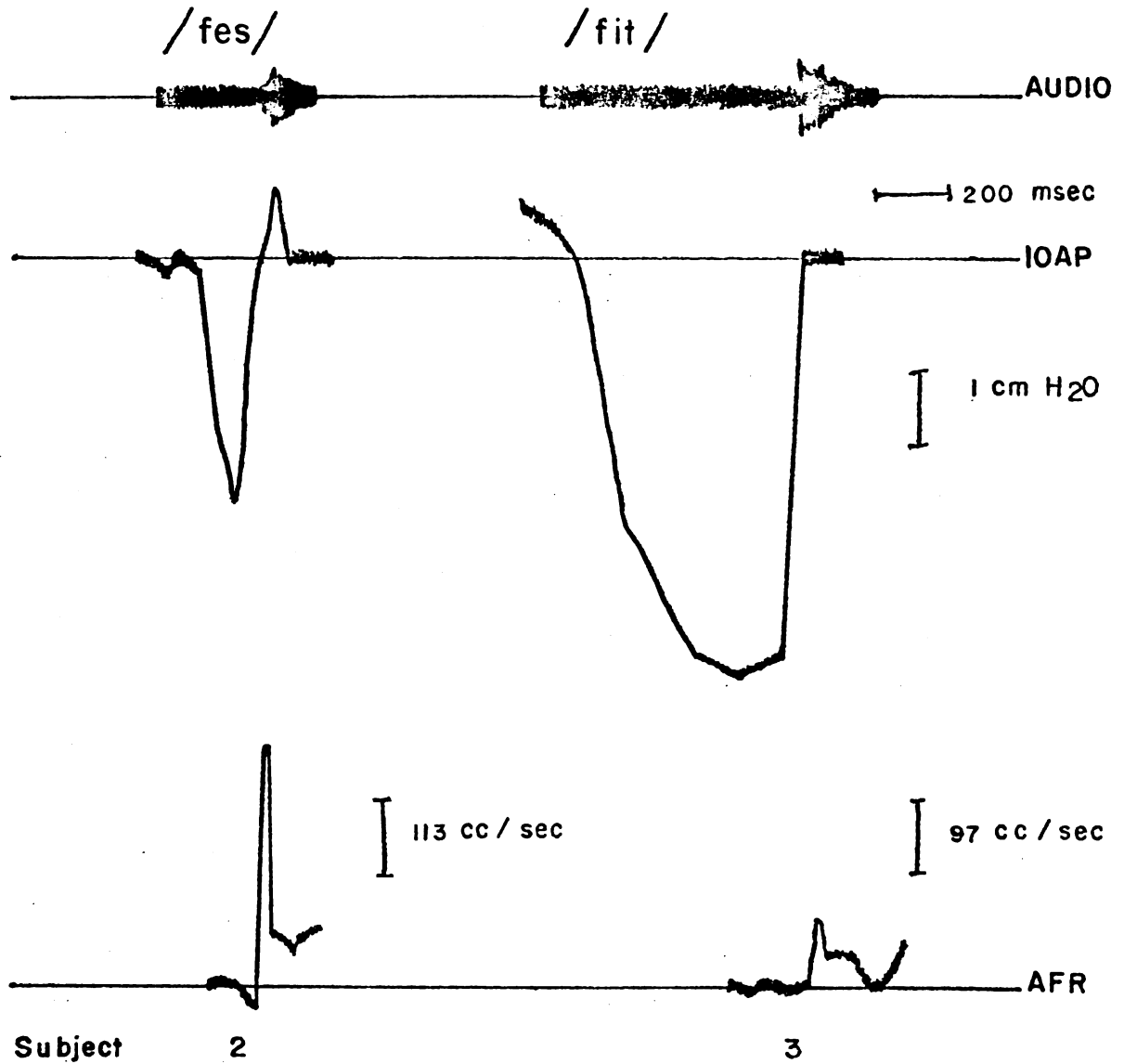


Figure 10. Two productions by hearing-impaired subjects demonstrating change in manner of production from fricative to stop production.

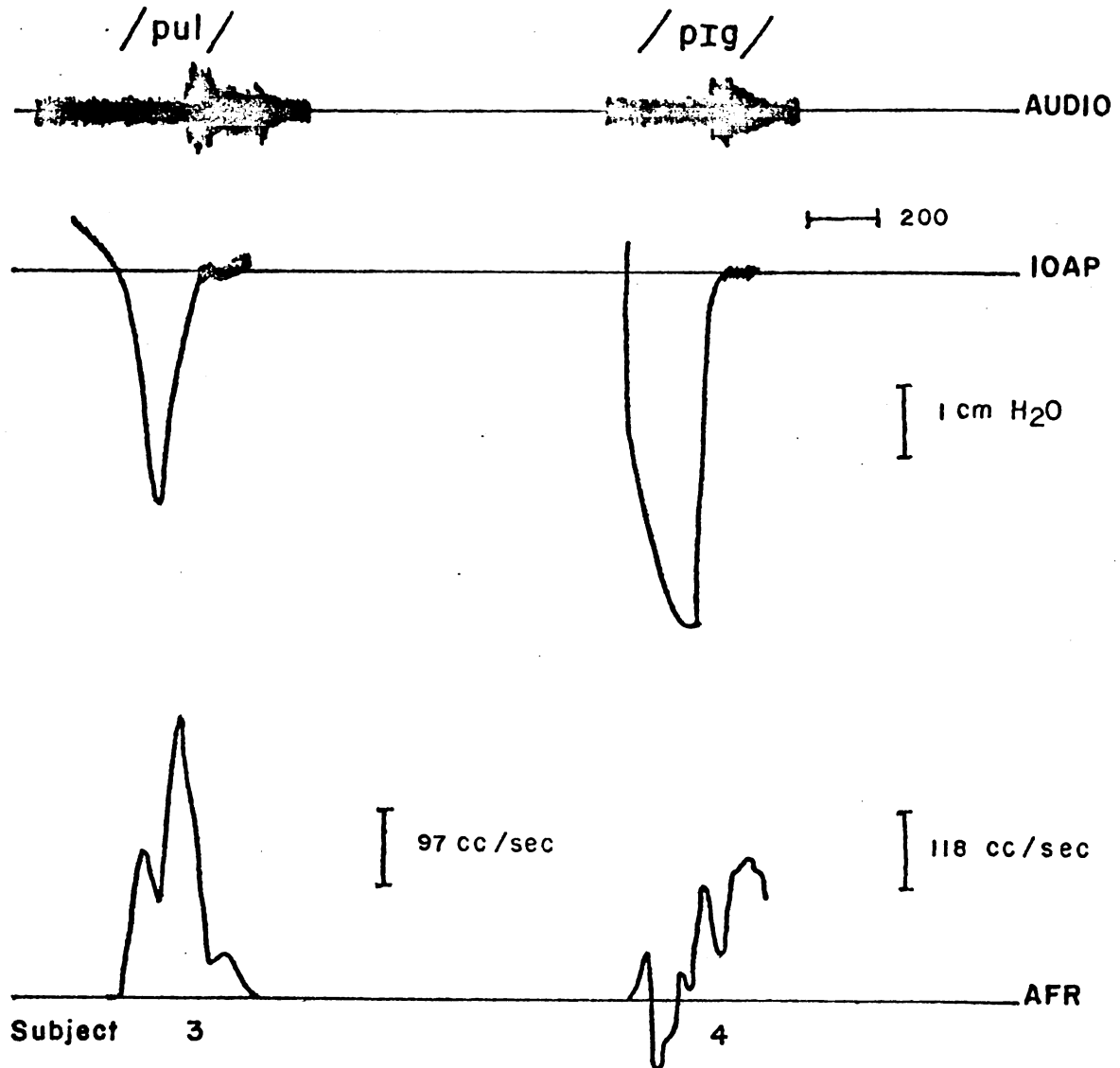


Figure 11. Two productions by hearing-impaired children demonstrating change in manner of production from stop to fricative production.

was observed in 3 percent of the possible cases of stop consonant production in the experimental group.

Inefficient Air Stream Valving

Prolonged air flow rate.--This pattern was characterized by the presence of very high volume velocities of air flow where low air flow rates would be expected, as observed in the production tracing of /bi/ (see Figure 12). That is, high volume velocity air flow rates were found to occur following /b/ and continuing through the vocalic portion of the word. This pattern was observed a total of 21 times among six hearing-impaired children.

In an attempt to explain the physiological events that must occur during production of a prolonged air flow pattern, the author attempted to simulate this pattern (see Figure 13). In both cases, the voiceless-fricative was produced in a stop manner and was followed by prolonged air flow during the vocalic part of the word, and air release was restrained until the onset of voicing. The /f/ is produced with a pressure build-up due to anterior oral constriction. Release of the constriction and, consequently release of pressure, occurred without concomitant air flow. As the voicing began for the rest of the word, expiratory muscle effort was initiated, which in turn resulted in the prolonged air flow for the vocalic portion of the word.

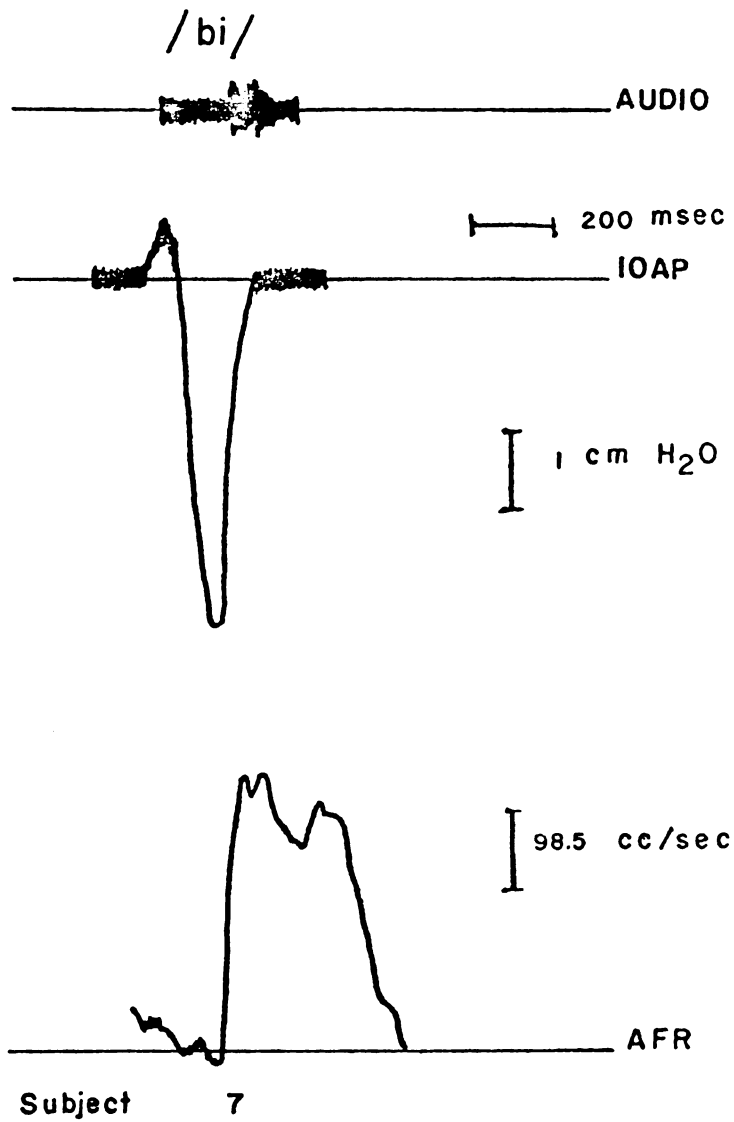


Figure 12. Production by hearing-impaired Subject 7 demonstrating prolonged AFR.

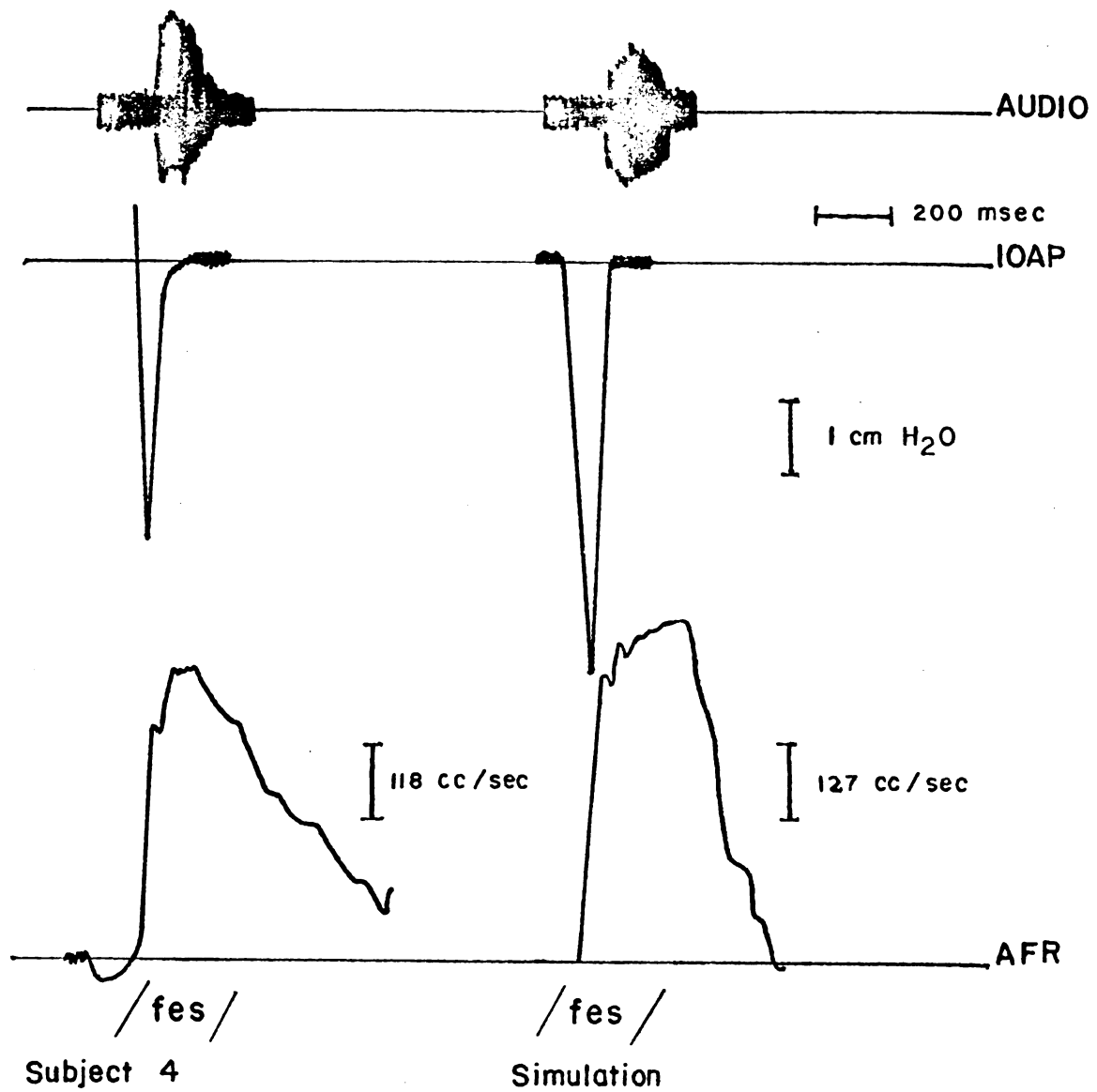


Figure 13. Prolonged AFRs produced by a hearing-impaired child and a simulated production by the author.

High intraoral air pressure peaks associated with very small air flow rates.--This pattern was characterized by an unusually high air pressure peak followed by a very low volume of air flow. Figure 14 depicts Subject 8's production of /but/. He built up a tremendous amount of intraoral air pressure (18.1 cm H₂O with 720 msec duration) with a subsequent air flow rate of 221 cc/sec. Four of the subjects produced a total of 18 similar patterns.

An attempt to simulate this pattern was made by the experimenter (see Figure 15), which resulted in a pattern of very high intraoral air pressure (25 cm H₂O) with a very long duration (980 msec) associated with relatively small air flow. The pattern seemed to be the result of a very tight, prolonged anterior oral cavity constriction associated with a simultaneous tensing of the neck, chest, and abdominal muscles. With the release of pressure, the muscular relaxation occurred and very little air flowed from the oral cavity. In addition, a relatively low respiratory volume may be present at the onset of the production.

Reduced Intraoral Air Pressure Duration

Four of the hearing-impaired subjects exhibited unusually narrow peaks in 30 productions. Generally, for voiceless-fricatives, a duration of approximately 185 msec would be expected, based upon average values for normal

/but/

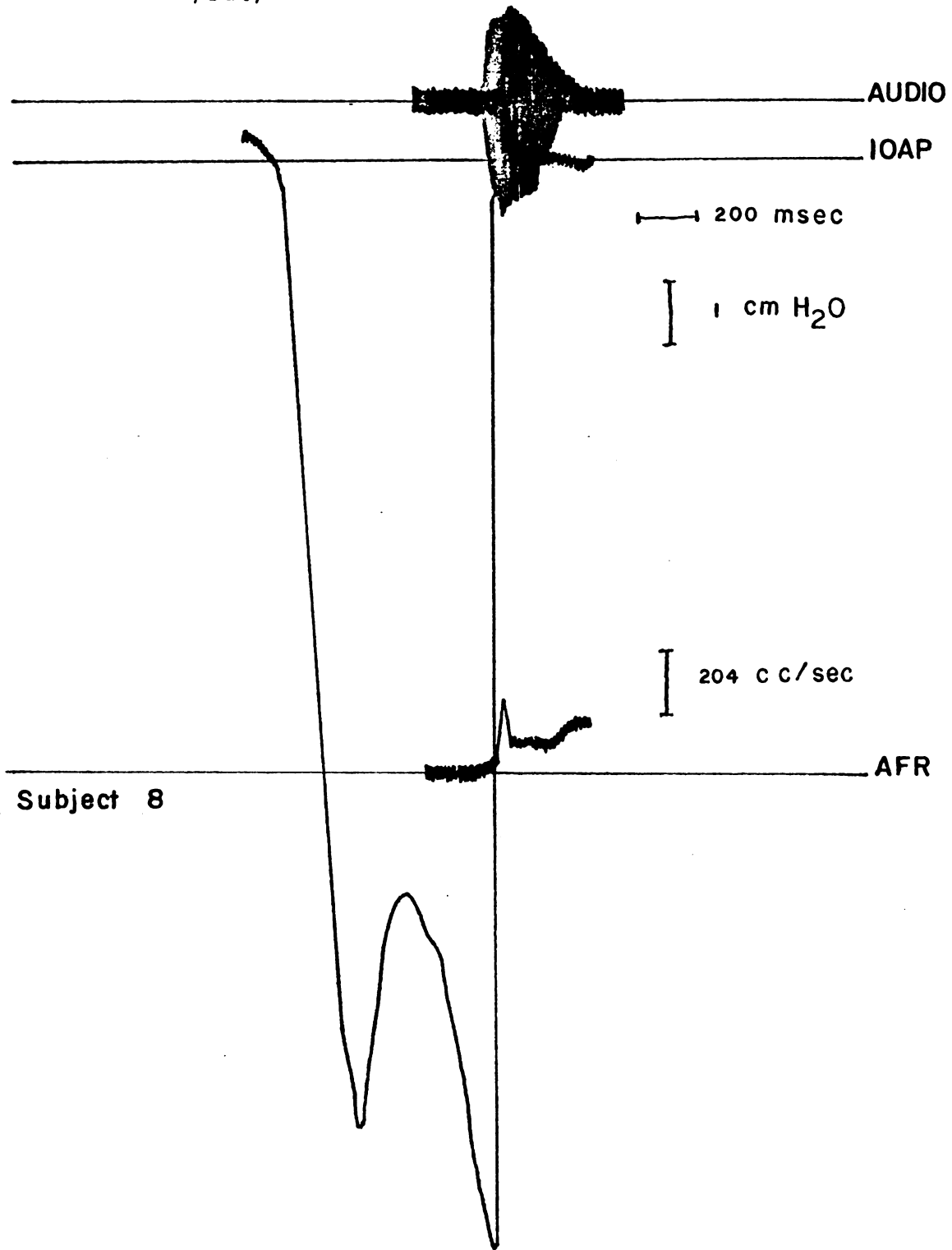


Figure 14. An example of high IOAP associated with small AFR, produced by a hearing-impaired child.

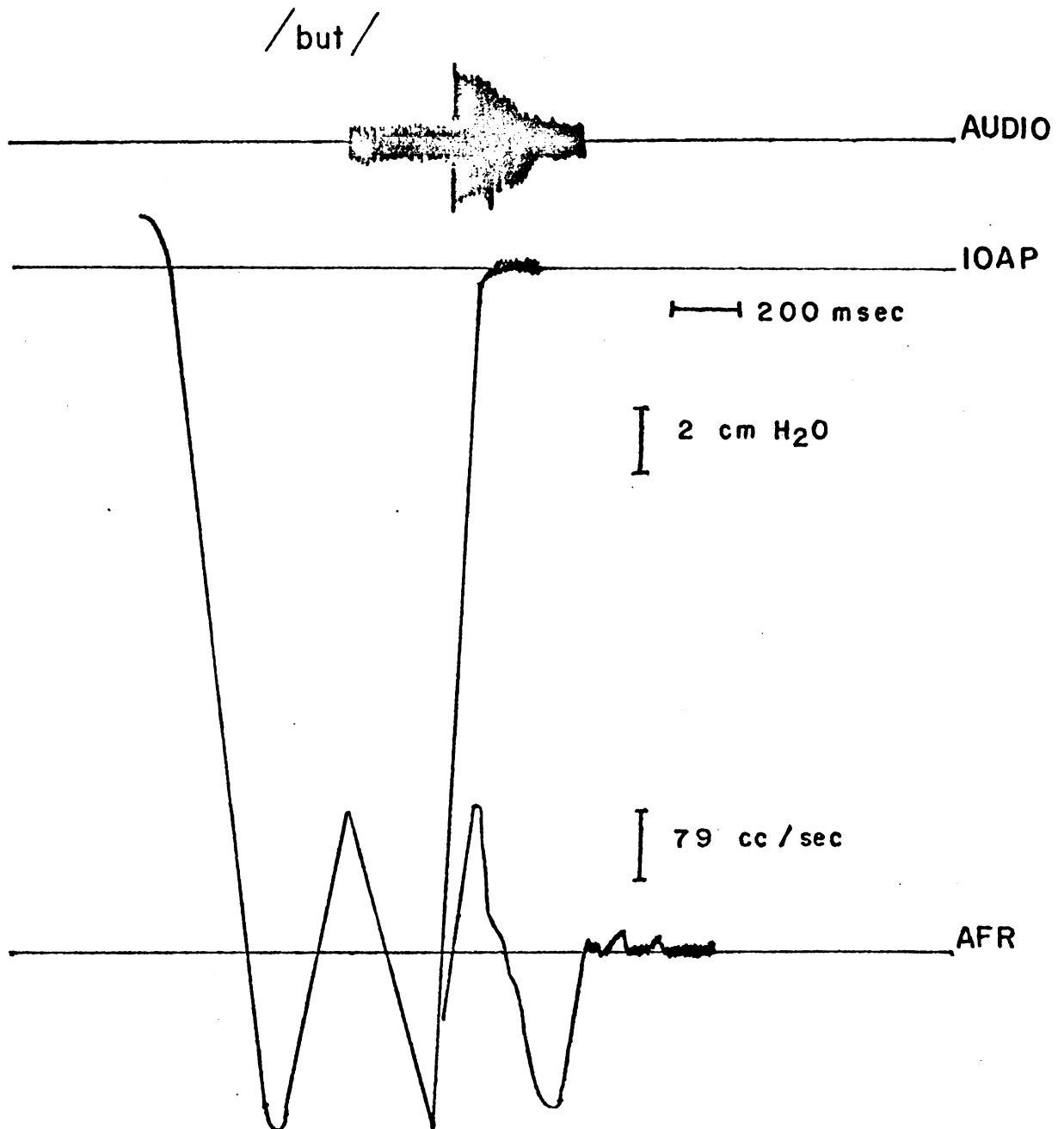


Figure 15. Simulation by the author of high IOAP associated with low AFR.

hearing adults (see Appendix E). However, as can be seen in Figure 16, Subject 4 produced a pressure peak for the voiceless-fricative in /fes/ in only 100 msec. Subject 5 produced the word /but/. From previous normative data one would expect a voiced-stop to be produced in about 130 msec (a voiceless-stop in about 180 msec) (an average of the values in Appendix D). However, this production of /but/ occurred with a pressure peak of only 70 msec. Associated with this rapid rate of production was a change in the manner of Subject 4's production of /f/ from a fricative to a stop production. This change in production was true of most of the examples of fricatives produced with very narrow pressure peaks.

Simulation of reduced intraoral air pressure durations for both a voiceless-fricative and a voiced-stop can be found in Figure 17. Neither attempt was as brief as those patterns produced by the hearing-impaired children, but they are smaller (120 msec) than would normally be expected. Production appeared to be accomplished with an extremely brief, but firm contact in the anterior oral cavity. Release was immediate after the contact.

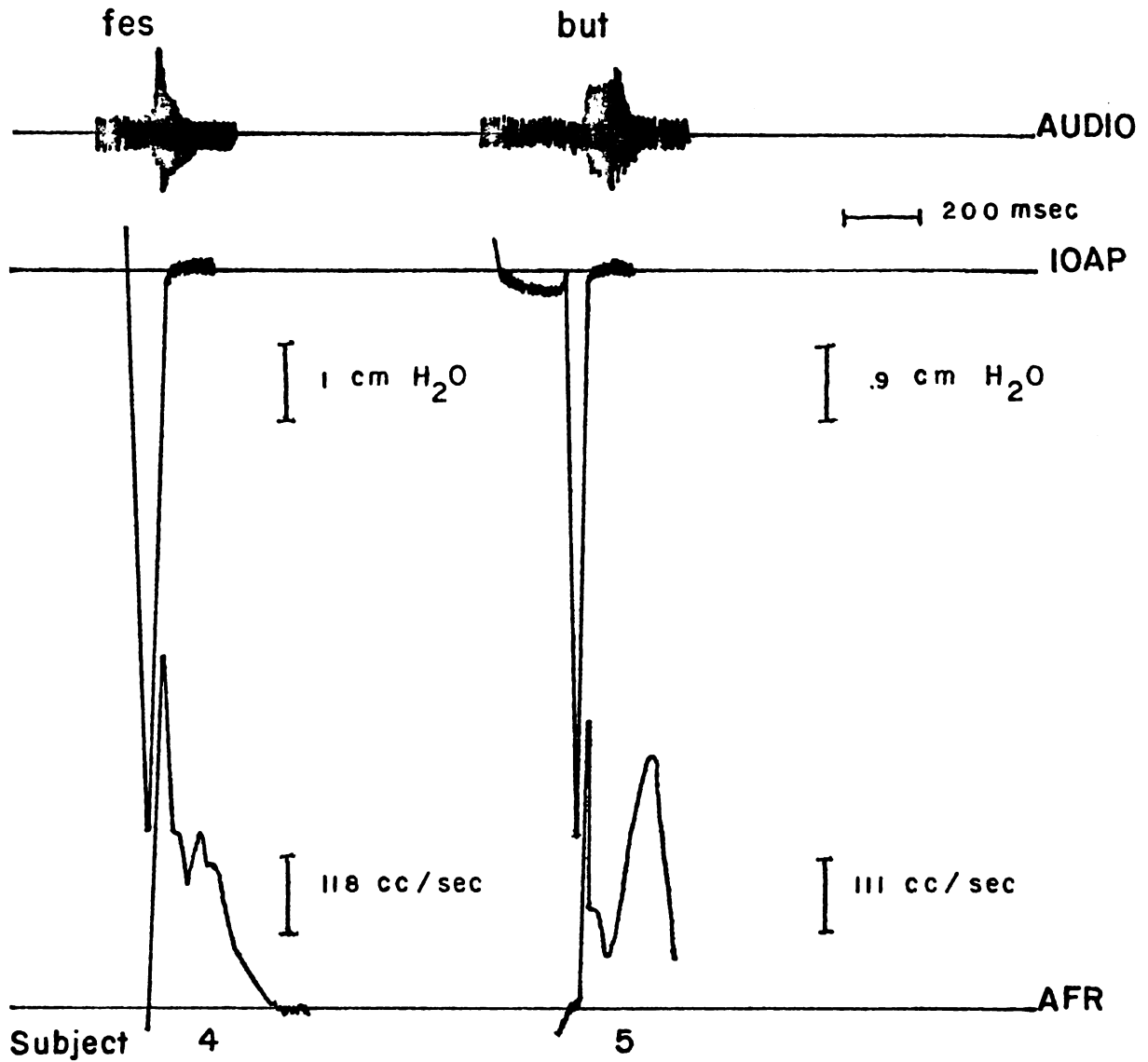


Figure 16. Two examples of reduced IOAP peaks produced by hearing-impaired subjects.

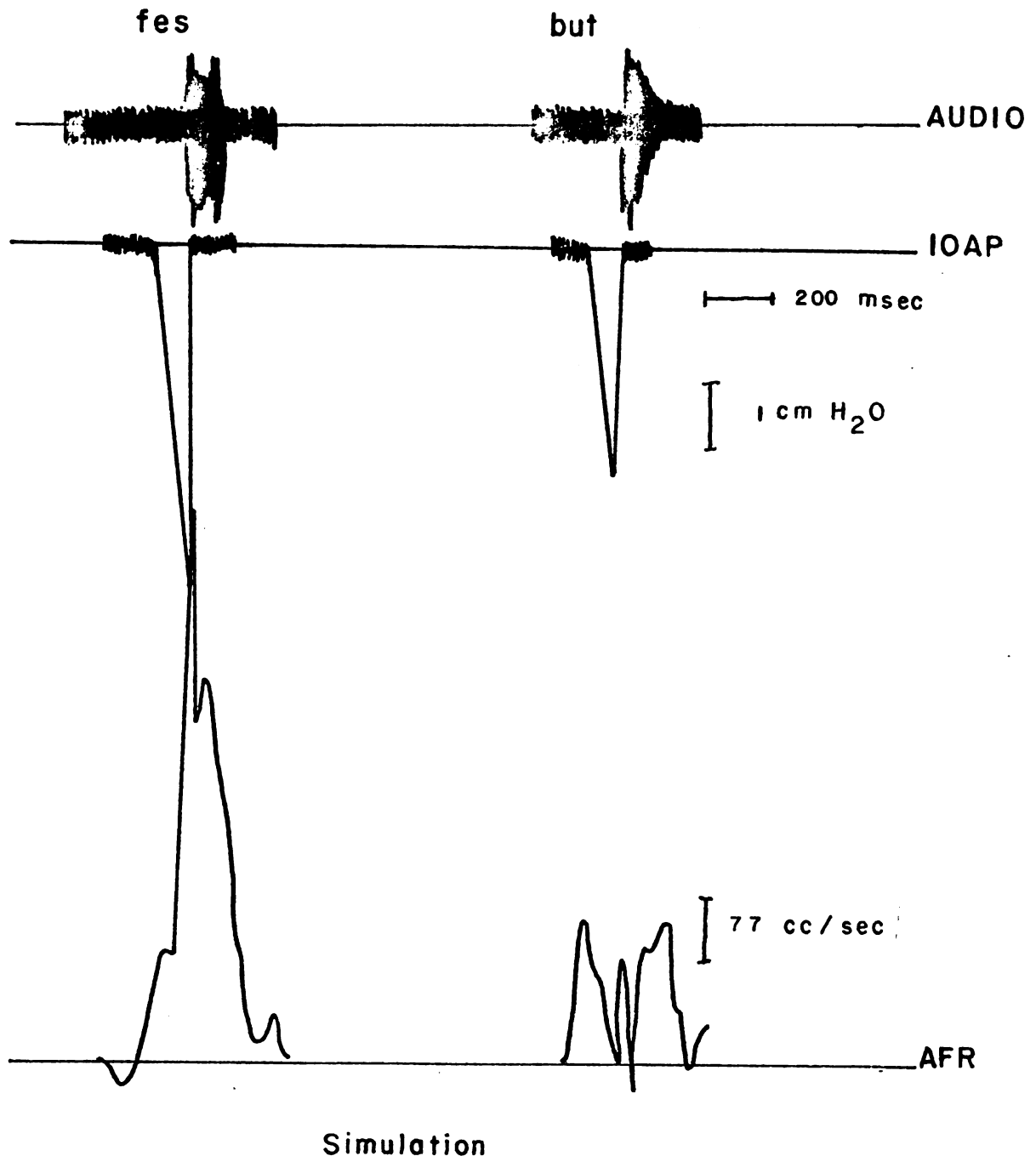


Figure 17. Simulation by the author of reduced IOAP peaks.

Educational Background

No correlation was observed between the type of educational program and specific aerodynamic patterns of speech production. Each child had a unique combination of speech characteristics. Further, there was no direct correlation of aerodynamic patterns and oral speech ability. Further research with a larger sample size is recommended.

CHAPTER IV

DISCUSSION

Results of the present study indicated that the experimental group, as compared to the control group, had: (1) greater average intraoral air pressure peaks; (2) lower average air flow rates for voiceless consonants; (3) higher average air flow rates for voiced consonants; and (4) greater average duration of intraoral air pressure. Further, the experimental group exhibited greater inter- and intra-subject variability than the control group.

Lack of stop consonant voiced-voiceless distinction was indicated by the mean values for intraoral air pressure peaks and durations in both the normal-hearing children and the hearing-impaired children. Both groups, however, exhibited the expected mean value differentiation of air flow rate between voiced and voiceless stop consonants.

Among the normal-hearing children, fricative consonant voiced-voiceless distinction was apparent in all three of the aerodynamic parameters under study. The hearing-impaired children exhibited mean values for peak pressure, pressure duration, and air flow rate for the

fricative consonants which indicated blurring of the voiced and voiceless cognates. Qualitative analysis of the data revealed four unusual patterns which appeared to be characteristic of the speech of the hearing-impaired children in this study.

Indications of greater average intraoral air pressure among the hearing-impaired children are consistent with the findings of a previous study of hearing-impaired adults (Hutchinson and Smith, 1974). In the Hutchinson and Smith (1974) investigation, the experimental group exhibited higher mean values than the normal-hearing adults, for all consonant classes studied. With the exception of the voiceless-fricative consonants, the hearing-impaired children in the present study also exhibited higher mean values for consonant production, as compared to the normal-hearing children.

The lack of a clear mean value pressure difference between voiced and voiceless cognates produced in this study by the hearing-impaired children substantiates earlier perceptual (Hudgins, 1934; Hudgins and Numbers, 1942) and aerodynamic investigations (Hutchinson and Smith, 1974). The lack of voiced-voiceless distinction was revealed not only in the overall mean values of the hearing-impaired children, but also in the mean intraoral air pressure values for the individual subjects (Appendix C). Interestingly,

the normal-hearing children also exhibited some voiced-voiceless blurring in the intraoral air pressure and duration mean values for stop consonant production.

Unlike the Hutchinson and Smith (1974) study which reported no significant differences in air flow rate data between hearing-impaired and normal-hearing adults, the present study did reveal some differences. The hearing-impaired children exhibited higher mean air flow rates for voiced consonants and lower mean air flow rates for voiceless consonants compared to the control group. For adults, an air flow difference between voiced and voiceless cognates would be expected, with the voiceless consonants exhibiting higher values (Hutchinson, 1973). The hearing-impaired adults studied by Hutchinson and Smith (1974) did show this commonly expected pattern of reduced air flow for voiced consonants. All of the children in the experimental group of the present study exhibited higher air flow rates for the voiceless stop consonants than for the voiced stop consonants, as would be expected. However, six of the ten hearing-impaired children showed a reversal of this pattern for the fricative consonants. Gilbert and Dixon (1974) also found indistinct voiced-voiceless contrasts with relation to oral air flow.

The intraoral air pressure duration data for the hearing-impaired children in this study were consistent with

the results found by Hutchinson and Smith (1974) for the hearing-impaired adults. In both studies the experimental groups exhibited greater mean pressure durations than the control group. This prolongation may be an effect of emphasizing the production of isolated phonemes in speech therapy techniques. Hearing-impaired children are known to produce monosyllabic words with twice the duration of normal-hearing children (John and Howarth, 1965), and consonant prolongation may contribute to this characteristic.

The children in the control group of the present study exhibited the expected duration differences between voiceless and voiced consonant cognates (Prosek and House, 1974). However, the difference between voiceless-stop consonants and voiced-stop consonants was small. Although the hearing-impaired children also exhibited a small but expected difference between the voiceless-stop consonant and the voiced-stop consonant, they exhibited a reverse pattern for the fricative consonants, i.e., the voiced-fricatives were slightly higher than the voiceless-fricatives. These values indicate indistinct voiced-voiceless contrasts for both stops and fricatives produced by the hearing-impaired children and for stop-consonants produced by the normal-hearing subjects (i.e., the values for the normal-hearing children were unusually close, even though the value differences exhibited between the voiced-voiceless cognates were in the expected direction). Similar

results were obtained for the hearing-impaired adults in the Hutchinson and Smith (1974) study. These subjects exhibited the correct duration differences between voiceless and voiced consonants, but the magnitude of difference was not large.

The data discussed previously must be interpreted with some caution in view of the extreme variability noted among the hearing-impaired population. In almost every parameter measured, the experimental group had a larger range of variability than did the control group. This is accountable, in part, to the fact that six of the hearing-impaired subjects had intraoral air pressure values, for at least one consonant class which were above +1 standard deviation for the control group, and three hearing-impaired subjects had values below -1 standard deviation for the control group. Similar conditions existed for intraoral air pressure duration. Five hearing-impaired children exhibited pressure durations for at least two consonants which exceeded the largest duration value found among the normal-hearing children, and two hearing-impaired subjects exhibited pressure durations for at least two consonants which were below the lowest value found among the normal-hearing subjects. In addition, a large degree of intra-subject variability was present among the experimental population.

Together, these two conditions of variability make any general statement concerning the total population of hearing-impaired children tenuous. General trends do exist and have been presented. However, the universal fact about the speech and language behavior of hearing-impaired children is the wide range of variability, as reflected in the wide range of oral language ability demonstrated by hearing-impaired children.

Further examination of the mean peak pressure, pressure duration, and air flow rate values (see Appendix C) reveals another interesting observation. The hearing-impaired subjects exhibited very similar mean values for peak pressure and pressure duration for /p/ and /b/ and for /f/ and /v/, however the mean air flow rate values clearly differentiate between the voiced and voiceless cognates of both the stop consonants and the fricative consonants. The normal-hearing children also exhibit this condition for the stop consonants; that is, they exhibited similar peak pressure duration values for /p/ and /b/, but very dissimilar air flow values for these two consonants. Thus the hearing-impaired children have exhibited a pattern similar to the normal-hearing children for the stop consonants, with neither group showing the definite pattern characteristic of the normal-hearing adult. The mean air flow rate values maintain the voiced-voiceless consonant distinction, whereas

the other parameters do not (for both groups) for /p/ and /b/ and for the experimental group for /f/ and /v/). This may be a factor of different respiratory driving forces. Further research is necessary in this area.

The normal-hearing children demonstrate a clear difference in peak pressure, pressure duration and air flow rate mean values between the voiced and voiceless fricatives studied. This pattern is consistent with the normative data for adults. Perhaps the expected voiced-voiceless pressure contrast is effected by developmental forces, in which the production of the /v/-/f/ contrast is achieved before the /p/-/b/ contrast. The sample size of the present study, the age range represented, and the number of phonemes examined leaves these questions unanswered.

Visual examination of the aerodynamic tracings revealed four unusual patterns of speech production characteristic of the experimental population. These patterns were not observed among the normal-hearing children. The first three patterns, indistinct voiced-voiceless contrasts, change in manner of production, and inefficient air stream valving were similar to the Hutchinson and Smith investigation of hearing-impaired adults (1974). The fourth pattern, reduced intraoral air pressure durations, appeared to be unique to the hearing-impaired children.

The inability of hearing-impaired children to produce consonant cognates with the appropriate air pressure and/or air flow differences was observed in the quantitative data and was further evident by visual examination of specific aerodynamic tracings (Figure 8). This pattern was expected in view of the previous findings of perceptual (Hudgins, 1934; Hudgins and Numbers, 1942) and aerodynamic (Gilbert and Dixon, 1974; Hutchinson and Smith, 1974) investigations.

Two types of changes in the manner of consonant production were observed in the speech of the hearing-impaired children. Fricative consonants were produced in a stop manner in 48 percent of the possible cases of fricative production. In 3 percent of the possible cases, a stop was produced as a fricative by the hearing-impaired children. These two types of changes are consistent with patterns produced by hearing-impaired adults (Hutchinson and Smith, 1974). The earlier perceptual studies by Hudgins (1934) and Hudgins and Numbers (1942) also described substitutions and distortions in the speech of the hearing-impaired, which might be the result, in part, of changes in the manner of consonant production.

Eight of the hearing-impaired children exhibited at least one of the two types of inefficient air stream

valving. Hutchinson and Smith (1974) also observed this pattern in the adult hearing-impaired. These subjects, children and adults, reversed the typically expected pattern of air flow, i.e., where low air flow rates would be expected, the hearing-impaired had very high flow rates, and in other cases where normal-hearing speakers would exhibit high flow rates, the hearing-impaired subjects exhibited minimal flow rates. Attempted simulation of these production patterns led the author to believe that they were concomitant with inappropriate articulatory and expiratory muscle action. Hutchison and Smith (1974) suggested that this inefficient management of the air stream may be related to the prosodic distortions (Hudgins, 1934; Hudgins and Numbers, 1942; Stark and Levitt, 1974) present in the speech of the hearing-impaired. Boone (1966) described frequent, inappropriate pauses observed in cinefluorographic and acoustic studies of the deaf. These pauses might also be related to certain disturbances of the vocal stream seen in relation to the speech patterns described above. Specifically, the action of the respiratory muscles appeared to deviate from normal muscle action in pattern 3--inefficient air stream valving--and in pattern 4--reduced intraoral air pressure duration.

Four of the hearing-impaired children exhibited a pattern of extremely narrow pressure peaks for consonant

production. This pattern was not found among the hearing-impaired adults studied by Hutchinson and Smith (1974). Simulation of this type of production indicated it may be the result of a very brief, but firm contact of the anterior oral cavity.

Implications for Further Research

Aerodynamic techniques hold promise for investigation of both direct and indirect procedures used in therapeutic intervention. Use of the aerodynamic equipment in conjunction with an optical oscilloscope as a bio-feedback device is an example of potential direct intervention. This procedure was used by two adult subjects in the Hutchinson and Smith (1974) investigation with significant success. The oscilloscope provided a usable modality, visual cues, which aided the hearing-impaired adults in modifying their vocal productions. Research is needed to determine the complete range of effects that can be expected with this technique. Data is needed on durability and carry-over effects of the procedure and on its effectiveness with a wider range of phonemes. Moreover, its effectiveness with children has not, as yet, been investigated.

The area of diagnostics offers a more indirect, but perhaps a more immediately feasible use of the

aerodynamic technique for remediation of speech. However, use of the aerodynamic parameters in diagnostic evaluation requires reliable normative data. Because the findings of the present study indicate that normative data on adults may not generalize entirely to children, further research specific to children is necessary. Data is needed on a wide range of phonemes produced by children. It is also important to collect these data from a group of children representing a wide age range to determine the possible effects of maturation upon the aerodynamic characteristics of the hearing-impaired children.

Once reliable normative data on children is available, aerodynamic evaluation can aid identification of deviant and/or compensatory patterns of production specific to the hearing-impaired child. Identification of these patterns of production would indicate appropriate goals to work toward in an intervention program.

Summary

Quantitative analyses of the data revealed that the experimental group, as compared to the control group, had: (1) greater average intraoral air pressure peaks; (2) lower average air flow rates for voiceless consonants; (3) higher average air flow rates for voiced consonants; and (4) greater average duration of intraoral air pressure. Further, the

experimental group exhibited greater inter- and intra-subject variability than the control group.

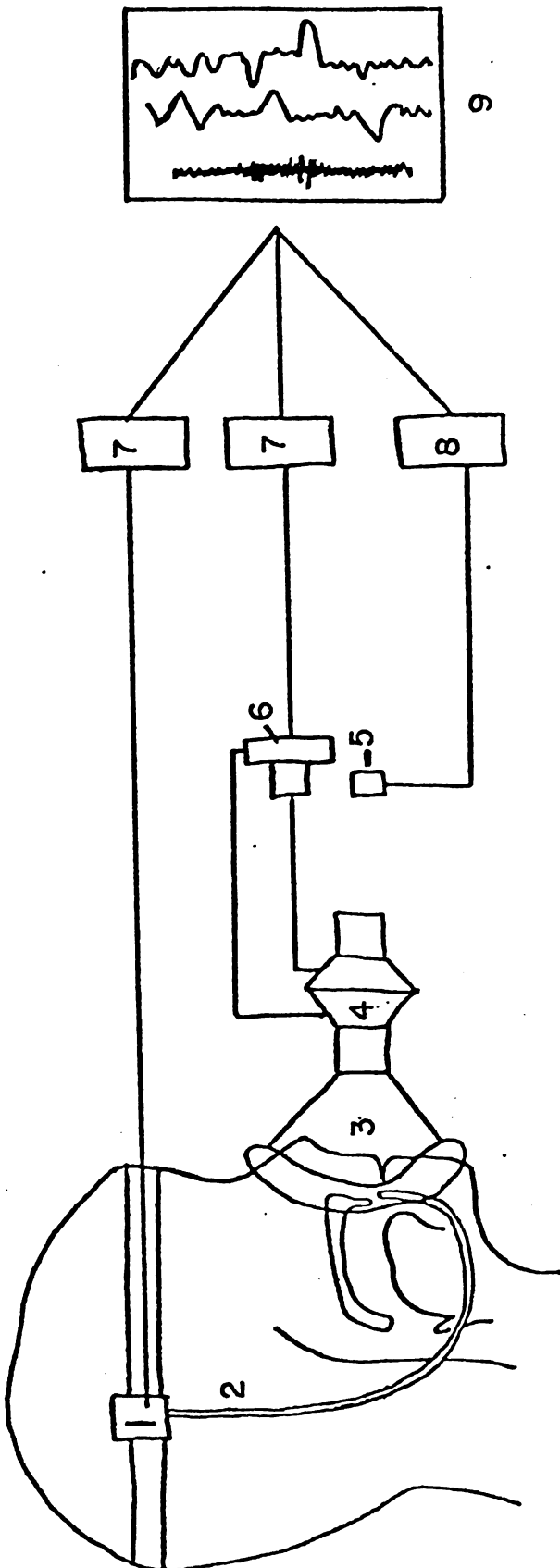
Both the experimental group and the control group failed to exhibit a clear stop consonant voiced-voiceless distinction for intraoral air pressure peaks and duration values, but did exhibit this voiced-voiceless distinction for air flow rate values. Among the normal-hearing children, the fricative consonant voiced-voiceless distinction was apparent in all aerodynamic parameters under study. The hearing-impaired children exhibited mean values for peak pressure, pressure duration, and air flow rate for the fricative consonants which indicated indistinct voiced-voiceless contrasts.

Qualitative analyses of the data revealed four unusual patterns which appeared to be characteristic of the speech of the hearing-impaired children in this study. These patterns included: (1) indistinct voiced-voiceless contrasts; (2) change in manner of production; (3) inefficient air stream valving; and (4) reduced intraoral air pressure durations.

Further research is needed to obtain reliable normative data specific to children. Investigation of the potential value of the aerodynamic technique for diagnostic evaluation and as a bio-feedback device also needs additional study.

APPENDICES

Appendix A



6. Pressure transducer
7. Bridge amplifier
8. Galvanometer amplifier
9. Optical oscillograph

1. Pressure transducer
2. Catheter
3. Face mask
4. Pneumatograph
5. Microphone

Schematic representation of the aerodynamic equipment.

APPENDIX B

RELIABILITY DATA

(In mm on Paper)

<u>IOAP Peaks</u>		<u>IOAP Duration</u>		<u>AFR</u>	
<u>Test</u>	<u>Retest</u>	<u>Test</u>	<u>Retest</u>	<u>Test</u>	<u>Retest</u>
45	45	165	165	10	10
156	156	11.5	12	15	14.5
49	49	9	9	37	37
95	95	10.5	10.5	7.5	7.5
125	125	13	13	20	20
65	65	12	11.5	29	30
103	104	10.5	10.5	22.5	22.5
132	132	10	10	30	30
68	68	11	11	54	54
57	57	11.5	11.5	23.5	23.5
54	54	8.5	7.5	101	101
43	43	10.5	10.5	31.5	31.5
77	77	13.5	12.5	20.5	21
110.5	110	18.5	18.5	33	33
107	107	9	9	69	69
86	86	13.5	14	22	22
57	57	12.5	12.5	16.5	16.5
79	79	12	12	8	8
69	69	10	10.5	62	62
174	175	11	11	31	31
78	78	14	14.5	43	43
59	59	5	5	50	50
114	114	5.5	5.5	71	71
165	165	12.5	12.5	53	53
99	99	12	12	23	23
Correlation = .99		Correlation = .99		Correlation = .99	

APPENDIX C

DATA BY CONSONANT CLASS FOR EXPERIMENTAL AND CONTROL GROUPS

	Consonants	IOAP Peaks	IOAP Durations								AFR	
			Onset		Offset		Total					
			X	sd	X	sd	X	sd	X	sd	X	sd
Experimental Group	/p/	9.4	4.6	165.1	81.4	78.4	40.8	243.4	95.7	521.5	216.9	
	/b/	9.6	6.1	176.1	97.7	65.2	29.7	246.1	108.0	318.0	174.2	
	/f/	7.7	3.9	165.5	87.3	80.7	46.8	246.2	106.5	262.2	137.8	
	/v/	7.5	3.6	168.8	91.6	81.8	48.1	253.2	114.0	258.4	135.5	
		(cm H ₂ O)		(msec)		(msec)		(msec)				
Control Group	/p/	8.2	2.5	132.4	63.5	73.9	23.0	209.6	66.0	715.4	340.4	
	/b/	7.9	3.5	143.9	60.7	58.0	32.0	202.1	74.3	276.0	120.6	
	/f/	7.8	2.9	146.8	33.3	76.4	14.8	225.1	39.3	289.7	120.4	
	/v/	4.9	2.5	115.8	44.1	78.1	22.1	192.4	56.9	181.1	75.2	
		(cm H ₂ O)		(msec)		(msec)		(msec)				

APPENDIX D

COMPARATIVE MEAN IOAP DURATIONS (IN MSEC) FOR FOUR CONSONANT CLASSES REPORTED IN THIS STUDY (CHILDREN) AND IN SEVERAL PREVIOUS STUDIES (ADULTS)

Investigator	Voiceless Stops	Voiced Stops	Voiceless Fricatives	Voiced Fricatives
Subtelny et al. (1966)	190.0	150.4	215.2	180.9
Prosek ^a (1973)	151.7	96.7	145.6	116.9
Hutchison (1973)	194.3	147.7	194.1	166.8
Hutchinson and Smith (1974) (Hearing-impaired adult subjects)	265.5	246.2	281.7	271.8
Kornhauser (1975) (Hearing-impaired children)	243.4	240.4	246.2	253.2

^aAverage data for consonant in stressed contexts within a sentence.

APPENDIX E

IOAP TOTAL DURATION MEAN VALUES FOR EACH SUBJECT (in msec)

Experimental Subjects	/p/	/b/	/f/	/v/
E ₁	346.7	271.1	206.7	268.3
E ₂	210.0	255.6	275.0	225.0
E ₃	230.0	247.8	348.4	271.7
E ₄	210.0	157.8	108.4	133.4
E ₅	244.5	281.1	275.0	373.3
E ₆	177.8	94.4	175.0	101.7
E ₇	246.7	280.0	336.7	293.3
E ₈	222.2	297.8	230.0	215.0
E ₉	332.2	277.8	291.7	390.0
E ₁₀	216.7	252.2	215.0	243.4
Control Subjects	/p/	/b/	/f/	/v/
S ₁	221.1	218.9	219.2	213.4
S ₂	210.0	225.6	226.7	208.3
S ₃	204.4	215.6	220.0	218.3
S ₄	200.0	177.8	235.0	181.7
S ₅	291.1	237.8	240.0	203.4
S ₆	187.8	126.7	208.4	136.7
S ₇	232.2	273.9	228.4	256.7
S ₈	166.7	200.0	216.7	168.4
S ₉	186.7	158.7	193.4	135.0
S ₁₀	193.4	198.9	248.4	208.4

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Accepted by the faculty of the Department of
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of the requirements for the degree of Master of Arts.

Thesis Committee

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