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RESIDUAL HEARING AND SPEECH PRODUCTION IN DEAF CHILDREN

by

CLARISSA R. SMITH

A dissertation submitted to the Graduate Faculty in Speech in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

1972

This manuscript has been read and accepted for the Graduate Faculty in Speech in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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CHAPTER ONE

INTRODUCTION

The catastrophic effect of congenital deafness on the acquisition of speech and language by children has been a matter of great educational and social concern. While many children who are classified as deaf achieve usable speech, the speech of most profoundly deaf children is not a viable instrument for verbal communication. It is the cause of daily communication breakdown, a frustrating and unrewarding experience for the children and their listeners alike. The problem has been the object of many forms of attack, with results that are mainly discouraging; the concentrated efforts of generations of people have not yet provided the deaf child with a satisfactory replacement for the easy acquisition of speech that the hearing child enjoys.

That no greater advances have been made may be due to the fact that the problem has not been adequately delineated. Knowledge gained in recent years concerning the acoustics and the perception of speech signals has not been fully applied to a description of the relationships between hearing and speech production in deaf children. Little is known about the manner in which the deaf child is able to use the hearing that he has. Available descriptions of deaf speech itself are mainly qualitative and are lacking in many details. And the relative importance of the many other variables that may enter into the deaf child's success or failure in achieving acceptable speech is not well understood.

A great deal of research in recent years (Levitt and Nye, 1971) has gone into the design of equipment intended either to feed back information to the deaf child on his own speech production, or to provide him with input from the speech of others through other sense modalities than hearing. Many of these devices have concentrated on particular aspects of the speech signal, such as voicing, frication, nasality, plosion. Faced with a production displaying many disturbances of largely unknown relationship to each other, researchers have isolated one aspect or another and attempted to improve on it, without knowing much about the effect on total speech production that the improvement would have. Another approach has been to present the entire speech signal visually or tactually, either as a waveform or a spectral envelope, though the complex coding of information in the acoustic signal is probably not translatable by any other sensory system. In any event, no device has given substantial improvement over a wide population or a period of time. It appears possible that the wrong questions are being asked; the right answers, always supposing there are any, are unlikely to be found with this shotgun approach.

It seems necessary to attempt a more detailed over-all description of the errors in the speech of deaf children than has generally been done. In particular, we need to examine more closely the relationships between the residual hearing of the children and their speech production, in order to gain knowledge about the way in which deaf children make use of the information they can extract from the auditory signal. From this knowledge might come new approaches to the development of ways to augment that information.

No one questions the fact that deaf children speak poorly because they hear poorly. A surprising number of studies of their speech have been satisfied to stop at that explanation. The subjects in many studies have been described as 'deaf'. Other studies have classified children in terms of some average of the hearing for pure tone, and any comparison of hearing with speech production has been made in terms of these averages. It was the opinion of Hudgins (1940) that the pure tone audiogram does not predict the capacity of deaf children to profit from speech training. In contrast, both Hirsh and Boothroyd (1) believe that the pure tone audiogram is currently the best predictor of speech development for the young deaf child. There is not much information in support of either point of view, but the significance of a deaf child's ability to deal with auditory inputs other than the meaningless pure tone signal surely deserves to be further explored.

A number of investigators have indicated the necessity for a more detailed study of auditory capacity in relation to speech. Boothroyd (1970) points out that the existence of auditory sensitivity in certain frequency ranges does not guarantee the existence of adequate frequency and time resolution or sufficient dynamic range for the development of speech perception. Elliott(1967) describes the need to explore all auditory capabilities for hearing at high audiometric levels. Hood (1966) found no relationship between residual hearing and speech skills in the population of his study, which consisted largely of children who wore no hearing aids, had not received auditory training, and communicated chiefly with sign, but he suggests that a closer relationship might be found in children who wore aids, received training, and communicated by speech.

In the present study, an audiological evaluation, a recorded

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(1) In Levitt and Nye, <u>op. cit.</u>, p. 85.

sample of speech, and information on a variety of background variables were obtained for a group of deaf children. The speech samples were presented to persons inexperienced with the speech of deaf children, to obtain a measure of the intelligibility of the speech, and were, in addition, transcribed by expert phoneticians. The inter-relationships of this analysis with the audiological findings and with certain of the background variables were examined in an attempt to answer the following questions:

1) What are the specific relationships between a deaf child's hearing, for pure tones and for speech, and the articulatory and prosodic features of his own speech production?

2) What variables in addition to hearing may account for divergence in individual children from the general relationships that may be found?

3) What is the relative importance to perceived speech intelligibility of various articulatory and prosodic features of the children's speech?

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Auditory sensitivity of deaf children

The terms 'deaf' and 'deafness' have been used with a variety of meanings, not all of them appropriate, to describe a number of different conditions and a wide range of hearing impairments. There may indeed be more than one use of the word. However, the standard definition of 'deafness' is that of the American Academy of Ophthalmology and Otolaryngology (Davis, 1965): A person who is deaf has a hearing threshold level for speech greater than 92 decibels; the hearing threshold level for speech is the simple average of the hearing threshold levels, in decibels, at the frequencies 500/1000/2000 Hz, with reference to the ISO 1964 standard (International Organization for Standardization, 1964).

Studies of children in schools for the deaf typically do not give a detailed description of auditory sensitivity. Instead, they report the mean or the range of sensitivity, often in terms of the average just mentioned, or, in earlier work, in terms of some weighted percentage of hearing loss that is difficult to translate into present day terms. Individual pure tone response levels are sometimes reported, without analysis, as incidental data.

More expansive analyses of auditory sensitivity of children in schools for the deaf are found in the studies of Elliott (1967), Montgomery (1967) and Boothroyd (1969).

Elliott examined audiometric responses in 177 children at Central Institute for the Deaf, 92 of whom had no handicap other than deafness. These were in the age groups 3-9 to 8-11 (n = 41); 9-1 to 11-6 (n = 20); and 12-0 to 16-2 (n = 31). She presented grouped audiometric data for frequencies 125 Hz through 8000 Hz, including the half octaves 3000 Hz and 6000 Hz, in terms of the median and interquartile range at each frequency. For the 9 to 11 year-old group, which was nearly identical to the younger and older groups, the medians were 125 Hz, 65 dB; 250 Hz, 75 dB; 500 Hz, 85 dB; 1000 Hz, 100 dB; 2000 Hz, 110 dB; 3000, 4000 and 6000 Hz, greater than 110 dB. The interquartile range extended approximately 10 dB on either side of the median. For the three groups of deaf children, 1 child did not respond in either ear at 1000 Hz, 13 did not respond at 2000 Hz, and 33 at 4000 Hz. Elliott computed means separately for data representing actual responses within the limits of the audiometer (termed 'regular') and data representing the maximum of the audiometer + 5 dB (termed 'maximum'). The mean average at 500/1000/2000 Hz was 94.2 dB for 'regular' data and 99.3 dB for 'maximum' data, both re: ISO 1964 standard.

Montgomery also studied pure tone responses by level and frequency, in 83 deaf children at Donaldson School for the Deaf, Edinburgh, and compared this with percentage articulation loss of their speech, calculated from a phonemically comprehensive speech sample. He found that the 'speech frequencies' for the deaf included much lower frequencies than the usual pure tone average of 500/1000/2000 Hz. Forty percent of the children in his study did not respond in the better ear at 2000 Hz. Analysis by means of X^2 showed that the frequencies most usefully associated with percent articulation loss were 125, 500, 1000 and 2000 Hz in the better ear and 4000 Hz in the poorer ear. Montgomery suggested that lower frequencies than 500/1000/2000 Hz would be useful indicators of potential speech ability in a population characterized by progressively more severe impairment in the higher frequencies.

Boothroyd reported on hearing levels of 187 students at Clarke School for the Deaf. The children were grouped for comparison in various ways, including age, sex, etiology and onset of deafness. These groups displayed no great differences except that the perinatally deaf children as a group had hearing at somewhat higher frequencies than the school at large, while the postnatally deaf had hearing somewhat poorer than the rest. Averaged hearing levels ranged from 65 to over 110 dB (ISO) with 80% of the children having hearing poorer than 90 dB .

In an early study, Kerridge (1938) examined the hearing of 456 children in several London schools for the deaf. She reported that 3% had no hearing in either ear, 6% had no hearing in one ear, 10 % had no hearing for speech frequencies. With average hearing poorer than 90 dB, the speech of 80 % of the children was described as poor, regardless of years of special education or intelligence, which Kerridge assumed to be important to speech development. The audiometric standard was not mentioned.

Hughson, Ciocco and Palmer (1939) reported on the hearing of 460 pupils of the Pennsylvania School for the Deaf. Again, the exact audiometric reference is not known, but they gave medians for the left ear, which was slightly better than the right at all frequencies, as follows: 125 Hz, 68.2 dB; 250 Hz, 81.4 dB; 500 Hz, 93.6 dB; no response at higher frequencies.

It is worth noting that while Elliott (1967) does give some data for 3000 and 6000 Hz, the hearing sensitivity of deaf children at half-octave frequencies is ignored by all other investigators. No studies have been found that measured hearing at 750 or 1500 Hz; this in spite of the fact that a typical audiogram of a deaf child might show a response at 500 Hz and none at 1000 Hz, or a response at 1000 Hz and none at 2000 Hz.

Supra-threshold measures and discrimination of complex stimuli

A multitude of studies have examined the auditory response of moderately hearing-impaired subjects to speech and other stimuli under various conditions. Comparatively little of this research has been extended to include the severely and profoundly hearing-impaired or children at schools for the deaf.

LaBenz (1956), while his 100 adult subjects included no deaf persons, has contributed data that may have some application to severe impairments. He presented his subjects with phonetically balanced words under conditions of low-pass filtering at 2000, 1500, 1000 and 500 Hz; and band-pass 200-500, 250-750, 500-1000, 750-1500, 1500-2000 and 2000-3000. The words were presented at 30 dB re: the subject's speech threshold. In the low-pass 500 Hz condition, persons with sensory-neural, conductive and mixed hearing losses attained the same average score as normal listeners. As progressively higher frequencies were added to the signal, the normal listeners increased in percent correct response much more rapidly than those with sensory-neural impairment. In the band-pass conditions 250-750 Hz and 500-1000 Hz, these listeners also scored lower than any other subjects, which seemed to imply a distortion of the usual frequency-intensity relationships of phonemes.

Boothroyd (1967) used filtered speech to examine frequency dependence in 25 children, ages 8-15, with a range of hearing averages (500/1000/2000 Hz) from 45-95 dB. He employed phonetically balanced word lists at varying high and low-pass filter levels, and found, for each subject, the cross-over frequency, i.e., that frequency where there was an equal percent correct response in high-pass and low-pass conditions. This frequency was found to move systematically downward as a function of the slope of the audiogram, measured as the difference in response to 250 and 2000 Hz. Boothroyd concluded that children with more steeply sloping audiograms depended on low-frequency components in the perception of speech more than did children with flat audiograms. Severity of the hearing loss had no effect on the cross-over frequency.

Later, Boothroyd (1970) reported on the use of a set of simplified speech stimuli in the testing and training of deaf children. Since the majority cannot give a speech reception threshold, speech detection is measured, using as stimuli the phonemes /u/, /ɑ/, /ʃ/ and /s/, which produce detection responses roughly equivalent to the pure tone levels at 500, 1000, 2000 and 4000 Hz, respectively. In addition, he described a binary choice procedure for testing speech sound recognition, wherein the stimuli differed in number of syllables (clock, Santa Claus); in vowel duration (moon, stick); in first formant frequency (u, ɑ); or in second formant frequency (u, i). Boothroyd points out that to some extent, pure tone levels can be used to predict the potential for speech sound recognition. With response to sound up to 500 Hz, a child should be able to distinguish between sounds on the basis of temporal patterns and voicing. First formant differences should be detectable with measureable hearing up to 1000 Hz, and second formant differences with hearing up to 2000 Hz. He adds, however, that even in a frequency range where there is sound sensitivity, there may not be adequate frequency and time resolution or a sufficient dynamic range for the development of perceptual skills.

Pickett et al (1970) used a closed set six-choice test of phoneme feature recognition to examine speech reception in 99 deaf college students at Gallaudet College. They found that distinctions termed 'low continuant' (a certain classification of differences in manner of articulation), voicing, and place of articulation were recognized, in that order, for initial consonants, and voicing, low continuant and place for final consonants; that the first formant of vowels and the duration of vowels was recognized by all subjects except those with the most profound hearing losses; and that recognition of the second formant of vowels was poor for most subjects. There was no significant correlation between scores and duration of hearing aid use. The correlation between scores and hearing level averaged at 1000 and 2000 Hz was -.66, which was significant at better than .01. The additional findings were: 1) The phonetic features used by deaf listeners to perceive and discriminate speech sounds are the same as those used by normal listeners. 2) Sensory-neural listeners have better residual reception for low frequency speech patterns, such as voicing, nasality and the first formant of vowels, than for the middle and the high frequency patterns, such as the bursts of noise after unvoiced stops, the fricative consonants, and the second and higher vowel formants. 3) The superiority of low-frequency pattern recption holds over a rather wide range of degrees and types of sensory-neural impairment. 4) Initial consonants are perceived better than final consonants by hearing-impaired listeners. 5) Vowel discrimination is better than consonant discrimination for severely impaired listeners. 6) These listeners can discriminate the second formant information in speech more effectively when the formant is low; that is, in back vowels rather than front vowels.

This finding is similar to that of Lawrence and Byers (1969) who tested discrimination for pairs of voiceless fricatives in association with various vowels. Their subjects were adult males with normal hearing through 1000 Hz and steep high frequency losses. The poorest hearing at 2000 Hz was 70 dB (ISO) and at 4000 Hz, 100 dB. The confusions classified themselves for all listeners into two groups: /s - ʃ/ and /f - θ/, but all fricatives were more often correct in association with back vowels as opposed to front vowels. It appeared that listeners were receiving more formant information for back vowels, as well as information contained in low frequency energy, relative intensity and duration of the fricative noise.

The stimuli in the preceding experiments all consisted of real speech. Most of what is known in psychoacoustics has been learned from normal listeners, using less meaningful but more readily specifiable stimuli. A few investigators have begun to address themselves in this way to the auditory behavior of deaf persons.

Gengel (1969) studied the difference limen for frequency in deaf children. His subjects were 23 deaf children, aged 10-17 years, and 21 hearing-impaired children, aged 10-15 years. The mean hearing levels of the deaf group at 250 and 500 Hz, the frequencies of interest in this study, were 68.5 dB and 81.1 dB, respectively. Gengel presented tones at these frequencies as reference, with comparison tones ranging in six steps from 253 to 346 Hz (low frequency) and from 504 to 628 Hz (higher frequency). Two conditions were examined: one wherein both tones in a pair were at the same intensity, the other wherein the second tone was from 2 to 10 dB higher than the first. The children were tested in three sessions. If was found that for the deaf children, the difference limen for frequency at the third session was approximately half that of the first session. However, for the variable amplitude condition, the difference limen was about twice that of the fixed amplitude condition; the inference was that in the fixed-amplitude condition, the children were using loudness as well as pitch in making their judgements. At the third test session, DLF for the deaf children was 22 Hz at 250 and 48 Hz at 500, in the variable amplitude condition. There was a moderately significant correlation between hearing level and DLF at 500 Hz, but not at 250 Hz.

Pickett, Daly and Brand (1965), Pickett and Martony (1970) and Martin, Pickett and Colton (1970) have studied the discrimination of listeners with severe sensory-neural impairment for various types of low frequency vowel- or vowel-like information. Pickett, Daly and Brand reported on the discrimination of spectral cut-off frequency for bursts of narrow band noise at several frequencies. ΔF was varied from 25 to 100 Hz, and subjects made same-different judgements. At 250 Hz, the performance of the hearing impaired listeners was not much different from that of normal hearing listeners: ΔF of 25 Hz resulted in 60% correct response in the hearing impaired subjects and 67% in the normals. ΔF of 100 Hz gave 96% correct in hearing impaired subjects and 100% correct in normals. This difference amounted to $\Delta F/F$ at 250 Hz of .15 and .12 for the two groups. At 500 Hz, however, $\Delta F/F$ was .08 for the hearing impaired, and .03 for the normal listeners.

Pickett and Martony conducted a similar experiment using synthesized vowels, similar in spectral envelope to the low-passed noise of the previous experiment, with a fundamental frequency of 125 Hz. They found that when the reference formant frequency was 205 Hz or 275 Hz, the performance of severely hearing-impaired listeners in discriminating a change in the formant became as good as normal performance after some practice. When the formant frequency was 400 or 825 Hz, the subjects with better hearing at 500 and 1000 Hz achieved normal performance, while the subjects with poorer hearing at those frequencies required 2 to 4 times as great a frequency difference. It was found, however, that with the formant frequency held constant, group threshold for a change in sound energy was .5 dB. A series of tests then examined discrimination of pairs of mid and back vowels /ɑ, ʌ, ɔ, o, U, u/ having first and second formants in a range similar to that of the synthetic vowels. The average response was 87% correct for the two choice test. The rank order of subjects in percent correct response was the same as their rank order for synthetic vowels with F equal to 275, 400 and 800 Hz. The synthetic vowel discrimination task therefore seemed to be a good predictor of natural vowel discrimination for low formant vowels. It was pointed out that all the speech sound differences that depend on frequency discrimination of normal formant positions are larger than 5% and most are between 25 and 50 %.

Discrimination of formant transitions for synthetic vowels by severely hearing impaired listeners was investigated by Martin, Pickett and Colton. They found that their subjects quickly learned to discriminate a second formant transition of 25-50 Hz, but that they could not approach this performance with any amount of practice when a strong low frequency first formant was added to the signal. This was attributed to the masking effect of the low frequency formant on the higher one.

Phoneme production

The production of speech sounds by deaf children has been studied more extensively than any other aspect of their communicative behavior, with findings that are all generally comparable: namely, that the deaf child exhibits ineffective coordination of respiratory,phonatory and articulatory gestures, together with inaccurate and overly slow movement of the articulatory mechanism.

The classic study of deaf children's speech is that of Hudgins and Numbers (1942), with 192 deaf and hearing-impaired children from the Clarke and Mt. Airy schools. The method was to have the children read simple sentences, which were recorded. The experimenters transcribed the utterances phonetically, and experienced teachers of the deaf (between 5 and 10 listeners per child) listened to the recordings for intelligibility. A categorization of errors of rhythm was included, but defects in voice quality and other aspects of speech production were not considered. The major types of articulatory error, separately classified according to vowels and consonants, were:

Consonant errors:

1) Non-function of the releasing (initial)consonant. Typically, the proper degree of closure is not made, thus preventing air pressure from producing the consonantal effect. The perceived effect is that of dropping the consonant.

2) Voiced-voiceless confusions.

3) Errors in clustered consonants. These errors took one of two forms: a) one or more of the members making up a cluster was dropped; or, b) the members of the cluster were spoken too slowly, with the result that adventitious syllables were added to the word.

4) Errors involving abutting consonants. For two

adjacent syllables with abutting consonants, an adventitious syllable is added between the arresting consonant of the first syllable and the releasing consonant of the second.

5) Errors of nasality of consonants.

6) Substitution of one consonant for another, in addition to substitutions already considered under (2) and (5).

7) Non-function of the arresting (final) consonant. The consonantal movement was either too slow, incomplete, or dropped entirely. The effect was that the syllable was not arrested and the vowel trailed off slowly.

Vowel errors:

1) Substitution of one vowel for another.

2) Errors involving diphthongs: either the diphthong was split into two separate vowels, or one of the components, usually the final member, was dropped.

3) Neutralization of simple vowels. The vowel loses its distinctive quality and becomes more like a neutral vowel (schwa). The effect was that syllables were shortened and not given their expected degree of stress.

4) Diphthongization of pure vowels.

5) Nasalization of vowels.

The first three errors in each category were the most frequent. In both consonants and vowels, the most frequent errors involved sound combinations requiring a fusion of two or more articulatory gestures. A slowing of the component movements separated ordinarily adjacent or co-articulated phonemes, making their timing unnatural. Voiced-voiceless errors, nasality, and errors of releasing consonants, showed an increase in frequency with increasing hearing loss; however, a proportionately greater number of errors of substitution, compounds and final consonants was made by the less severely impaired children. The authors' explanation was that these children had acquired speech partially through the avenue of hearing and that the acoustic characteristics of the respective phonemes were therefore influential.

A recent articulatory study was done by Nober (1967) who administered the Templin-Darley Test of Articulation to 46 deaf children, ranging in age from 3 to 15 years. The children were classified by averaged hearing level at 500/1000/2000 Hz. Only the older children in the best-hearing of the four groups achieved a 3-year-old level of articulation skill. The 12-15 year-olds with a 61-70 dB pure tone average (audiometric reference not given) achieved the 4-year-old level. The first ten in the rank order of consonants correctly articulated were /b/ (79% correct), /p/,/f/, /w/, /l/, /θ/, /m/, /r/, /n/, /v/. The poorest were /s/, /z/, /ŋ/. The best vowels were /ʌ/ and /ɔ/, both 80% correct and the poorest was /ɝ/.

A quite comprehensive investigation of the linguistic and intellectual skills, the verbal and articulatory attainments and the intelligibility of speech of deaf children was recently completed by Markides (1970). He studied 58 deaf, 27 partially hearing and 25 normal-hearing children, aged 7 and 9 years. Hearing losses were categorized by the average of 500/1000/2000 Hz, giving the following groups of subjects: Group 1, 60 dB and better, n = 20; Group 2, 61-80 dB, n = 19; Group 3, 81-100 dB, n = 24; Group 4, 101 dB and poorer, n = 22. The mean hearing level of the two poorest groups was 95 dB. The British Standard, which is similar to ISO 1964, was presumably in use, although not specified. The children received a linguistic test, a test of comprehension of spoken language, a vocabulary test (Ammons Full Range), an articulation test constructed by the author, consisting of 24 monosyllables on picture cards, chosen to test a representative number of vowels, consonants and diphthongs, and an intelligibility test. The intelligibility data will be discussed in a succeeding section.

The principal findings of the articulation test, according to the experimenter's phonetic transcription of the children's utterances, were:

<u>Vowels</u>: The two poorest groups with respect to hearing misarticulated nearly 56% of all vowels and diphthongs, with the diphthongs being poorer than the vowels. Most frequent substitutions were for /I/, followed by /ʌ/. Substitutions were not limited to adjacent vowels in the vowel space, nor to vowels of a similar tongue formation. Most neutralization of vowels occurred for /æ / and /ɛ/. Errors of prolongation were greatest for back vowels, /ɒ , ɔ and u/. Diphthongization of pure vowels was the least common error but occurred oftenest for /i/, which was heard as /iə/ or /iu/, and for /ɒ/, heard as / ɔI/ or /oU/.

<u>Consonants</u>: The deaf children made errors on nearly 72% of the consonants. Omission was the most frequent error, followed by substitution, and distortion was the least frequent. Final consonants were poorer than initial. Groups of consonants were examined separately: 1) Plosives: a) The most frequently omitted were /g,d,k/. b) Plosives were usually substituted for plosives, with a tendency for voiced to become voiceless. c) Substitution in manner was relatively frequent, as, /p/ for /m/. 2) Nasal consonants: a) Nearly all the children omitted /ŋ /. b) The most frequent substitution involved manner of articulation, as /p/ for /m/ and /t/ for /n/; i.e., the point of closure of the vocal tract was correct but the dropping of the velum was absent. 3) Fricatives: a) /s/, /z/, and / ʃ / were the most difficult. b) /t/ and /p/ were the most frequent substitutions for fricatives, while

interchanging of /s,z ʃ / was also frequent. 4) Other consonants: the most frequent error was on /tʃ /. Overall, the most frequent misarticulations were for /s,z,ʃ and ʒ /, which is in agreement with the findings of Nober (1967), op.cit. The correlation between the number of articulatory errors and the hearing average was .78 (p less than .001).

There are no other major studies on the general topic of the articulation of the deaf child.

Angelocci, Kopp and Holbrook (1964) studied the frequencies and amplitudes of the fundamental and first three formants of 10 General American vowels, in deaf and normal hearing 11- to 14-year old boys. They found that the mean was higher and the range greater, for both fundamental frequencies and amplitudes of all vowels, in the deaf than in the normal hearing children, but that the range of frequencies and amplitudes of vowel formants in the deaf speech was much narrower than normal for individual subjects. This seemed to indicate that the deaf child attempts to achieve vowel differentiation with minimum articulatory effort, by varying the fundamental frequency and amplitude of the voice. A plot of the frequency of f_1 against the frequency of f_2 showed almost complete overlap for the deaf speakers' vowel areas. In effect, the ten vowels turned into one ill-defined central vowel. While the means of the formants occupied a far more limited frequency area for the deaf than for the normal, the tremendous inter-subject ranges suggested a high degree of inaccuracy in the placement of the articulators.

Martony (1966) used the method of segmentation and distinctive feature classification to analyze the speech of 3 deaf boys, ages 13-15. He found a lack of synchrony between articulation and phonation, as for example at the junction between a fricative or nasal consonant and the following vowel; prominent errors in velar function involving abnormal and misplaced nasalization of vowels; and a super-stationery form of vowels, wherein transitions were often missing, or, if present, they were too short, indicating overly abrupt articulatory movements.

Recent physiological studies of the articulatory gestures of deaf speakers are few in number. Two that may be mentioned are those of Huntington, Harris, Shankweiler and Sholes (1968) and Brannon (1966).

Huntington et al carried out an electromyographic study, with surface electrodes, on the lip and tongue movements during production of CVC monosyllables, by two deaf speakers. They showed that the articulatory features of deaf speech were similar to normal speakers', for visible articulations. Phonetic transcriptions of the deaf utterances corroborated these findings and also showed that the vowel productions of the deaf speakers were unintelligible.

Brannon used a glossal transducer to compare tongue movement of deaf and normal hearing children, aged 12-15 years. The most conspicuous finding was the extreme slowness with which the deaf children moved their tongues for individual phonemes, phoneme combinations, and connected speech. They were extremely deviant from normal in the duration of glossal motions. In addition, they added unnecessary tongue motions, thus not moving their tongues efficiently from one placement to the next. Within a sentence, there were 3 or 4 of these extra tongue motions, on average. Brannon added that breath control was poorly established, the deaf children tending to utter single words on a single breath, creating a staccato sound and exhausting the entire breath supply with each emission. He suggested that deaf children make a visual to motor conversion in speech processing instead of auditory to motor, and that therefore their speech control is conscious and kinesthetic-tactile in nature; for this reason, it is dependent on higher brain centers than the automatic control of normal speech.

Non-articulatory aspects of deaf children's speech

Hudgins (1934, 1937, 1946) made a number of studies of speech coordinations and breath control in deaf children's speech. His findings were: 1) Short, irregular breath groups, often with only one or two words, and breath pauses interrupting the speech flow at improper places; 2) excessive expenditure of breath on single syllables; 3) false grouping of syllables and misplacements of accents; 4) a slow, labored methodical utterance; 5) lack of coordination between breathing muscles and articulatory organs. He ascribed the confusion between voiced-voiceless cognates of a phoneme pair to a lack of differentiation in intra-oral pressure; 6) excess of nasal resonance, and leakage of air through the nose during consonant production; 7) as the result, notably, of the first four of these phenomena, the speech of deaf children is either non-rhythmic or abnormal in its rhythmic structure, with serious effects on intellibility.

A similar observation with respect to phrasing was made by Lafon et al (1967), who made narrow band spectrographic analyses of melodic patterns in the utterance of 30 normal hearing children and 30 deaf children. For all the normal subjects, the intonation or melodic pattern was characteristic for each utterance; therefore, the authors reason, the intonation of an utterance must be an important factor in the identification of what is said. The deaf children divided the sentences as though not organizing a whole utterance, but giving each word the value of a sentence. The children were grouped according to length of time spent in special education, and again according to hearing levels at 500 Hz. On the basis of the latter, the children with poorest hearing had intonation curves most different from the normal. There was not much difference between the children on the basis of length of special education, but the authors noted a tendency for an improvement in melodic pattern at the beginning of education, which then levelled off, and suggested that too much emphasis in their training was placed on articulation.

The impression of nasality in the speech of deaf children was the subject of a study by Colton and Cooker (1968). Their subjects were 26 deaf speakers with a mean age of 18 years and a mean pure tone average of 90 dB. These were matched with a control group of normal speakers. Listeners heard the recorded speech of these two groups played backward to remove judgements of articulation from consideration, and made direct magnitude estimation of the degree of nasality present. The deaf speakers were heard as more nasal than the normal, with hardly any overlap between groups. However, when the normal speakers read the same material in a word-by-word fashion instead of with appropriate phrasing, most of the samples were considered to be as nasal as many of the deaf speakers. It was suggested that the slow tempo of deaf speech may be a cause of the perceived nasality.

Fundamental frequency measures of deaf and normal hearing children were studied by Green (1956) with the Purdue Pitch Meter. Deaf children did not appear to differ significantly from normal children in mean fundamental frequency. Deaf boys and girls, and younger vs. older deaf children, could be distinguished from each other on the basis of mean fundamental frequency. There were no differences found relative to speech training methods. The deaf children exhibited a restricted range of inflections; there were upward shifts in the fundamental in over 50% of all syllables spoken. It appeared , as Hudgins (1934) had previously stated, that the deaf children took breath on every syllable and expended it all, which would mean a strong sub-glottal air pressure and hence a probable upward shift in frequency, at the start of each syllable.

The time elements in deaf children's speech have been the direct subject of a number of investigations. Voelker (1938) studied the overall rate of utterance of 98 children in the primary grades of the Ohio School for the Deaf, and of a group of normal hearing children of the same ages. The rate of words per minute of the deaf children's speech ranged from 28 to 145 with a mean of 69, while that of the normal hearing children ranged from 134 to 210 with a mean of 164. There was, in other words, hardly any overlap between the two groups.

John and Howarth (1965) postulated that a large number of the errors that have been observed in deaf children's speech may in fact be errors of duration. These included the lengthening of vowels and consonants, the inappropriate pauses between words and faulty stress patterns, and also the occurrence of intrusive sounds, caused by the slow and inaccurate movement of the articulators from one position to another. In turn, these errors might partly be the result, as suggested by Lafon, of preoccupation with the articulation of individual phonemes. John and Howarth studied the effect on 30 deaf children, ages 6 to 14, of short periods of training in which the entire emphasis was on achievement of normal rate and normal durations of words, phonemes and phrases. Articulatory errors were ignored. The largest group of children had average hearing at 500/1000/2000 of 100 dB or more, British Standard. However, it was postulated by the authors that the time characteristics of speech can be received by children who have any residual hearing at all. The response of naive judges to the before and after training recordings indicated an 11% increase in the number of words correctly understood, and a tripling in the number of syntactic sentence structures correctly recognized (as, "The (something) did (something).") There was no significant difference in the amount of improvement displayed by the children on the basis of either age or degree of hearing impairment. Since articulatory correctness could hardly have improved and may, in some instances, have deteriorated, the improvement in word and structure recognition could be attributed to the nearer approximation to normal temporal and intonational patterns.

Calvert (1961) studied the durational characteristics of plosive and fricative consonants in deaf speech, with the hypothesis that the voiced-voiceless errors found by other investigators might be due to durational distortions rather than to the presence or absence of voicing. Calvert had speakers who were deaf, others who were normal-hearing, and others, also normal-hearing, who simulated deaf speech. In a preliminary investigation to determine the level of material necessary to enable listeners to identify deaf speakers reliably, he found that this judgement could not be made accurately on the basis of sustained vowels, and required at least a diphthong or a CVC syllable. He therefore used syllables of the form /hə-CVC/ as speech material. This was additional corroboration of the Hudgins and Numbers finding cited above, that the errors in deaf speech are associated with movement of the articulators from one position to another. Calvert's results indicated systematic differences for deaf speakers in duration of the release period of plosives and, in particular, a reversal of the normal ratio of duration of the stressed vowel to the adjoining consonant. He concluded that relative durations of consonant and stressed vowel were more important causes of the misperception of voicing than the absolute durations of consonant phonemes.

Hood (1966) attempted to determine the relative importance of physical characteristics in the perception of speech rhythm of the deaf. His subjects were 22 males ages 15-5 to 21 years, all but 7 of whom had a pure tone average at 500/1000/2000 of 90 dB or poorer. The subjects were chosen to have as wide a range of intelligibility of speech as possible. When intelligibility scores were obtained (with CHABA sentences), they ranged, in fact, from 9 to 94 %. The measurement of speech rhythm was achieved by filtering one of the sentence lists read by the deaf subjects, at 500 Hz low-pass, and comparing listeners' ratings of the rhythm of these sentences with speech intelligibility as obtained from the unfiltered speech of the same talkers. Acoustic analysis was made of two filtered sentences for the six deaf subjects judged best in rhythm, and the six judged poorest. The intonation patterns of the deaf speakers had the same configurations as the normal, although the deaf speakers used less than normal variation in fundamental frequency and intensity. These variables had a much less pronounced effect on rhythm ratings than did duration. The findings suggested that high intelligibility was associated with speech rhythm ratings above a certain level, and fell off rather sharply below that level. The correlation between total duration and rhythm ratings was .92.

Wilson and Irvin (1970) examined deaf speakers' production of the voiced-voiceless pairs /p-b/ and /k-g/ in CV utterances, with a view to determining the differences between deaf and normal speech in closure time, burst plus aspiration time, and ratio of duration of the consonant to the succeeding vowel. They found, as did Calvert, a distortion in deaf speakers for these time relationships. The deaf speakers did not differentiate voiced-voiceless pairs on the basis of voice onset time or duration of aspiration. Closure times were much longer than normal, and the duration of the aspiration following a voiceless plosive was much shorter.

Intelligibility of deaf children's speech

Since the major interest of the present study is in factors affecting the intelligibility of the speech of deaf children, the examination of these portions of the literature has been reserved until the last.

In the investigation by Hudgins and Numbers (1942), the children read lists of simple sentences, which were recorded and heard by experienced teachers of the deaf. These listeners wrote down everything they could understand in the sentences, but credit for the intelligibility score was allowed only for sentences that were fully understood. The obtained correlations with intelligibility for the various error categories ranged from -.28 for substitutions to -.58 for errors of releasing consonants. The total number of consonant errors was correlated -.70 with intelligibility, and the total number of vowel errors -.61. For the group with the poorest hearing, the average intelligibility was 21% in Clarke School and 9% in Mt. Airy.

Brannon (1964) used congenitally deaf subjects, aged 12-15 years, with hearing level averages of 75 dB or poorer (ASA standard. The ISO equivalent is 86 dB). Naive listeners heard the recorded speech of these children. The range of intelligibility scores was 7.8% to 35.6% with a mean of 20.7 %. The articulation score on the Templin Darley test was correlated .79 with intelligibility.

In the intelligibility portion of the study by Markides (1970), each child read and recorded descriptions of five pictures. These recordings were assessed by naive listeners, who wrote down what they could understand (as well as separate panels of trained teachers.) The intelligibility score for each child was the percentage of words correctly understood by the listeners as a function of all the words the child produced; each child had two scores, one from the naive listeners and one from the teachers. The mean intelligibility score obtained from the naive listeners was 19.1% and for the teachers, 31%, with a correlation of .94 between the scores of the two groups. The error categories most highly correlated with intelligibility were total consonant errors and final consonant errors(r for each category, -.89). Within the categories, the error type most affecting intelligibility was that of omissions ($r = -.76$).

In Boothroyd's study (1969) of hearing levels at Clarke School, the children were graded in intelligibility by teachers in training. Using 70% intelligibility as the dividing point, Boothroyd found a significant relationship for this intelligibility level and a response/no-response dichotomy, for every frequency from 250 Hz upward. With hearing at 75 or 80 dB at 1000 and 2000 Hz, a child had an 80% chance of being in the good intelligibility group. With hearing at 95 or 100 this probability dropped to about 20 %. Boothroyd found a marked cut-off point at 90 dB, a tendency for speech to deteriorate sharply with hearing poorer than that level.

In the study by John and Howarth (1965), the mean score for naive listeners in hearing the first version of the children's speech, before the training session, was 19%. The startling similarity of laymen's intelligibility scores in listening to deaf children's speech indicated by the studies just cited surely indicates that this percentage level has a very high validity.

In virtually all of the studies that have been mentioned in this review, the particular phenomenon of deaf speech production or auditory perception that was being investigated was closely related to degree of hearing loss, as measured by pure tone audiometry. In a 2 x 2 contingency table analysis of response/no response at audiometric frequencies, against above/below mean articulation score, Montgomery (1967) found significant chi squares at 125, 250, 1000 and 2000 Hz in the better ear, and at 4000 Hz in the poorer ear. Kerridge (1938) found that with average hearing poorer than 90 dB, the speech of most children was poor, regardless of intelligence or years of special education. Hudgins and Numbers (1942) found that phoneme errors in all categories increased with greater hearing loss, the most affected being errors of voicing and nasality. Errors of rhythm, which were correlated -.71 with intelligibility, also increased with decreasing hearing. Hudgins (1934) made the same observation with respect to incoordinations in speech. Markides (1970) obtained a correlation of -.75 between averaged hearing loss and intelligibility, while Brannon (1964) obtained -.87.

It may therefore be recognized from the work of many investigators that amount of residual hearing accounts for the major portion of the variance in the performance of deaf children on tasks related to speech skills. It is also clear, however, that much remains to be defined concerning the auditory abilities of deaf children, particularly in the direction of relating these in a quantified fashion to specific parameters of speech. The present study will attempt to fill in some of the gaps.

CHAPTER THREE

PROCEDURE

I. Subjects

The deaf subjects were 40 children who were pupils at a day and residential school for the deaf in New York City. The method of instruction in this school is entirely oral, and every effort is made to have all pupils wear amplification, either personal or classroom, throughout the school day and to ensure that personal amplification is used at home. The children were equally divided in the age groups 8 to 10 (at least 8 years old and less than 11) and 13 to 15 (at least 13 years old and less than 16). There were 10 boys and 10 girls in each age group.

The subjects were selected from a pool of names suggested by the school, through examination of the educational, audiological, psychological and pupil personnel records of each, with attention to the following criteria:

1. Some measurable audiometric response, according to previous testing, at least to 750 Hz in at least one ear.
2. Congenital deafness.
3. No other presently apparent physical or psychological anomalies other than deafness.
4. Enrollment in the school for at least 3 years.

The first criterion was necessary in order to make feasible the administration of the planned audiological test battery. The second removed the unmanageable variable of exposure to language and speech prior to loss of hearing. The third avoided central nervous system damage, visual perceptual disturbances, slow mental development and other factors that could have interfered with speech development. The fourth ensured some continuity and similarity of speech training throughout the group. However, in order to obtain a sufficiently large group while satisfying all other criteria, criterion 4 was relaxed for two subjects (Child 10 and Child 24) who had each been in the school two years.

In addition, since the children would be required to read sentence material for collection of the speech sample, it was ascertained from achievement test scores that each child possessed at least second grade reading skill.

It was not possible from the number of children that could be made available, to match exactly the numbers of children of deaf and of hearing parents. One child in the older group and 8 in the younger group were the children of deaf parents. Sign was designated as the principal language in the homes of seven of these. A language other than English was spoken in six homes. Five children of deaf parents and eight other children had at least one deaf sibling.

A recently obtained score on the Wechsler Intelligence Scale for Children was available for all but five subjects. A score on the Leiter or the Wechsler-Bellevue tests was available for these five. Since children of slow mental development were deliberately excluded from selection, these scores ranged from 92 to 140.

The school kept no records of family income. However, an estimate of socio-economic status was made based on the parent(s) occupation. According to this system, half the children could be considered to come from homes in the lower middle economic group, 19 from the middle economic group and 1 from the upper middle.

From examination of correspondence with the home, teachers' comments and other available information, an attempt was made to determine the quality of parental motivation operating on each child, since this has been considered an important factor in the achievement of goals by handicapped children. As a check on the judgements thus formed, the school director of pupil personnel was given a list of all the children and asked to indicate his experience of the parental cooperation in each instance as good, fair or poor. His thinking agreed in nearly every case with the opinion that had been formed by the investigator. Where there was disagreement, the director's opinion was taken.

Other information obtained from the records on each child included the most recent classroom grades received in speech and lipreading, the ages when deafness was first suspected, when the first hearing aid was acquired and when special education was begun, all available past audiological information, and the condition and adequacy of use of the present hearing aid.

Deafness had been diagnosed in the first year of life for 24 of the children; during the second year for 12; later than the second year for 4. The age of obtaining the first hearing aid ranged from 1 to 5 years. The age of beginning special education ranged from 11 months to 11 years. For the largest number (16 children) this age was between 2 and 3 years.

Complete background information for the 40 children is shown in Appendix A-1.

II Materials and equipment

The test battery for the children consisted of:

1) Pure tone measures.
    a. Pure tone air conduction, measured from 125 to 6000 Hz, including half octaves.
    b. Uncomfortable loudness level for tones at 250 and 1000 Hz.

2) Measures of sensitivity for speech.
    a. Speech detection level.
    b. Response level for spondee words.

3) Special tests of recognition (supra-threshold).
    a. Phoneme recognition test, designed for this study.
    b. Speech approximation test, designed for this study.

4) Recording of children's speech.

1 - a. It was decided to test pure tone only air air conduction, since examination of the previous audiological records of the children showed none with evidence of a valid and significant air-bone gap.

1 - b. Measurement of uncomfortable loudness level was brief. Its chief purpose here was to ensure the feasability of the ensuing supra-threshold tests.

2 - a. Speech detection is generally found near the response level for 250 Hz. It served here as a check on the pure tone response , since it was anticipated that a response to spondee words would not be found in many of these children.

2 - b. The stimulus for speech response level was a set of six pictures arranged on a large card, and taken from the book *What's Its Name?* (Utley, 1950). They represented the words cowboy, ice-cream, baseball, airplane, birthday (a cake) and playground. All of these words except ice-cream are among the most highly intelligible of spondee words, according to Curry and Cox (1966). It has been the author's personal experience that *ice-cream* is a highly intelligible word to children. The set of pictures appears in Appendix C-2.

3 - a. A test of phoneme recognition was designed for the study.

Various tests of speech discrimination for children are in existence (Haskins, 1952; Watson, 1957; Myatt and Landes, 1963; Siegenthaler, 1966; Pickett, 1970; Ross and Lerman, 1970). The Haskins and Watson tests consist of open items, requiring either a verbal response, which is not suitable for use with deaf children, or a written response, which is slow and subject to spelling errors. The closed-response item does not have these drawbacks, and, if designed for minimal contrasts, lends itself to the analysis of confusions. Such a test yields a phoneme score rather than a word score. Boothroyd (1970) has suggested that a subject who will recognize a limited number of complete words may still recognize a significant number of speech sounds. Therefore a phoneme score should be more sensitive to differences in recognition skills and less influenced by differences in language skills, than a word score. The Myatt and Landes test is a picture test comprised of a series of 20 closed response sets of four pictures each, but its phonemic composition was not quite what was desired because it includes many diphthongs and because the consonant sets are not constructed to contrast specific feature differences. The same objections applied to the picture identification test of Ross and Lerman. The Siegenthaler test is a picture test that isolates place and manner of articulation, and voicing, but since it presents only pairs of words to be discriminated, the likelihood of chance correct response is very great. Pickett has used a rhyme test of six-word closed sets, designed for deaf college students, but both the vocabulary and the ensemble size are beyond the capabilities of a young child.

The test that was designed presents minimal triplet sets, thus reducing the likelihood of correct chance response to one-third. A picture test would have been desirable, but it proved impossible to construct a sufficient number of sets of three rhyming words that would be picturable and still investigate the desired features. The children were required to read and circle their responses , therefore the vocabulary was limited to highly familiar words. A pilot study that was performed immediately prior to the present research had disclosed what appeared to be a tendency for certain consonant phoneme substitutions to appear in the speech of deaf children. These were incorporated into the phoneme recognition test insofar as possible. They included /h/ substituted for /s/ and /k/, /j/ for /l/ and /dʒ/, /s/ for /ʃ/, and /d/ for any and all of the following: /ʃ/, /ð/, /g/, /t/, /j/, /z/, /θ/, /n/, /l/, /tʃ/, and /k/. Opportunities for a number of these confusions to occur were provided in the word sets.

The word sets that were constructed are shown in Table 2, Chapter 4. The correct response is the first item in each set in the table. In Items 1-8, place of articulation changes, with voicing and manner constant; Items 9-16, manner of articulation changes, with place and voicing constant; Items 17-24, place and manner change with voicing constant; Items 25 through 36 contain contrasts of voiced-voiceless cognates with nasals. This particular voicing-manner contrast was chosen, like the sets above, because of the large number of errors of this type made in speech production by the children in the earlier study. Based on the same information, place-voice contrasts were not included, because the children made few of these errors. Items 37 to 50 are vowel contrasts The first 10 items sample tense-lax (durational) differences, both adjoining and distant in the vowel space. For these items, the tense or lax member of a pair was always chosen as the correct response. For example, in the sequence beet - bit -

boot, the correct response was beet, and in the sequence luck-lock-look, the correct response was luck.

The response sheet that was used by the children appears as Appendix C-3. The order of the sets was randomized. The position of the correct response within each set, i.e., the first, second or third word position, was also randomized, except for the tense-lax distinctions noted, where the correct response was chosen for each set.

For test items of the extreme simplicity of these, it was felt that a gain function derived with normal listeners would be unrealistically steep. The test was tried with six normal-hearing young children at a comfortable listening level and all obtained scores of 100%.

The spondee words for speech response level and the phoneme recognition test were recorded by a trained male talker whose dialect is typical of educated speech of the New York City area. Recording was done on one channel of an Ampex AG 500 recorder, using a Norelco D24E microphone. The words were spoken with equal effort. The investigator timed a 4-second pause between stimuli, hand-cued the talker, and monitored the level, which remained within ± 2 dB, on the VU meter of the Ampex. No carrier phrase was used with the spondee words. For the phoneme recognition test, the talker spoke the carrier "The next word is --" followed by a slight pause and the stimulus word. Since no stimulus word had an initial vowel, the carrier was chiefly an alerting signal, and the pause was felt to be appropriate to set off the stimulus for the deaf children. Three practice items preceded the test words.

A spectrum analyzer (Kay Sonagraph Type 7029A) was used to obtain spectrograms of the test words in the phoneme recognition test in order to have some information about the frequency ranges and energy in the talker's voice. The fundamental frequency of the voice varies from 140 to 160 Hz. The formant structure is well defined. Free vowels before voiceless plosives, always of short duration, tend in this speaker to be unusually short. The first and second formants of the vowels that appeared in the vowel test items were as follows (for comparison, the data on the same vowels given by Peterson and Barney, 1952, are shown in parenthesis):

Stimulus vowel:	i	ɪ	ɑ	æ	ʊ	u	ʌ
F_1 (Hz)	270	400	700	650	460	300	650
	(270)	(390)	(730)	(660)	(440)	(300)	(640)
F_2	2500	2000	1150	1700	1000	920	1200
	(2290)	(1990)	(1090)	(1720)	(1020)	(870)	(1350)

3 - b. In addition to errors of phoneme production, prosodic or suprasegmental errors of stress, rate and intonation are prevalent in the deaf child's speech. In order to investigate the recognition of these non-articulatory aspects, a speech approximation test was designed.

The equipment used to produce the tape-recorded stimuli for this test consisted of:

2 Hewlett-Packard oscillators, Type 202C.
2 Grason-Stadler Electronic Switches, Type 829C.
2 Grason-Stadler Interval Timers, Type 471-1.
2 Grason-Stadler power supplies, Type 471-2.
2 Ampex tape recorders, Model AG 500.
2 Alison Laboratories Variable Filters, Model 2 BR
Daven attenuator, Type T-2513
Bruel and Kjaer level recorder, Type 2305.
Tektronix oscilloscope, Type RM 564.

Block diagrams of the arrangement of equipment are seen in Appendix B-1.

The test was in five sections. Each of the first four sections consisted of a series of tone stimuli, differing, respectively, in duration, frequency, rate pattern, and intensity. The fifth section presented low pass filtered sentences to be identified on the basis of duration, intonation contour, word stress and phrasing. All these elements could be presumed to be present in the low frequency information available to the deaf children.

A response book was made using visual symbols to represent sounds. Pitch was represented by height on the page, loudness by size of the symbol, duration by length of the symbol. The designs were cut from brightly colored adhesive plastic paper and fastened on white paper. Lettered instructions explained each section. Each section was preceded by practice items.

The duration, frequency and intensity portions each had three levels of difficulty. At the first level, there was a single tone to be identified as short or long, high or low, loud or soft, these parameters having been identified with the proper visual symbols during the practice items. At the second level, there were patterns of two to be identified, as long-short, low-high, loud-loud. At the third level there were patterns of three, such as short-long-long. The section on rate was in two levels, where the first required the identification of a tone series as fast or slow, and the second presented patterns such as - -- -. The exact specifications of the stimuli and sample pages from each section of the response book (without color) appear in Appendix C-4. The test had four trials at each level.

A Peters audiometer, Model AP 6 , calibrated to the ISO(1964) reference standard, was used for pure tone measures; a Grason-Stadler speech audiometer, Model 162, with associated microphone and a Viking

Tape Deck, Model 433 for the other measures. Both were equipped with Telephonics TDH-39 earphones in MX-41AR cushions. The output of the earphones was measured immediately before, during, and immediately after the collection of data, using a Bruel and Kjaer sound level meter Type 2203 and artificial ear Type 4152. The measured sound pressure levels at the earphones of the Peters audiometer appear in Appendix B-2. They remained within ± 3 dB or better of the reference level throughout the testing period, except at 125 and 6000 Hz, where an appropriate correction was made in recording the response levels.

The zero reference level in the Grason-Stadler speech audiometer was at 21.5 dB sound pressure level. The attenuator was linear within .5 dB from 60 to 110 dB Hearing Level, which more than covered the range of interest, and the earphones differed from each other by only .5 dB. The gain settings for zero VU of the various calibration tones on the speech audiometry and speech approximation test tape were marked on the face of the audiometer for convenience in testing.

4. Recording of children's speech. The speech samples of the children were recorded on a Tandberg Model 11 tape recorder using low print-through tape (Scotch # 131) and an AKG microphone, Model D-202E. The response of the tape recorder, as measured using a Bruel and Kjaer sine random generator Type 1024 and level recorder Type 2305, and the response of the microphone as provided by the manufacturer are shown in Appendices B-3 and B-4. For later re-recording, the tapes were played from the Ampex AG 500 into the Tandberg Model 11. The response of this system is shown in Appendix B-5.

All children read a list of 20 sentences or sentence pairs and the older group read an additional 9 sentences. The sentences read by the whole group ranged in length from 5 to 11 words. The list included 3 questions and 1 complex but no compound sentences. The material was designed with some suggestions about vocabulary from the teaching supervisor at the school. The first 20 sentences or sentence pairs fulfill the following requirements: 1) a transition from each of the seven places of articulation to each of the vowels /i/, /æ/ and /u/, with the exception of lingua-dental into /u/, where no word exists that is in any child's vocabulary; 2) a transition out of each of these same vowels to each place of articulation; 3) all consonants represented in initial, medial and final position, except for those with a frequency of occurrence in the spoken language of less than .1% (Denes, 1963); 4) no sound of interest appears in an unstressed syllable; and 5) no sound of interest appears in the initial or final word of a sentence. An additional 9 sentences for the older children presented somewhat greater complexities of construction. They also included for examination the consonant clusters /sk/ initial and final, /ks/ final, /sp/ initial, /ps/ final, which were felt to represent a good sampling of the children's ability to produce clusters.

The set of 29 sentences appears in Appendix C-5.

III Experimental procedure

All of the children were seen during a period of approximately three weeks in early autumn, 1970. Audiological measures and recordings of speech were made in a sound-treated 2-room suite at the school. Each child was seen for a single session, lasting slightly less than one hour. No child showed any negative behavior or unwillingness to complete the session, although several of the younger ones required a brief rest at some point. The order of the sessions was alternated, half the children receiving the audiological evaluation first and half making the speech recording first, to balance any fatigue effect. All the children were accustomed to audiological testing and no conditioning time was required. Conventional hand-raising response was used in making pure tone measurements.

The form used for audiological evaluation appears as Appendix C-1. Pure tone air conduction response was measured for each ear at all test frequencies 125-6000 Hz. Threshold was always taken from the ascending approach. Two responses on a level were required. The audiometer used had an additional 20 dB available above the usual 110 dB Hearing Level, but it was decided not to measure above 110 dB, and a failure to respond at this level was called No Response. The decision not to measure at hearing levels greater than 110 dB was taken in order to make possible the future extension of data to facilities where a high-level audiometer might not be available.

Uncomfortable loudness level was investigated for tones at 250 and 1000 Hz each ear, but very few children indicated discomfort to the maximum level tested.

Detection level for voice was found for each ear, using monitored microphone voice and the word Hello with the child's name. Two measures were obtained.

Before testing for speech response level, the investigator gave the child the words using microphone voice with lipreading. The child's response was to point to the appropriate picture. No child had difficulty identifying the words and pictures when presented in this manner. The investigator then first attempted to obtain a response with microphone voice, again using the ascending approach. If this could be ob -

tained, the tape-recorded words were attempted. Where obtainable, the response level for the tape recorded words was entered.

The remainder of the testing was presented to one ear only. Ideally, all material should have been presented to each ear and then to the aided ear(s) in the sound field, but limitations of time made this impractical. The ear selected was that in which the hearing aid was worn (25 children). If the child wore binaural aids (14 children) or no aid (1 child), the ear selected was the one with the better speech response (6 children). If no speech response had been obtained, the ear selected was the one in which a pure tone response had been obtained for a higher frequency (4 children). If none of these criteria could be applied, the right ear was used (5 children).

The phoneme recognition and speech approximation tests were presented at 30 dB re: the response level for spondees, if one had been obtained, otherwise at 30 dB re: the response level of the test ear at 250 Hz. If these levels were not attainable in the audiometer, the presentation was at 105 dB Hearing Level. This resulted in a presentation level of at least 25 dB re: threshold in the test ear at 250 Hz, for 33 of the children. For 3 children, the level with the same reference was 20 dB; for 2 children, subjects 19 and 14, it was 15 dB, and for 2, subjects 30 and 40, it was 10 dB. In 2 cases the hearing level selected for presentation was uncomfortable for the child and was reduced 5 dB.

For the phoneme recognition test, the child was shown that he was to circle one word of the three in each set. The investigator started the tape and then sat with the child long enough to be sure the task was understood, and also checked on the continuing performance at intervals during the test. It was possible to hear the stimuli clearly by leakage from the earphones because of the high levels used. No child showed any confusion about the task after the first one or two practice items.

The speech approximation test was the last item in the audiological evaluation. The investigator demonstrated to the child with the first practice items that he was to point to the symbol corresponding to the sound he heard. With the practice items for each section, the investigator gave immediate feedback concerning the correctness of the response. If a child had difficulty with any practice item, the tape was rewound and the item repeated.

At the completion of the audiological evaluation the child put on his hearing aid if he had brought it, and then recorded the speech sample. He was positioned to face the microphone at about zero azimuth and an approximately constant distance of 10" from lips to microphone was maintained. No practice in reading the sentences was given before the recording started. Instead each child read each sentence twice while recording, and the better version was later selected for analysis. In the pilot study mentioned above, the children read all the sentences once through before recording and it was noted that the practice was often better than the performance. This was in agreement with the observations of Stewart (1968) concerning the instability of the speech of deaf children.

The completed recordings of the children's speech were re-recorded and distributed on 40 listening tapes in such a manner that each tape contained all 20 of the sentences that had been read by the entire group of children, and either 4 or 5 of the additional sentences read by the older children, with each child being heard only once on a tape. The re-recorded sentences were set at equal VU readings.

The order of sentences and children on the tapes varied but was not entirely random. To balance for order effect of children, those who appeared at the beginning of tapes 1 - 10 appeared at the end of tapes 11-20 and similarly with tapes 21 - 30 and 31 - 40. To balance for order effect of sentences, the order of tapes 1 - 20 was reversed for tapes 21 - 40. A strip of leader tape separated each sentence from the next to facilitate rewinding for repeated listening.

To obtain a measure of the intelligibility of the children's speech, each of these tapes was heard by 3 listeners. Since no listener heard more than one tape, there were 120 listeners in all. These were all volunteers, recruited chiefly from among the staff and students of various departments at the Graduate Center, The City University of New York. The criteria for their selection were:

1) No significant previous experience in hearing the speech of deaf persons.
2) Under 35 years of age.
3) Normal hearing.
4) Native speaker of English.

The first criterion was established since a large group of experienced listeners was not available and there could be no mixing of experienced with inexperienced listeners. An occasional encounter with a deaf individual did not constitute 'experience' by our criteria, but such a statement as "My brother had a deaf friend who was at our house a lot," excluded a listener from the study.

The age limit (eventually raised to 38) was established because the listening task was a difficult one and it has been shown (Bergman, 1971) that older persons perform more poorly than younger ones on complex listening tasks.

Normal hearing was here defined as a response level no poorer than 15 dB (ISO) on either ear, at any frequency 250-4000 Hz. Each listener was given a screening test of hearing at the start of his session.

English was stipulated as the native language in order to ensure that no bias due to linguistic background would add to the listener's difficulty in understanding the speech of the children.

The 120 listeners ranged in age from 16 to 38 years and included 51 males.

From one to three persons (the maximum for any tape) participated at any session. Each read a set of typed instructions (Appendix D-1) defining his task, which was to write down as much as he could of what each child said, making liberal use of contextual information. Listening was done via binaural matched TDH-39 phones in Grason-Stadler .001 cushions. A comfortable output level was set for the tape player. The instructions offered the listener the option of hearing each sentence twice, but it was quickly discovered that all listeners wanted the repetition and thereafter each sentence was routinely played twice in succession. There was no time limit. The listeners wrote their responses and then immediately added a judgement of each child's intelligibility on a 1 to 5 scale, where 1 represented good intelligibility.

The responses of the 120 listeners were scored word by word and an intelligibility score obtained for each child on words correctly understood as a percentage of 1) all words in each sentence and 2) selected key words in each sentence.

The same tapes were turned over to a group of skilled phoneticians for transcription. In all, twelve phoneticians participated. Each received as many listening tapes as he had agreed to attempt, together with recording forms and instructions (Appendix D-2, D-3). The recording forms, one page per sentence, gave the intended sentence in phonemic transcription (IPA), one phoneme/column, with space for the phonetician's transcription of the child's actual utterance. The instructions were to transcribe as broadly as possible and use diacritical markings only where absolutely necessary, indicating an unrecognizable substitution as such rather than giving a narrow phonetic transcription. This was done in order to have as much congruence as possible between the transcriptions of the various raters. As a check on inter-rater reliability, five identical sentences were added to the tapes sent to all the raters. Raters transcribed from one to seven listening tapes. The resulting transcriptions of all 980 sentences were then translated into a numerical code and punched onto cards for computer analysis.

An additional set of tapes was prepared, consisting of five consecutive utterances by each of the 40 children. These tapes were given to three experienced speech pathologists, who judged them with respect to non-phonemic and suprasegmental aspects of speech; voice quality, pitch, control, intonation, stress, fluency and rate. These judges used a check-list form (Appendix D-5) which simply indicated whether a particular aberrancy was present in a child's speech or not.

CHAPTER FOUR

RESULTS

This chapter will examine the audiological findings for the 40 subjects, the intelligibility data and the speech production data, together with the inter-relationships among the three and the interaction with certain background variables.

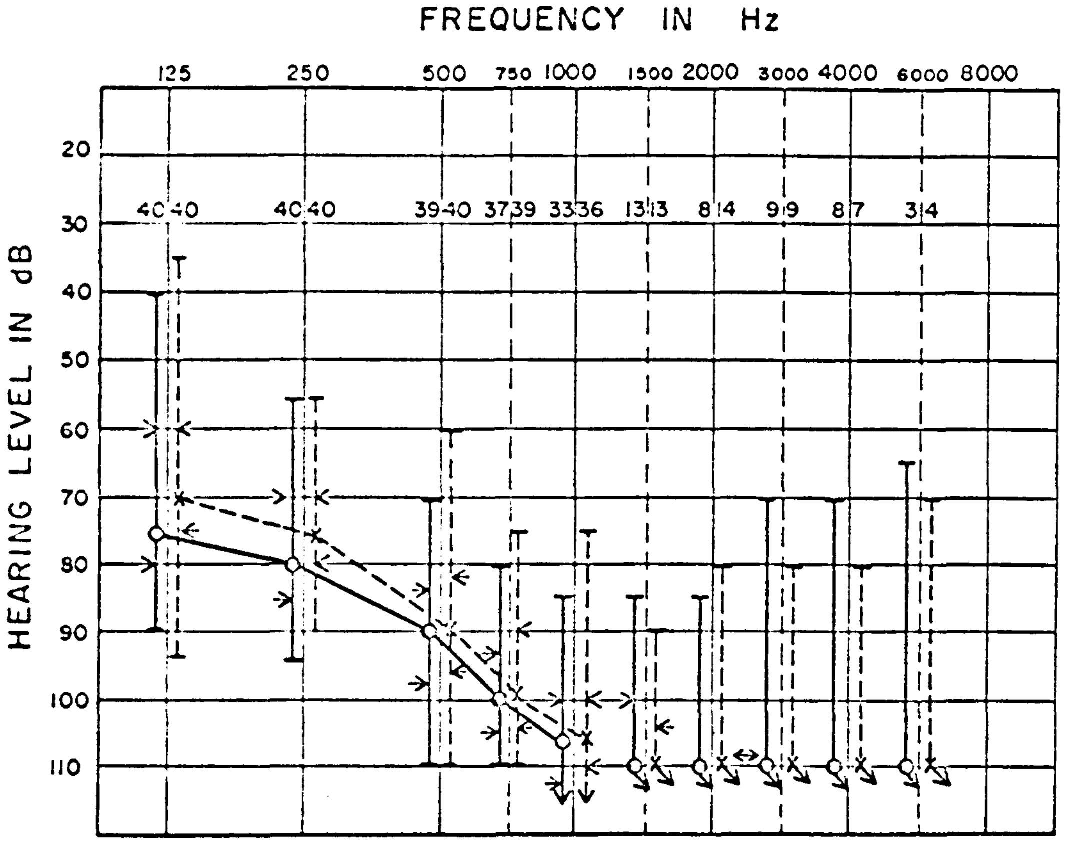
I.Audiological findings

Pure tone audiometry

The composite audiogram of the 40 children is shown in Fig. 1. The audiometric symbols represent the median response level for right and left ears at each test frequency. The total range is shown by the vertical lines associated with each audiometric symbol and the interquartile range (central 50% of responses) by the small arrows. The numbers at the top of each range are the number of ears responding. At 1500 Hz and above, the downward arrows indicate that the median was No Response. A No Response was recorded if a child did not respond to a particular frequency at 110 dB (ISO), the highest hearing level tested. Except for left ears at 2000 Hz and right ears at 3000 Hz, the first quartile level was also poorer than 110 dB at 2000 Hz and above. All but 3 children had hearing in the better ear of 92 dB or poorer at the average of 500/1000/2000 Hz. If a child did not respond at one of these frequencies, the level 115 dB (110 dB + 5 dB) was used in computing the average. The pure tone response levels of the 40 children appear in Appendix A-2.

For all children, the mean of the hearing averages at 500/

Fig. 1. COMPOSITE AUDIOGRAM OF 40 DEAF SUBJECTS, SHOWING MEDIAN AND RANGE OF PURE TONE AIR CONDUCTION RESPONSES. INTERQUARTILE RANGE INDICATED BY SMALL ARROWS. EARS RESPONDING AT EACH FREQUENCY INDICATED BY NUMBERS AT THE TOP OF EACH RANGE.


FREQUENCY IN Hz
125
250
500
750
1000
1500
2000
3000
4000
6000
8000
HEARING LEVEL IN dB
20
30
40
50
60
70
80
90
100
110
40 40
40 40
39 40
37 39
33 36
13 13
8 14
9 9
8 7
3 4

1000/2000 Hz was 101 dB and the median was also 101 dB, indicating a fairly symmetrical distribution. For older children, the mean was 99.2 dB and for younger children, 102.75 dB. For the younger children with hearing parents (12) and those with deaf parents (8) the averages were virtually identical, 103 and 102.5 dB, respectively. Only 1 child in the older group was the child of deaf parents.

The average of 500/1000/2000 Hz is traditionally used in describing hearing levels. However, it has been suggested (Montgomery, 1967) that lower frequencies would be more useful in relating the hearing of deaf children to their speech, in particular since very many deaf children cannot respond within audiometric limits at 2000 Hz. In the present group, 24 children out of 40 did not respond in either ear at 2000 Hz. Thus the levels at 2000 Hz recorded for those ears are not real data. However, all but 3 children did have a response in at least one ear at 1000 Hz. Various combinations of low frequencies were tried in correlations with the intelligibility data, resulting in a decision to use the average of 125/500/1000 Hz to describe hearing level.

Risberg and Martony (1970) have proposed a classification method wherein the hearing up to 1000 Hz and the hearing above 1000 Hz are considered separately and expressed as a letter and number combination. This system was tried on the data from the present population, but resulted in the placement of over half the children in the next-to-bottom group (Risberg's C-5). This did not seem to discriminate satisfactorily among children, although Ahlstrom (1970), using a modification of Risberg's method, found a high correlation between the audiogram classes, hearing for speech and speech intelligibility.

Using the average of 125/500/1000, the mean for all children was 86.5 dB and the median was 88 dB. For older children, the mean was 83.3 dB and for younger, 89.7 dB. For the younger children with hearing parents, the mean was 90 dB and for the younger with deaf parents, 89.1 dB. It thus appeared that in terms of either hearing average, the younger children had somewhat poorer hearing than the older children. This may have been a function of poorer response to testing, but all the children were experienced at undergoing audiological evaluation and seemed to the experimenter to be responding well.

Table 1A shows the foregoing means and medians for the two hearing averages. Table 1B shows, for each test frequency, the number of children for whom that was the highest frequency of response. Data are for one ear of each child, the ear that was used in administering the phoneme recognition test, as explained in Chapter Three.

TABLE 1 A. MEAN AND MEDIAN HEARING LEVELS FOR AVERAGE 500/1000/2000 Hz AND AVERAGE 125/500/1000 Hz.

	125/500/1000 Hz		500/1000/2000 Hz	
	Mean	Median	Mean	Median
All children	86.5 dB	88 dB	101 dB	101 dB
Older	83.3	85	99.2	101.
Younger	89.7	89	102.8	103.
Young, hearing parents	90.	89.	103.	105.5
Young, deaf parents	89.1	89.	103.	105.

The correlation coefficient (r) between the average at 500/1000/2000 Hz and the average at 125/500/1000 Hz. is .89. Between 500/1000/2000 and the highest frequency of response, -.72; and between 125/500/1000 and the highest frequency of response, -.62 (p less than .001 for these correlations.)

TABLE 1 B HIGHEST FREQUENCY OF AUDIOMETRIC RESPONSE, TEST EAR.

	750	1000	1500	2000	3000	4000	6000
Younger	4	9	0	1	1	2	3
Older	1	8	4	2	1	4	0
Cumulative:							
Younger	4	13	13	14	15	17	20
Older	1	9	13	15	16	20	20

Speech audiometry

Detection level for microphone voice ranged from 55 to 95 dB, Hearing Level. Seventeen of the 40 children had a measurable response level for spondee words, either by microphone voice or tape. These response levels ranged from 65 to 100 dB. In only one subject was the response level for spondees found at 5 dB above detection, the difference most often found in subjects with a lesser degree of hearing impairment. For all others, the difference between detection level and response level was 10 to 20 dB.

Table 2 shows the subjects' responses to each item on the phoneme recognition test. The items are arranged here according to contrast type, with the first word in each row as the correct response. The randomized form used by the children will be found in Appendix C-3.

It is appropriate to consider consonant and vowel items separately, since the confusions that occurred are directly dependent on

TABLE 2
RESPONSES ON PHONEME RECOGNITION TEST, ALL CHILDREN

Place contrasts *

sat	fat	hat
10	25	5
pea	tea	key
8	16	16
bum	dumb	gum
13	16	11
she	he	see
18	7	15
let	wet	yet
21	15	4
read	weed	lead
29	9	2
sit	sip	sick
13	9	18
big	bid	bib
24	5	11
136	102	82

Total error: 57.5%

Manner contrasts

new	zoo	do
27	13	0
bill	mill	will
20	8	12
lot	dot	not
14	8	18
zip	dip	lip
18	5	17
wet	bet	met
19	4	17
me	be	we
27	5	8
pan	pad	pal
24	6	10
buzz	bud	bun
12	8	20
161	57	102

Total error: 49.6%

Place-manner contrasts

fair	chair	pair
16	11	13
mumps	dumps	jumps
15	9	16
gee	we	D
19	10	11
then	den	men
10	8	22
do	you	moo
13	13	14
hen	ten	when
11	17	12
bug	bum	buzz
23	9	6
mass	map	match
6	17	17
113	94	113

Total error: 65.9%

Voicing contrasts

mat	bat	pat
22	16	2
bark	mark	park
24	6	10
pill	mill	bill
20	9	11
two	do	new
27	7	6
D	tea	knee
8	22	10
nip	tip	dip
22	9	9
sup	sub	some
8	21	11
rib	rip	rim
12	12	16
come	cup	cub
20	10	10
pat	pad	pan
22	7	11
seed	seat	seen
24	4	12
bun	but	bud
23	6	11
232	129	119

Total error: 51.6%

Vowel contrasts

beet	bit	boot
16	6	18
Pete	pit	pot
13	21	6
hot	hut	hoot
20	12	8
not	nut	neat
15	19	6
luck	lock	look
11	11	18
suck	sock	sick
16	14	10
hit	heat	hut
30	2	8
fit	feet	foot
12	10	18
fool	full	feel
14	17	9
pull	pool	pill
21	13	6
pal	pool	peel
25	6	9
lid	lead	led
12	22	6
full	fool	fall
19	6	15
pot	pet	put
16	10	14
240	169	151

Total error: 57.1%

* the first item in each row is the correct response.

the available responses. For consonants, a greater variety of error possibilities was presented in each class and this might remove biasing effects. There were fewer consonant errors if voicing was present in all members of an item than if they were voiceless. Glides were recognized well, as were nasals. There was a tendency for continuants to be confused with each other (e.g. zip-lip, buzz-bun). There was no tendency over-all for items wherein the contrast was in the final consonant to be missed more frequently than those wherein the contrast was in the initial consonant. Initial consonant errors amounted to 55.2% of occurrences and final errors to 56.6%. This might be an artifact of the way the words were presented: a carrier phrase, then a pause, then the stimulus word. The effect might be to cause the final consonant to receive more emphasis than in continuous speech.

The design of the vowel items provided possibilities for a number of confusions between checked-free pairs or between vowels with a similar first formant. Table 3 displays these as individual matrices. Each small section shows the responses on a single item, with the stimulus vowel indicated to the upper left. Items where the confusion is between similar first formants are horizontally arranged. Items where the confusion is between members of a checked-free pair are arranged vertically. The following observations may be made: When a first formant confusion is available, it occurs frequently, provided the stimulus vowel has a high second formant, as in the sets /i I u/, /I i U/. If the stimulus vowel has a low second formant, the alternative with a high second formant is not chosen; the checked or free alternative is chosen, as in /u U i/, /U u I/. If there is no

TABLE 3

FIRST FORMANT AND CHECKED-FREE CONFUSIONS IN PHONEME RECOGNITION TEST. THE STIMULUS VOWELS ARE SHOWN OUTSIDE THE FIGURES. THE RESPONSES TO EACH ARE SHOWN BY THE NUMBERS WITHIN THE FIGURES. F_1 CONFUSIONS ARE HORIZONTAL. CHECKED-FREE CONFUSIONS ARE VERTICAL.

i

i 16	ɪ 6	u 18

i 13
ɪ 21
a 6

ɪ

ɪ 12	i 10	ʊ 18

ɪ 30
i 2
ʌ 8

ʊ

ʊ 19	ʊ 21
u 6	u 13
ɔ 15	ɪ 6

u

u 14
ʊ 17
i 9

a

a 15	a 15
ʌ 19	ʌ 12
i 6	u 8

first formant confusion available and the stimulus is a free vowel, the corresponding checked or lax vowel is the confusion, as in /ɑ ʌ i/, /æ ʌ u/, /i I ɑ/. If the checked vowel is the stimulus and there is no available first formant confusion, the correct response is likely to be chosen, as in /U u ɔ/, /I i ʌ/. Overall, /U/ was the response to /I/ three times as often as /I/ was the response to /U/, and /u/ was the response to /i/ twice as often as /i/ was the response to /u/. This may be compared with the finding of Pickett (1957) for normal hearing subjects, when the higher formant structure of vowels was masked by noise.

Table 4 gives the mean and standard error of the mean for percentage of errors made in the 50-item test according to various groupings of the children, and the results of the t test for differences between means.

TABLE 4 MEAN PERCENTAGES OF ERRORS ON PHONEME RECOGNITION TEST

	ALL CHILDREN	OLDER, HEARING PARENTS	YOUNGER, HEARING PARENTS	YOUNGER, DEAF PARENTS
N	40	19	12	8
Mean	56	50.8	59	63
$s_{\bar{x}}$	1.7	2.8	2.6	2.
t		2.20+ df = 29	1.18 df = 18	

+ p less than .05

There is a moderately significant difference between the older and younger children of hearing parents, and some difference, not statistically significant, between the younger children of hearing and of deaf parents.

Relations between audiological measures

Table 5 summarizes the audiological findings for the 40 children. It shows the average in dB at 125/500/1000 Hz, the response level for spondee words if obtained, the highest frequency of response in the test ear and the percent correct on the phoneme recognition test.

Table 6 gives values of the correlation coeffecient for pure tone response levels and the various items of the phoneme recognition test. Data for frequencies above 1000 Hz are not tabled because of the small numbers of children responding.

The average at 500/1000/2000 Hz has a slightly higher correlation with the total phoneme recognition test (total number of errors) than has the average at 125/500/1000 Hz. 1000 Hz alone, however, has the highest correlation with total errors as well as with errors on items involving manner of articulation and vowels. Errors in recognition of place of articulation show no significant correlation with any pure tone measure, in contrast with populations having a lesser degree of hearing impairment, where hearing at higher frequencies is of major importance to the recognition of place of articulation (Pickett, 1968). This may be because the energy in the upper part of the speech spectrum is insufficient for the high intensity levels required by most deaf children; or it may be that, due to cochlear damage, there is poor frequency resolution at high frequencies in the auditory mechanism of most of the children.

Highest frequency of response in the test ear shows a signif-

TABLE 5

SUMMARY OF AUDIOLOGICAL FINDINGS, ALL CHILDREN

Subject	Sex	Average in dB, 125/500/1000 Hz	Response level, spondees	Highest frequency heard (Hz)	PRT % correct
Older group, hearing parents					
1	f	88	--	1500	42
2	f	80	--	4000	30
3	m	91	--	1000	38
4	m	75	90	1500	54
5	f	93	--	1000	40
6	f	81	85	1000	56
7	m	78	90	1000	60
8	f	73	80	2000	50
9	f	90	--	2000	44
10	m	70	65	4000	76
11	f	85	--	1000	40
12	m	73	--	3000	42
13	m	80	--	4000	52
14	f	100	--	750	38+
17	m	86	90	1000	64
19	m	98	--	1000	38+
20	m	61	65	4000	68
22	f	85	--	1500	46
23	f	90	100	1000	40

+ Presentation level 15 dB re: response at 250 Hz

Subject	Sex	Average in dB, 125/500/1000 Hz	Response level, spondees	Highest frequency heard (Hz)	PRT % correct
Older, deaf parents					
18	m	90	--	1500	40
Younger group, hearing parents					
15	m	90	--	3000	34
16	m	81	--	4000	42
21	f	88	--	1000	42
24	f	98	100	1000	40
25	m	91	--	1000	52
26	f	81	75	6000	46
27	m	88	95	4000	60
29	m	100	--	750	30
30	m	105	100	750	36*
32	f	83	--	1000	30
33	m	85	80	6000	52
39	m	91	95	1000	42

TABLE 5, (cont.)

Younger group, deaf parents

28	f	88	--	1000	34
31	m	98	--	1000	30
34	f	76	80	2000	36
35	f	90	—	6000	48
36	m	86	--	1000	38
37	f	90	90	750	42
38	f	85	--	1000	32
40	f	100	—	750	36*

Presentation level 10 dB re: response at 250 Hz

TABLE 6

VALUES OF THE CORRELATION COEFFICIENT FOR VARIOUS HEARING MEASURES

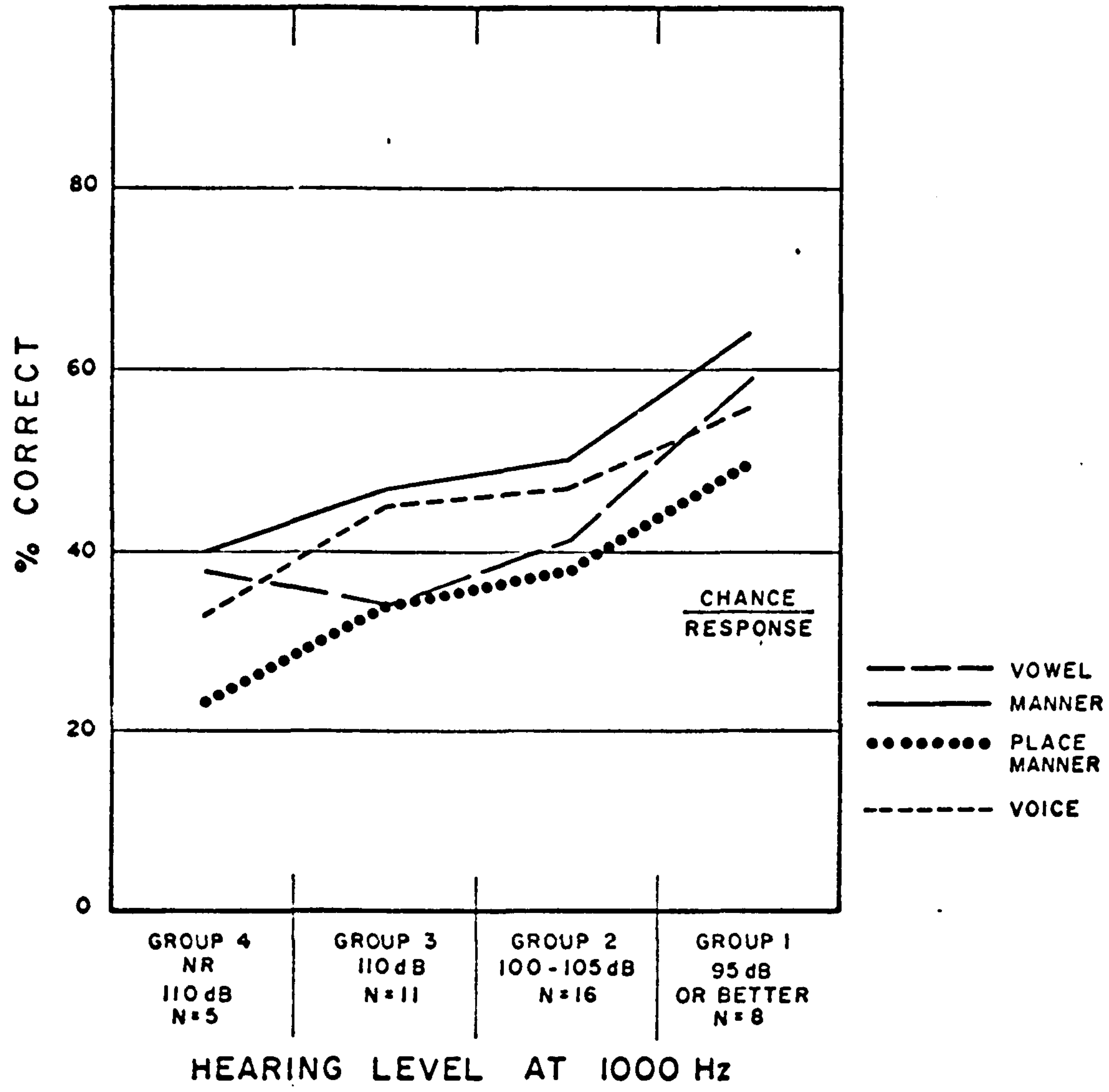
	Highest frequency heard	Average in dB, 125/500/1000 Hz	PRT, total errors	PRT, place errors	PRT, manner errors	PRT, place-manner errors	PRT, voicing errors	PRT, vowel errors
Average in dB, 500/1000/2000 Hz	-.72	.89	.61	.05	.46	.41	.47	.44
Highest frequency heard		-.62	-.43	-.22	-.46	-.08	-.20	-.33
Average in dB, 125/500/1000 Hz			.57	-.02	.44	.39	.55	.38
Hearing level, 125 Hz			.39	-.05	.40	.17	.40	.24
Hearing level, 250 Hz			.39	.04	.29	.33	.34	.23
Hearing level, 500 Hz			.42	-.06	.18	.43	.50	.25
Hearing level, 750 Hz			.57	.07	.44	.37	.48	.38
Hearing level, 1000 Hz			.62	.10	.47	.40	.42	.48

(df = 38 p(05) = .31 p (01) = .40 p(.001) = .51) icant correlation with total score and with manner and vowel errors. The relationship is difficult to display because of the small number of children in the upper frequency groups. However of the 14 children with hearing at 2000 Hz and higher, 9 were above the mean of 44% correct on the phoneme recognition test.

Inasmuch as the response level at 1000 Hz was highly correlated with several parts of the test, the responses were examined with subjects divided according to response level at that frequency. There were 8 children with hearing levels at 1000 Hz of 95 dB or better; 16 with hearing levels of 100-105 dB; 11 with hearing levels of 110 dB; and 5 with no response at 1000 Hz at 110 dB. For each section of the test a mean score was obtained for each of these groups of children. These group means for percentage of correct response to each type of test item are shown in Figure 2. Responses to items concerned with place of articulation are not included since they show little change as the result of hearing level at this frequency.

With a single reversal, the proportion of correct response to vowel items in the poorest hearing-level group (Group 4), the correct responses increase as the hearing level at 1000 Hz improves. The smallest improvement occurs between groups 2 and 3 , comprising children whose hearing level at 1000 Hz was 100 to 110 dB. The sharpest improvement is in the responses of Group 1, over Group 2, on vowel items and those involving manner of articulation. Manner items are best for all groups and place-manner items poorest. Voicing items are a little poorer than manner items, and vowel items considerably poorer, for Groups 2 and 3. If considered separately, children

Fig. 2. PERCENTAGE OF CORRECT RESPONSE TO ITEMS ON PHONEME RECOGNITION TEST, SUBJECTS GROUPED ACCORDING TO HEARING LEVEL AT 1000 Hz.


% CORRECT
0
20
40
60
80
CHANCE
RESPONSE
VOWEL
MANNER
PLACE
MANNER
VOICE
GROUP 4
NR
110 dB
N=5
GROUP 3
110 dB
N=11
GROUP 2
100-105 dB
N=16
GROUP 1
95 dB
OR BETTER
N=8
HEARING LEVEL AT 1000 Hz

of deaf parents made the same number of errors as the whole group on items of place and place-manner of articulation. They made 6% more errors on items of manner of articulation and voicing, and 12% more errors on vowel items.

Speech approximation test

Scores for correct response on the speech approximation test ranged from 35 to 75 out of a possible 90. The tonal portions correlated with hearing level at 500 Hz and had a moderate correlation (p less than .05) with intelligibility. However, this experimental procedure did not show the close relationship with various aspects of speech production that had been expected, and raw data only are reported. The major problem with the tonal portion of the test was not that the children performed poorly in the task but that they performed too well, probably because the contrasts offered in the test stimuli were too gross, and the children therefore could not be differentiated on the basis of the scores. It is hoped that refinement of the stimuli in future will improve the usefulness of the procedure. The interested reader will find details of the procedure in Appendix C-4 .

II Speech production.

Analysis of intelligibility data

An intelligibility score was obtained for each child from the responses of naive listeners to the recorded speech of the children. This was a percentage of words correctly understood (average of all listeners) as a function of selected key words in the 20 sentence list. In addition, each listener gave each child an intelligibility rating from 1 to 5, with 1 representing best intelligibility, and these ratings were averaged for each child. The intelligibility score represented an objective measure of the listeners' responses to the children's speech and the intelligibility rating represented their subjective opinion of the speech. These two measures were not always consistent. Listeners sometimes gave a child a high rating for intelligibility when, in fact, they had understood few words correctly.

The words in the sentence lists were ranked in order of the number of times they were correctly understood. For the selected words that were scored, the range was from mommy, understood 58.3% of the time, to dishes, zero percent. Despite precautions taken with the sentence vocabulary (Chapter 3) some of the words were unfamiliar to some of the children. Child # 15 hesitated so long at six different places in the sentence list that the experimenter supplied the word. The child then repeated it, but these words were not scored. A number of children had difficulty with the words Duke and huge, which were frequently given as /dʌk/ and /hʌgi/. Unfamiliarity might be expected to have an adverse effect on word intelligibility. The lowest reading level of the group of children, from scores obtained 3 months prior to testing, was 2.0. However, such words as dog, ball, and Bob, which would be known to a child at the lowest reading level, were intelligible a smaller percentage of the time than others which would belong to a higher reading level, such as piece, shopping and behave. This suggests that unfamiliarity of words had a small effect.

This impression is corroborated when each of the 20 sentences that were read by all the children is inspected, with children pooled, for proportion of words correctly understood. The mean intelligibility in percent for each sentence is shown in Table 7. All the sentences were less intelligible when spoken by the younger than when spoken by the older children. However, there does not appear to be a particular pattern related to sentence length or possibly difficult words. Sentence 8, which is short and composed of familiar words, is the poorest understood, for both younger and older children. Sentence 20, for which the same description holds, is among the poorest, for the younger children. Sentence 4, which is longer, is better, and sentence 5, which contains more advanced words, from a reading level standpoint, than sentence 4, is better yet.

Table 8 shows the results of an analysis of variance between sentences, children and listeners. There is a large, highly significant variation in intelligibility between children, a moderately large variation in intelligibility between sentences, and a relatively small, yet statistically significant interaction between children and sentences. A separate analysis showed between-listener effects to be negligibly small compared to the between-subject and between sentence differences.

In Table 9 are shown the mean and standard error of intelligibility scores for all children and for the groups with hearing and with deaf parents. The differences between groups are greater than were found between the same groups for scores on the phoneme recognition test, but similar in direction.

TABLE 7

MEAN INTELLIGIBILITY IN PERCENT FOR EACH OF 20 SENTENCES. ENTRY IS PERCENTAGE OF ALL WORDS CORRECTLY UNDERSTOOD.

Sentence	No. of words	Older children	Younger children	All children
1	5	44.7	27.7	36.1
2	7	41.4	27.9	34.6
3	10	32.8	9.7	21.3
4	10	33.3	14.9	24.1
5	9	29.3	15.7	22.5
6	7 - 7*	37.7	12.8	25.3
7	8 - 4	31.8	9.3	20.6
8	6 - 3	16.6	4.3	10.5
9	7	26.9	14.3	20.6
10	11 - 5	16.8	5.0	10.9
11	8 - 4	23.8	8.6	16.2
12	6 - 6	19.2	9.9	14.5
13	8	16.7	9.9	13.3
14	5 - 2	27.4	9.3	18.3
15	10	31.0	8.2	19.6
16	8	25.6	9.2	17.3
17	8	29.2	5.4	17.4
18	7	29.8	7.6	18.7
19	7	28.9	20.0	24.3
20	6	25.6	8.6	17.1

*The utterance consisted of two sentences. Number of words in each is shown.

TABLE 8

RESULTS OF ANALYSIS OF VARIANCE OF SENTENCES, CHILDREN AND RATERS

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F RATIO
Sentences	11.79	19	.621	29.4
Children	100.55	39	2.578	122.7
Sentences x children	50.13	741	.068	3.2
Replications	33.40	1600	.021	

TABLE 9 COMPARISON OF INTELLIGIBILITY SCORES OF CHILDREN, ACCORDING TO PARENTS' HEARING.

	ALL CHILDREN	OLDER, HEARING PARENTS	YOUNGER, HEARING PARENTS	YOUNGER, DEAF PARENTS
N	40	19	12	8
Mean	18.7%	28.5	14.2	4.2
$s_{\bar{x}}$	3.2	5.6	2.6	1.5

Analysis of phoneme production.

Reliability of raters. The 5 identical sentences transcribed for inter-rater reliability by each of the twelve participating phoneticians were examined one phoneme at a time. A point was scored against a rater each time his opinion was not that of the majority. If there was no majority (there were sometimes as many as 7 different transcriptions of the same phoneme production given) a point was scored against each of the twelve. The mean number of disagreements noted in this way, for the 120 phonemes in the 5 sentences, was 40.6 (standard error 1.5) or about 33%. In order to minimize the error of failure to recognize a true difference, the number of disagreements of each rater was examined for divergence from the mean at the 90% confidence level ($t_{.10} = 1.81$). One rater of the twelve exceeded the desired confidence level, at $t=1.85$. The four tapes transcribed by this rater contained a total of two sentences per child. His bias was chiefly to hear vowel quality closer to target than the other raters and to note the presence of phonemes where others noted omissions. Had he been entirely consistent with the others, the effect would be to increase slightly the number of omissions and vowel errors, which is already very large. Phonetic raters who received more than one sentence list had different orders of children, and there was probably not much biasing effect of any one rater.

Analysis of data . The transcribed sentences of all the children were translated into a numerical code, from which the following matrices were produced by computer:

1. Pooled confusion matrix (all words): all phonemes in 20 sentences, with sentences and children pooled. This matrix included entries not only for all target phonemes but also for non-English phonemes that were substituted, unidentifiable substitutions and omissions.

2. Pooled confusion matrix (selected words); similar to the above, except that selected key words in the 20 sentences were used. Sentences and children pooled. This matrix appears as Appendix E-1. Except where otherwise stated, the analysis and discussion of pooled phonemes refers to this matrix.

3. Confusion matrices as in (2) for each of the 40 children.

4. One matrix per sentence, with children pooled, to examine the errors of phonemes in specific environments.

5. Matrix of phonemes classified by type of error, i.e., errors of place, manner and voicing for consonants, and of frontness, height, rounding and free vs. checked for vowels, with sentences and children pooled. (Appendix E-2)

6. Similar matrix for each child.

7. Matrix of interpolated elements occurring in conjunction with each phoneme; added release or attack sounds or syllables, intrusive or excrescent phonemes and nasalization.

Over-all errors. The selected words used in the analysis contained 200 consonant and 110 vowel and diphthong tokens that were analyzed, for a total of 12,400 phonemes analyzed for the 40 children. There were 1105 identifiable vowel and diphthong errors, or 25% of all vowels and diphthongs; 1899 identifiable consonant errors, or 24 % of all consonants. In addition, there were 490 unidentifiable substitutions and 1792 omissions for a total of 5286 errors on target phonemes or about 43%.

Table 10A shows the target consonant phonemes in rank order of percent correct production, for all occurrences in selected words, and the percentage of occurrences in initial, medial and final position that were errors. The figures in parentheses are the percentage of occurrence of each phoneme in each position that were omissions.

Consonants with a bilabial place of articulation head the list of correct productions, followed by all the glides, and /f/, /v/ and /n/. Plosives in the alveolar and velar region, /h/ and the lingua -dental fricatives follow. Near the bottom are /ŋ/ and the alveolar and palatal fricatives. Affricates have the greatest proportion of error.

The single most frequent error for nearly all consonants was omission. The only exceptions were /p/ and /b/, which were substituted for each other, with the voiceless-to-voiced error considerably more frequent; /f/ for which /v/ was substituted; /θ/ and /ð/ which were replaced by /t/ and /d/; and /w/ for which /b/ was the most frequent substitution.. While there is no difference in the mean proportion of errors in initial and medial position, there is a marked increase for errors in the final position and a major proportion of these were omissions. The glottal stop was a frequent substitution for the plosives (except bilabial plosives) and also for /h/.

/p/, /t/, /k/, and /s/ were analyzed in cluster positions in 9 sentences read by the older children only. There was generally omission of one element or the other in these clusters (Table 10 B). For example, 10% of all occurrences of initial /s/ were omissions, while

TABLE 10 A RANK ORDER OF % CORRECT PRODUCTION OF CONSONANT PHONEMES IN SELECTED WORDS, AND % ERROR EACH WORD POSITION.

Phoneme+	Number of occurrences (40 children)	% Correct production	% Error and (%omission) for occurrences in each word position.#					
			Initial		Medial		Final	
/b/	400	85	11	(1)	10	(10)	43	(15)
/w/	400	79	23	(1)	30	(3)	--*	
/m/	520	72	34	(1)	25	(3)	29	(10)
/p/	280	70	25	(0)	26	(≠0)	39	(10)
/f/	360	70	24	(2)	33	(5)	45	(15)
/l/	480	70	26	(8)	24	(10)	37	(25)
/v/	240	64	40	(3)	27	(6)	49	(25)
/n/	680	61	26	(5)	36	(20)	40	(30)
/r/	360	55	38	(1)	76	(20)	--	
/j/	40	53	50	(15)	--		--	
/d/	600	40	41	(8)	43	(24)	65	(39)
/k/	640	40	53	(16)	50	(20)	74	(44)
/h/	400	39	56	(33)	68	(35)	--	
/θ/	200	38	63	(1)	64	(13)	58	(13)
/ð/	240	38	70	(5)	43	(5)	55	(13)
/t/	560	37	41	(4)	68	(55)	73	(41)
/g/	160	36	48	(1)	63	(15)	100	(67)
/ŋ/	120	30	--		76	(44)	90	(80)
/s/	280	24	75	(10)	75	(10)	76	(39)
/ʃ/	120	22	65	(5)	80	(15)	90	(32)
/z/	600	21	72	(0)	60	(8)	83	(50)
/dʒ/	120	18	73	(5)	--		88	(55)
/tʃ/	160	16	78	(5)	80	(16)	95	(47)

+ /hw/ and /ʒ/ were not targets.
* no occurrence.
\# For example, 43% of occurrences of final /b/ were errors. This included 15% of occurrences that were omissions.

TABLE 10 B OCCURRENCE OF ERROR IN CERTAIN CLUSTERS. OLDER CHILDREN.

Phoneme	For occurrences in initial clusters		For occurrences in final clusters	
	% Error	% Omission	% Error	% Omission
/p/	35	5	20	10
/t/	30	10	63	45
/k/	70	40	58	35
/s/	72	47	74	54

47 % of all occurrences of /s/ in initial clusters were omissions. This increased to 54% of occurrences of /s/ in final clusters, against 39% for final /s/ alone.

The total errors of each consonant phoneme were separated into the classes of single feature errors (place, manner, or voicing), two-feature errors (place and manner, place and voice, manner and voice) and three-feature errors (place, manner and voicing.) Table 11 shows, for each consonant phoneme, the percentage of all the errors of that phoneme that could be placed in these categories.

Among voiced-voiceless cognates, substitution toward the voiced member of the pair was more common than substitution toward the voiceless. For example, 57.8% of all errors of /p/ are shown as simple voicing errors, represented by the substitution of /b/. Except for the glottal stop substitution, errors of manner and voicing predominated over errors of place of articulation. The low proportion of distortions will be noticed. This is partly due to the fact that the phoneticians were encouraged to transcribe broadly. If a phoneme was recognizable as itself, they tended to give it its phonemic symbol with no other indications. Another factor is the large number of omissions. /ŋ/ for example is never transcribed as distorted. It cannot be distorted because it is seldom produced at all. The fairly large number of distortions and unidentifiable substitutions for /b/, the phoneme most often produced correctly, is explained by the fact that /b/ was seldom omitted; the four bilabial consonants all have low percentages of omission. The other consonant with a low proportion of omissions is /ɣ/, which was replaced in the major portion of occurrences by /d/.

The percentage of errors for vowel phonemes are shown in Table 12,

TABLE 11

CONSONANT PHONEME ERRORS ACCORDING TO FEATURE. EACH ENTRY IS A PERCENTAGE OF THE TOTAL ERROR OF THE GIVEN PHONEME. DATA POOLED OVER ALL CHILDREN.

Phoneme	One feature			Two feature				Omissions	Distortions	Unidentifiable substitutions	Total*
	Place	Manner	Voice	P-M	P-V	M-V	P-M-V				
/b/	3.5	26.3	28.0	3.5	1.8	0.	0.	15.7	5.3	15.7	99.7
/w/	2.4	40.0	0.	31.8	0.	1.2	0.	7.1	3.5	12.9	98.8
/m/	0.	63.1	0.	3.4	0.	9.4	1.3	14.1	1.3	7.4	99.8
/p/	2.4	0.	57.8	3.6	1.2	14.5	3.6	10.8	2.4	2.4	98.7
/f/	3.7	0.	32.7	10.9	0.	0.	24.3	13.1	1.9	14.0	99.9
/l/	0.	.7	0.	19.9	0.	0.	12.0	49.6	1.4	15.6	99.2
/v/	0.	0.	30.0	33.3	0.	0.	3.4	26.4	2.3	4.6	99.9
/n/	4.9	6.7	0.	5.2	0.	3.4	6.7	65.9	.3	6.7	99.9
/r/	27.3	1.2	0.	18.6	0.	0.	2.5	31.1	3.1	16.1	99.9
/j/	0.	15.8	0.	42.1	0.	0.	5.3	31.6	0.	5.3	99.9
/d/	2.5	3.0	10.2	5.5	12.5	.5	1.3	54.7	.2	8.8	99.3
/k/	16.6	3.3	9.0	11.2	2.6	1.0	2.3	45.5	.7	7.5	99.6
/h/	1.2	16.7	.4	2.9	.4	0.	9.8	57.9	0.	10.2	99.5
/θ/	1.6	0.	8.1	33.1	2.4	0.	30.6	13.7	4.0	6.5	99.9
/ð/	1.3	0.	6.0	67.8	.6	0.	8.7	10.1	.6	5.4	100.
/t/	20.4	1.1	11.6	3.3	1.6	2.0	2.3	50.9	.8	5.4	99.4
/g/	1.4	3.8	7.8	3.9	13.6	2.9	3.9	46.6	1.9	13.6	99.9
/ŋ/	10.7	0.	0.	1.2	0.	0.	6.0	80.9	0.	1.2	99.9
/s/	7.0	18.9	3.3	6.1	1.4	11.7	4.7	35.0	2.3	9.3	99.4
/ʃ/	16.0	2.1	2.1	34.0	2.1	2.1	9.6	22.3	2.1	7.4	99.9
/z/	3.3	9.7	5.6	3.3	2.7	1.6	6.2	54.8	2.7	10.5	99.9
/dʒ/	0.	10.1	1.0	22.2	0.	5.1	8.1	46.5	1.0	5.1	99.0
/tʃ/	0.	9.8	0.	47.4	0.	3.	8.3	25.6	2.3	3.8	99.9

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* Deviations from 100% due to rounding errors.

with vowels ranked in order of correct production. All vowels and diphthongs that occurred in the selected words of the 20 sentence list are shown in the table. However, the sentence list was designed to display only /i/, /æ/ and /u/ ; other vowels occurred randomly. For this reason, two English diphthongs, /aU/ and /ɔI/, do not occur at all.

TABLE 12 OCCURRENCE OF VOWEL PHONEME ERRORS IN SELECTED WORDS, 20SENTENCE LIST. CHILDREN POOLED. RANK ORDER OF % CORRECT.

Phoneme	Occurrences (40 children)	% Error
/ʌ/	40	7.5
/ɑ/	360	15.8
/ɛ/	280	21.0
/u/	360	25.3
/æ/	800	25.4
/U/	80	26.3
/I/	640	30.8
/ɔ/	240	32.9
/oU/	200	36.0
/i/	920	38.4
/aI/	200	41.5
/ə/	240	47.9
/eI/	240	48.3
/ɝ/	40	60.0
/ju/	40	80.0
/ɚ/	40	85.0

Of the vowels of particular interest, /u/ had the lowest percentage of error, with /æ/ essentially identical and /i/ considerably poorer. There was no systematic tendency for any particular consonant environment to effect one of these more than another.

The low central vowels were most often produced correctly, and there was a tendency for all vowels to drop to a more neutral position. /i/ and /I/ were the most frequent substitutions for each other, with /I/ being substituted for /i/ a little over twice as often as /i/ was substituted for /I/ /U/ was the most frequent substitution for /u/ but /ʌ/ was substituted for /U/ more often than was /u/ . /ʌ / was also the most frequent substitution for /ɑ/. /u/ became diphthongized frequently as did /ɔ /. The commonest error in the diphthongs was failure of the off-glide, or, in the case of /ju/, of the on-glide. Many vowel phonemes could not be described in terms of any standard target and were labelled as unidentifiable substitutions.

Instances of added sounds and syllables were analyzed in conjunction with each phoneme. These occurrences, combined for all phonemes, are shown as Table 13.

TABLE 13 OCCURRENCE OF ADDED SOUNDS AND SYLLABLES IN CONJUNCTION WITH ALL VOWELS AND CONSONANTS.

	Added attack vowel	Added attack cons.	Preceding advent. syllable	Added release vowel	Added release cons.	Following advent. syllable
Vowels	5	133	9	87	43	31
Consonants	20	79	11	182	21	43

	Intrusive vowel	Excrescent consonant	Nasalization
Vowels	14	60	534
Consonants	81	66	18

For vowels, nasalization and added attack consonants were the most frequent errors. For consonants, an added release vowel, generally in word final position, was the most frequent error.

There was a much greater tendency for certain errors in phoneme production to occur together than others. These relationships are shown in Table 14. Total vowel errors have the highest correlation with total number of phoneme errors and also with prosodic score. Errors of manner, omissions and errors of place and manner all have some intercorrelations, but place errors have a low correlation with other aspects and voicing errors none at all.

Analysis of prosodic data The analysis of prosodic or suprasegmental aspects of the children's speech, performed by three speech pathologists, was in terms of 19 separate variables of voice quality, pitch, phonatory control, intonation, stress, fluency and rate of speech. For 13 of these parameters, there was agreement of all three raters on at least 50% of the children. These were harsh or breathy voice quality, voice pitch (too high or too low), intermittent phonation, spasmodic variations of pitch and loudness, insufficient or excessive variability of intonation, inappropriate stress, and rate of speech (too fast, too slow, monotonous, uncontrolled variability.) The children's scores on these variables were subjected to factor analysis. The anticipated reduction of the data did not occur; at least 8 factors were required to account for 89% of the variance. This suggested that the various errors operated independently of one another. However, the strongest loadings appeared to be on variables concerned with rate, and with control of pitch and intonation. Results of the factor analysis appear in Appendix E-3. Since these were not clear cut, it was decided to examine, as the prosodic score for each child, the total number of aspects judged abnormal or inadequate in his speech, by all three raters. Thus a high score indicated that a child's speech presented many abnormalities in suprasegmental aspects, in the opinion of the raters; a low score, that

TABLE 14

VALUES OF THE CORRELATION COEFFICIENT FOR COVARIANCE OF ERRORS IN SPEECH PHONEME PRODUCTION

	Place errors	Manner errors	Voicing errors	Vowel errors	Omissions	Place-manner errors	Place-voice errors	Manner voice errors	Place-manner voice	Prosodic score
Total errors	.39	.55	.09	.89	.82	.51	.37	.23	.58	.58
Place errors		.09	-.20	.31	.32	.15	.50	.20	.37	.04
Manner errors			-.06	.36	.45	.36	.19	.29	.45	.22
Voicing errors				.27	-.19	-.01	-.11	-.09	.10	.00
Vowel errors					.59	.38	.24	.14	.36	.61
Omissions (all types)						.39	.31	.24	.50	.36
Place-manner errors							.13	.13	.30	.27
Place-voice errors								.18	.52	.16
Manner-voice errors									.01	-.19
Place-manner-voice errors										.24

(df = 38 p(.05) = .31 p(.01) = .40 p(.001) = .51)

few abnormalities were judged to be present. This total score had a correlation of .58 with the total phoneme errors. The correlations of all the separate prosodic variables with all types of speech phoneme error, may also be seen in Appendix E-3.

Relation of speech production errors to intelligibility

Table 15 presents a summary of all speech production characteristics of the children, arranged by quartiles of intelligibility. The intelligibility scores ranged from 76.1% down to zero percent, and the distribution is non-symmetrical. While the mean is at 18.7%, the median is at 11.5%, and one quarter of the scores cover nearly half of the range.

The selected words in the sentence list presented 310 target phonemes 200 consonants, 110 vowels. Based on this number of targets, the children as a group made 15.4% consonant errors (mean); an additional 14.5% omissions; 9% vowel and diphthong errors; 4% unidentifiable substitutions. The consonant and vowel errors included in these percentages are on identifiable errors only, and do not include those errors represented by the categories of omissions and unidentifiable substitutions. It will be noted that vowel and diphthong errors were 2/3 as great in proportion as all consonant errors, although there were only half as many vowels in the speech sample as consonants.

Figure 3 displays the mean percentage of each type of speech error for each quartile of intelligibility. Errors of place-manner-voice,place-voice and manner-voice are omitted from the figure, since their total percentage for all children was 3.5%. It may be seen that place errors are virtually the same for all quartiles of intelligibility

TABLE 15

SPEECH PRODUCTION CHARACTERISTICS OF SUBJECTS

	Subject	Age group, parents' hearing*	Total phoneme errors (Possible 310)	Intelligibility score	Total prosodic score (Possible 39)	Intelligibility rating +
1 st Quartile	8	o-h	77	76.1	10	2.3
	10	o-h	75	64.6	7	2.3
	7	o-h	47	61.7	10	2.3
	20	o-h	61	60.9	6	2.3
	17	o-h	92	46.9	8	2.3
	6	o-h	78	44.9	3	2.7
	13	o-h	80	42.4	10	2.3
	26	y-h	114	30.5	14	3.0
	27	y-h	114	26.7	11	3.0
	12	o-h	133	26.3	9	3.3
2 nd Quartile	4	o-h	127	25.9	6	2.7
	24	y-h	124	23.0	10	3.0
	33	y-h	137	21.0	13	3.0
	9	o-h	98	16.9	16	3.0
	30	y-h	119	15.6	10	3.3
	19	o-h	124	14.8	14	3.7
	2	o-h	120	14.8	5	3.7
	22	o-h	107	13.2	8	3.3
	23	o-h	105	12.8	15	3.7
	16	y-h	162	12.3	15	4.7
3 rd Quartile	21	y-h	139	10.7	11	3.0
	36	y-d	142	10.3	15	4.7
	37	y-d	161	9.5	14	4.3
	14	o-h	130	9.5	13	4.0
	39	y-h	154	9.1	10	4.0
	32	y-h	164	7.4	13	4.7
	34	y-d	148	7.0	10	3.3
	29	y-h	177	5.8	18	4.3
	25	y-h	164	5.8	12	4.7
	11	o-h	107	5.3	11	3.7
4 th Quartile	40	y-d	142	3.3	12	4.0
	3	o-h	208	3.3	15	5.0
	15	y-h	199	2.9	17	4.7
	38	y-d	172	2.1	13	3.7
	28	y-d	191	1.2	15	4.7
	1	o-h	160	1.2	10	4.0
	35	y-d	179	.4	12	4.3
	18	o-d	225	.4	12	4.3
	5	o-h	145	.4	17	4.7
	31	y-d	213	.0	20	5.0

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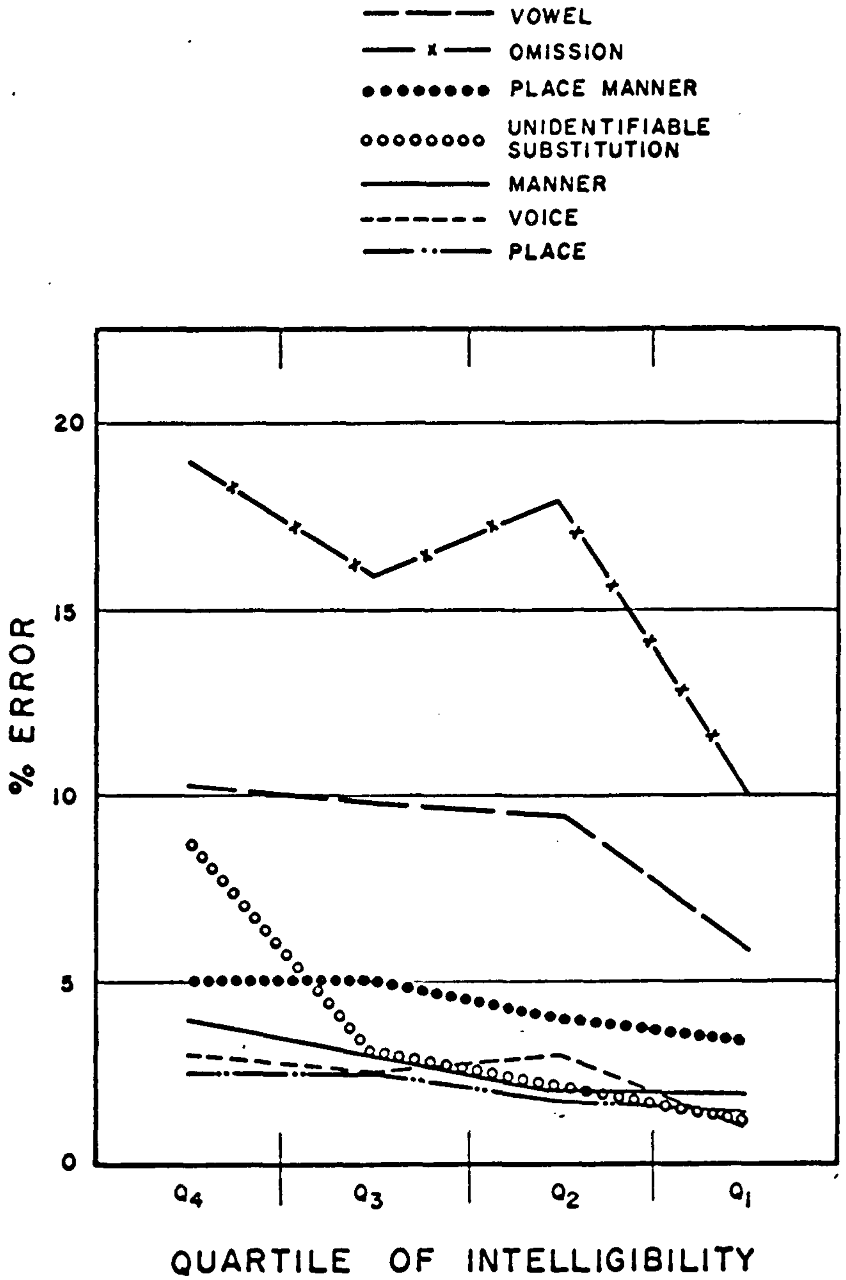
* o: older y: younger
h: hearing d: deaf

\+ 1 = best rating

Fig. 3 PHONEME PRODUCTION ERRORS ACCORDING TO QUARTILES OF INTELLIGIBILITY. PERCENTAGES BASED ON ALL PHONEMES IN SELECTED WORDS. ERRORS OF PLACE-VOICE, MANNER-VOICE, AND PLACE-MANNER-VOICE OMITTED.


VOWEL
OMISSION
PLACE MANNER
UNIDENTIFIABLE SUBSTITUTION
MANNER
VOICE
PLACE
% ERROR
20
15
10
5
0
Q4
Q3
Q2
Q1
QUARTILE OF INTELLIGIBILITY

and that voicing errors also remain much the same, with a reversal in direction between the second and third quartile. There is a systematic decrease in percentage of omissions, manner errors and place-manner errors in going from the fourth to the first quartile. The rate of decrease in vowel errors becomes substantially greater between quartiles 2 and 1 and there is a very large decrease in unidentifiable substitutions between quartile 4 and quartile 3.

The older and younger children of deaf and of hearing parents were inspected by groups for differences in phoneme production errors and in prosodic score. The mean and standard error for these groups, with the result of the _t_ test, are shown in Table 16.

TABLE 16 COMPARISON OF PHONEME PRODUCTION ERRORS AND PROSODIC SCORES OF CHILDREN, ACCORDING TO PARENTS' HEARING.

Phoneme errors

	ALL CHILDREN	OLDER, HEARING PARENTS	YOUNGER, HEARING PARENTS	YOUNGER, DEAF PARENTS
N	40	19	12	8
Mean	135.9	110.2	147.3	168.5
$s_{\bar{x}}$	6.6	8.4	7.8	8.9
t			3.21+ df = 29	1.78 df = 18

+ p less than .01

Prosodic score

Mean	12	10.7	12.8	13.9
$s_{\bar{x}}$	.56	.89	.78	1.0
t			1.80 df = 29	.79 df = 18

In total errors of phoneme production, a significant difference appears between the older and the younger children. No differences between any of the groups are displayed by the prosodic score. The mean phoneme production errors of these same groups are shown in Figure 4. It will be noted that vowel errors, omissions and unidentifiable substitutions show the most marked differences between groups, with errors of place, voice and manner differing only slightly from one to another.

The intelligibility scores predicted by the total phoneme errors ($r = -.80$) were obtained by means of a straight line regression. Deviations from this predicted score appear to be linked to prosodic errors, among other variables. These deviations are shown in Figure 5. Data are shown separately for older and younger children, and hearing of the parents is indicated as a parameter. The deviation of intelligibility scores of the older children from the predicted score follows a consistent pattern. A lower prosodic score is reflected in intelligibility that is higher than the predicted, while a higher prosodic score is associated with intelligibility lower than the predicted. For the younger children, the deviations from the predicted scores are smaller, and the pattern of the residuals, if any, appears to be reversed. The intelligibility of younger children would appear to be predicted to a greater extent by the number of phoneme errors in their speech.

Table 17 presents values of the correlation coefficient for the various classes of speech production errors, the intelligibility score and the intelligibility rating. This table corroborates the information seen in the graph of Figure 3. Place errors have no sig-

Fig. 4 PHONEME PRODUCTION ERRORS OF CHILDREN ACCORDING TO PARENTS' HEARING. PERCENTAGES BASED ON ALL PHONEMES IN SELECTED WORDS. ERRORS OF PLACE-VOICE, MANNER-VOICE AND PLACE-MANNER-VOICE OMITTED .

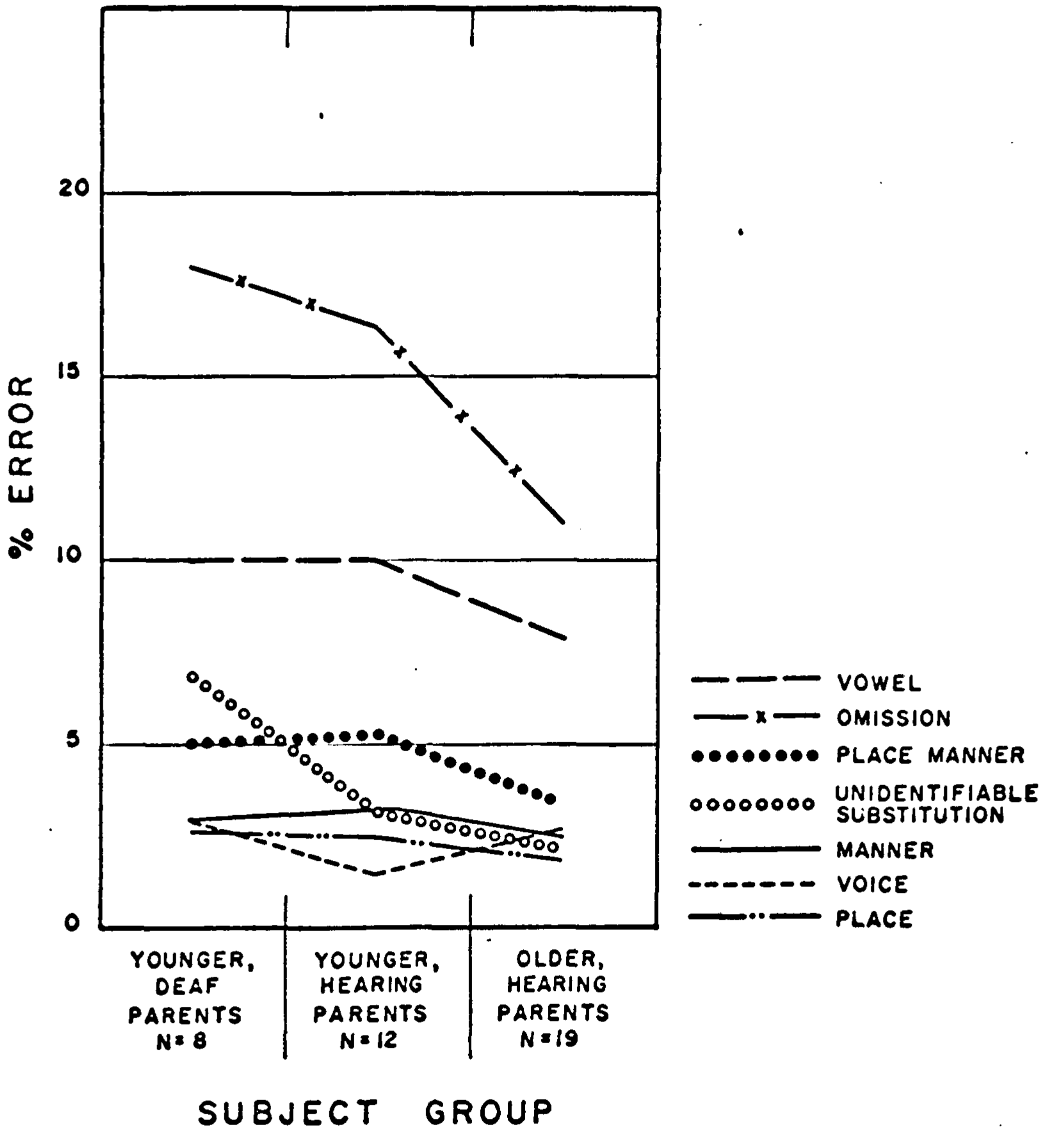

% ERROR
20
15
10
5
0
YOUNGER, DEAF PARENTS N = 8
YOUNGER, HEARING PARENTS N = 12
OLDER, HEARING PARENTS N = 19
SUBJECT GROUP
VOWEL
OMISSION
PLACE MANNER
UNIDENTIFIABLE SUBSTITUTION
MANNER
VOICE
PLACE

FIG. 5 DEVIATION FROM INTELLIGIBILITY PREDICTED BY TOTAL SPEECH PHONEME ERRORS ($r = -.80$) AS A FUNCTION OF PROSODIC SCORE. PREDICTED INTELLIGIBILITY NORMALIZED TO ZERO.

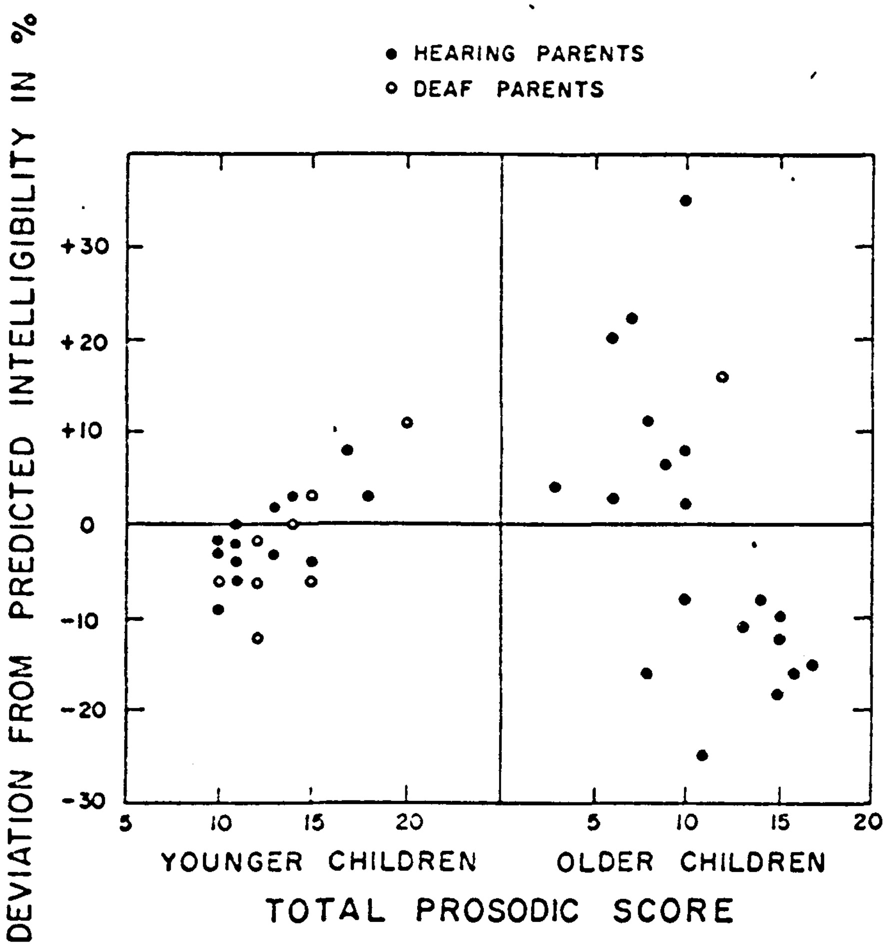

● HEARING PARENTS
○ DEAF PARENTS
DEVIATION FROM PREDICTED INTELLIGIBILITY IN %
+30
+20
+10
0
-10
-20
-30
5
10
15
20
5
10
15
20
YOUNGER CHILDREN
OLDER CHILDREN
TOTAL PROSODIC SCORE

TABLE 17

VALUES OF THE CORRELATION COEFFICIENT FOR SPEECH PRODUCTION ERRORS, INTELLIGIBILITY SCORE AND INTELLIGIBILITY RATING

	Intelligibility score	Intelligibility rating
Total phoneme errors	-.80	.87
Place errors	-.20	.24
Manner errors	-.48	.39
Voicing errors	-.36	.26
Vowel and diphthong errors	-.75	.86
Omissions (all types)	-.65	.63
Place-manner errors	-.43	.54
Place-voice errors	-.18	.27
Manner-voice errors	-.33	.15
Place-manner-voice errors	-.49	.44
Total prosodic score	-.37	.62
Intelligibility rating	-.83	

(df = 38 p(.05) = .31 p(.01) = .40 p(.001) = .51)

nificant correlation with intelligibility. Voicing errors, while occurring in large numbers, have a modest correlation with intelligibility. Vowel errors, omissions, and errors involving manner of articulation, in that order, have the strongest correlation with both the intelligibility score and the intelligibility rating.

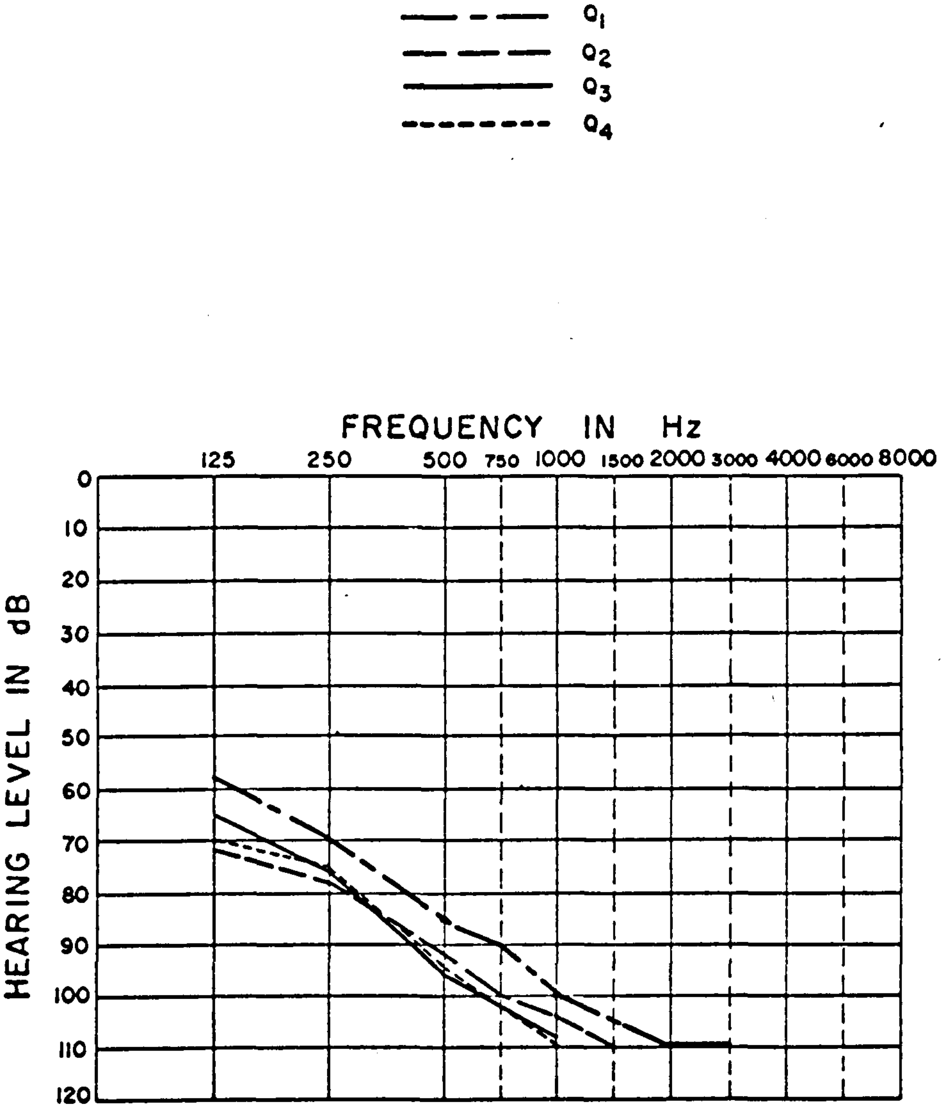
III Relationship of hearing measures to speech production.

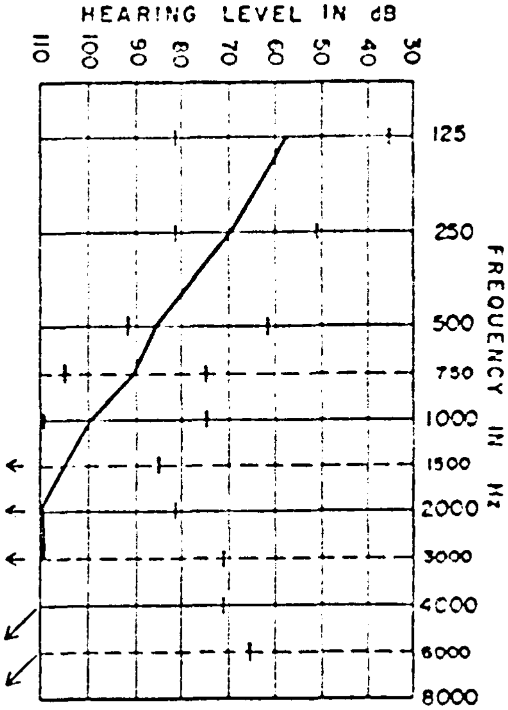
The median and range of hearing levels for each quartile of intelligibility are shown in the audiograms of Figure 6. Quartile 1, the most intelligible children, shows slightly superior hearing sensitivity at all frequencies and, in particular, shows a median response a full octave higher (3000 Hz) than is seen in Quartile 2. Quartile 2 shows a median response out to 1500 Hz, as against 1000 Hz for Quartiles 3 and 4. There is little else to distinguish the medians of Quartiles 2, 3 and 4, but it will be noted that the range, shown at each frequency by the small horizontal marks, becomes steadily poorer in advancing from Quartile 1 to Quartile 4. Connected arrows at the bottom of the audiogram indicate that the median at that frequency is No Response. Arrows not connected, below a frequency, indicate that the bottom of the range is No Response.

Table 18 shows the correlation coefficients for various hearing measures, the intelligibility score and the intelligibility rating. Frequencies above 1000 Hz are not tabled because of the small number of responses. There were, however, no older children with hearing above 1500 Hz in Quartiles 3 or 4. Of the 18 children who responded above 1000 Hz, 13 are in Quartiles 1 and 2. These

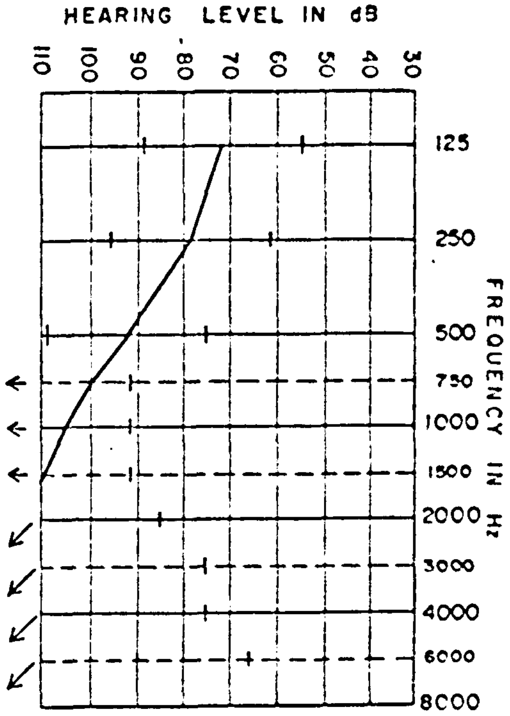
4

Fig. 6. MEDIAN AUDIOGRAMS OF CHILDREN IN THE FOUR QUARTILES OF INTELLIGIBILITY (LARGE FIGURE) AND MEDIAN AUDIOGRAMS FOR EACH SEPARATE QUARTILE (SMALL FIGURES). IN THE SEPARATE AUDIOGRAMS, THE TOTAL RANGE IS SHOWN BY THE SMALL HORIZONTAL MARKINGS AT EACH FREQUENCY.

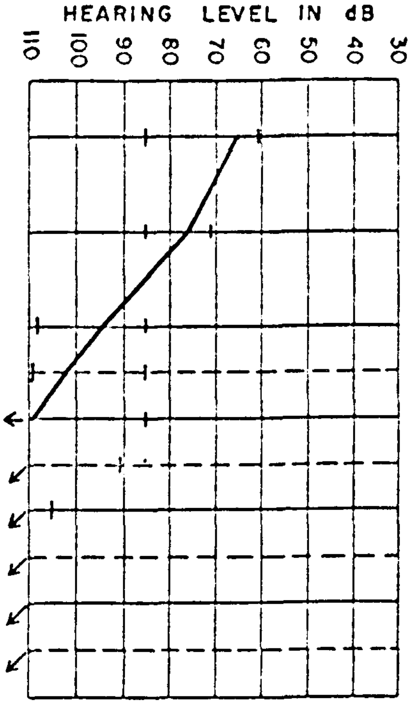

Q_1
Q_2
Q_3
Q_4
FREQUENCY IN Hz
125
250
500
750
1000
1500
2000
3000
4000
6000
8000
HEARING LEVEL IN dB
0
10
20
30
40
50
60
70
80
90
100
110
120


HEARING LEVEL IN dB
110
100
90
80
70
60
50
40
30
125
250
500
750
1000
1500
2000
3000
4000
6000
8000
FREQUENCY IN Hz

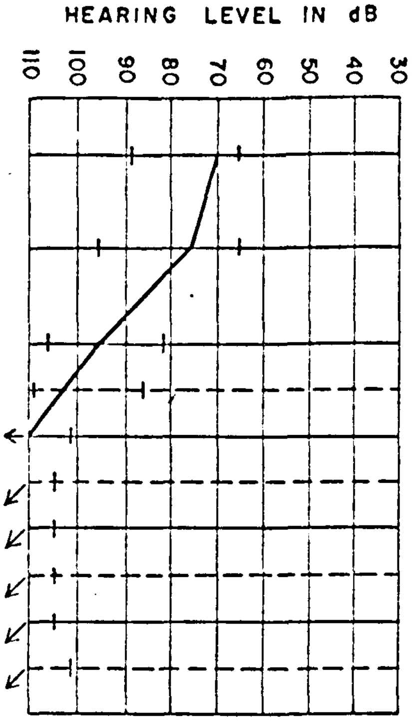
Q1


HEARING LEVEL IN dB
110
100
90
80
70
60
50
40
30
125
250
500
750
1000
1500
2000
3000
4000
6000
8000
FREQUENCY IN Hz

Q2


HEARING LEVEL IN dB
110
100
90
80
70
60
50
40
30

Q3


HEARING LEVEL IN dB
110
100
90
80
70
60
50
40
30

Q4

TABLE 18

VALUES OF THE CORRELATION COEFFICIENT FOR HEARING MEASURES AND INTELLIGIBILITY

	Intelligibility score	Intelligibility rating
Average, 500/1000/2000 Hz	-.59	.58
Average, 125/500/1000 Hz	-.65	.53
Highest frequency, test ear	.35	-.28
Hearing level, 125 Hz	-.54	.35
Hearing level, 250 Hz	-.40	.18
Hearing level, 500 Hz	-.48	.42
Hearing level, 750 Hz	-.57	.56
Hearing level, 1000 Hz	-.55	.56
PRT, total score	.78	-.70
PRT, place errors	.03	.00
PRT, manner errors	-.57	.48
PRT, place-manner errors	-.49	.36
PRT, voicing errors	-.65	.65
PRT, vowel errors	-.63	.56

(df = 38 p(.05) = .31 p(.01) = .40 p(.001) = .51)

included 9 older and 4 younger children.

Contingency tables (2 x 2) were drawn for response/ no response at each frequency 1500 to 4000 Hz, compared with above/ below mean intelligibility. The X^2 computed for these contingency tables appears in Table 19. The relationship is significant at each frequency except 1500 Hz.

TABLE 19 VALUES OF X^2 OBTAINED FROM 2 x 2 CONTINGENCY TABLES FOR HEARING AT HIGH FREQUENCIES AND SPEECH INTELLIGIBILITY

Above/ below mean intelligibility	X^2	Smallest expected cell value
Response/ no resp. 1500 Hz	2.89	7.5
Response/ no resp. 2000 Hz	5.57	4.2
Response/ no resp. 3000 Hz	4.89	3.6
Response/ no resp. 4000 Hz	4.33	2.9

df = 1 X^2 .05 = 3.84 X^2 .02 = 5.41

It will be noted in Table 18 that the average of 125/ 500/1000 Hz has a better correlation with intelligibility than the average of 500/1000/2000 Hz. This is probably due in part to the large number of entries of 115 dB as the response level at 2000 Hz. 750 Hz, a frequency not routinely tested in many audiological facilities, has the highest correlation with intelligibility of any single frequency. However, the phoneme recognition test has the highest correlation of any hearing measure with both the intelligibility score and the intelligibility rating.

These relationships may be examined in scattergrams, Figures 7 and 8. Figure 7 shows the percent speech intelligibility as compared with the average at 125/500/1000 Hz, with parents' hearing as the parameter. It will be noticed that there is no elbow at any point in the data; no hearing level below which speech suddenly deteriorates. This same lack of a definite cut-off is observed if intelligibility is compared in the same manner with the average of 500/1000/2000 Hz. Figure 8 compares phoneme recognition test scores with speech intelligibility. The means of the respective measures are shown in each figure. There is a fairly small number of data points that do not fall into the expected quadrants. Most of those who are above the mean in speech intelligibility are also above the mean score on the phoneme recognition test.

Figure 9 displays the deviations of actual intelligibility scores from those predicted by a straight line regression from scores on the phoneme recognition test. The principal difference in the prediction as a function of age appears to be that older children show a somewhat greater tendency to have higher intelligibility than the predicted. The extent of divergence of actual from predicted intelligibility is very similar for the children of deaf and of hearing parents, though the scores of children of deaf parents are nearly all poorer than predicted.

Table 20 presents values of the correlation coefficient for hearing measures and errors in speech production. There is little difference in the values shown for the two three-frequency averages, and for the individual frequencies 500 Hz, 750 Hz, 1000 Hz., with re-

A

FIG. 7 SCATTERPLOT SHOWING SPEECH INTELLIGIBILITY IN PERCENT AS A FUNCTION OF AVERAGE HEARING AT 125/500/1000 Hz. HEARING OF PARENTS IS THE PARAMETER.

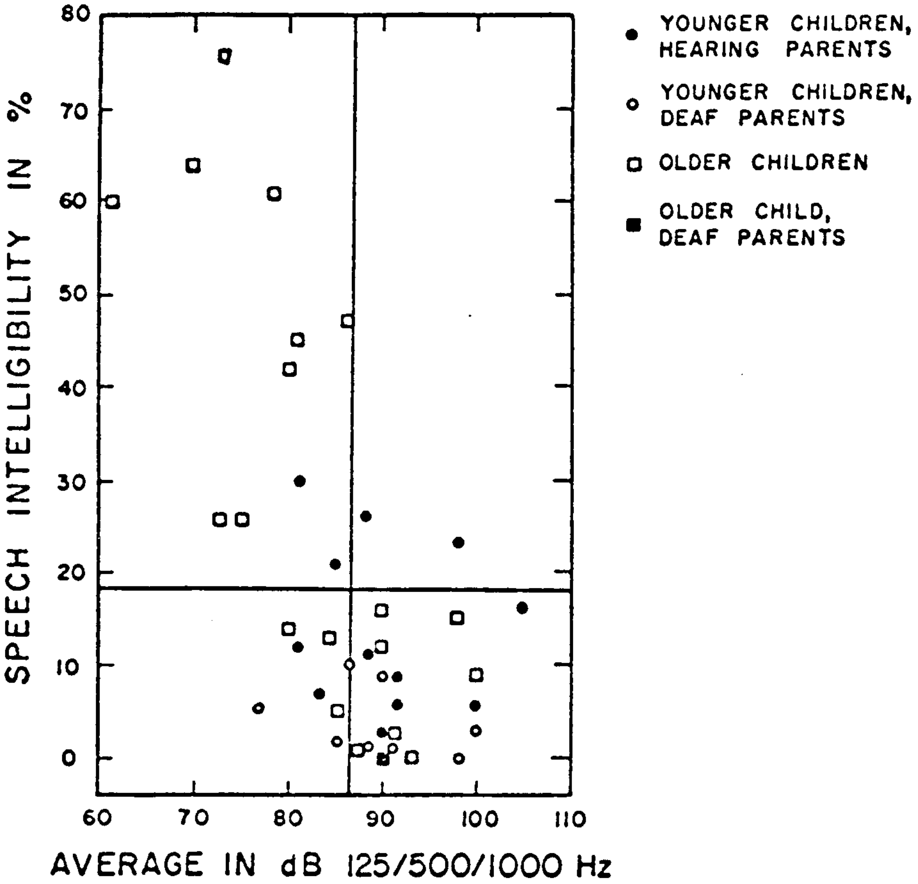

80
70
60
50
40
30
20
10
0
SPEECH INTELLIGIBILITY IN %
60
70
80
90
100
110
AVERAGE IN dB 125/500/1000 Hz
● YOUNGER CHILDREN, HEARING PARENTS
○ YOUNGER CHILDREN, DEAF PARENTS
□ OLDER CHILDREN
■ OLDER CHILD, DEAF PARENTS

FIG. 8 SCATTERPLOT SHOWING PHONEME RECOGNITION IN PERCENT AGAINST SPEECH INTELLIGIBILITY IN PERCENT

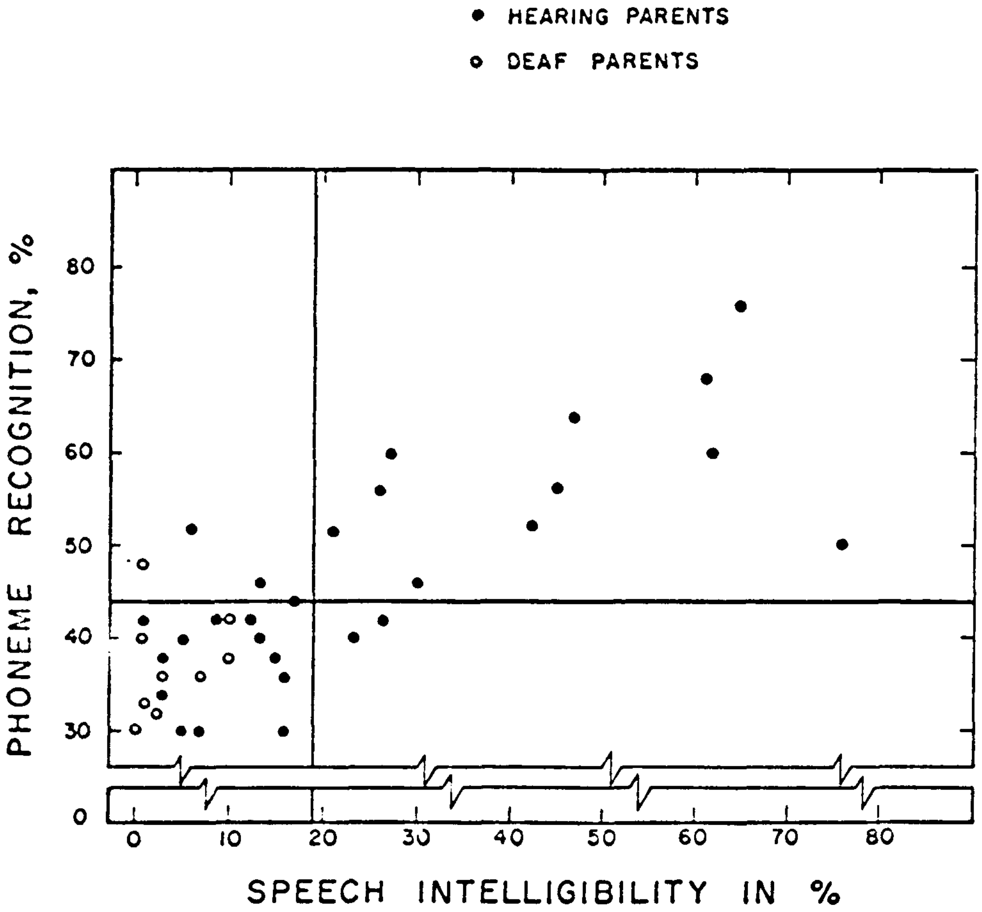

● HEARING PARENTS
○ DEAF PARENTS
PHONEME RECOGNITION, %
80
70
60
50
40
30
0
0
10
20
30
40
50
60
70
80
SPEECH INTELLIGIBILITY IN %

FIG.9 DEVIATION FROM INTELLIGIBILITY AS PREDICTED BY PHONEME RECOGNITION TEST (r = .78) AS A FUNCTION OF AGE. PREDICTED INTELLIGIBILITY NORMALIZED TO ZERO.

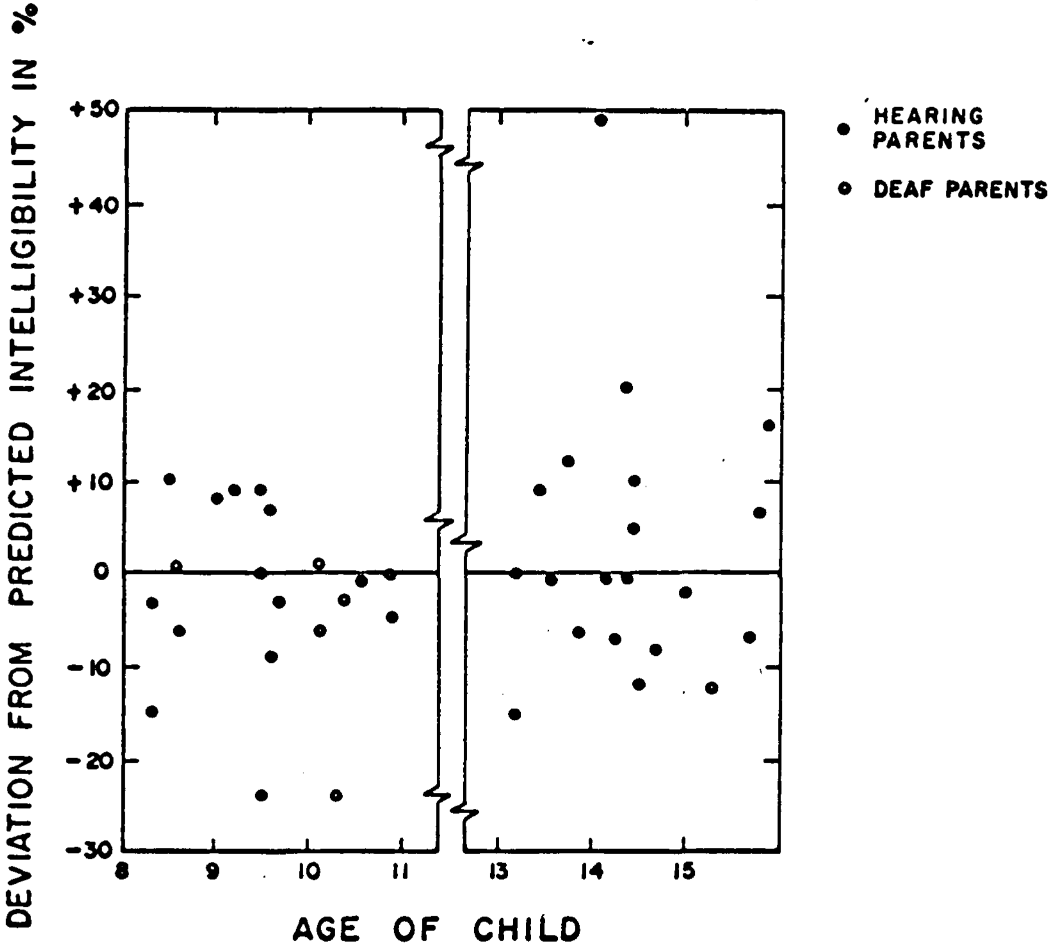

DEVIATION FROM PREDICTED INTELLIGIBILITY IN %
+50
+40
+30
+20
+10
0
-10
-20
-30
8
9
10
11
13
14
15
AGE OF CHILD
● HEARING PARENTS
○ DEAF PARENTS

TABLE 20

VALUES OF THE CORRELATION COEFFICIENT FOR HEARING MEASURES AND ERRORS IN SPEECH PRODUCTION

	Total phoneme errors	Place errors	Manner errors	Voicing errors	Vowel errors	Omissions
Average in dB, 500/1000/2000	.48	-.07	.22	.37	.50	.23
Average in dB, 125/500/1000	.46	-.15	.21	.37	.46	.23
Highest frequency heard	-.13	.10	.02	.40	-.24	.08
Hearing level 125 Hz	.28	-.15	.10	.34	.31	.09
Hearing level 250 Hz	.17	-.28	-.02	.36	.19	.05
Hearing level 500 Hz	.41	-.12	.23	.32	.38	.24
Hearing level 750 Hz	.48	-.03	.09	.34	.54	.29
Hearing level 1000 Hz	.46	-.07	.18	.22	.46	.28
PRT total errors	.64	.08	.28	.23	.61	.54
PRT place errors	-.03	.00	-.07	-.29	.04	.20
PRT manner errors	.42	.17	.06	.28	.43	.30
PRT place-manner errors	.35	.12	.38	.07	.23	.34
PRT voicing errors	.60	-.06	.25	.29	.57	.50
PRT vowel errors	.53	.07	.24	.25	.50	.45

Table 20 (cont.)

	Place-manner errors	Place-voice errors	Manner-voice errors	Place-manner voice errors	Prosodic score	Intelligibility rating
Average in dB 500/1000/2000	.39	.09	.12	.21	.27	.58
Average in dB 125/500/1000	.41	.05	.05	.27	.24	.52
Highest frequency heard	-.15	.19	.07	.00	.03	-.28
Hearing level 125 Hz	.24	-.06	-.10	.29	.12	.35
Hearing level 250 Hz	.16	-.01	.10	.05	-.02	.18
Hearing level 500 Hz	.36	.08	.09	.13	.27	.42
Hearing level 750 Hz	.42	.09	.21	.09	.26	.56
Hearing level 1000 Hz	.45	.14	.18	.22	.22	.56
PRT total errors	.34	-.04	.26	.33	.30	.70
PRT place errors	-.02	.00	-.04	-.20	-.08	.00
PRT manner errors	.29	.15	.24	.30	.10	.48
PRT place-manner errors	.16	.01	.14	.25	.09	.36
PRT voicing errors	.23	.02	.10	.39	.43	.65
PRT vowel errors	.30	-.04	.31	.23	.28	.60

(df = 38 p(.05) = .31 p(.01) = .40 p(.001) = .51)

spect to total phoneme errors. Voicing and vowel errors in speech production have some correlation with the pure tone measures shown, as have errors combining place and manner of articulation. Other types of speech errors show no relationship to these pure tone measures. Total errors on the phoneme recognition test show a closer correlation with total speech errors than any pure tone measure.

IV Effect of additional variables.

A considerable amount of background information on the children was collected at the time of selecting the subjects for testing. Of this material, in addition to the parents' hearing status, which has been examined extensively in the foregoing pages, the factors that seemed to have a possible bearing on speech intelligibility were the quality of parents' cooperation with the school (as a reflection of parental motivation), the age when the child obtained his first hearing aid and when he began special education, and the adequacy of use of the hearing aid.

A chart of these variables, according to quartiles of intelligibility, appears as Table 21. Each entry is number of children. Males were in the majority in the first quartile, indicating that they were slightly better speakers than the females in this sample. Eight children received hearing aids or special education before the age of 2 years; none received both. Of the 8 children, 6 are in the lower two quartiles of intelligibility. That is, the more intelligible speakers obtained hearing aids and began special education later than the poorer. This does not appear to be a function of poor identification. Twenty-four of the 40 children were diagnosed as deaf in the first year of

TABLE 21

BACKGROUND AND RELATED INFORMATION ON THE CHILDREN, BY QUARTILES OF INTELLIGIBILITY SCORE. ENTRY IS NUMBER OF CHILDREN.

	Age at test						Sex		Parents' hearing		Sibs' hearing		Language in home			Parent coop- eration			Age first hearing aid			Age began special education			Use of aid		
	8+	9+	10+	13+	14+	15+	M	F	H	D	H	D	Eng.	Sign	Oth.	G	F	P	-2	2-3	3+	-2	2-3	3+	G	F	P
Quartile 1	1	1	0	4	3	1	7	3	10	0	8	1	8	0	2	4	4	2	0	1	9	0	4	6	9	1	0
Quartile 2	2	2	0	0	4	2	5	5	10	0	7	2	8	0	2	8	1	1	0	6	4	2	5	3	10	0	0
Quartile 3	1	4	3	0	1	1	4	6	7	3	5	4	6	3	1	7	2	1	2	2	6	2	4	4	8	0	2
Quartile 4	1	1	4	2	1	1	4	6	4	6	3	6	5	4	1	4	4	2	1	2	7	1	3	6	6	2	2
Totals	5	8	7	6	9	5	20	20	31	9+	23	13*	27	7	6	23	11	6	3	11	26	5	16	19	33	3	4

+ includes 5 of those with deaf siblings.
* in each quartile, one child had no siblings.

life and 36 before age 2.

More children in the upper two quartiles were good hearing aid users, in the opinion of the school, than in the lower two quartiles. In the matter of parental cooperation, Quartiles 1 and 4 were identical.

Fair and poor use of hearing aid were lumped together to form a dichotomous variable, good/poor use of aid. In the same way, a dichotomous variable was formed for good/poor parental cooperation. Analysis was then carried out by means of X^2 on 2 x 2 tables with the following variables: good/poor use of hearing aid, above/below mean intelligibility; good/poor use of aid, above/below mean prosodic score; good/poor use of aid, above/below mean number of phoneme errors; male/female, above/below mean intelligibility; good/poor parent cooperation, above/below mean intelligibility. In none of these did the X^2 demonstrate a difference approaching the .05 level of significance.

There were 8 children with hearing parents and deaf siblings. Three of these were in the upper two quartiles, five in the lower. However, three of these five also had at least one hearing sibling. Two children of deaf parents had hearing siblings. One of these was the most intelligible of the children of deaf parents; the other was among the poorest. There appears, at least among these small numbers, to be no tendency for a difference in intelligibility to attach to the hearing of the deaf child's siblings.

A correlation coefficient obtained between the intelligence test scores of the children and their speech intelligibility was -.17, representing no relationship at all. This agrees with the findings of previous studies that, at least within the range of 'normal' intelligence, I.Q. score is unrelated to speech skills.

CHAPTER FIVE

DISCUSSION AND CONCLUSIONS

The principal aim of this study was to describe the relationships between residual hearing and speech production in deaf children. The major finding is a close association between phoneme production and speech intelligibility and the ability to recognize phonemic features auditorally.

There was a high correlation between intelligibility and scores on the closed-set test of phoneme recognition, both for individual parts of the test and for scores as a whole. There was a strong correlation also between particular types of errors in phoneme production and particular portions of the phoneme recognition test. The findings of previous studies concerning the relationship of pure tone levels to development of intelligible speech are corroborated; but it would appear that a more direct measure can now be developed in terms of actual components of the speech signal and the deaf child's ability to perceive them.

For most of the children in this study, the recognition of speech features was reflected in the ability to produce intelligible speech, even in the absence of ability to recognize whole words; there were a number of children for whom no speech response level could be found with spondee words, who nevertheless scored above the mean on the phoneme recognition test and who were in the upper two quartiles of intelligibility. This is in agreement with the statement of Boothroyd (1970) that a phoneme score is a more sensitive measure of recognition skills in speech than a word score.

A second finding of this study is that the intelligibility of speech of the children of deaf parents, who comprised 9 of the 40 children in the group, was generally poorer than that of the children of hearing parents. Previous studies of the speech of deaf children have not, to our knowledge, examined this factor. It was not possible in selecting the sample of children for our population to match exactly the numbers of children with deaf and with hearing parents. Therefore it would not have been correct to compare all the children of deaf parents with all the children of hearing parents; all except one of the children with deaf parents were in the younger group. But each comparative measure between the two groups of younger children showed the same tendency for the children of deaf parents to perform more poorly. The other background variables examined showed little or no relationship to speech intelligibility.

Insofar as the hearing of the child is the main factor in determining the intelligibility of his speech, there is some justification for regarding this sample as typical of children in schools for the deaf. In the study by Boothroyd (1969) of 187 children at Clarke School for the Deaf, the median response to pure tone of the entire group was from 5 to 10 dB poorer at 125, 250 and 500 Hz than the median for the present group. However, the hearing level at 1000 Hz and the 1000 Hz cut-off were the same. Of 83 children reported on by Montgomery (1967), 3 did not respond at 1000 Hz, 22 at 2000 Hz. The data of Elliott (1967) on 92 children at Central Institute for the Deaf show a median response at 2000 Hz of 110 dB. However the mean average of her subjects at 500/1000/2000 Hz, including those for whom 115 dB was recorded at frequencies where there was no response (termed 'maximum' data), was 99.3 dB, as compared with 101 dB for our group, which is a very small difference. The present study used the average of 125/500/1000 Hz to describe hearing levels instead of the usual average of 500/1000/2000 Hz because the majority of the 40 children studied could not give a response to pure tone at 2000 Hz. It would appear from the studies with larger groups that hearing levels are quite similar in other schools for the deaf. If a response at 1000 Hz is common in deaf children and one at 2000 Hz is uncommon, then the traditional average is inapplicable to the hearing of these children and cannot be properly compared with their skills in speech production. If this is the case, then the lower frequency average may be a more useful description of their hearing levels than the traditional one. In this study, the average of 125/500/1000 showed the same correlation with total speech phoneme errors as the average of 500/1000/2000, but a slightly better correlation with intelligibility of speech.

There was a modest correlation between the highest frequency of response and speech intelligibility, but it is believed that this was due to wide variations caused by the small numbers of children with sensitivity at higher frequencies. If individual children are examined, of the 10 children in the upper quartile of intelligibility, all but 3 had a response to pure tone at least to 2000 Hz. Though no definite cut-off was seen either in level or frequency, it appears from our data that the hearing sensitivity of the deaf child, as it relates to the intelligibility of his speech, may be summarized in terms of the average level at 125/500/1000 Hz and the extent of hearing into the higher frequencies. Such a description of the deaf child's hearing is exactly the same in principle as the one proposed by Risberg and Martony (1970) which, when applied to our data, put children with a spread of speech intelligibility from the highest to the lowest all into the same grouping. It is our opinion that this is due to the overly wide ranges of hearing levels in the low frequency bands of the Risberg and Martony system, and that a refinement of this aspect would result in a more reliable indication of the deaf child's residual hearing for pure tone as related to his speech. Martony (1) points out that the pure tone audiogram can only give some indication of the child's potential for auditory reception and for speech, and that additional measures are necessary.

Examination of the data on speech production reveals some similarities and differences with respect to the study of Hudgins and Numbers (1942). Omission of the initial consonant was less frequent in the present study than omission of the final consonant. Voiced-voiceless confusions were frequent in both studies. However our correlation of -.36, between these confusions and speech intelligibility, is slightly lower than the -.44 reported by Hudgins and Numbers. Errors in clustered consonants were found in both studies, with omission of one member as the commonest error. The correlation coefficient for consonant phoneme errors and intelligibility in the earlier work is the same as reported here for identifiable consonant errors: -.70. The present data agree exactly with the earlier data on types of vowel errors, but show a higher correlation, -.75, for vowel errors and intelligibility than the -.61 reported by Hudgins and Numbers.

The present findings, those of Nober (1967) and those of

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(1) J. Martony, personal communication, May, 1972.

Markides (1970) are in essential agreement on the order of correct consonant production: the bilabial consonants, the glides, and /f,v/ are most often correct, and the palatal and alveolar fricatives, the affricates and /ŋ/ are the poorest.

A comparison of the correlations in various studies between speech intelligibility and total proportion of phoneme errors shows comparable results:

Study	Correlation coefficient	Intelligibility scores based on:
Brannon, 1964	-.79	Naive listeners
Montgomery, 1967	-.80	Teachers' ratings
Markides, 1970	-.87	Naive listeners
Present study	-.80	Naive listeners

A much closer correspondence is found in the mean intelligibility, to naive listeners, of the recorded speech of deaf children. All scores were derived in the same manner: words correctly understood as a function of all words.

Study	Percent intelligibility to naive listeners	Age of children
Brannon, 1964	20.7	12-15
John and Howarth, 1965	19.0	6-14
Markides, 1970	19.1	7 and 9
Present study	18.7	8-10, 13-15

These studies spanned the same age groups as our children, though all three did not include all ages. Hearing levels of the children were also comparable. The unusual consistency of these findings suggest an avenue of questioning. The percent intelligibility of speech obtained in the present study was related to the proportion of children of deaf and of hearing parents involved. If there had been fewer children of deaf parents, the findings suggest that the mean intelligibility of the group might have been higher; while if there had been more, the mean intelligibility might have been lower. The fact that four studies, at least, using comparable procedures, arrive at very nearly identical results, suggests that the proportion in schools for the deaf at the present time of children of deaf and of hearing parents may be the same as the proportion in our sample, or very nearly. The difference in speech intelligibility between these two groups of children certainly calls for examination on a much larger population.

Further, the intelligibility of the older children in the present group was superior to that of the younger, even not including the children of deaf parents in the younger group. If the intelligibility of younger deaf children's speech is indeed poorer than that of older, it would be of great interest to determine whether the speech of young children of deaf parents improves to the same degree as that of young children of hearing parents. This aspect could not be examined at all, because only one older child had deaf parents.

However, the difference in intelligibility between the younger and older children in the sample must be interpreted with great caution because the younger children had somewhat poorer hearing than the older. Figure 7 shows that only one younger child had average hearing at 125/500/1000 Hz better than 80 dB, while 6 older children had average hearing at those frequencies of 80 dB or better. The one younger child was a child of deaf parents. Therefore no firm conclusions can be drawn at present with respect to age-related differences. It will be necessary to re-examine as many as possible of the younger group of children, at some future time.

It would appear that the difference in the speech of young children of deaf parents must be due to the lack of early auditory experience of speech, affecting their ability to make use of the information their residual hearing will permit them to receive. The 8 young children of deaf parents could be matched quite closely with 8 young children of hearing parents, for age, average hearing level at low frequencies, and extent of hearing sensitivity to higher frequencies. When these matched pairs were compared, only 2 children of deaf parents had speech intelligibility comparable to that of their counterparts. One child of deaf parents was considerably above the mean in score on the phoneme recognition test, without this being reflected in better speech. This was not true of the children of hearing parents; with a single exception, every child who was above the mean on the phoneme recognition test was in the first or second quartile of intelligibility. The matter is complicated by an ongoing as well as an early lack of auditory experience of speech in the home; according to the obtainable information, seven of the nine deaf families used sign at least partially as the language for communication at home.

It is necessary to examine what the phoneme recognition test is measuring. The test may be giving an indication of the ability of the child's entire auditory receptive and integrative system to deal with properties of the speech signal, given the amount of information relative to those properties that the peripheral hearing deficit will allow as input. Another possibility is that recognition of phonemic features is reflecting and being effected by all other factors that may effect speech intelligibility, notably the amount of the hearing deficit and the consequent degree of early auditory experience. It is not altogether clear in these children which is effecting what;

learning of speech may result in better listening to speech. But if the phoneme recognition test is examining the whole system better than a pure tone test can, then an improved version of such a procedure as the speech approximation test that was attempted here might successfully examine the ability of the child to deal with basic properties of the speech signal.

The correlations obtained between portions of the test and aspects of phoneme production are clearly related to hearing sensitivity in low frequencies. Much of the information on voicing in speech is carried in the low frequency portion of the spectrum. There were substantial inter-correlations between scores on voicing items in the phoneme recognition test, speech intelligibility, and the low-frequency average; and between these same scores, intelligibility, and vowel production errors.

At no point in the study was there evidence of a relationship between errors involving place of articulation either in recognition or production and any hearing abilities, or between place of articulation errors and intelligibility of speech. The poorest groups in intelligibility made the same proportion of place errors in speech as the best. This is reasonable from the standpoint that children with the least amount of hearing, particularly in the low frequencies, may learn earlier in life to watch the faces of those around them who are speaking. Place of articulation. insofar as it is the one visible element of speech production, thus becomes the earliest learned of their speech behaviors. Much acoustic information on place of articulation is carried in the higher frequencies of the speech spectrum and requires appreciation of rapid spectral and dynamic changes. The deaf child, even if he has sensitivity in these frequency regions, may not be able to use this information in the same manner as a normal listener.

It is apparent in Figure 3 that identifiable consonant errors in speech production remain in much the same proportion from one quartile of intelligibility to the next. Vowel and diphthong errors, omissions and unidentifiable substitutions decrease quite systematically from the poorest to the best speakers. Examination of the vowel errors that occurred showed many instances of diphthongization. Chiefly however, the errors were in the direction of neutralization together with a high degree of distortion of normal vowel durations. House (1961) has pointed out that duration of vowels, particularly as applied to their position preceding voiced or voiceless final consonants, is phonological in the language. Therefore it is part of the listener's learned auditory experience of speech. The poor identification of the vowels of deaf children has been described by Angelocci, Kopp and Holbrook (1964) and quantified in terms of atypical ratios of $f_1 - f_2$. The major physiological correlate of these improper ratios is inaccurate placement of the tongue. It may be questioned in deaf children whether poor vowel placement is the result of improper consonant targets, or whether, in fact, the children, having poor appreciation of the quality of most vowels, never aim for a true vowel target and naturally produce a neutral vowel as a substitute for every other vowel, regardless of consonant environment. Lach, Ling et al (1) Have found that deaf babies 10 to 20 months old babble on a low central

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(1) Cited by D. Ling in Levitt and Nye, 1971, p. 63.

vowel, with no high front or high back vowels. For whatever reason, the vowels of deaf children fail to have appropriate durations and seldom reach target. This failure, of course, does not occur in isolation. The articulatory process is one of precisely timed and interactive movements. With respect to articulatory movement, the consequences for deaf children of the lack of early auditory feedback appear to combine a general phenomenon of undershoot with a failure to develop appropriate target sequencing.

Some of the contribution of vowel errors to lack of intelligibility may lie in the fact that vowels carry a substantial proportion of the prosodic information in speech (Bronstein, 1960, page 132.) A clear pattern of the relationships between prosodic aspects of speech and intelligibility did not emerge in this study. However there was a significant correlation between the intelligibility ratings –– the listeners' judgements of the children's speech quality –– and such prosodic factors as intonation, pitch control, rate of utterance. Hood (1966) found that speech rhythm (chiefly associated in his study with duration) was strongly related to speech intelligibility, and suggested that in a child whose articulation was good while intelligibility remained poor, the concentration of training should be on rhythm aspects. Speech training of deaf children, including the application of aids designed to provide sensory input through other modalities than hearing, has put much attention on articulation. It appears that this concentration may be misplaced.

The most frequent comment of the inexperienced listeners who participated in the intelligibility study was that what they were hearing sounded like a foreign language (German, Dutch, Russian, Chinese were among those mentioned.) Hearing an unfamiliar pattern, to which his experience of English does not apply, a listener cannot bring his knowledge of the statistics of his language to bear in an attempt to synthesize the meaning of the utterance. The young children of deaf parents did not make more identifiable phoneme errors of any type than the other children, that resulted in their poorer intelligibility. They made more omissions and unidentifiable substitutions. We believe that training toward improvement in the stress and intonation patterns of the young deaf child's speech would enable a listener to put back these missing elements and would result in better intelligibility. This seems to be the implication of the study by John and Howarth, who found a marked improvement in intelligibility of deaf children's speech as the result of a brief training period directed toward stress and durational aspects. This approach would also seem to be the most promising of those currently being investigated in the area of tactual and visual sensory aids.

Conclusions

1. Scores on the total and some individual portions of the phoneme recognition test showed significant correlations with both phoneme production and speech intelligibility in the deaf children studied. In attempting to develop measures that might be predictive of speech skills in the young deaf child, procedures involving auditory recognition of speech- and speech-like sounds should be a promising approach. Recognition of voicing and vowel distinctions in the phoneme recognition test were closely correlated with speech intelligibility. Training toward successful audiological evaluation, a common procedure with

young deaf children, might be directed as early as possible toward recognition of stimuli of these kinds.

2. The most important background variable in the development of intelligible speech was the hearing of the child's parents. There was a marked difference in intelligibility of speech between the children of deaf and of hearing parents. There was no obvious relationship between speech skills and parental motivation, measured intelligence, age of acquisition of a hearing aid or age of beginning special education. Some importance seemed to attach to adequacy of use of a hearing aid.

3. A breakdown of phoneme production errors as a function of intelligibility showed that errors of place of articulation and voicing remained essentially in the same proportion for all speakers. Errors of manner and place-and-manner showed a slight systematic decrease from the poorest to the best speakers. Omissions decreased sharply but not quite systematically. Vowel errors showed the most marked and systematic decrease as intelligibility improved. Another indication of this effect was the high level of correlation between total vowel errors and intelligibility.

A number of studies have shown the average intelligibility of the recorded speech of the deaf child to naive listeners to be about 20%. It is important, though difficult, to find means for discovering the correction factor that must exist for real life, face-to-face situations. An assessment of the success of the deaf child at verbal communication in general, and not only to his parents and teachers, is vital; it is against this that the adequacy of any training procedures or devices must be measured.

CHAPTER SIX

SUMMARY

This study was undertaken in the hope of providing a quantitative description of errors in deaf children's speech, together with an analysis of relationships between their residual hearing and their speech production. The findings, it was hoped, might suggest new avenues of approach for speech training and for research in sensory aids, and might also prove to be of predictive value in estimating a young deaf child's potential for good speech development.

The specific questions of the study were the following:

1) What are the specific relationships between a deaf child's hearing, for pure tone and for speech, and the articulatory and prosodic features of his own speech production?

2) What variables in addition to hearing may account for divergence in individual children from the general relationships that may be found?

3) What is the relative importance to perceived speech intelligibility of various articulatory and prosodic aspects of the children's speech?

The subjects were 40 congenitally deaf children, in the age groups 8-10 and 13-15. All had hearing for pure tone at least to 750 Hz according to previous testing, and had been in the same educational environment for at least 3 years, and none had any discernible handicap other than deafness. The children received an audiological evaluation, including a closed-set test of phoneme recognition designed for the study, and recorded a set of sentences designed to test all consonant phonemes and a specific set of vowels.

The recorded speech of the children was presented to naive listeners for a measure of intelligibility and to expert phoneticians for transcription. A measure of prosodic errors was also obtained. The results of these analyses were compared with the hearing measures.

The traditional use of the average of 500/1000/2000 Hz to describe hearing level was found to be inapplicable to this group of children, since the majority did not give a response to pure tone at 2000 Hz. The average of 125/500/1000 Hz was selected for use in the analysis. Since other studies show that a hearing response at 1000 Hz and not at 2000 Hz is fairly typical of children in schools for the deaf, it was felt that the lower frequency average might be a generally useful one in describing the hearing of deaf children. For the sample in this study, the lower frequency average had a correlation with speech intelligibility scores of -.65.

The intelligibility scores ranged from 76% down to zero percent, with a mean of 18.7%. This figure was notably similar to the mean intelligibility of deaf children's speech found in several previous studies.

The phoneme recognition test scores had the highest correlation (r = .78) with intelligibility of any hearing measure. The ability to recognize phonemic features in speech was reflected in the ability to produce intelligible speech. Test items involving the recognition of voicing and vowel distinctions showed a significant correlation with intelligibility and also with the low frequency hearing average. Early evaluation of the young deaf child's ability to recognize these distinctions would be desirable as a possible indication of his potential for good speech development.

The speech of the children of deaf parents was found to be markedly less intelligible than that of the children of hearing parents, presumably because of a lack of early auditory experience of speech. This difference has not received attention in previous studies of the speech of deaf children. There would appear to be important educational implications in the question of whether the same finding would occur in other populations of deaf children. There was no obvious relationship between speech skills and parental motivation, measured intelligence, age of acquisition of a hearing aid or age of beginning special education.

Analysis of phoneme production errors showed that errors of place of articulation occurred in the same proportion in the best and the poorest speakers, and had no significant correlation with intelligibility. Voicing errors, while very numerous, had a modest correlation with intelligibility. Vowel errors, omissions and errors of manner of articulation were most highly correlated with intelligibility. Of these, vowels showed the most marked systematic decrease in going from the poorest to the best speakers.

The data obtained for prosodic errors in the children's speech were too highly variable to allow a clear interpretation. However there was some evidence that disruption of normal prosodic patterns helped make the speech of the children unrecognizable to the listeners. It was recommended that speech training for the deaf child should be directed toward appropriate stress and intonation patterns. This was also felt to be the most promising of the current areas of sensory aids research.

APPENDICES

APPENDIX A-1

BACKGROUND INFORMATION ON DEAF CHILDREN

BACKGROUND DATA

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	1	13.2	1	1	2	1	1	2	3.1	2	5	118	124	0	1	3.
	2	15.9	1	1	1	1	1	2	2.8	3	5	93	0	0	2	2.
	3	13.9	2	1	3	1	3	2	3.0	3	3	117	0	0	2	1.
	4	14.3	2	1	0	3	3	3	4.0	4	4	128	0	0	2	4.
	5	14.5	1	1	1	1	2	2	8.5	5	5	111	0	0	1	3.
	6	13.5	1	1	2	1	1	3	2.9	4	3	114	117	0	2	3.
	7	14.4	2	1	0	1	1	3	2.0	2	3	122	107	0	1	2.
	8	14.1	1	1	1	3	3	3	4.3	2	1	104	100	0	1	3.
	9	15.0	1	1	1	1	1	2	0.9	2	3	125	122	0	1	2.
	10	13.2	2	1	1	1	1	2	11.0	2	2	110	0	0	3	5.
	11	15.7	1	1	2	1	1	2	1.0	4	3	131	0	0	1	2.
	12	14.5	2	1	1	1	2	3	4.0	2	2	92	0	0	3	4.
	13	13.8	2	1	1	1	2	2	3.0	2	3	118	0	0	2	3.
	14	14.2	1	1	1	1	2	3	2.0	3	5	96	100	0	1	2.
	15	10.6	2	1	1	1	1	2	3.0	3	3	100	105	0	1	3.
	16	8.3	2	1	1	1	1	2	3.6	2	2	111	133	0	2	2.
	17	13.6	2	1	1	1	2	2	3.5	2	4	106	0	0	3	3.
	18	15.3	2	2	2	2	3	3	1.5	4	3	118	0	122	1	2.
	19	14.5	2	1	1	1	2	3	1.5	3	2	140	118	0	1	3.
	20	15.8	2	1	1	3	2	3	2.7	3	3	0	0	114	2	5.
	21	10.9	1	1	1	3	1	3	2.0	3	1	121	0	0	1	1.
	22	14.7	1	1	1	1	1	2	3.0	5	4	113	0	0	1	3.
	23	14.4	1	1	3	1	1	2	2.5	2	2	106	114	107	2	2.
	24	8.5	1	1	2	3	1	1	2.2	2	2	0	0	108	1	2.
	25	9.5	2	1	3	1	1	2	1.4	3	2	118	133	0	2	3.
	26	9.2	1	1	1	1	3	3	4.5	2	2	0	111	0	2	4.
	27	8.3	2	1	1	1	1	2	2.2	2	2	122	0	0	2	3.
	28	9.7	1	2	2	2	1	3	2.6	3	3	129	119	0	1	3.
	29	9.6	2	1	1	1	1	2	2.5	3	5	118	0	0	1	4.
	30	9.0	2	1	1	1	1	2	2.5	2	2	0	118	0	1	2.
	31	10.1	2	2	0	2	1	3	2.4	3	4	127	147	0	1	3.
	32	9.5	1	1	1	1	2	3	3.2	4	3	100	100	0	2	3.
	33	9.6	2	1	1	1	1	3	2.8	2	3	100	106	0	3	3.
	34	10.9	1	2	0	2	3	3	3.5	3	3	96	109	0	1	4.
	35	10.3	1	2	1	1	2	3	3.2	2	2	114	0	0	1	2.
	36	9.5	2	2	1	2	1	3	3.0	3	5	118	131	0	1	3.
	37	10.1	1	2	2	2	1	3	3.0	3	3	125	0	0	1	1.
	38	8.6	1	2	2	3	2	2	3.5	3	2	122	127	0	1	3.
	39	8.6	2	1	3	1	1	2	2.1	3	2	0	140	0	1	3.
	40	10.4	1	2	2	2	2	3	2.3	3	1	117	112	0	1	4.

See next page for key.

APPENDIX A-1

BACKGROUND INFORMATION ON DEAF CHILDREN

BACKGROUND DATA

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	13.2	1	1	2	1	1	2	3.1	2	5	118	124	0	1	3.4	2	2	2
2	15.9	1	1	1	1	1	2	2.8	3	5	93	0	0	2	2.5	2	1	2
3	13.9	2	1	3	1	3	2	3.0	3	3	117	0	0	2	1.4	2	3	2
4	14.3	2	1	0	3	3	3	4.0	4	4	128	0	0	2	4.0	1	1	2
5	14.5	1	1	1	1	2	2	8.5	5	5	111	0	0	1	3.0	3	3	2
6	13.5	1	1	2	1	1	3	2.9	4	3	114	117	0	2	3.6	1	1	2
7	14.4	2	1	0	1	1	3	2.0	2	3	122	107	0	1	2.0	1	1	2
8	14.1	1	1	1	3	3	3	4.3	2	1	104	100	0	1	3.6	1	1	2
9	15.0	1	1	1	1	1	2	0.9	2	3	125	122	0	1	2.5	1	1	1
10	13.2	2	1	1	1	1	2	11.0	2	2	110	0	0	3	5.0	2	1	2
11	15.7	1	1	2	1	1	2	1.0	4	3	131	0	0	1	2.5	2	3	2
12	14.5	2	1	1	1	2	3	4.0	2	2	92	0	0	3	4.0	2	2	2
13	13.8	2	1	1	1	2	2	3.0	2	3	118	0	0	2	3.0	1	1	2
14	14.2	1	1	1	1	2	3	2.0	3	5	96	100	0	1	2.0	2	1	2
15	10.6	2	1	1	1	1	2	3.0	3	3	100	105	0	1	3.7	1	1	2
16	8.3	2	1	1	1	1	2	3.6	2	2	111	133	0	2	2.5	2	1	2
17	13.6	2	1	1	1	2	2	3.5	2	4	106	0	0	3	3.0	2	1	2
18	15.3	2	2	2	2	3	3	1.5	4	3	118	0	122	1	2.0	1	1	2
19	14.5	2	1	1	1	2	3	1.5	3	2	140	118	0	1	3.0	1	1	2
20	15.8	2	1	1	3	2	3	2.7	3	3	0	0	114	2	5.0	1	1	2
21	10.9	1	1	1	3	1	3	2.0	3	1	121	0	0	1	1.0	1	1	2
22	14.7	1	1	1	1	1	2	3.0	5	4	113	0	0	1	3.6	1	1	2
23	14.4	1	1	3	1	1	2	2.5	2	2	106	114	107	2	2.5	2	1	2
24	8.5	1	1	2	3	1	1	2.2	2	2	0	0	108	1	2.0	1	1	2
25	9.5	2	1	3	1	1	2	1.4	3	2	118	133	0	2	3.0	1	1	2
26	9.2	1	1	1	1	3	3	4.5	2	2	0	111	0	2	4.5	1	1	1
27	8.3	2	1	1	1	1	2	2.2	2	2	122	0	0	2	3.0	1	1	2
28	9.7	1	2	2	2	1	3	2.6	3	3	129	119	0	1	3.0	1	1	2
29	9.6	2	1	1	1	1	2	2.5	3	5	118	0	0	1	4.0	1	1	2
30	9.0	2	1	1	1	1	2	2.5	2	2	0	118	0	1	2.0	1	1	1
31	10.1	2	2	0	2	1	3	2.4	3	4	127	147	0	1	3.5	2	2	2
32	9.5	1	1	1	1	2	3	3.2	4	3	100	100	0	2	3.8	1	1	1
33	9.6	2	1	1	1	1	3	2.8	2	3	100	106	0	3	3.5	1	1	2
34	10.9	1	2	0	2	3	3	3.5	3	3	96	109	0	1	4.0	2	3	2
35	10.3	1	2	1	1	2	3	3.2	2	2	114	0	0	1	2.0	1	1	2
36	9.5	2	2	1	2	1	3	3.0	3	5	118	131	0	1	3.0	1	1	1
37	10.1	1	2	2	2	1	3	3.0	3	3	125	0	0	1	1.5	1	1	2
38	8.6	1	2	2	3	2	2	3.5	3	2	122	127	0	1	3.2	1	1	2
39	8.6	2	1	3	1	1	2	2.1	3	2	0	140	0	1	3.2	1	1	1
40	10.4	1	2	2	2	2	3	2.3	3	1	117	112	0	1	4.4	1	1	2

See next page for key.

Appendix A-1 (cont.)

Key to background data :

Column:

1. Subject number.
2. Age at time of testing, in decimals.
3. Sex. 1 = female, 2 = male.
4. Parents' hearing. 1 = hearing. 2 = deaf.
5. Hearing of siblings. 1 = hearing. 2 = deaf. 3 = siblings of each category. 0 = no siblings on record.
6. Language used in home. 1 = English. 2 = Sign. 3 = other.
7. Parental cooperation. 1 = good. 2 = fair. 3 = poor.
8. Socio-economic level. 1 = upper middle. 2 = middle. 3 = lower middle.
9. Age of beginning special education, in decimals.
10. Speech grade, previous semester.
11. Lipreading grade, previous semester.
12. Score on WISC.
13. Score on Leiter.
14. Score on Wechsler-Bellevue.
15. Age when deafness diagnosed. 1 = before 1 year. 2 = 1 to 2 years. 3 = later than 2 years.
16. Age when hearing aid first given, in decimals.
17. Adequacy of hearing aid. 1 = good. 2 = poor. 3 = no aid.
18. Adequacy of use of aid. 1 = good. 2 = fair. 3 = poor.
19. Past audiograms show deteriorating hearing. 1 = yes. 2 = no.

APPENDIX A-2

PURE TONE AIR CONDUCTION RESPONSES OF DEAF CHILDREN, IN dB RE: AUDIOMETRIC ZERO (ISO)

Frequency in Hz

CHILD		125	250	500	750	1000	1500	2000	3000	4000	6000
1	r	75	85	90	95	105	105	---	---	---	---
	l	75	65	90	85	100	105	---	---	---	---
2	r	60	60	75	90	105	110	---	105	110	---
	l	70	70	80	90	95	---	---	---	---	---
3	r	60	80	105	110	110	---	---	---	---	---
	l	70	80	105	105	110	---	---	---	---	---
4	r	50	70	75	85	95	110	105	---	---	---
	l	60	75	75	90	90	105	---	---	---	---
5	r	75	100	110	---	---	---	---	---	---	---
	l	70	70	100	110	110	---	---	---	---	---
6	r	80	70	70	85	95	---	---	---	---	---
	l	75	75	70	95	100	---	---	---	---	---
7	r	60	80	85	90	105	---	---	---	---	---
	l	60	75	75	85	100	---	---	---	---	---
8	r	55	70	85	95	100	105	---	---	---	---
	l	35	60	85	90	100	105	110	---	---	---
9	r	80	75	90	105	105	---	---	---	---	---
	l	70	80	90	110	110	---	110	---	---	---
10	r	40	50	85	80	85	95	95	95	100	105
	l	60	70	85	85	90	100	105	105	110	110
11	r	65	70	85	96	105	---	---	---	---	---
	l	65	75	80	105	105	---	---	---	---	---
12	r	45	55	85	90	100	100	110	105	---	---
	l	50	55	70	95	100	105	110	110	---	---
13	r	55	75	85	90	100	105	105	100	95	---
	l	85	80	95	100	105	---	---	---	---	---
14	r	85	90	100	110	---	---	---	---	---	---
	l	85	85	100	105	110	---	---	---	---	---
15	r	75	85	95	100	105	110	105	110	110	---
	l	70	75	90	105	110	105	110	105	---	---
16	r	60	75	95	100	100	---	---	---	---	---
	l	60	70	80	95	105	105	110	110	110	---

APPENDIX A-2 (cont.)

Frequency in Hz

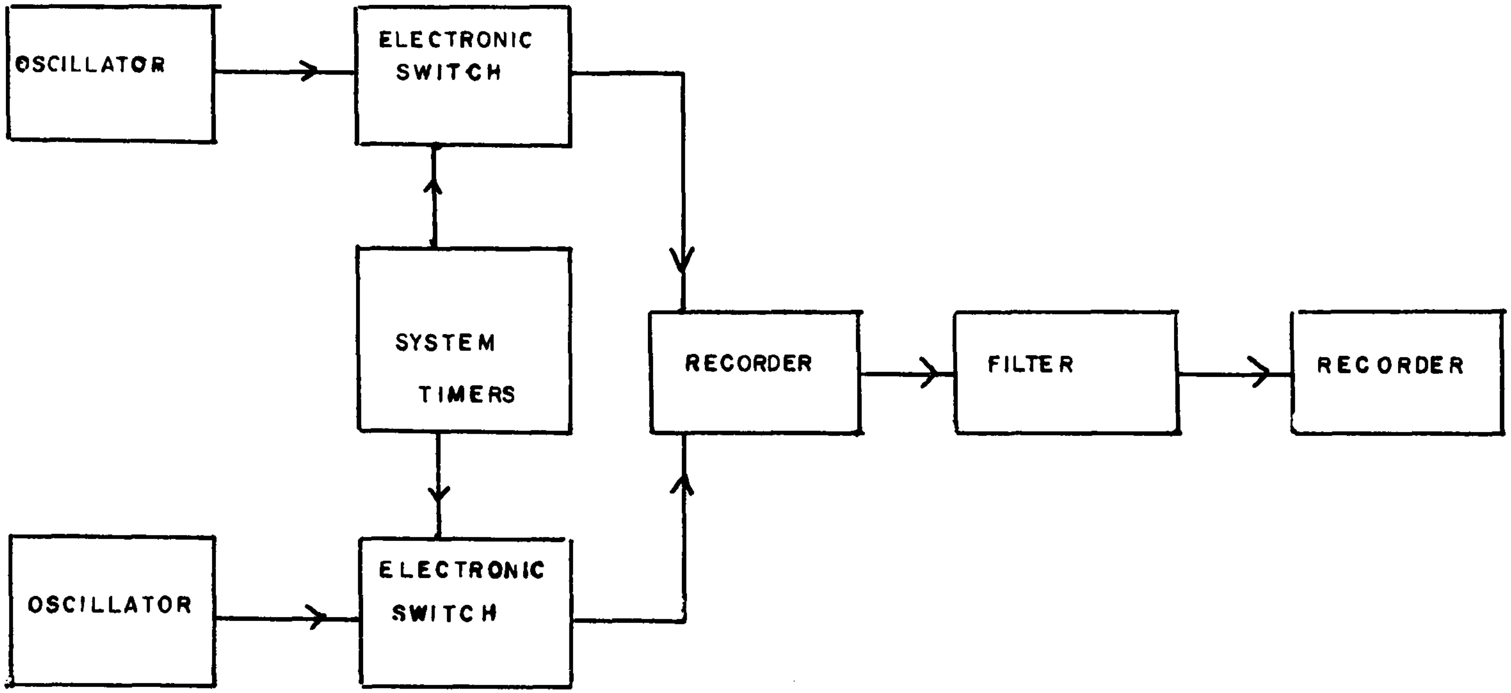
		125	250	500	750	1000	1500	2000	3000	4000	6000
17	r	60	80	90	105	110	---	---	---	---	---
	l	60	75	95	100	110	---	---	---	---	---
18	r	70	70	95	100	105	110	---	---	---	---
	l	65	70	90	95	105	110	105	---	---	---
19	r	80	95	100	105	110	---	---	---	---	---
	l	85	90	105	110	105	---	---	---	---	---
20	r	85	85	100	110	---	---	---	---	---	---
	l	50	55	60	75	75	100	105	110	110	---
21	r	70	75	90	100	110	---	---	---	---	---
	l	65	75	95	90	105	---	---	---	---	---
22	r	80	75	80	90	95	110	---	---	---	---
	l	85	75	85	90	95	---	---	---	---	---
23	r	75	85	95	100	100	---	---	---	---	---
	l	70	65	80	90	100	---	---	---	---	---
24	r	90	85	90	100	105	---	---	---	---	---
	l	90	80	95	100	110	---	---	---	---	---
25	r	80	70	90	100	105	---	---	---	---	---
	l	75	85	95	100	105	---	---	---	---	---
26	r	60	80	90	95	95	85	80	70	70	65
	l	75	80	95	100	100	95	90	85	85	90
27	r	75	70	85	95	105	---	110	105	100	---
	l	75	75	85	95	105	---	110	110	105	---
28	r	75	65	80	105	110	---	---	---	---	---
	l	75	70	85	105	110	---	---	---	---	---
29	r	70	90	110	110	---	---	---	---	---	---
	l	75	80	110	110	---	---	---	---	---	---
30	r	90	95	110	110	---	---	---	---	---	---
	l	95	95	110	---	---	---	---	---	---	---
31	r	90	85	95	100	110	---	---	---	---	---
	l	85	90	95	100	110	---	---	---	---	---
32	r	45	70	95	105	110	---	---	---	---	---
	l	45	70	110	110	110	---	105	---	---	---

APPENDIX A-2 (cont.)

		Frequency in Hz									
		125	250	500	750	1000	1500	2000	3000	4000	6000
33	r	55	80	105	100	95	90	85	75	75	65
	1	55	70	100	100	95	90	85	80	80	70
34	r	90	95	---	---	---	---	---	---	---	---
	1	60	75	85	85	85	90	105	---	---	---
35	r	80	90	95	105	110	110	---	110	---	---
	1	70	75	95	100	105	110	105	110	105	100
36	r	60	75	90	105	110	---	---	---	---	---
	1	65	70	90	100	105	---	---	---	---	---
37	r	60	75	95	105	---	---	---	---	---	---
	1	60	75	95	110	---	---	---	---	---	---
38	r	75	80	90	100	105	---	---	---	---	---
	1	65	75	80	100	110	---	---	---	---	---
39	r	70	85	100	100	110	---	---	---	---	---
	1	70	85	95	105	110	---	---	---	---	---
40	r	90	95	95	105	110	---	---	105	105	---
	1	90	95	95	105	---	---	---	---	---	---

APPENDIX B-1

BLOCK DIAGRAM OF EQUIPMENT USED TO PRODUCE STIMULI FOR SPEECH APPROXIMATION TEST (TONES).



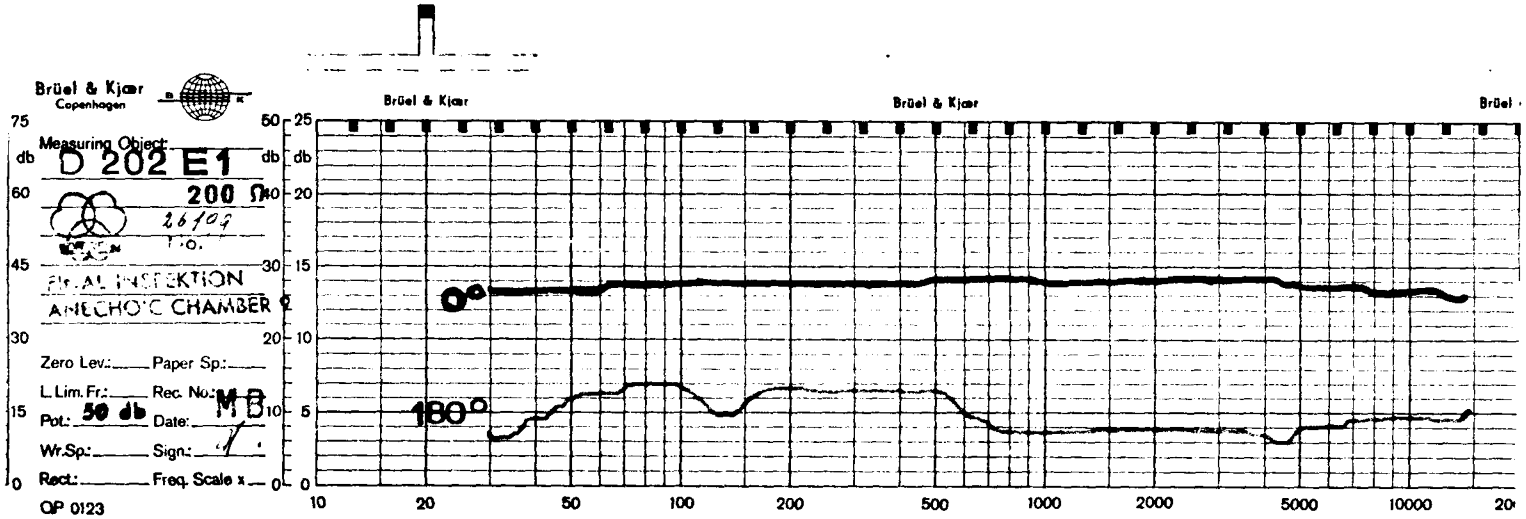
APPENDIX B-2

OUTPUT SOUND PRESSURE LEVELS AT EARPHONES OF PETERS MODEL AP-6 AUDIOMETER, MEASURED BEFORE, DURING AND AT CONCLUSION OF AUDIOLOGICAL TESTING. TELEPHONICS TDH-39 EARPHONE IN MX-41AR CUSHION.

Frequency in Hz	125	250	500	750	1000	1500	2000	3000	4000	6000
Attenuator setting (dB)	50.	60.	75.	75.	75.	75.	75.	75.	75.	65.
Reference (dB)	92.8	84.5	85.1	81.5	82.2	83.0	84.5	85.1	83.3	75.0
August 17, 1970										
Red phone	93.5	84.0	85.0	80.7	79.3	80.0	82.2	85.7	84.8	82.8
Blue phone	97.5	86.1	85.0	81.4	80.3	80.6	83.0	85.8	86.5	83.5
September 22, 1970										
Red phone	94.0	84.5	84.8	80.5	79.0	79.0	82.0	85.7	85.0	82.5
Blue phone	96.0	86.0	84.5	81.0	80.0	80.0	82.5	85.4	86.0	83.5
October 21, 1970										
Red phone	93.0	83.7	85.2	81.4	80.5	79.5	82.0	83.1	83.8	76.5
Blue phone	94.5	83.8	83.6	80.6	80.5	80.0	81.5	83.5	86.0	77.5

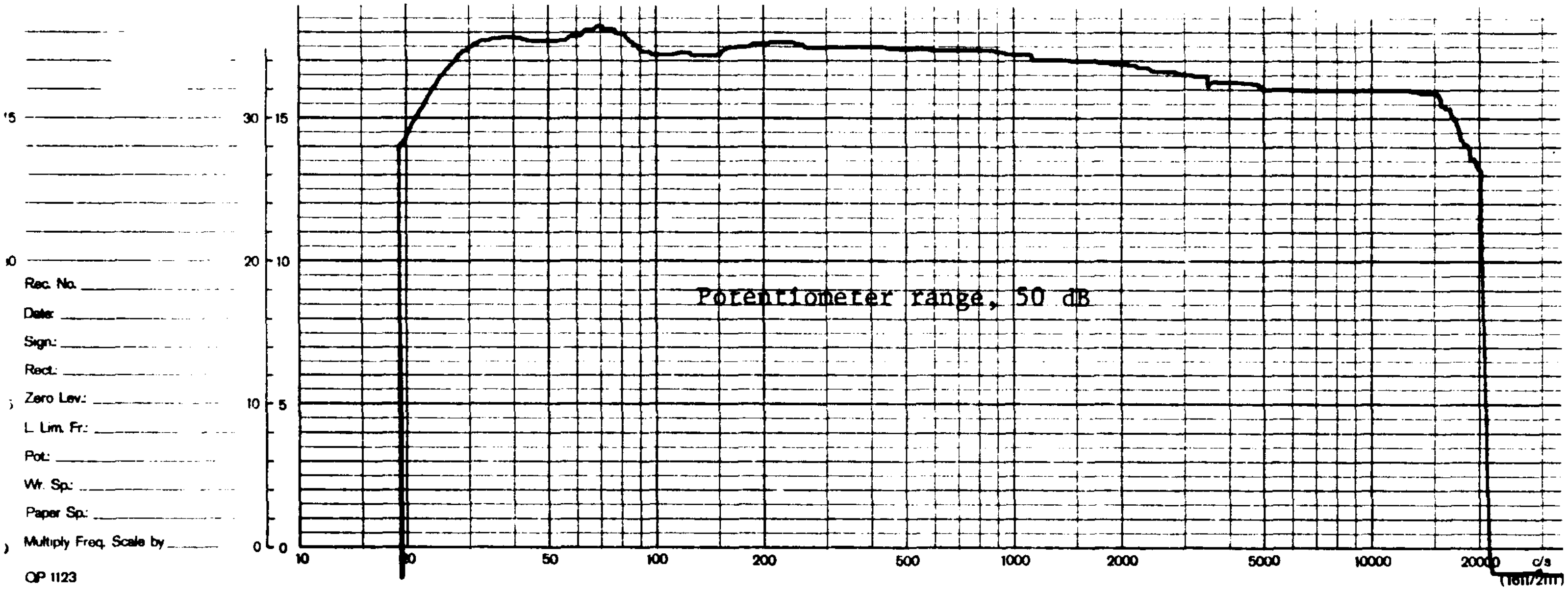
APPENDIX B-3

FREQUENCY RESPONSE OF D-202-E MICROPHONE USED IN RECORDING SPEECH SAMPLES



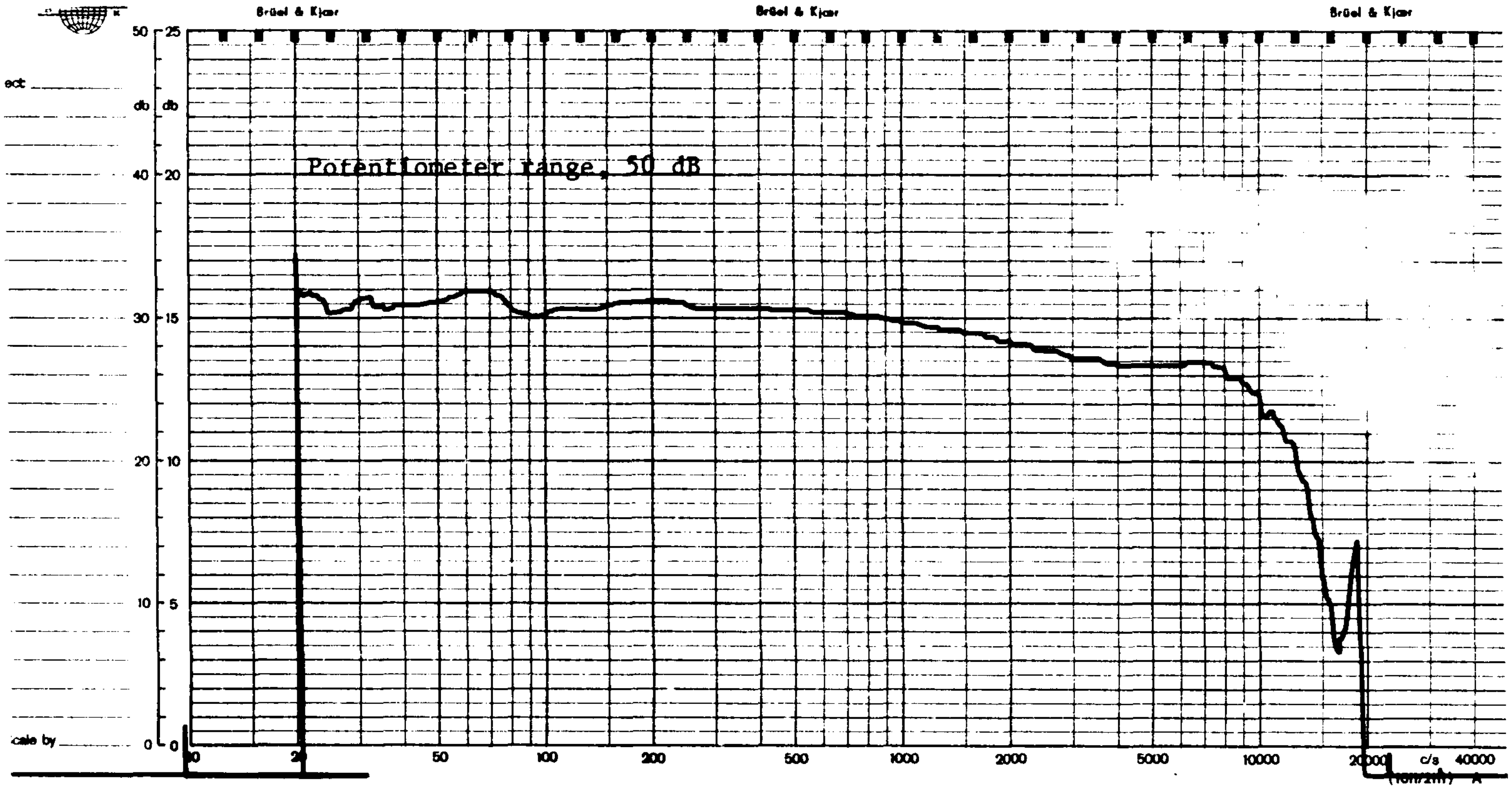
APPENDIX B-4

FREQUENCY RESPONSE OF TANDBERG MODEL 11 TAPE RECORDER USED IN RECORDING SPEECH SAMPLES



APPENDIX B-5

FREQUENCY RESPONSE OF AMPEX AG-500 INTO TANDBERG MODEL 11, USED IN RE-RECORDING SPEECH SAMPLES



APPENDIX C-1

AUDIOLOGICAL EVALUATION FORM

Subject #______
Order of test ______

AUDIOLOGICAL EVALUATION

NAME ______________________________ DATE________ TIME________ SEX______

Aid worn ______________________________ Ear____ Settings________________

Condition of aid ____

Test reliability______________________ Child's reactions________________

PURE TONE FREQUENCY

	125	250	500	750	1000	1500	2000	3000	4000	6000
Right	___	___	___	___	___	___	___	___	___	___
Left	___	___	___	___	___	___	___	___	___	___

UCL

	250	1000
Right	___	___
Left	___	___

CHANGE PHONES

DETECTION
"Hello (name) " in dB Hearing Level. 2 measures, ascending.

Right _______ Left _______

SPEECH THRESHOLD
Spondee pictures, in dB Hearing Level. 2 out of 3 responses, ascending.

Right _____ Left _____

SPEECH DISCRIMINATION (Separate response sheet.) Select ear _____ in which aid is worn. If binaural aids or no aid worn, select better ear _____ according to pure tone frequency cutoff ______ or SRT _____.

Presentation level: 30 dB re: threshold at 250 Hz ______

105 dB H.L. ______

SPEECH APPROXIMATION TEST

1. **Duration**
   Demonstration page . TURN.

   Practice (LONG at top of page.) SHORT_____ LONG_______ LONG______

   Trials (Same page.) LONG_____ SHORT_____ LONG_______ LONG______

TURN PAGE

Trials. # 2 _____ TURN. # 3 _____ TURN. # 2_______ TURN. # 1_______ TURN.

Trials. # 1 _____ TURN # 3 _____ TURN. # 1 _____ TURN. # 2 _____ TURN.

continued, next page.

Appendix C-1, cont.

2. **Pitch**

Demonstration page. TURN.

Practice (HIGH at top of page.) HIGH______ LOW_____ HIGH______

Trials (same page). LOW_____ HIGH______ LOW_____ LOW________

TURN PAGE

Trials. # 1 _____ TURN. # 2 _____ TURN. # 2 ______ TURN. # 3______ TURN.

Trials. # 2_____ TURN. # 1 _____ TURN. # 3 ______ TURN. # 1______ TURN.

3. **Rate**

Demonstration page. TURN.

Practice (FAST at top of page.) SLOW ______ FAST _____ FAST______

Trials (same page.) SLOW ____ SLOW ______ FAST _____ FAST______

TURN PAGE

Trials. # 3______ TURN. # 1______ TURN. # 2______ TURN. # 2_____ TURN.

4. **Intensity**

Demonstration page. TURN.

Practice (LOUD at left.) LOUD_______ LOUD______ SOFT_______ LOUD_______

Trials (same page). LOUD______ SOFT______ LOUD______ SOFT_______.

TURN BOOK

Trials. # 1______ TURN. # 3_____ TURN. # 2______ TURN. # 2______ TURN.

Trials. # 2_____ TURN. # 3_____ TURN. # 2______ TURN. # 3______ TURN.

5. **Sentences**

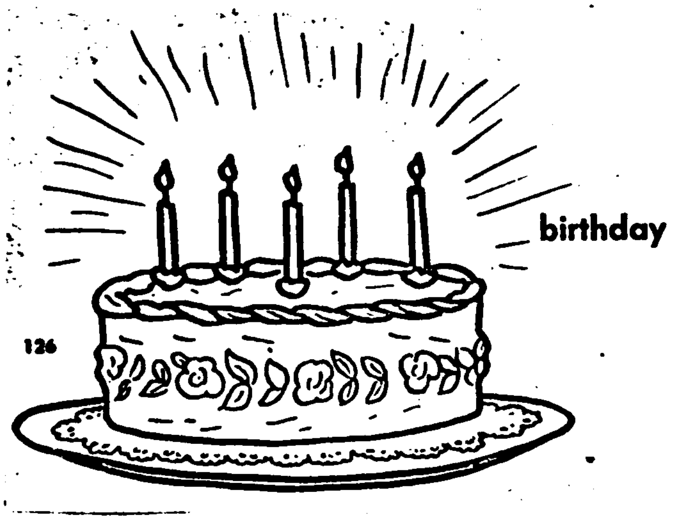
Practice. # 2_______ TURN # 1 _______ TURN.

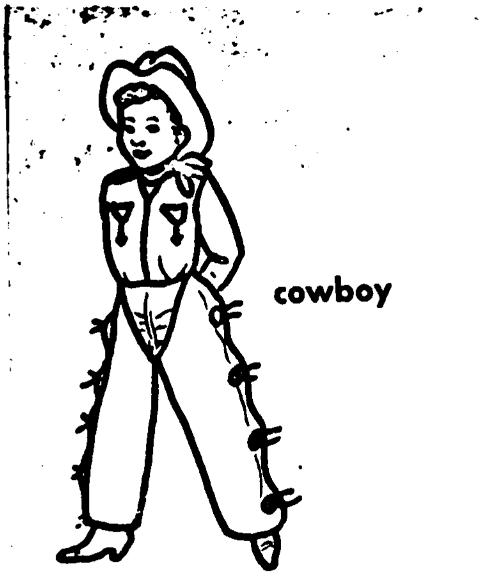
Trials.
 # 3 _____
 # 2 _____
 # 1 _____
 # 2 _____
 # 1 _____
 # 2 _____
 # 3 _____
 # 2 _____

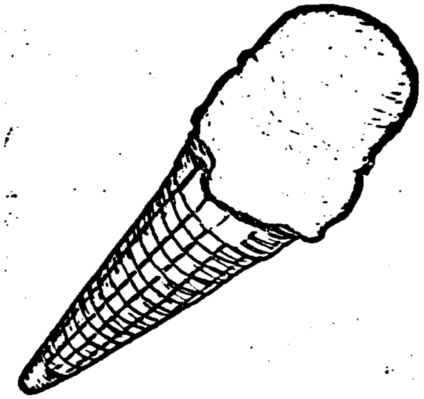
 # 2 _____
 # 3 _____
 # 3 _____
 # 1 _____
 # 3 _____
 # 2 _____
 # 2 _____
 # 2 _____

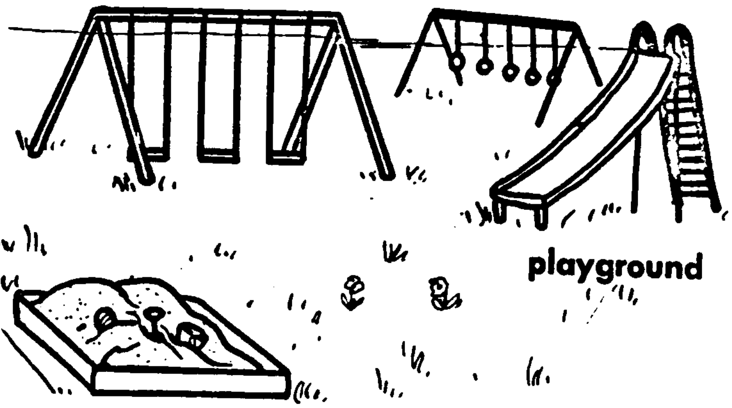
APPENDIX C-2

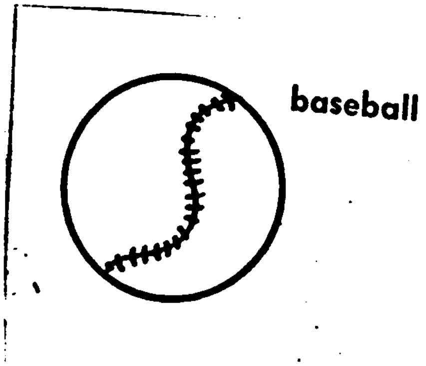
PICTURE CARD USED FOR SPEECH RESPONSE LEVEL

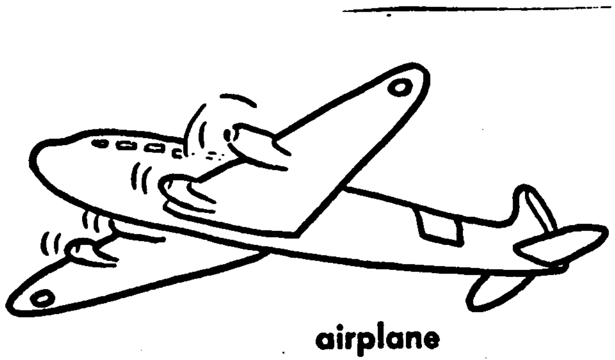












APPENDIX C-3

RANDOMIZED RESPONSE FORM FOR PHONEME RECOGNITION TEST

DRAW A CIRCLE LIKE THIS AROUND THE WORD YOU HEAR.

BOY	DOG	TOP	CHAIR	FAIR	PAIR	MAT	PAT	BAT
HOP	RUN	SIT	MARK	PARK	BARK	HE	SEE	SHE
TREE	CAT	BOOK						

ME	BE	WE	PETE	PIT	POT	RIM	RIP	RIB
BUM	GUM	DUMB	FALL	FULL	FOOL	SICK	SUCK	SOCK
BUT	BUN	BUD	CUP	CUB	COME	MOO	DO	YOU
TIP	DIP	NIP	THEN	DEN	MEN	BID	BIB	BIG
PET	POT	PUT	LOT	DOT	NOT	FEEL	FULL	FOOL

FEET	FOOT	FIT	HOT	HUT	HOOT
BET	MET	WET	SIP	SIT	SICK
POOL	PULL	PILL	BUD	BUZZ	BUN
WHEN	TEN	HEN	ZOO	NEW	DO
BILL	MILL	WILL	KNEE	D	TEA

WE	D	GEE	PEEL	PAL	POOL
PEA	TEA	KEY	MUMPS	DUMPS	JUMPS
WET	LET	YET	PAD	PAN	PAL
BUM	BUZZ	BUG	FAT	SAT	HAT
MASS	MAP	MATCH	HEAT	HIT	HUT

ZIP	DIP	LIP	WEED	LEAD	READ
BIT	BOOT	BEET	SEAT	SEED	SEEN
LEAD	LID	LED	PAT	PAN	PAD

APPENDIX C-4

CONSTRUCTION AND RECORDING OF STIMULI FOR SPEECH APPROXIMATION TEST

Since the intent of the test was not to seek difference limens but only to investigate ability to identify patterns, the components of the stimuli were made widely enough different to allow for easy recognition. They were as follows, with all rise-fall times 10 msecs.:

> Duration: Stimuli were tones of 250 Hz with durations of .5 and 1.5 seconds. For the patterns of two and three tones, the off-time was .6 seconds.
>
> Frequency: Stimuli were tones of 250 and 350 Hz, duration 1 second, off-time in patterns, 1 second. Since the tones were recorded, it was necessary to determine the intensity ratio between the two that would be present at normal threshold. However, no reference standard exists for 350 Hz. Therefor the normal threshold values for a TDH-39 earphone into a Bruel and Kjaer Type 4152 artificial ear, at 125, 250 and 500 Hz were plotted on log paper and a curve fitted through all three points. From this it was determined that threshold at 350 Hz would be -7 dB with reference to threshold at 250 Hz, and this ratio was maintained in recording.
>
> Rate: Stimuli were tones of 250 Hz, .6 secs. on, .5 or 1.5 secs. off.
>
> Intensity: Stimuli were tones of 250 Hz, 1 sec. duration, off-time in patterns .6 secs. The lower intensity tone was -3 dB with reference to the 250 Hz tones in the preceding sections, and the higher intensity tone was +10 dB with respect to the same reference.

The levels of all stimuli were measured before and after recording, using a Tektronix Type RM 564 oscilloscope. After editing, the tape was re-recorded with filtering at 500 Hz low-pass. A separate 250 Hz calibration tone was placed at the start of each section.

The sentences for Part 5 of the speech approximation test were recorded by the same talker as the sppech response level and phoneme recognition test materials. A 400 Hz calibration tone was set on the tape at 3 dB below the average peak level of the sentences. Tone and sentences were then traced on a Bruel and Kjaer Type 2305 level

Appendix C-4, continued.

recorder. The sentences were then low-pass filtered to remove as much phonemic information as possible, leaving only information carried by the low frequency end of the vocal spectrum. The filter cut-off level for the sentences was determined as follows:

A tape was made containing 12 sentences, three at each of four different low-pass filter cut-offs: 390, 450, 510 and 600 Hz. The sentneces were in random order. The tape was played twice to each of 5 normal hearing adults, who were asked on the first playing to give as much of the sentence as they could understand, and on the second playing, to identify it from a group of three on a page. The choices on the page were the same as those planned for the test. A filter cut-off level was sought that would give minimum intelligibility while allowing maximum recognition when a choice was presented. No listener understood any of the three sentences filtered at 390 Hz, but when asked to choose these sentences from groups of three, one listener made one error, while the other four chose all the sentences correctly. At the next highest cut-off level, 450 Hz, all listeners got at least one of the three sentences correct or partially correct on the first hearing. There were further increases in correct comprehension at the two higher cut-off levels. Therefor the 390 Hz cut-off was chosen.

The filtered sentences, together with the unfiltered 400 Hz calibration tone, were again traced on the level recorder. To compensate for the loss of power through filtering, the sentences were then re-recorded with the amount of attenuation individually adjusted for each sentence, so that the calibration tone, as determined by a

Appendix C-4, continued.

third tracing, was again 3 dB below the peaks.

Each sentence appeared in the response book on a page with two others designed to be phonemically similar but to differ with respect to duration, stress, phrasing or intonation contour. There were 4 sets of each type, or 16 in all. Two practice trials preceded the 16 test items.

To obtain a standard of normal performance on the speech approximation test, 5 normal-hearing adults and 18 normal hearing children, in the same age groups as the deaf children, carried out the procedure. One of the first subjects, an 8-year old boy, scored 69% correct on the sentence portion. With the consideration that the sets of 3-choice sentences might be confusing or linguistically difficult for young children, 5 more 8-year old children were tested with the procedure. They used 1) the 16 3-choice sentence items, and 2) a group of 2-choice sentence items. The number of 2-choice items was increased to 20. For the 3-choice sentence sets, the scores of these younger children ranged from 56% to 100%. For the 2-choice sets, the scores ranged from 75% to 100%. Since a 44% range of normal performance would be too broad to serve as a standard, the 2-choice, 20-item version was substituted for the 3-choice, 16-item version in testing the younger group of deaf subjects.

As expected, both adults and children attained near perfect scores on the rest of the test.

Appendix C-4, continued.

SCORES OF SUBJECTS ON SPEECH APPROXIMATION TEST

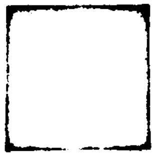
Child	Part 1	Part 2	Part 3	Part 4	Part 5
1	12.0	5.0	8.0	12.0	12.0
2	10.0	3.0	7.0	9.0	8.0
3	12.0	9.0	6.0	12.0	10.0
4	12.0	10.0	7.0	12.0	8.0
5	7.0	7.0	3.0	7.0	4.0
6	12.0	9.0	8.0	12.0	10.0
7	12.0	12.0	8.0	12.0	9.0
8	12.0	12.0	5.0	12.0	4.0
9	8.0	10.0	7.0	12.0	8.0
10	12.0	6.0	6.0	12.0	8.0
11	12.0	6.0	7.0	12.0	6.0
12	12.0	3.0	6.0	11.0	8.0
13	12.0	12.0	8.0	12.0	10.0
14	10.0	7.0	5.0	12.0	9.0
15	8.0	8.0	7.0	12.0	8.0
16	12.0	10.0	7.0	12.0	13.0
17	12.0	11.0	8.0	12.0	8.0
18	11.0	12.0	8.0	12.0	10.0
19	12.0	10.0	7.0	12.0	9.0
20	12.0	12.0	8.0	12.0	11.0
21	11.0	8.0	8.0	12.0	14.0
22	12.0	12.0	5.0	12.0	5.0
23	12.0	4.0	7.0	12.0	6.0
24	8.0	7.0	5.0	12.0	9.0
25	11.0	9.0	5.0	12.0	13.0
26	11.0	6.0	6.0	11.0	13.0
27	12.0	9.0	7.0	10.0	13.0
28	7.0	5.0	7.0	12.0	14.0
29	8.0	7.0	6.0	9.0	13.0
30	11.0	7.0	6.0	7.0	10.0
31	10.0	9.0	8.0	12.0	6.0
32	8.0	7.0	6.0	12.0	12.0
33	7.0	7.0	4.0	11.0	13.0
34	12.0	5.0	6.0	12.0	11.0
35	10.0	6.0	7.0	12.0	12.0
36	9.0	12.0	6.0	12.0	14.0
37	12.0	9.0	7.0	12.0	9.0
38	11.0	7.0	7.0	12.0	11.0
39	12.0	9.0	8.0	12.0	9.0
40	11.0	10.0	6.0	12.0	10.0

Appendix C-4, continued.

SAMPLE STIMULI FROM SPEECH APPROXIMATION TEST. PART 1 - DURATION.

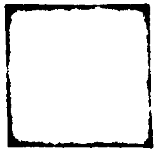
THIS IS LONG.

THIS IS SHORT.



Speech approximation test - duration, continued.

SHOW ME THE ONE YOU HEAR.



Speech approximation test - duration, continued.

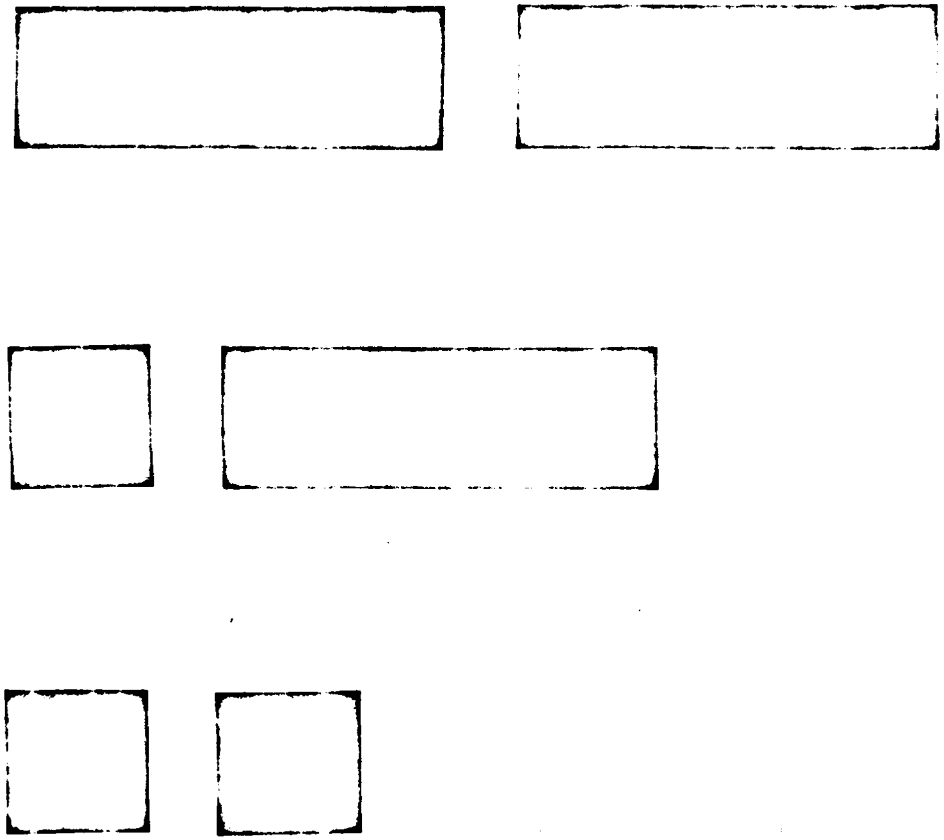
NOW LISTEN FOR TWO.
SHOW ME THE TWO YOU HEAR.

THIS ?

OR
THIS ?

OR
THIS ?

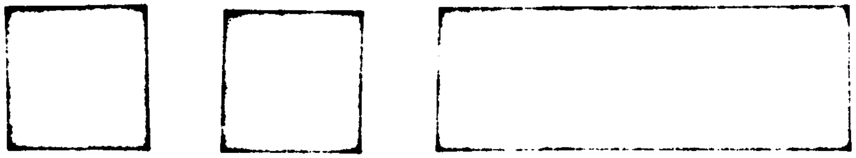
Speech approximation test - duration, continued.



Speech approximation test - duration, continued.

NOW LISTEN FOR <u>THREE</u>.
SHOW ME THE <u>THREE</u> YOU HEAR.

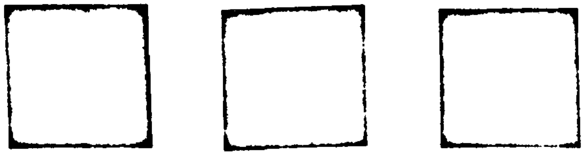
THIS ?



OR THIS ?

OR THIS ?

Speech approximation test - duration, continued.



SAMPLE STIMULI FROM SPEECH APPROXIMATION TEST. PART 2 - PITCH

THIS IS HIGH.

(PINK)

THIS IS LOW.

(BLUE)

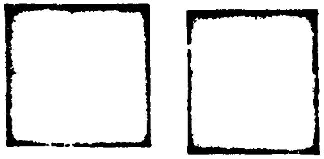
Speech approximation test - pitch, continued.

SHOW ME THE
ONE YOU HEAR.

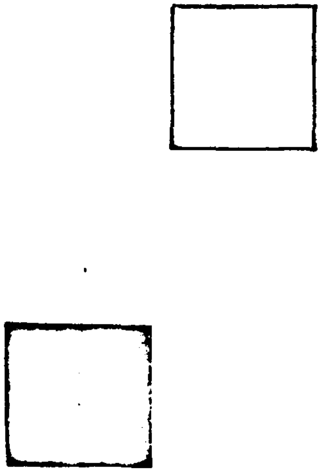
Speech approximation test - pitch, continued.

NOW LISTEN FOR TWO.
SHOW ME THE TWO YOU HEAR.

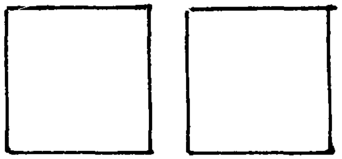
THIS?



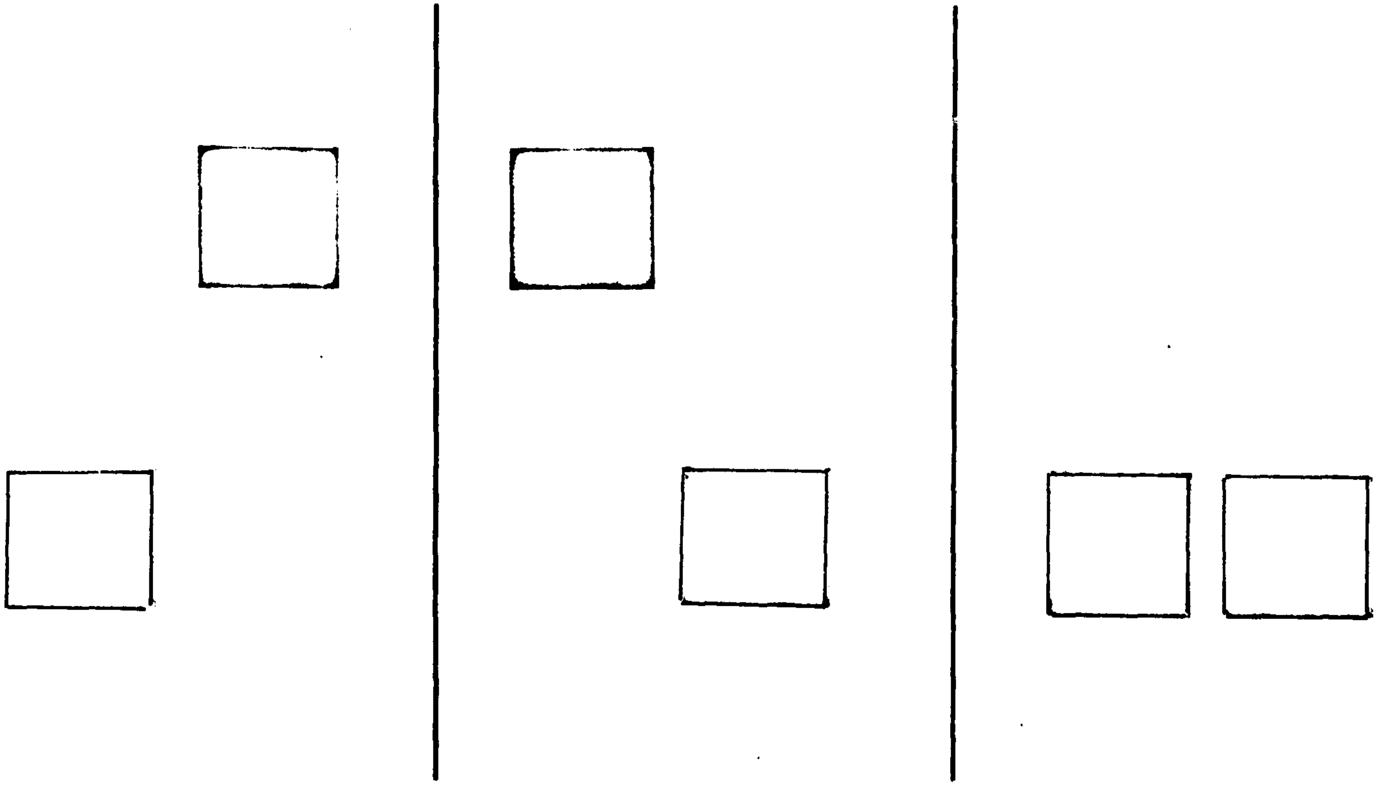
OR THIS?



OR THIS?



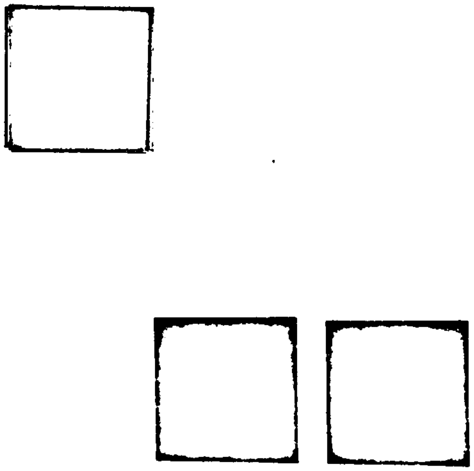
Speech approximation test - pitch, continued.



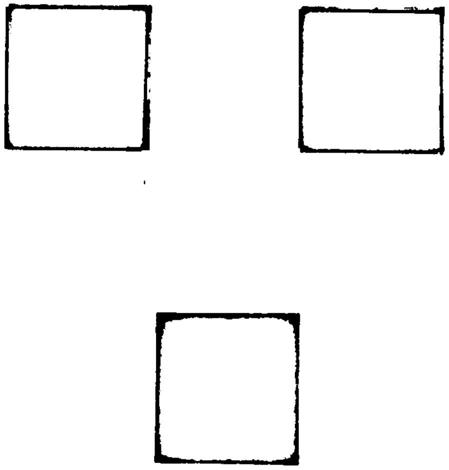
Speech approximation test - pitch, continued.

NOW LISTEN FOR THREE.
SHOW ME THE THREE YOU HEAR.

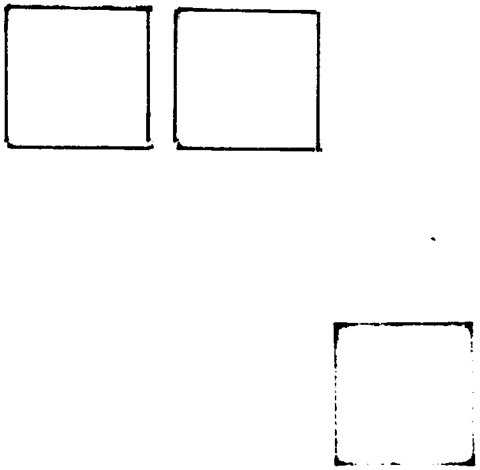
THIS?



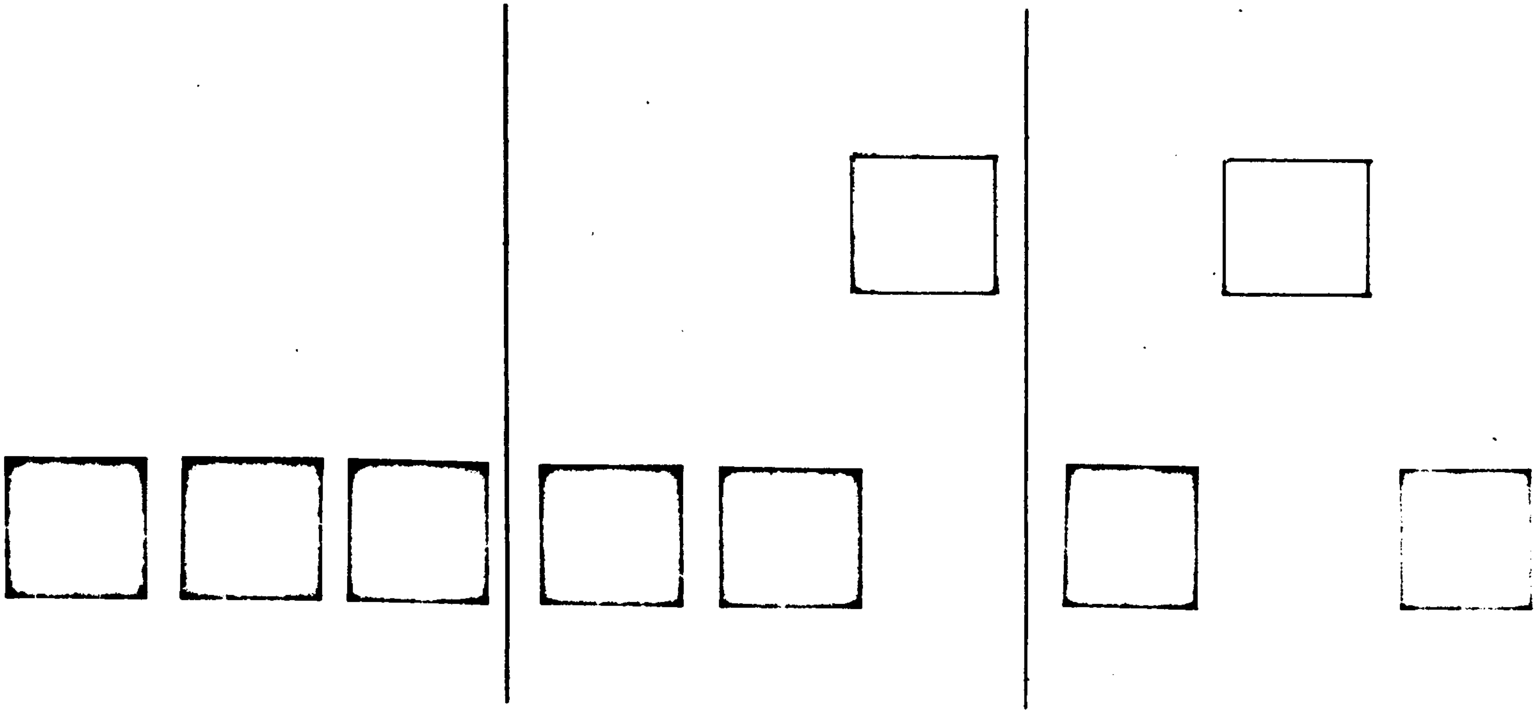
OR THIS?



OR THIS?

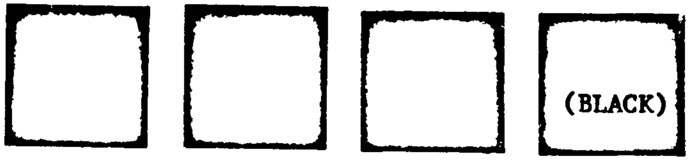


Speech approximation test - pitch, continued.



SAMPLE STIMULI FROM SPEECH APPROXIMATION TEST. PART 3 - RATE.

THIS GOES FAST.



THIS GOES SLOWLY.

Speech approximation test - rate, continued.

SHOW ME THE ONE YOU HEAR.

☐ ☐ ☐ ☐

☐ ☐ ☐ ☐

Speech approximation test - rate, continued.

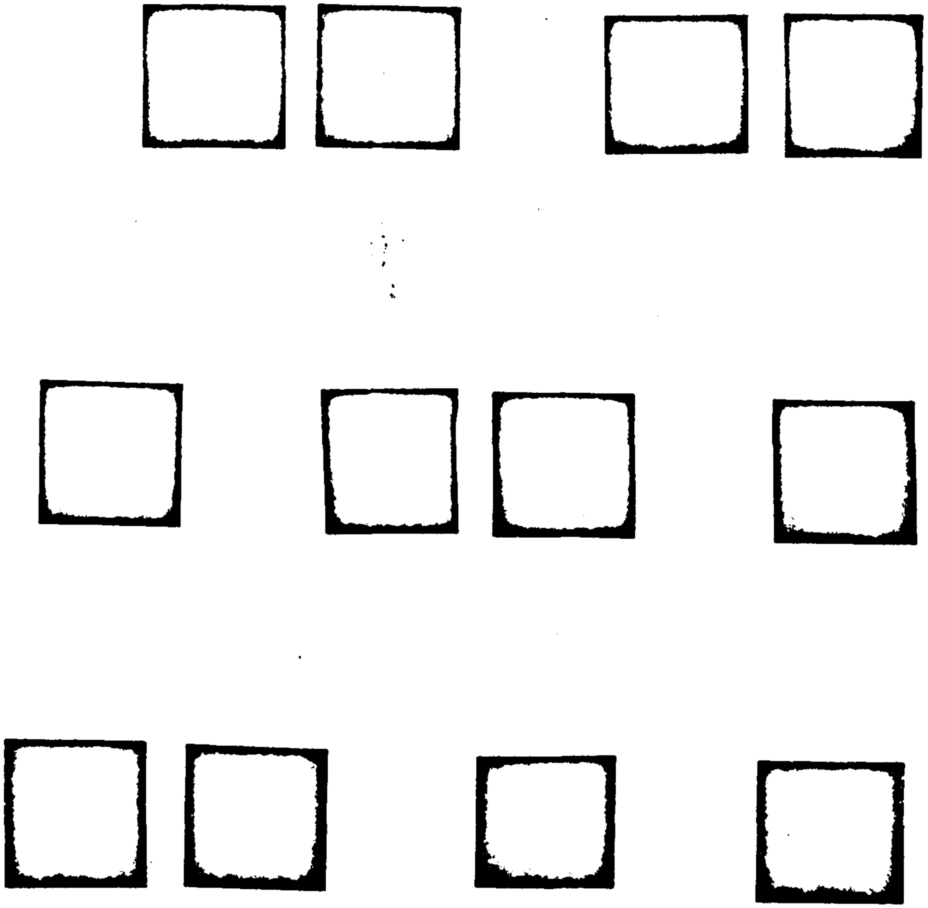
WHAT DO YOU HEAR NOW?

THIS?

OR
THIS?

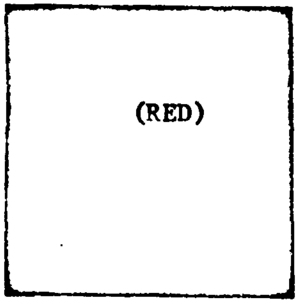
OR
THIS?

Speech approximation test - rate, continued.

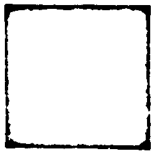


SAMPLE STIMULI FROM SPEECH APPROXIMATION TEST. PART 4 - INTENSITY

THIS IS BIG.

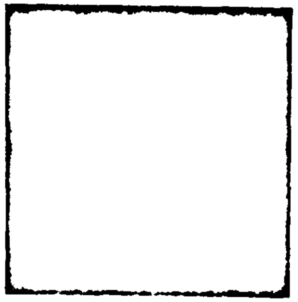


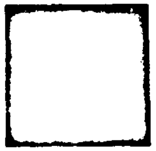
THIS IS LITTLE.



Speech approximation test - intensity, continued.

SHOW ME THE ONE YOU HEAR.

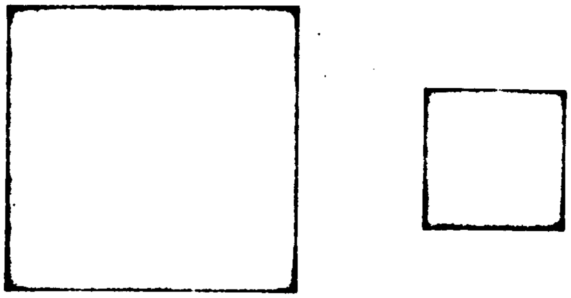




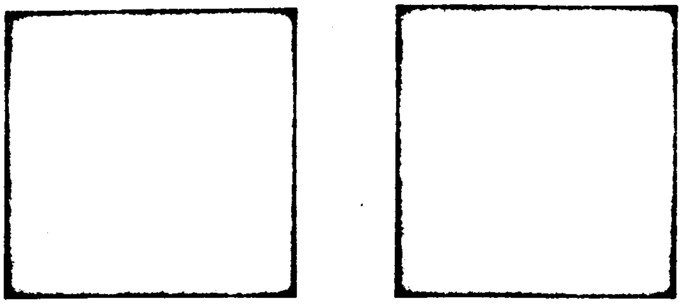
Speech approximation test - intensity, continued.

NOW LISTEN FOR TWO.
SHOW ME THE TWO YOU HEAR:

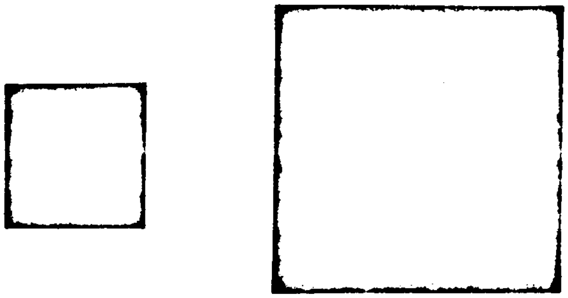
THIS?



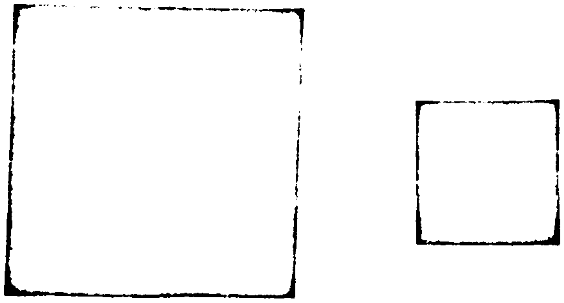
OR
THIS?

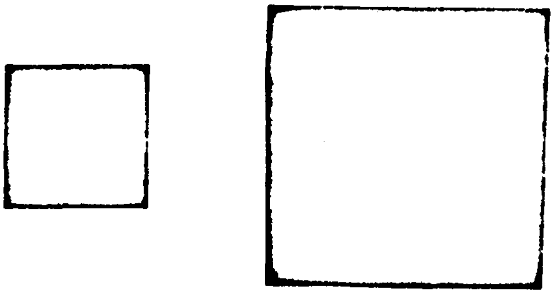


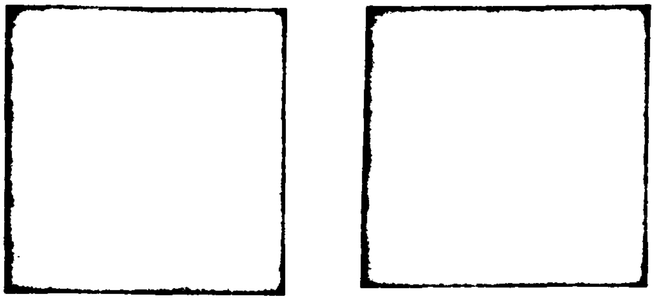
OR
THIS?



Speech approximation test - intensity, continued.



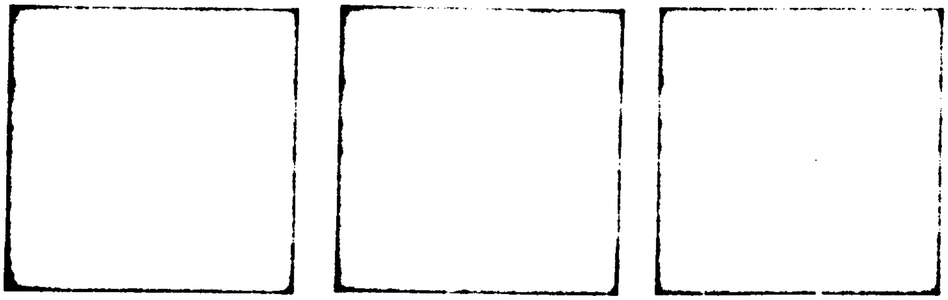




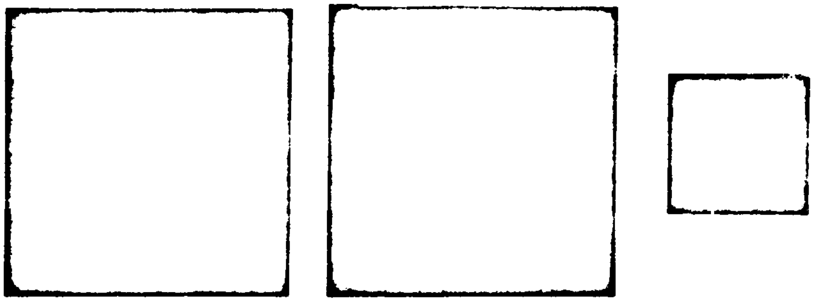
Speech approximation test - intensity, continued.

NOW LISTEN FOR THREE.
SHOW ME THE THREE YOU HEAR.

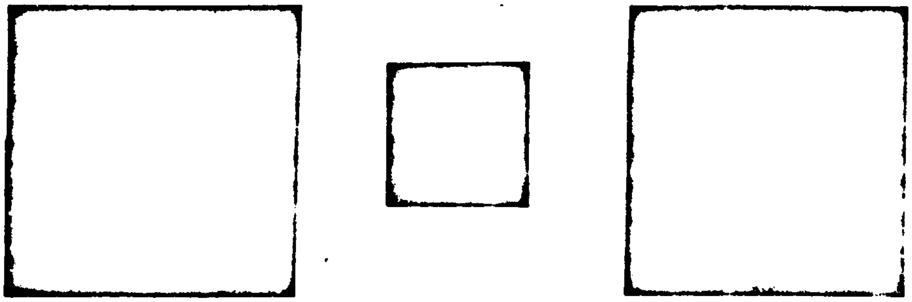
THIS?



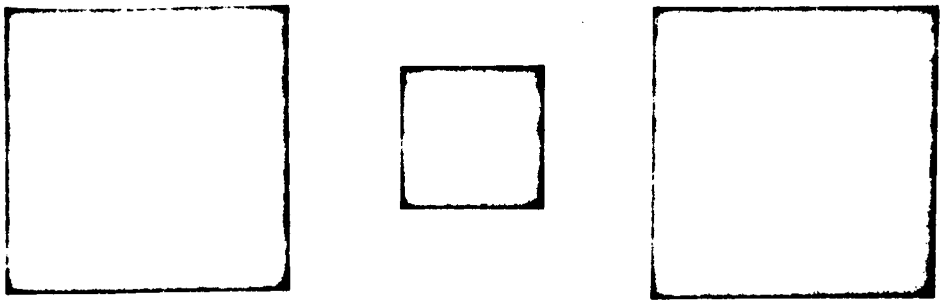
OR
THIS?

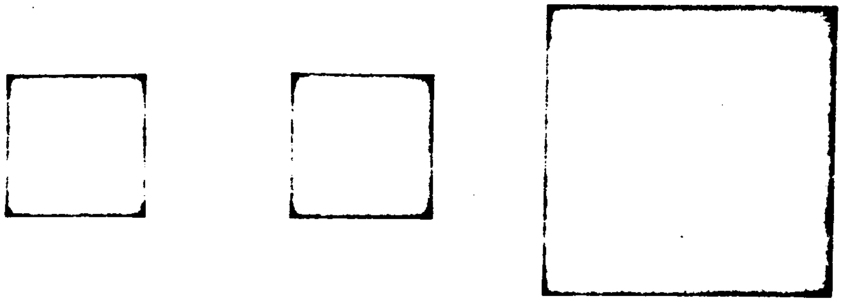


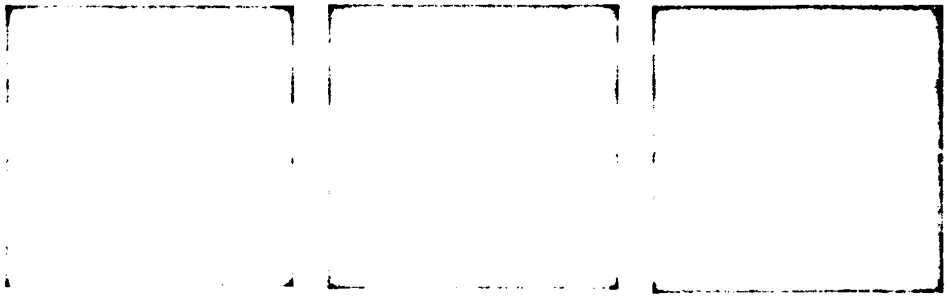
OR
THIS?



Speech approximation test - intensity, continued.







SAMPLE STIMULI FROM SPEECH APPROXIMATION TEST
PART 5. FILTERED SENTENCES
PRACTICE ITEMS

LISTEN TO THE MAN

DID HE SAY THIS?

WILL JIM PLAY BALL WITH TED?

OR THIS?

JIM WILL COME TO SCHOOL TODAY.

Speech approximation test. Filtered sentences, continued.

1) Sample stimulus sets for older children. Each group of 3 sentences appears alone on a single page.

Sentences differing in intonation:

Do you want ice cream and cake?

Do you want ice cream,   or cake?

I don't want ice cream and cake.

Sentences differing in duration:

He runs fast.

He runs faster than I.

He runs faster than anyone I know.

Sentences differing in stress:

Her name is Joan and *His* name is Jim.

Give *Joan* the ball and give *Jim* the bat.

I can see *Joan*, but I can't see *Jim*.

Sentences differing in phrasing:

I met two boys,   Jim and Ted.

I see Jim,   but Ted has gone.

I play with Jim,   Tom,   and Ted.

2) Sample stimulus sets for younger children. Each group of 2 sentences appears alone on a single page.

Do you want ice cream and cake?

I dont want ice cream and cake.

I have a dog.

I have a dog named Mike.

APPENDIX C-5

SENTENCE LISTS FOR COLLECTION OF SPEECH SAMPLE

I. ALL CHILDREN

1. I like happy movies better.
2. My mommy takes me shopping after school.
3. The leaves will be red and yellow in the fall.
4. I saw a fat man on the roof this morning.
5. The tooth paste was all over the bathroom floor.
6. I want chocolate ice cream, thank you. And a piece of cake with it.
7. I think he'd better keep away from here. He can't behave himself.
8. Did Jack find the orange ball? I need it.
9. I wish I could read that book.
10. Uncle Bob has a new dog, and Duke is his name. He is huge and lazy.
11. Go and see the rabbit in the box. He's a week old.
12. It's cool on the beach now. We have matches for the fire.
13. The wagon has food and dishes on it.
14. Everybody watches Lassie on T.V. Do you?
15. The zipper on my coat is no good any more.
16. It's very mean to laugh at other people.
17. Will anybody tell me who these girls are?
18. It's easy to swim in deep water.
19. A baby has no teeth or hair.
20. Who will feed the cat today?

continued on next page.

Appendix C-5, continued.

II. OLDER CHILDREN ONLY.

21. The tools and gasoline are in the shed. Don't lost the key.

22. I lost my boots, and I need new shoes for school.

23. The school roof leaks all the time.

24. The moving van will stop in front of the house.

25. Do you really feel this gadget is going to work?

26. This guy painted zebra stripes on his car.

27. Go and ask for more cups and spoons, will you please?

28. The cry of an eagle rang in the sku.

29. We took a ride up the Thruway in Larry's new car.

APPENDIX D-1

INSTRUCTIONS TO LISTENERS

You are going to hear 24 or 25 utterances recorded by deaf children. Most of them are single sentences. A few consist of two consecutive sentences. There are no repetitions of utterances; each child says something different. You may have each utterance played twice.

The speech of these children ranges from good to very poor. You are to write down whatever you think the child says. After each utterance, write a number from 1 to 5, where 1 means clearly understandable and 5 means completely unintelligible. Note: Even the best of these children do not sound like a normal-hearing speaker. Do not wait to hear normal speech. If the child's speech sounds fairly clear, he should get a good rating.

If some words are unclear but you can guess at them with the help of the rest of the sentence, put them in. If you can only catch an isolated word or two,write them down, indicating their approximate position in the sentence, which might look like '___ ___ boy ___ not ___ ___'.

Have you any questions?

APPENDIX D-2

INSTRUCTIONS TO PHONETICIANS

Enclosed you will find a tape reel containing ______ utterances of deaf children. The utterances are in lists of 24 or 25 each. Most are single sentences. A few are two sentences spoken consecutively. A short strip of leader tape separates each utterance from the next, to facilitate rewinding for repeated listening. A long strip of leader tape signifies the end of a list. Headphones are preferred for listening, but a good quality loudspeaker may be used.

Also enclosed are evaluation sheets, one to each sentence. The tape (list) number and the item number appear in the upper left hand corner of each sheet. It is essential that the sheets be used with the corresponding tapes. Neither children nor utterances are represented more than once in a single list. From one list to another, you will hear the same utterances spoken in a different order by different children.

On each evaluation sheet you will find the sentence the child speaks, written phonemically in International Phonetic Alphabet. This represents what we believe to be a reasonable (though not the only) pronunciation of this sentence in standard Eastern American English. Please give your transcription of the child's actual utterance, also in IPA, in the spaces immediately below this representation. Any additional comments on particular phonemes may then be written vertically in the columns provided.

Although many of the sounds produced by deaf children do not correspond to any standard phonemic target, you are asked to transcribe as broadly as is reasonably possible, since we are primarily interested in gross phonemic differences. Use an X for a non-identifiable substitution and a dash for complete omission. When necessary, you may wish to use some diacritical markings to indicate special departures from expected pronunciation, such as /ʔ / for glottal stop, /~/ for added nasalization, / ː / for unusual prolongation,/ ʰ/ for unusual aspiration. Interpolated sounds, of which there are a number, may be written on the lines between phonemes. If you find additional diacritical markings necessary, beyond those suggested above, please provide us on a separate page with a key or description of those you used.

When you have completed your transcription, please return the sheets and the tape to me at the address below. Thank you very much.

Clarissa Smith
Speech Dept., Room 902
City University of New York Graduate
Center
33 W. 42nd Street, N. Y.,N.Y. 10036

APPENDIX D-3. SAMPLE OF RATING PAGE USED BY PHONETICIANS

TAPE # ________ **ITEM #** _______ **SUBJECT #** _______ **SENTENCE #** 16 **It's very mean to laugh at other people.**

[ɪ	t	s		v	ɛ	r	i		m	i	n		t	u		l	æ	f		æ	t		ʌ	ð	ɚ		p	i	p	ə	l]								

APPENDIX D-4

INSTRUCTIONS TO PROSODIC RATERS

Enclosed are two tape reels with sentences of 20 children on each reel, and also:

1) a list of sentences;
2) a page giving the age and sex of each child and the numbers of the sentences he reads;
3) sufficient check-list evaluation sheets for the 40 children.

There are 5 utterances per child. Most are one sentence. A few are two sentences in length. Each child reads each utterance twice, except where specifically noted on (2) above.

There is no limit on the number of times you may listen to each child. It is suggested that you listen to each one once through 'cold' without following the sentence list, to assist you in judging the child's overall intelligibility, although your increasing familiarity with the sentences will have some effect on this.

The other judgements concern the prosodic aspects of voice and speech (not phonemic errors). The evaluation sheets provide one column per child. You are asked to check any item in the column that is applicable. This may mean that more than one item is checked for a given aspect of speech or voice. For example, under speech fluency, you might want to check 'Inappropriate pauses' and also 'Interpolation of extraneous speech elements'.

Most items are self-explanatory but here are a few definitions or examples:

Intonation (excessive variability). Variability in fundamental frequency inappropriate to the meaning.
Intermittent **phonation**. Breaks in the voice, not under the speaker's control.
Interpolation of extraneous speech elements. Added sounds or syllables. For example, a typical rendition of swim for a deaf child is /swɪmi/ . (Even more typical is /zwɪpi/ but you are not concerned with substitutions.

Thank you very much for your help.

APPENDIX D-5. PAGE USED FOR PROSODIC RATINGS.

CHILD NO.:															
VOICE A. Quality 1. Harsh or rough															
2. Breathy															
3. Hyper- or hyponasal															
B. Pitch 1. Too high															
2. Too low															
C. Control 1. Intermittent phonation															
2. Spasmodic variations of pitch and loudness															
D. Intonation 1. Insufficient variability															
2. Excessive variability															
SPEECH A. Stress 1. Inadequate stress															
2. Inappropriate stress															
B. Fluency 1. Inappropriate pauses															
2. Inappropriate prolongation of sounds															
3. Repetition of sounds															
4. Interpolation of extraneous speech elements															
C. Rate 1. Inappropriately fast															
2. Inappropriately slow															
3. Inappropriately varied a) Monotony															
b) Excessive or uncontrolled variability															

OVERALL RATING: Rate the speaker with a single number on a 5-point scale:

1. Speech is easily understood. Not characterized by voice and/or articulation errors.
2. Speech is understood. It does exhibit some voice and/or articulation errors.
3. Speech may be understood once the listener is familiar with it.
4. Speech is very difficult to understand, contains gross voice and/or articulation errors.
5. Speech is totally unintelligible.

RATING:															

APPENDIX E-1

POOLED CONFUSION MATRIX OF CONSONANT PHONEMES, SELECTED WORDS. *

		PRODUCED																											
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	11	557	167	25	10	8	0	5	4	10	26	0	1	6	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0
	12	56	434	23	4	6	0	11	2	10	30	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	1	5	220	14	5	0	0	1	8	6	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	14	8	9	39	593	31	1	1	0	17	24	0	0	8	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	2	2	7	297	2	0	1	9	7	0	1	3	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	3	7	160	4	4	12	12	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	1	1	1	2	0	55	1	5	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	18	4	1	1	0	2	3	14	267	8	4	0	0	1	1	1	4	0	1	0	1	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0	0	37	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	9	23	4	0	8	0	1	2	2	124	0	0	3	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
T	21	0	0	1	0	0	0	0	0	1	3	16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A	22	0	1	0	0	1	0	0	0	0	8	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	23	0	3	28	8	9	0	1	0	9	4	0	0	122	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
G	24	2	1	3	2	29	0	0	1	2	4	0	0	1	114	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	26	1	0	1	0	5	1	1	1	5	12	0	0	1	0	4	127	0	0	0	0	0	0	0	0	0	0	0	0
	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28	2	1	0	0	1	0	2	8	5	1	1	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0
	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	196	48	0	1	0	0	1	0	0	0
	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	340	0	1	0	1	0	2	0	0
	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	206	41	10	4	1	0	0	1
	32	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	3	37	229	2	6	0	2	0	2
	33	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	7	250	35	2	1	1	0
	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	8	54	0	0	0	0
	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	16	1	4	0	0	251	35	0	0
	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	1	0	0	20	151	0	0
	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	35	34	0	0	2	2	76	10
	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	12	95	0	0	1	2	9	80
	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	40	22	5	1	3	1	7	1
	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	35	1	3	0	6	5	3
	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	6	1	1	2	0	3	0
	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	43	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	1	6	6	2	2	0	0	0
	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	5	5	0	1	0	3	0
	46	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	17	2	0	0	0	0	0
	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	91	0	2	0	0	1	2	0	0
	48	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	8	17	1	1	0	2	0	0
	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	1	0	0	0	11	0	0
	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	1	0	1	2	7	0	0
	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
	53	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	8	0	0	0	0	0	0

* See page following matrix for key to numerical code.

Appendix E-1, continued.

										PRODUCED																			
		39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	50	61	62	53	54	65	65
	11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	32	19	7	18	3	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	4	23	9	1	12	8	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	6	1	3	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	23	16	2	1	3	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	9	5	5	0	1	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	16	1	1	0	1
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1	2	0	2	0
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	14	23	1	2	1	0
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	1	52	0	0
T	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	7	1	0	0	0	0
A	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	21	0	0
R	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	0	2	6	0	30
G	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	4	0	0	0	3	29
E	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	0	1	1	0	30
	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	1	3	1	0	1
	29	0	0	1	0	0	0	0	0	11	2	0	0	0	1	0	1	0	2	0	0	1	2	2	0	2	9	0	0
	30	0	0	0	0	0	0	0	0	13	0	0	1	0	0	0	0	0	1	0	0	1	3	9	0	3	9	0	0
	31	4	0	2	1	5	0	1	0	3	7	0	0	0	0	3	1	0	61	1	1	0	3	19	0	1	180	1	0
	32	2	3	2	0	1	0	1	2	0	7	1	2	1	3	7	0	1	42	1	0	0	1	32	0	6	197	5	0
	33	3	0	1	0	27	0	1	0	2	1	1	4	0	1	0	13	3	55	8	0	0	3	29	0	3	175	1	0
	34	0	0	0	0	3	0	0	0	1	0	2	0	0	3	0	3	2	11	1	0	0	2	14	0	1	48	2	0
	35	1	0	0	0	0	0	0	0	3	1	0	0	0	1	1	0	0	3	0	3	0	2	15	0	0	14	2	0
	36	0	0	0	0	0	0	0	0	5	2	0	1	0	0	1	0	0	3	0	0	0	2	4	0	2	29	0	0
	37	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	0	1	5	8	0	0	17	0	0
	38	0	0	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	1	0	0	0	1	8	0	1	15	0	0
	39	64	7	2	0	3	0	0	0	0	3	2	0	0	0	2	0	1	8	0	0	0	5	20	0	1	75	2	0
	40	27	105	0	1	4	0	1	3	1	12	4	1	0	2	1	0	6	28	2	0	0	13	51	0	2	266	8	0
	41	9	2	26	1	1	0	2	0	0	0	2	0	0	2	0	0	0	10	1	0	0	2	7	0	0	21	0	0
	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	43	0	0	0	1	147	1	0	1	0	1	1	2	0	5	2	1	0	41	0	0	0	0	25	0	7	142	1	0
	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	45	4	3	12	1	4	0	27	0	0	2	1	0	0	2	1	2	0	11	1	0	0	3	5	0	0	34	0	0
	46	2	4	5	9	0	0	1	17	0	0	0	0	1	1	0	0	0	2	0	0	0	1	5	0	4	46	0	0
	47	0	0	0	0	0	0	0	0	365	0	0	1	1	0	0	0	0	1	0	0	2	2	11	0	3	21	3	0
	48	1	0	0	0	2	0	0	0	4	399	9	1	1	1	8	0	1	14	0	0	0	1	18	0	9	176	4	0
	49	0	1	0	0	0	0	0	0	1	8	36	0	0	0	0	0	0	5	0	0	0	0	1	0	0	68	0	0
	50	0	0	0	0	0	15	0	0	11	0	0	316	2	0	0	0	0	0	0	1	3	3	11	0	0	6	0	0
	51	0	0	0	0	0	1	0	0	6	1	0	43	198	1	2	0	0	2	0	0	2	5	26	0	1	50	0	0
	52	0	0	0	0	0	0	0	0	1	3	0	0	0	21	3	0	0	1	0	0	0	0	1	0	0	6	0	0
	53	0	1	0	0	5	0	0	0	0	14	0	1	1	1	338	0	0	12	0	0	1	2	22	0	0	70	1	0

EXIT

Appendix E-1, continued.

<u>Key to phoneme confusion matrix</u>:

11	/i/	29	/p/	47	/m/
12	/I/	30	/b/	48	/n/
13	/ɛ/	31	/t/	49	/ŋ/
14	/æ/	32	/d/	50	/w/
15	/ɑ/	33	/k/	51	/r/
16	/ɔ/	34	/g/	52	/j/
17	/U/	35	/f/	53	/l/
18	/u/	36	/v/	54	/x/
19	/ʌ/	37	/θ/	55	/ɣ/
20	/ə/	38	/ð/	56	/ʔ/
21	/ɝ/	39	/s/	57	/ç/
22	/ɚ/	40	/z/	58	/ɸ/
23	/eI/	41	/ʃ/	59	/β/
24	/aI/	42	/ʒ/	60	Intended phoneme distorted.
25	/aU/	43	/h/		
26	/oU/	44	/hw/	61	Unidentifiable substitution
27	/ɔI/	45	/tʃ/		
28	/ju/	46	/dʒ/	62	Intended vowel diphthongized.
				63	Word misread.
				64	Omission.
				65	Word left out.
				66	Intended diphthong fails.

APPENDIX E-2

IDENTIFIABLE CONSONANT ERRORS CLASSIFIED BY ERROR TYPE.

CONSONANT ERRORS

	P	M	V	PM	PV	MV	PMV	TOTAL
29	2	0	48	3	1	12	3	69
30	2	15	16	2	1	0	0	36
31	72	4	41	12	6	7	8	150
32	9	11	37	20	45	2	5	129
33	64	13	35	43	10	4	9	178
34	2	4	8	4	14	3	4	39
35	4	0	35	11	0	0	26	76
36	0	0	20	29	0	0	3	52
37	2	0	10	41	3	0	38	94
38	2	0	9	101	1	0	13	126
39	15	40	7	13	3	25	10	113
40	16	47	27	16	11	8	30	155
41	15	2	2	32	2	2	9	64
42	0	0	0	0	0	0	0	0
43	3	41	1	7	1	0	24	77
44	0	0	0	0	0	0	0	0
45	0	13	0	63	0	4	11	91
46	0	10	1	22	0	5	8	46
47	0	94	0	5	0	14	2	115
48	13	18	0	14	0	9	18	72
49	9	0	0	1	0	0	5	15
50	2	34	0	27	0	1	0	64
51	44	2	0	30	0	0	4	80
52	0	3	0	8	0	0	1	12
53	0	1	0	28	0	0	17	46
TOTALS	276	352	297	532	98	96	248	

P - place. M - manner. V - voicing. PM - place and manner.
PV - place and voice. MV - manner and voice.
PMV - place, manner and voicing.

Appendix E-2, continued.

IDENTIFIABLE VOWEL ERRO

VOWEL ERRORS

	F	H	R	T	FH	FR	FT	HR	HT	RT	FHR
11	0	0	0	167	8	4	0	0	35	0	0
12	0	27	0	56	0	0	0	0	0	0	21
13	0	19	0	0	0	0	0	0	1	0	8
14	0	48	0	0	0	17	31	0	8	0	1
15	0	0	0	0	0	2	7	0	0	9	1
16	0	4	0	0	0	7	0	0	4	0	2
17	0	0	0	0	0	1	0	0	1	0	7
18	0	3	0	0	0	4	0	0	14	0	2
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	1	0	0
22	0	0	0	0	0	0	0	0	0	0	0
TOTALS	0	101	0	223	8	35	38	0	64	9	42

F - fronting. R - rou

Appendix E-2, continued.

IDENTIFIABLE VOWEL ERRORS CLASSIFIED BY ERROR TYPE.

H	FR	FT	HR	HT	RT	FHR	FHT	FRT	HRT	FHRT	TOTAL
	4	0	0	35	0	0	0	0	0	42	256
	0	0	0	0	0	21	6	2	0	30	142
	0	0	0	1	0	8	5	0	0	7	40
	17	31	0	8	0	1	0	1	0	24	130
	2	7	0	0	9	1	4	0	0	8	31
	7	0	0	4	0	2	0	15	0	12	44
	1	0	0	1	0	7	0	0	0	4	13
	4	0	0	14	0	2	0	1	0	13	37
	0	0	0	0	0	0	0	0	0	2	2
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	0	0	0	1	0	4	6
	0	0	0	0	0	0	0	0	0	0	0
8	35	38	0	64	9	42	15	20	0	146	

F - fronting. R - rounding. T - tenseness. H - height.

APPENDIX E-3

PROSODIC DATA, RAW SCORES

Child	Variable *												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	0	0	1	0	0	3	0	2	0	1	3	0
2	1	0	1	0	1	3	1	3	2	1	0	0	2
3	2	0	0	0	1	1	3	0	2	0	3	3	0
4	0	1	0	0	0	0	2	0	0	1	1	0	1
5	0	1	3	1	1	3	1	2	2	0	0	0	3
6	0	0	0	0	0	1	1	0	0	0	0	1	0
7	0	0	0	0	0	2	0	3	2	0	0	0	3
8	0	0	1	0	0	2	0	2	2	0	2	1	0
9	0	1	2	0	0	3	0	3	3	1	0	0	3
10	1	0	0	0	0	0	2	0	2	0	0	2	0
11	0	0	0	0	0	3	0	3	3	0	0	0	2
12	0	0	0	0	1	1	2	0	2	1	0	2	0
13	1	0	0	1	0	1	2	0	2	1	0	2	0
14	0	1	2	0	0	3	2	1	1	0	0	2	1
15	0	0	0	0	3	3	2	2	2	0	2	2	1
16	1	0	1	0	0	3	3	0	2	0	2	1	2
17	1	1	0	2	0	0	2	0	0	1	0	1	0
18	1	0	0	1	0	1	3	0	2	1	0	2	1
19	0	2	0	0	0	3	3	0	2	0	1	2	1
20	1	1	0	1	0	1	1	0	0	0	0	1	0
21	1	0	2	0	0	1	3	0	1	1	0	1	1
22	0	0	0	0	0	2	2	1	0	1	0	1	1
23	1	0	0	0	0	3	3	1	3	0	1	3	0
24	0	0	1	0	0	1	3	0	1	0	1	3	0
25	0	0	0	1	1	1	3	1	2	0	0	1	2
26	1	0	1	0	1	1	3	0	3	0	1	3	0
27	0	0	0	0	0	3	2	1	2	1	0	0	2
28	0	1	2	0	1	2	1	2	3	0	0	2	1
29	0	1	1	0	0	3	3	0	3	1	2	2	2
30	2	0	0	0	0	1	3	0	1	1	0	1	1
31	1	1	3	0	1	3	1	3	3	1	0	1	2
32	1	1	0	1	0	0	3	0	2	0	1	3	1
33	1	0	0	0	0	1	3	0	2	0	3	3	0
34	2	0	0	0	0	0	3	0	2	0	0	3	0
35	1	0	0	0	0	2	2	1	3	0	0	2	1
36	0	1	3	0	1	2	1	1	2	1	0	2	1
37	2	0	0	1	0	1	3	1	2	0	1	3	0
38	0	0	2	0	0	2	2	0	2	0	2	2	1
39	0	0	0	0	1	1	3	0	1	0	2	2	0
40	1	1	0	1	0	0	2	0	2	1	1	3	0

*See Rotated factor matrix for variable identification.

ROTATED FACTOR MATRIX. LOADINGS ON 13 PROSODIC VARIABLES

Variable 1. Voice quality: harsh or rough.

-.18367	-.03256	-.10478	.05408	-.09413	-.07110	-.15405	.94704
.00713	-.08064	-.10055	.00801	-.00507			

Variable 2. Voice quality: breathy.

.04839	-.07580	.96538	-.01623	-.11825	-.03119	.06455	-.09913
-.03641	.16498	.04639	.00195	-.00224			

Variable 3. Pitch: too high.

.15310	-.06582	.18835	.11352	.09760	.10301	.14663	-.08547
-.05209	.92529	.12578	.00020	.01366			

Variable 4. Pitch: too low.

-.05976	-.03475	.12172	-.09480	-.96017	-.04437	-.05108	.08942
-.09663	-.08611	-.14172	.00220	-.00739			

Variable 5. Control: intermittent phonation.

.05121	.03025	-.02913	.08417	.04205	.98255	.01750	-.06392
.07218	.08616	.06352	.00246	.01653			

Variable 6. Control: spasmodic variations of pitch and loudness.

.20700	.01446	.08185	.23197	.25553	.11009	.35467	-.16383
.03771	.19197	.79190	-.01235	.02876			

Variable 7. Intonation: insufficient variability.

-.93439	.02308	-.07701	-.00810	-.04891	-.00306	-.17070	.19019
.16555	-.13103	-.06160	.00724	.06506			

Variable 8. Intonation: excessive variability.

.67914	.03198	-.02767	.27516	.07310	.21403	.38527	-.04961
-.14103	.12571	.27308	.02917	.38481			

Continued on next page.

Rotated factor matrix, continued.

Variable 9. Inappropriate stress.

```
    .05470      .07191     -.01775      .96629      .09668      .08820      .07413      .05235
    .05639      .10126      .13554      .01316      .02109
```

Variable 10. Rate: inappropriately fast.

```
    .02029     -.97311      .07467     -.06919     -.03378     -.03013      .10908      .03064
   -.15465      .05728     -.00897     -.00936     -.00304
```

Variable 11. Rate: inappropriately slow.

```
   -.20368      .17318     -.03954      .05796      .10468      .08112     -.14385      .00701
    .93924     -.04980      .01958      .00973     -.01288
```

Variable 12 . Rate: monotonous.

```
   -.47706      .21098      .01833      .27133     -.04543      .03519     -.68230      .15235
    .20359     -.01305     -.13561      .31532      .04934
```

Variable 13. Rate: excessive or uncontrolled variability.

```
    .18884     -.08229      .10494      .20270      .04699      .03126      .88591     -.14266
   -.10815      .17888      .20742      .09011      .04739
```

Appendix E-3, continued

VALUES OF THE CORRELATION COEFFICIENT FOR PROSODIC VARIABLES* AND PHONEME ERROR TYPES

ERROR TYPE	VARIABLE												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Place	.13	-.06	-.07	.01	.00	.16	.15	.05	.02	-.15	-.22	.23	-.13
Manner	.10	-.11	-.11	.28	-.07	.18	.21	-.25	.06	.21	.00	.12	.06
Place-Manner	-.02	-.29	.00	.42	.03	.37	.32	-.27	.07	.10	.05	.19	-.10
Voicing	.02	.01	-.02	.19	.00	-.22	-.09	-.02	.05	.06	.03	.10	-.10
Vowels	.02	-.08	.21	.28	.06	.43	.33	.12	.13	.20	-.15	.23	.07
Omissions	.16	-.16	.03	.16	-.05	.36	.54	-.06	.05	.12	-.31	.38	-.13
Place-Voice	.32	-.03	-.19	.07	-.13	.10	.30	.07	.04	-.14	-.12	.27	-.03
Manner-Voice	-.11	-.39	.06	-.12	-.11	.21	.15	-.38	.13	-.35	.25	.18	-.24
Pl.-Man.-Voice	.16	.00	-.07	.23	-.02	.17	.23	.04	.08	.11	-.21	.26	-.10
Total errors	.16	-.11	.15	.31	.01	.48	.44	-.01	.20	.12	-.18	.33	-.05

(* see rotated factor matrix for variable identification.)

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