AUDITORY DISCRIMINATION OF CODED SPEECH

BY DEAF CHILDREN

by

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ABSTRACT

Auditory Discrimination of Coded Speech by Deaf Children

Four studies constitute this series of experiments in which profoundly deaf children were trained to discriminate linearly amplified speech and speech coded by three different processes. The purpose of the experiments was to determine whether subjects could acquire better speech discrimination skills with frequency transposed (Coded) speech than with conventional linear amplification. In none of the four studies were discrimination scores for coded speech significantly different from scores for linearly amplified speech. In the final experiment, coded speech to the right ear and linearly amplified speech to the left did not lead to better results than either form of amplification presented binaurally.

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Introduction

Profoundly Deaf Subjects

Subjects with profound hearing loss, who hear only sounds of low frequency at high levels of intensity, may comprise up to one third of pupils attending schools for the deaf (Huizing, 1959; Watson, 1961; Ling, 1964a). Because ability to discriminate speech and thus to communicate is drastically restricted by such severe deafness, several alternative or supplementary cue systems employing other sensory and motor modalities have been developed to facilitate communication with deaf persons. Traditionally, these have included lip-reading, fingerspelling, signing, or some combination of these (DiCarlo, 1964).

More recent experimental approaches include cued speech (suggested by Cornett, 1967), tactual vocoding (studied by Pickett, 1963 and Kringlebotn, 1968) and the visual display of certain characteristics of running speech (demonstrated by Upton, 1968).

Remedial Amplification

The use of hearing aids which provide linear amplification over the main speech frequencies (300 - 3000 Hz) has become widespread over the past few decades. However, no form of linear amplification can fully compensate for profound hearing loss (Davis and Silverman, 1960). This is because only a part of the acoustic pattern of voiced sounds lies within the frequency range audible to such subjects, (Potter, Kopp and Green, 1947: Fletcher, 1953). Nevertheless, Hudgins (1954), Clarke (1957), Ling (1959), Van Uden (1960) and Watson (1961), among others, have provided evidence that the use of residual audition through linear amplification can help deaf children acquire, monitor and maintain voice patterns such as rhythm, intonation and stress in their speech. Ling (1964b, 1966) also found that extending the low frequency range of hearing aids for profoundly deaf subjects from 300 Hz to 100 Hz resulted not only in better audition of these voice features but also in significantly improved discrimination of vowels.

Sensory Deprivation

Whetnall (1964) considered the use of hearing to be essential for language learning but suggested that the use of residual hearing could be truly effective only during infancy. Tervoort (1964) agreed with Whetnall that infancy constituted a critical period for the development of communication by speech and believed that unless a child had learned to speak before four years of age it would be too late for him to acquire natural language. This view was not, however, based on experimental evidence.

Though much of the work carried out within the conceptual framework supplied by Hebb (1949) shows that visual deprivation in early life may cause permanent impairment in later functioning (Melzack, 1962: Hubel and Wiesel, 1963a; 1963b: Krech, 1964) it is still a matter of conjecture whether auditory deprivation limited to the early years could produce such long term effects (Gauron and Becker, 1959: Sterritt and Robertson, 1964). Certainly, continuing auditory deprivation which prevents the perception of acoustic patterns has marked overall effects on human behaviour (Myklebust, 1964). The use of speech transposed down in frequency so that high frequency patterns become audible to subjects with low frequency hearing residue may provide evidence regarding the amelioration of sensory deprivation.

Discrimination Capacity and Residual Hearing

The perception of frequency transposed speech patterns by subjects with profound hearing loss must clearly depend on adequate auditory discrimination ability over their range of residual hearing. Such discrimination was studied by Strizver (1959). He found that there were wide differences in ability between subjects. However, those with good differential thresholds at 500 Hz tended to obtain the best scores for speech discrimination. Filtered speech was employed by LaBenz (1956), who reported that discrimination scores for speech in the bandwidth 250 - 750 Hz were poorer for subjects with sensorineural loss than for subjects with normal hearing or other types of hearing loss. LaBenz also reported marked variability in performance among listeners. Mazéus (1968) has proposed a system by which differential thresholds within the residual range for intensity, frequency and time can be measured. Its use to date does not, however, appear to have been documented.

Pickett and Martin (1968) studied the frequency discrimination of filtered noise bursts by twelve subjects with severe sensori-neural hearing loss. Results from tests repeated until measures became stable showed their discrimination to be nearly normal at 250 Hz, poorer at

500 Hz and considerably poorer than normal at 1000 Hz and above. Pickett and Martony (1968), in research on complex sound discrimination in the hearing impaired, measured frequency discrimination for a simplified speechlike sound similar to a vowel formant. Tests were made in the regions of 225, 300, 430, 630 and 870 Hz. Large learning effects were noted. The more profoundly deaf the subjects, the poorer their discrimination tended to be, particularly as frequency increased.

Review of Relevant Literature

Perwitzschy (1925) was apparently the first to suggest that speech might be 'transposed' in such a way that its higher components could be shifted down in frequency and thus made audible to severely hard of hearing subjects. His attempts to design an electrical device which would halve the frequency range of speech yet preserve its temporal and other characteristics met with failure. When Hartley(1928) formulated his law,

($I = 2TW \log S$), which demonstrates speech information (I) to be a product of time (T), bandwidth (W) and (as he implies) intensity ($\log S$); it became evident that shifting down the frequency range of speech, as Perwitzschky had sought to do, could be accomplished only by trading bandwidth for time or by losing information.

Recording Techniques

Hartley's law is illustrated by playing back recorded speech at half speed, thus halving the frequency range but doubling the time required for transmission. This technique has been widely used in experiments with both hearing and deaf subjects (König and Eichler, 1954: Ochiai, Saito and Sakai, 1955: Springer, 1955: Schubert, 1960: Tiffany and Bennett, 1961: Klumpp and Webster, 1961: Oeken, 1963: Foulke and Sticht, 1966: and Bennett and Byers, 1967). Work using this process has suggested that discrimination is impaired more for male than for female speech.

Speech shifted in frequency by tape recording techniques may also be restored in time by removing segments of the recorded speech signal. If large segments of speech are removed, whole phonemes can be eradicated. However, if extremely small segments are removed some components of every phoneme may remain both audible and discriminable, though some information loss must occur. Segments of recorded speech may be removed automatically by using a playback device with a revolving head designed for the purpose. Völz (1961) constructed such a device.

Oeken (1963), who used Völz's apparatus, found that while his deaf subjects could learn to discriminate slow-played, time-restored speech with training, better results were obtained with conventionally amplified speech under the same experimental conditions. Bennett and Byers (1967), however, found that rhyming words slowed to 80% of normal speed were discriminated better than at normal speed by presbycusic subjects. Their finding that speech slowed by more than 20% yielded poorer results is in accordance with all other work using tape recording techniques.

In no study to date have the high frequency components of speech been emphasized before recording or playback. Male voices in particular would be shifted by slow-play in such a way that the fundamental and first formant characteristics could easily mask the higher information bearing components. If the latter were pre-emphasized, results with this form of frequency transposition might be improved.

The major disadvantage of transposition by tape recording techniques is the time lag required for recording and play back. This lag may create an impossible situation for subjects who have to supplement auditory cues by speech reading in face to face conversation.

Real-time Frequency Shift

Raymond and Proud (1962) devised a process in which speech was shifted down by the use of two radio-frequency carrier waves separated by either 400 Hz (for male voice) or 750 Hz (for female voice). The upper carrier wave was modulated by the speech input and the filtered side band was beat against the lower carrier-wave to reconvert the energy to the audio-frequency bandwidth. Effectively, the procedure shifted all speech sounds down in frequency by the extent to which the radio-frequency waves were separated. Reduction of bandwidth was accompanied by a reduction of information, since components naturally falling below the frequency of the shift were eliminated. The shifting of sounds by a constant factor also destroyed harmonic relationships.

Subjects' discrimination scores for this form of transposed speech improved with training but remained significantly below their scores for conventionally amplified speech. Although certain subjects on post-training tests achieved better discrimination scores with conventional amplification to one ear and shifted speech to the other, differences between this condition of amplification and others did not reach a significant level.

Raymond and Proud also reported that female speech shifted by 750 Hz was more intelligible than male voice shifted by 400 Hz. This difference, which was not discussed by the authors, may have been at least partly due to the masking of high frequency components by the extremely low frequency sounds created by the shifting procedure.

Coding Procedures

The first speech coding device was developed by Dudley (1939). It was known as the vocoder. A vocoder is a device which does not transmit speech itself but rather an analogous form of speech over a reduced bandwidth. In vocoders like Dudley's, a frequency analyzing network is used to define and transmit the fundamental pitch and a number of spectrum analyzing channels are used to sample the overall pattern of speech energy. Speech is synthesized in these vocoders by the use of oscillators or noise generators which correspond with the analyzing channels. The energy in each output channel is governed by the current in the corresponding analyzing channel.

In spectrum channel vocoders, phase information is completely lost and transients are distorted in proportion to the amount bandwidth is reduced. Several other types of vocoder have been developed, each with its own advantages and disadvantages (Schroeder, 1966).

Discrimination of Coded Speech by Deaf Subjects

Guttman and van Bergeijk (1958) reported a study in which coded speech was used with deaf subjects. Only a brief description of the apparatus and results was provided. The apparatus was a vocoder which halved the frequency range of speech. Vowels and consonants were reported to be equally intelligible. Consonant confusions were largely within major phonetic classes, though errors in discrimination were most frequent among fricatives.

Pimonow (1963, 1965) reported the construction of eleven different vocoders. Of the final two models, one (parole synthêtique) synthesized the fundamental voice components and utilized six spectrum channels to present coded speech from the bandwidth 200 - 700 Hz in the range 30 - 300 Hz. The other (parole compensée) amplified speech normally from 50 - 700 Hz and employed two channels to convert energy from 700 - 2000 Hz and 2000 Hz to 7000 Hz respectively to the same bandwidth as the bass-band channel, on which it was superimposed. Pimonow (1965) reported that deaf subjects trained with the former, and hard of hearing children trained with the latter, all learned to discriminate speech to some extent. However, these studies were apparently observational rather than experimental. In contrast, Bouillon (1967), who used both types of vocoder with young deaf subjects, found that discrimination scores after training with each of Pimonow's two models did not differ significantly from those obtained after training with a conventional linear amplifier.

Lafon (1967) reports the use of a vocoder similar to that constructed by Pimonow for the hard of hearing (parole compensée). In Lafon's instrument, energy present in two bandwidths, one 1500 - 3500 Hz, the other 5000 - 7000 Hz, was coded and superimposed on a linearly amplified bass band which extended to 1000 Hz. While Lafon gave no details on his tests or procedures, he claimed that such coded cues allowed deaf children to identify different consonants.

Johansson (1961) and Wedenberg (1961) collaborated on the development and use of a different type of coding amplifier. One channel of this instrument provides high quality linear amplification. The other channel is used to beat speech sounds over 3000 Hz against a 4800 Hz reference tone. The resultant difference frequencies are filtered out and superimposed on the conventionally amplified speech. A number of studies reported by Johansson (1966) indicated that discrimination of speech coded by this process improved with training. These results are further discussed in relation to two of the four studies reported below (Experiment II and Experiment III) in which the Johansson-Wedenberg Transposer was employed.

Guttman and Nelson (1968) developed an instrument which generates low-frequency coded cues dependent on zero-crossing information derived from high-frequency speech energy. Experimental studies using the device with deaf children have been planned but not yet begun. As with the Johansson-Wedenberg Transposer, the coded informatiion generated by the device is superimposed on the natural low-frequency spectrum.

Sakai, Doshita, Niimi and Tabata (1968) have developed techniques for coding speech by means of an analog computer. These techniques have not been used to explore discrimination of coded speech by deaf subjects, but suggest the flexibility with which such work may be planned in the future. The authors report the use of three types of input, derived respectively from spectrum analysis, zero crossing analysis and formant extraction. The programmes permit processed information to be printed out or acoustically coded by digital-to-analog conversion.

EXPERIMENT I

DISCRIMINATION OF PARTIALLY VOCODED AND LINEARLY AMPLIFIED SPEECH BY SUBJECTS WITH LOW TONE RESIDUAL HEARING

Problem

In previous studies employing coding techniques reviewed above, either the entire speech range had been vocoded (Guttman and van Bergeijk, Pimonow), or high frequency cues had been coded and superimposed on a linearly amplified bass-band (Pimonow, Lafon, Johansson). In contrast, observations and experiments by the present writer (Ling 1964b, 1966) suggested the design of a system for the transmission of speech in its natural form from 70 - 700 Hz with speech components from 2 - 3 KHz vocoded and presented as analog signals in the adjacent band 750 - 1000 Hz.

The rationale of this system was that (a) the bass-band would be adequate for the transmission of fundamental, first formant, pitch, intonation, intensity and syllabic structures and that (b) the coded components presented in the bandwidth adjacent to the bass-band would provide additional rather than alternative cues for discrimination, since this procedure avoided superimposing coded signals on the natural speech pattern.

This experiment employed a five channel vocoder designed to meet the above criteria. Underlying the experiment was the hypothesis that this form of coding would permit subjects with low frequency residual hearing to discriminate speech more effectively than linear amplification.

Method

Subjects

Eight subjects were drawn from the Montreal Oral School for the Deaf. All had residual hearing for low frequencies, were normally intelligent, had made effective use of individual hearing aids for more than a year and had well-established reading skills. Details on the age, sex and hearing levels of the subjects are given in Table 1.1 below:

Table 1.1

Age, Sex and Hearing Levels of the Subjects

Case	Age	Sex	Hearing Level in Better Ear (I.S.O.) 125	250	500	1000	2000 Hz
1	14	M	55	60	75	95	110
2	9	F	75	95	110	*	*
3	10	M	75	95	105	*	*
4	8	F	75	90	95	110	*
5	12	F	75	90	100	95	*
6	8	M	60	65	90	110	*
7	9	M	75	80	100	*	*
8	9	M	65	75	90	100	95

* No response at 110 dB level.

Apparatus

Two instruments were used in both testing and training the subjects: the Ling-Druz Vocoder (LDV) and a speech training aid (STA) for linear amplification. The latter comprised the audio-amplifier of a Zenith Model ZA 100T audiometer. A Shure type 275 S microphone and Zenith type R1 miniature receivers were used with both instruments, each of which provided an acoustic gain of up to 60 dB. Custom fitted ear moulds of soft plastic were provided for each subject. The frequency response characteristic of the LDV was adjusted for this study as shown in Figure 1.1. The STA provided a smooth frequency response from 60 - 6000 Hz.

The test materials were words and nonsense syllables recorded by a female speaker at a speed of 7.5 ips with a Crown Model 1000 full track recorder and played back with a Uher Model 4000. Pictures corresponding to the words and printed cards corresponding to the nonsense syllables were prepared in such a way that

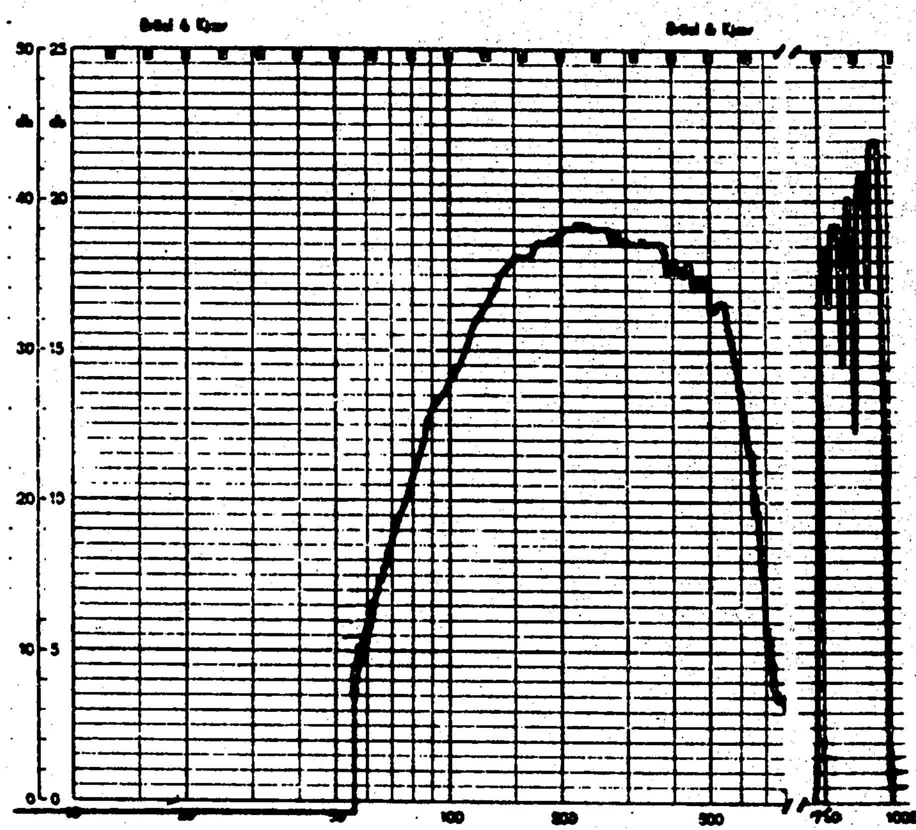

Figure 1.1

The air-to-air amplitude-frequency response of the Ling-Druz Vocoder (LDV) as adjusted for this study. The response from 70 - 700 Hz defines the bass-band. To the right of the break in the curve at 750 Hz are plotted the frequency positions of the five pure tone analog signals derived from the five analyzing channels between 2000 and 3000 Hz.

subjects could respond by pointing rather than speech.

Materials

The experimental design required four presentations of each of the five tests; two prior to training and two on completion of training. Four series of each of the five tests were constructed.

Test 1 measures discrimination between back, mid and front vowels occurring in familiar words, e.g. [book, bus, bee], [ball, bird, bed], [boot, barn, bib]. The three words in each item were illustrated, and on hearing the stimulus word subjects were required to select from the three pictures the one representing the word spoken. Each test series contained twelve such items.

Test 2 measures discrimination between classes of consonants, e.g. between nasals, plosives or fricatives. The long vowels [u], [a] and [i] were used to provide the acoustic environment for the consonants which all occurred in an initial position, e.g. [boo, woo, moo], [chah, tah, sah], [wee, bee, mee]. The three syllables in each item were printed and subjects were required to select from the three printed syllables the one representing the stimulus. The four series of this test each contained twelve such items.

Test 3 measures discrimination <u>within</u> classes of consonants. The short vowels [ɒ], [ʌ], and [I] were used to provide the acoustic environment for the consonants which were presented in the final position, e.g. [off, osh, oss], [uck, upp, utt], [imm, inn, ing]. Subjects were required to respond as in Test 2. Again, twelve items were used in each series.

Test 4 measures discrimination between intonation patterns. In each item, one of twelve vowels was presented, and subjects were asked to indicate by pointing to a pattern on a card whether it had a rising, falling, varied or flat pattern. The excursion of voice for the rising, falling and varied patterns was half an octave and the duration of the vowel was three seconds.

Test 5, unlike the preceding tests which used sub-word or suprasegmental components of speech, employed phonetically balanced (pb) lists devised by Watson (1957, p. 292). In this test, subjects were asked to repeat the words into the microphone of a tape recorder, and asked to guess if not sure of the word presented.

In the first four tests, correct responses were recorded with a check mark on a scoring sheet. Incorrect responses were noted so that they could be analysed for systematic error by confusion matrices. In Test 5, responses were transcribed by the examiner using the International Phonetic Alphabet, simultaneously with the recording of responses on tape. Both the examiner and his assistant were required to agree on the transcription of each response. Reference was made to the tape recording to ensure complete observer agreement. To increase the sensitivity of Test 5, responses were scored according to the number of correct phonemes each contained rather than the number of words correct. As a slightly different number of phonemes occurred in each word list, scores were expressed as percentages.

Procedure

Testing before and after training was carried out in accordance with a counterbalanced plan designed to control for order effects as shown in Table 1.2. Subjects 1 - 4 were trained on the speech training aid, and Subjects 5 - 8 on the vocoding instrument. Possible bias in scoring by the examiner (Rosenthal, 1966) was avoided since at no time during the experiment did he know which instrument any subject had been assigned to for training.

Testing was carried out in a distraction-free room in the Montreal Oral School for the Deaf. The examiner ensured that the receivers and earmolds were correctly fitted and then adjusted the output from the instrument in use to peak at approximately 125 dB SPL, the most comfortable listening level for the majority of subjects.

Each test was preceded by two or three practice

Table 1.2

Counterbalanced Design Used to Prevent Bias Due to Order Effects: Instruments Used and Test Series Administered

Group	Initial Testing				Final Testing			
A	LDV*	1	STA**	2	STA	4	LDV	3
B	STA	3	LDV	4	LDV	1	STA	2
C	STA	4	LDV	3	LDV	2	STA	1
D	LDV	2	STA	1	STA	3	LDV	4

* Ling-Druz Vocoder (LDV)

** Speech Training Aid (STA)

items so that subjects understood the task and knew what type of response was required. All five tests, including the practice items, could be completed on both instruments in less than forty minutes. The initial tests were administered the day before training began and the final tests the day after training was completed. Pre- and post-training test conditions were identical.

Training sessions for subjects were scheduled for twenty minutes each day over a period of twenty-two school days, with a total of seven hours and twenty minutes training for each subject. The training programme for subjects using the transposing instrument and for subjects using the speech training aid was identical. The daily sessions were scheduled in a systematically varied way so that no subject received training only in the morning when the therapist and subject were fresh, or only in the late afternoon when both might be fatigued. During each session approximately equal amounts of time were given to training in each of the five selected aspects of hearing for speech. The materials used for training were similar to the materials used for testing. Outside the training sessions all subjects wore individual hearing aids with extended low-frequency response and used loop induction systems and group hearing aids. All provided frequency response characteristics similar to those of the speech training aid used in this study.

Results

The data, presented in Tables 1.3 to 1.6, comprised the two groups' initial (pre-training) and final (post-training) scores for each test on each of the two instruments. Initial and final mean scores (number of items correct) for each group under each condition of amplification were compared as reported below. Student's t was computed for each paired measure.

1. Initial LDV Scores Compared with Initial STA Scores.

Differences between the mean scores for the

Table 1.3 Mean Correct Scores Achieved by Each Group on the Vocoder (LDV) and the Speech Training Aid (STA) in the Initial Tests.

	Test	Mean Score on LDV	Mean Score on STA	t value of difference
Group	1	5.50	7.0	1.26
Trained	2	5.75	4.50	0.95
on	3	4.75	4.0	0.60
LDV	4	4.25	5.25	0.53
	5	15.1	21.9	1.15
Group	1	4.50	7.0	2.59
Trained	2	6.25	3.75	2.89
on	3	3.25	5.0	1.70
STA	4	4.0	4.75	1.00
	5	12.6	12.8	0.02

Table 1.4 Mean Correct Scores Achieved by Each Group on the Vocoder (LDV) and the Speech Training Aid (STA) in the Final Tests.

	Test	Mean Score on LDV	Mean Score on STA	t value of difference
Group	1	6.25	6.50	0.15
Trained	2	5.75	5.0	0.55
on	3	4.25	4.50	0.26
LDV	4	8.50	7.25	0.78
	5	22.9	31.4	1.31
Group	1	3.25	5.75	1.43
Trained	2	4.50	5.50	1.41
on	3	3.75	4.75	0.60
STA	4	4.50	7.0	1.89
	5	14.8	21.7	2.65

Table 1.5 Mean Correct Scores Achieved by Each Group on the Vocoder (LDV) Finally as Compared with Initially.

	Test	Mean Final Score	Mean Initial Score	t value of difference
Group	1	6.25	5.50	0.68
Trained	2	5.75	5.75	0.00
on	3	4.25	4.75	0.40
the	4	8.50	4.25	2.20
LDV	5	22.90	15.10	3.37*
Group	1	3.25	4.50	1.67
Trained	2	4.50	6.25	1.70
on	3	3.75	3.25	0.42
the	4	4.50	4.0	0.33
STA	5	14.8	12.6	0.59

Table 1.6 Mean Correct Scores Achieved by Each Group on the Speech Training Aid (STA) Finally as Compared with Initially.

	Test	Mean Final Score	Mean Initial Score	t value of difference
Group	1	6.50	7.0	0.39
Trained	2	4.50	5.0	1.75
on	3	4.50	4.0	0.28
the	4	7.25	5.25	2.0
LDV	5	31.4	21.9	2.12
Group	1	5.75	7.0	1.00
Trained	2	5.50	3.75	2.78
on	3	4.75	5.0	1.00
the	4	7.0	4.75	1.19
STA	5	21.7	12.8	4.42*

* Significant beyond the .05 level.

pre-training tests on the two instruments did not reach a significant level for either group on any of the tests.

2. Final LDV Scores Compared with Final STA Scores.

Differences between the mean scores for the post-training tests on the two instruments did not reach a significant level for either group on any of the individual tests. However, when scores for all tests were pooled, mean final scores on the speech training aid achieved by the group trained on this instrument were significantly better than this group's mean final scores on the vocoder ($p < .05$).

3. Final LDV Scores Compared with Initial LDV Scores.

The group assigned to the vocoder for training achieved better results only on Test 5 finally as compared with initially ($p < .05$) Differences between this group's pre- and post-training test scores on the LDV, when pooled, however, were beyond the .01 level of significance. Differences between the initial and final scores on the vocoder achieved by the group assigned to the speech training aid did not reach a significant level.

4. Final STA Scores Compared with Initial STA Scores.

Differences between post- and pre-training tests did not reach a significant level for the group trained on the vocoder. For Test 5 and for the pooled scores for all tests, differences between mean scores for the group trained on the STA were significant beyond the .05 and .01 levels respectively.

Discussion

The results of Tests 1, 2 and 3 indicated that subjects made no significant gains through training in the discrimination of either the coded or conventionally amplified speech stimuli used.

Results of Test 1 suggest that first formant cues, inadequate by themselves for discrimination between vowels (Miller,1956), were not sufficiently complemented by the additional coded cues provided between 750 and 1000 Hz. While audible to the subjects, such closely spaced analog signals may not have been sufficiently differentiable as they were placed towards the upper limits of the subjects' range of audition.

Results of Test 2 and 3 may indicate that neither the distinctive acoustic features of nasality, plosion, turbulence nor the spectral differences in any group of these were adequately coded. On the other hand, subjects' difficulty in responding to the printed forms of nonsense syllables, a task which was as new to them as this form of auditory discrimination training, may have detracted from scores in both training and testing.

Results for Test 4 indicated that intonation patterns were as readily discriminated with the vocoder as with conventional amplification. In this respect the vocoding contrasts favorably with audio-frequency conversion, a transposition technique developed by Raymond and Proud (1962) which severely distorts pitch and intonation.

Both groups made significant progress in the discrimination of phonetically balanced words as evidenced by results for Test 5. Gains were demonstrated only with the instrument on which subjects were trained. These results suggest that subjects trained on the vocoder learned to discriminate coded speech.

It might be argued that increased scores were due to improved use of the conventionally amplified bass-band (70 - 700 Hz). The poorer results obtained by this group on final tests using conventional amplification (STA) refute this view. For the group trained with conventional amplification, the coded signals might have acted as noise detracting from the use of bass-band cues on the final test on the LDV.

The hypothesis that subjects trained with coded speech would achieve better scores than those trained with conventional amplification was not supported. The trend indicated by the pooled scores for all tests suggested the reverse. These results did not favour conventional amplification to a significant level as did those of Oeken (1963, 1964). His hard of hearing subjects, trained with conventional amplification, discriminated between words much more efficiently than similar subjects trained with speech lowered in pitch and clipped in time by tape recording techniques.

Discrimination of coded speech by subjects in this study did not appear to be so effective as that reported by Johansson (1961, 1966) and Wedenberg (1961) with selected subjects of comparable hearing loss. In the four series of studies summarized by Johansson (1966), certain subjects were reported able to discriminate more than twice as efficiently with coded speech as with conventional amplification. However, Johansson and Wedenberg did not use a control group who received training with conventional amplification. They compared the subjects' coded speech scores following training with the same subjects' scores for conventionally amplified speech without training. The results of the present study indicate that such a comparison may unduly favour the results obtained with the condition of amplification employed in the training period. Meaningful comparison of results obtained by Johansson and Wedenberg and those of the present study is also confounded by differences in materials and procedures.

EXPERIMENT II

COMPARISON OF TWO CODING PROCESSES

Problem

The results of Experiment I clearly demonstrated that discrimination of speech was at least as effective through linear amplification as through partial coding. However, the results did not indicate to what extent subjects trained on the vocoder learned to use the coded elements of speech. The availability of the Johansson-Wedenberg Transposer also made it possible to study subjects' acquisition of discrimination skill on a second instrument.

This experiment was designed to determine the extent to which coded speech cues could be discriminated on each of the two instruments, the Johansson-Wedenberg Transposer (JWT) and the Ling-Druz Vocoder (LDV). The hypothesis was that subjects could learn to use coded speech cues to augment discriminable information for both vowels and consonants provided by the bass-band of each instrument.

Method

Subjects

Eight different pupils attending the Montreal Oral School for the Deaf were selected. This was the maximum number that the therapist could effectively teach on an individual basis each day. All subjects met the following requirements: (1) classical low-tone hearing residue not extending above 2000 Hz at 110 dB I.S.O., (2) at least average intelligence, (3) freedom from any apparent additional handicap which could adversely affect learning, (4) effective use of hearing for more than one year and (5) a good attendance record. Details of the age, sex and hearing levels of the subjects are given in Table 2.1.

Apparatus

The Johansson-Wedenberg Transposer (JWT) and the Ling-Druz Vocoder (LDV) were used. Both channels of each instrument were checked for adequate function with standard Bruel and Kjaer equipment. The coded

Table 2.1

Age, Sex and Hearing Levels of Subjects in Experiment 2.

Case	Age	Sex	Hearing Level in Better Ear (I.S.O.) 125	250	500	1000	2000 Hz
1	6	M	60	65	80	95	*
2	10	M	75	95	105	*	*
3	10	M	70	75	90	100	*
4	12	F	60	80	90	95	110
5	14	M	55	60	75	95	110
6	10	M	60	70	95	*	*
7	8	M	60	60	80	105	*
8	6	M	65	80	105	*	*

* No response at or below 110 dB I.S.O.

output of each instrument contained sufficient information for the discrimination of consonants by normal listeners. The LDV was adjusted exactly as for Experiment I, except that narrow-band noise was selected as the analog output in the present study rather than pure tones. In both training and testing, the stimulus words were presented to both ears. The relative analog level of each instrument, which can be controlled by the operator, was adjusted to maximum for the training sessions. Testing both with and without analog signals was undertaken. Under the former condition, maximum analog was presented and under the latter, none. The bandwidth of the JWT without analog had a smooth response up to 6000 Hz and was much wider than that of the LDV, which extended only to 700 Hz. Under all four conditions of amplification, gain was adjusted to the subjects' most comfortable listening levels. The preferred output was approximately 125 dB SPL in all cases.

Tests were recorded by a female speaker, (the therapist who undertook the training), using a Uher

4000 Tape Recorder. Training was by live voice through a microphone provided with each instrument.

Materials

In Experiment 1, the tests which required identification of nonsense syllables proved difficult for the subjects, even though they had the reading skills required for the task. The test which yielded the best scores employed phonetically balanced lists of words familiar to children. This test was scored in relation to the number of syllables (not words) which the subjects repeated correctly in each list.

In the present experiment the tests were constructed in such a way that (1) only words familiar to the subjects were used, (2) these words could be illustrated by pictures and (3) no reading or speech skills were required.

Three tests were designed and recorded. As the experimental design demanded four presentations of each test, four equivalent series of each test were constructed.

Test 1 employed sixteen disyllabic words, familiar to the subjects, namely: airplane, baby, rabbit, cowboy, picture, wagon, lemon, squirrel, table, children, zebra, apple, mailman, hammer, giraffe and monkey. Each word was attractively illustrated by a coloured picture on a playing card. The cards were shuffled and arranged in random order on a table in front of the child. The subject was required to point to the picture representing the word spoken. Each series of the test contained a different random order of these sixteen words recorded with the primary stress on the first syllable of each. The pitch of the second syllable was consistently lower than that of the first. The test was essentially concerned with discrimination between sets of vowels.

Test 2 employed sixteen monosyllabic words familiar to the subjects, namely: boot, nest, dog, wheel, ball, deer, sun, house, girl, bear, man, boy, arm, skate, fish and book. The procedure for the administration of this test was the same as for Test 1. This test involved discrimination between vowels.

Test 3 employed sixteen sets of four monosyllabic words familiar to the subjects. The sets were structured so that discrimination between consonants was tested. The child was required to point to the picture in the set of four which represented the word spoken. Vowels differed between sets, but were held constant within each set. The sets were as follows:

[wolf, foot, book, cook]	[owl, cow, mouse, house]
[hair, chair, bear, pear]	[boat, goat, comb, coat]
[leaf, sheep, three, tree]	[ring, pig, dish, fish]
[rake, cake, train, rain]	[sled, egg, red, bed]
[moon, spoon, shoe, two]	[star, barn, jar, car]
[shirt, skirt, bird, girl]	[pan, man, flag, cat]
[kite, five, pie, tie]	[frog, box, dog, doll]
[store, four, horse, corn]	[sun, nuts, one, duck]

Procedure

The eight subjects were divided into two groups of four. Each group was assigned to one of the instruments, trained on that instrument for two weeks using maximum analog output and then tested with analog signal (a) present and (b) absent. Each group was then assigned to the other instrument and the procedure repeated. The training and testing were carried out in accordance with a counterbalanced plan designed to prevent bias due to major order and sequence effects. This plan is presented in Table 2.2.

In the administration of the tests, the writer and the therapist worked as a pair, one operating the equipment, the other recording the scores. At no time did the person scoring know whether or not coded signals were present. Thus bias for or against coding was avoided.

Training and testing were carried out in a quiet, distraction free room in the Montreal Oral School for the Deaf. The subject was seated comfortably at a small table, the earphones or receivers were fitted and the gain of the instrument was adjusted to the child's

Table 2.2
Counterbalanced Design Used to Prevent Bias Due to Order Effects in Training and Testing, Instruments Used and Test Series Administered.

Subject	First Test Series			Second Test Series		
1	JWT	A1*	B2**	LDV	B3	A4
2	JWT	A3	B4	LDV	B1	A2
3	JWT	B2	A3	LDV	A4	B1
4	JWT	B4	A1	LDV	A2	B3
5	LDV	A1	B2	JWT	B3	A4
6	LDV	A3	B4	JWT	B1	B2
7	LDV	B2	A3	JWT	A4	A1
8	LDV	B4	A1	JWT	A2	B3

* A with analog
** B without analog

most comfortable listening level. Lipreading was not allowed during the actual training or testing, so that discrimination of words had to be made on the basis of auditory cues only. The child was instructed to guess if unsure of a word.

Test items were recorded at five second intervals. For Tests 1 and 2 this interval was not adequate. The recorder was therefore held on pause after each stimulus word until the subject had made his response. The five second interval between stimulus words was quite satisfactory for the administration of Test 3, which required the selection of one picture from a set of four as opposed to one from a set of sixteen items.

The training sessions on each instrument were scheduled for forty minutes each day over a period of ten school days. The last session included the testing, which occupied about twenty minutes. Thus each child received six hours twenty minutes training on each instrument prior to testing. Training consisted of practice in discriminating the words used for testing.

An equal amount of time was allotted to work on the three sets of test materials.

In training each subject for Tests 1 and 2, the therapist began by selecting two of the sixteen pictures. She showed the child the pictures, named them and then asked him to repeat the words so that he could monitor his own speech. The therapist then asked the child to point to the picture as she named it. This process was repeated for successive pairs. As training progressed, the child was asked to identify one from an increasing number of pictures.

In training for Test 3, the therapist showed the child a set of four pictures. She named and asked the child to repeat each of the four words, enabling him to monitor his own speech. She then asked the child to point to whichever picture she named. This was done with all sixteen sets of four.

To ensure familiarity with the final testing procedure, each training session ended with a live voice test in which subjects had to discriminate between all sixteen items in Test 2 and between four items in each of the sixteen sets for Test 3. Results of these live voice tests were recorded.

Subjects used conventional group or individual hearing aids with extended low frequency response outside training sessions. Thus, apart from training sessions, their auditory experience of speech was in non-coded forms, comparable to the bass-band-only condition employed in testing.

Results

The basic data shown in Table 2.3 comprise the correct responses made by each subject on each test under each of the four conditions of amplification.

Inspection of the data indicates that mean scores with and without analog were about the same for the two instruments. Better scores were obtained for Test 3 than for the other two tests. This difference

Table 2.3

Scores (Number of Items Correct) for Each Subject on Three Tests Under the Four Conditions of Amplification, Using the Ling-Druz Vocoder (LDV) and the Johansson-Wedenberg Transposer (JWT).

Amplification Conditions		LDV + Analog			LDV - Analog			JWT + Analog			JWT - Analog			Sum
Test		1	2	3	1	2	3	1	2	3	1	2	3	
Subject	1	1	3	2	2	1	3	0	2	4	2	2	7	29
	2	3	5	11	6	2	6	5	4	4	1	2	5	54
	3	2	5	10	2	3	4	2	4	8	0	0	6	46
	4	3	7	11	6	7	6	2	3	5	1	2	3	56
	5	15	8	11	15	9	9	14	12	10	16	12	10	141
	6	5	3	3	1	3	5	3	1	7	2	0	4	37
	7	7	3	7	5	6	9	7	5	7	8	4	5	73
	8	0	2	3	0	4	5	0	3	0	1	1	5	24
Sum		36	36	58	37	35	47	33	34	45	31	23	45	460
Mean		4.5	4.5	7.2	4.7	4.4	5.9	4.1	4.3	5.6	3.9	2.9	5.6	

is to be expected since the task in Test 3 was to select one from four possible responses, compared with one from sixteen possible responses on the other two sets. Subjects 5 and 7, who had the best hearing at 250 Hz, obtained the best total scores and Subjects 1 and 8, the youngest children, the poorest. Only Subject 3 scored consistently better with coding than without it.

The data was treated by a three-way analysis of variance. The summary of this analysis is presented as Table 2.4.

There was no significant difference among the four conditions of amplification. In other words, the subjects' performance was not differentially affected by the presence of either type of coded speech or the use of either instrument. Differences between the three tests approached but did not reach a significant level. The interaction between the three tests and the four conditions of amplification, and the interaction between modes of amplification and subjects were not significant

Table 2.4

Summary of Analysis of Variance

	ss	df	M.S	F	F.95
Amplification (A)	21.084	3	7.02	1.49	3.07
Tests (T)	82.646	2	41.323	3.61	3.74
Subjects (S)	809.500	7	115.643		
A x T	10.103	6	1.683		
A x S	100.583	21	4.790		
T x S	160.688	14	11.477	3.86	1.94
A x T x S	125.230	42	2.982		

but the interaction between tests and subjects was significant beyond the .05 level. This indicates that certain subjects performed better on particular tests than on others.

The daily live-voice testing of all subjects, with analog signals present, yielded gradually increasing scores over the training period for all except the youngest child (Subject 1). The difference between the pooled scores on the three tests over the first three days of training and the similarly pooled scores over the last three days, was significant beyond the .05 level.

Discussion

In this study subjects with classical low-tone hearing residue did not appear to be able to discriminate coded speech any better than conventionally amplified speech. While scores under all four conditions of amplification tended to be poor, results indicate that coded speech is unlikely to have contributed to the gains made by subjects either in Experiment I or in the present study.

These findings appear to conflict with those of Johansson (1966), who reported that similar subjects made marked gains when trained on the JWT with analog cues. Johansson's studies were in Swedish and under different experimental conditions. The duration of the studies, the selection of subjects, the structure of the tests, the type and efficiency of training and the test procedures employed are additional variables. The results are, therefore, not comparable.

In the present study, all subjects were able to detect the analog signals. Further training might have enabled them to interpret the coded elements.

EXPERIMENT III

CODED SPEECH OVER AN EXTENDED TRAINING PERIOD

Problem

In the two experiments reported above, scores for coded speech were not significantly better than scores obtained by conventional amplification. The possibility that insufficient time had been allowed for the subjects to learn to interpret analog signals could explain the largely negative results. This study was designed as a partial replication of the second experiment, with four children receiving further training on the Johansson-Wedenberg Transposer over an extended period.

Method

Subjects

Four subjects, whose class schedules made them available for an extended period, were selected. All had participated in the second experiment. Table 3.1 shows ages, sex and hearing levels in the better ear.

Table 3.1

Age, Sex and Hearing Levels of Subjects

Case	Age	Sex	Hearing Level In Better Ear Hz. 125	250	500	1000	2000
1	6	M	65	80	105	*	*
2	6	M	60	65	80	95	*
3	8	M	60	60	80	105	*
4	12	F	60	80	90	95	110

* No response at or below 110 dB I.S.O.

Apparatus

The Johansson-Wedenberg Transposer was used for both testing and training the subjects. A Uher 4000 was employed in recording the test series.

Materials

Four further series of the three tests used in Experiment 2 were constructed. These were again recorded by the therapist.

Procedure

Testing before and after training was carried out in accordance with a counterbalanced plan designed to prevent bias due to order and sequence effects. This counterbalanced plan is presented as Table 3.2. Testing was carried out under the same conditions as in Experiment 2. Pre- and post-Testing conditions were identical. Additional live voice tests were carried out following each fifth training session of twenty minutes.

Training for the subjects, in which only transposition was employed, was scheduled over a period

Table 3.2

Counterbalanced Design Used to Prevent Bias Due to Order Effects in Initial and Final Tests, Amplification Conditions and Test Series Employed

Subject	Initial	Tests	Final	Tests
1	A1*	B2**	B3	A4
2	A3	B4	B1	A2
3	B1	A2	A3	B4
4	B3	A4	A1	B2

* A - with analog
** B - without analog

of thirty-six school days. In this period each child received a further 12 hours instruction. Thus, together with their experience in Experiment 2, each subject received a total of 18 hours, 20 minutes intensive individual training in auditory discrimination with this form of speech coding. In the training programme materials similar to, but not identical with, those employed in the test situation were used. Outside the training sessions all subjects wore individual hearing aids with extended low-frequency response characteristics and used loop induction systems and group hearing aids.

Results

The basic data shown in Table 3.3 comprise the correct responses made by each subject on each of the three sixteen-item tests.

Inspection of the data indicates that mean scores for vowels (Tests 1 and 2) tended to be slightly better (a) finally than initially and (b) when transposition as compared with conventional amplification was used. Subject 1 scored no better than chance at any time.

The data were treated by analysis of variance. Differences observed in the data did not approach a significant level either for initial compared with final scores, or for scores obtained with and without transposition.

Results obtained by live-voice testing using transposition confirmed the data presented in Table 3.3. These tests, carried out on seven occasions, i.e. weekly, showed (a) marked fluctuation in scores for all subjects and (b) no consistent improvement for any subject.

Discussion

Subjects' auditory discrimination, as measured in this study, improved marginally, if at all, through the use of coded cues. Differences between scores obtained with and without coding were minimal and could have been due to chance variation. While subjects made significant gains over the period of training provided in Experiments 1 and 2, the acquisition of discrimination skill in the

Table 3.3
Scores (Number of Items Correct) Obtained for Each Subject, Initially and Finally, With and Without Analog Present, On Each of the Three Tests

Order		INITIAL						FINAL						
Condition		With Analog			Without Analog			With Analog			Without Analog			
Test		1	2	3	1	2	3	1	2	3	1	2	3	Sum
Subject	1	2	2	4	1	3	5	2	1	5	1	1	5	32
	2	2	5	4	3	1	5	7	6	6	5	3	3	50
	3	4	8	9	6	6	8	7	6	6	4	3	5	72
	4	7	3	8	3	3	4	8	8	9	10	10	6	79
Sum		15	18	25	13	13	22	24	21	26	20	17	19	233
Mean		3.7	4.5	6.2	3.2	3.2	5.5	6.0	5.3	6.5	5.0	4.3	4.7	

course of this study was negligible.

Individual differences were marked. Scores appeared to be more related to the subjects' hearing than to the mode of amplification employed. Subjects with least hearing did worst, those with more hearing scored better. No subject scored consistently better with coded speech than with conventional amplification even though the training was carried out entirely with coded speech.

This experiment, in providing coded speech during training, was, of course, biased in its favor. The results might, therefore, have been expected to reflect this bias. It follows that an equivalent amount of training using conventional amplification might have resulted in scores favoring that condition, as evidenced by the results of Experiment 1.

Systematic manipulation of the many variables involved, including those mentioned in the discussion of Experiment 2, might explain ambiguities and discrepancies in the results and lead to new and perhaps fruitful insights into the possibilities and limitations of speech coding for profoundly deaf subjects.

The therapist, when asked to contrast the two coding instruments, reported that she found them equivalent. It was surprising, in view of the results obtained, to find that she favoured the use of coded speech in therapy. She reported, as did Johansson (1966) and Wedenberg (1961), that subjects appeared better able to reproduce speech sounds when coding rather than direct amplification was used. She considered that, while these forms of coding did not by themselves provide adequately differentiated acoustic patterns for effective auditory discrimination, they contributed to discrimination when supplemented by visual and tactile cues. She was able to demonstrate this convincingly, particularly with younger children and those with less severe hearing impairment. Similar observations in comparing coding and linear amplification systems were made by Bouillon (1967).

Some subjects trained with coding to discriminate between the sound [s] and [ʃ] were reported by Johansson to have reached 100% efficiency. However, these sounds could, in a given context, be discriminated by certain distinctive features which would not be adequate for discrimination in another context. An extreme example would be provided by similar subjects trained with conventional amplification to discriminate between [sa] and [ʃa] on the basis that the initial consonant of the first would be inaudible and of the other, audible. Such a distinction would not permit discrimination in another context. Another distinctive feature of the same type could be loud versus quiet where both [s] and [ʃ] were audible but not differentiable on the basis of spectral cues.

Ahlstrom, Risberg and Lindhe (1968) presented speech coded by the JWT to normal listeners through low pass filters and noise to simulate hearing loss and found systematic errors in discrimination. Subjects failed to make further gains in learning after one or two hours training and then constantly confused consonants within the same class, e.g. unvoiced stops [p, t, k], unvoiced fricatives [f, s, ʃ]. Analysis of confusion in the present study showed no consistent trends.

Conclusions

The results of Experiments I - III indicate that the two forms of coding contributed little or nothing to the discrimination of speech by these subjects with classical low-tone residual hearing. Results also suggested that adequate comparison of coded speech and direct amplification can only be made if subjects receive sufficient training on each system to achieve a crude limit of learning (Ferguson, 1956). This limit may be described as the point reached by subjects where little or no increase in discrimination scores occurs with further training. The purpose of such a procedure is not to demonstrate a greater increase of proficiency under one condition than under another after a fixed amount of training, but to determine whether a higher level of discrimination skill can ultimately result from the use of a particular amplification system.

Neither this nor previous experiments indicate the length of training necessary for subjects with low-frequency residual hearing to reach crude limits of learning on the tasks involved. Programmed instruction of the type developed by Doehring (1968) is appropriate to these tasks and could be used to provide the necessary repeated measures to determine these limits.

EXPERIMENT IV

DISCRIMINATION OF CODED SPEECH BY DEAF SUBJECTS TRAINED TO CRUDE LIMITS OF LEARNING WITH PROGRAMMED INSTRUCTION

Problem

Neither form of coded speech used in Experiments I - III proved to be superior to conventional, linear amplification. Two features which could have contributed to the subjects' difficulty in discriminating coded cues were (a) limited range of frequencies transposed by the instruments, (2000-3000 Hz for the LDV; 3300-4800 Hz for the JWT), and (b) the omission of mid-frequency speech components. The LDV produced nothing of speech from 750-2000 Hz, and the JWT, for subjects who had only residual audition, provided no cues from about 1000 Hz, their upper limit of hearing, to 3300 Hz, the lower limit of the transposed range.

The experimental designs of Experiments I - III were effective, but did not provide data on subjects' rates of learning. The present experiment employed programmed instruction so that this type of data could more easily be collected and so that more control over training variables could be exercised.

The instrument, specifically designed for this study, was another vocoder. To avoid the omission of the mid-frequency cues, it was constructed to analyse sounds from 1000 - 4000 Hz in ten logarithmically spread bandwidths. The ten analog channels were spaced at intervals of 100 Hz from 100 - 1000 Hz. The instrument also provided one linear channel and switching to permit (1) conventional amplification to both ears, (2) coded speech to both ears or (3) conventional amplification to one ear and coded speech to the other.

This experiment was designed to compare differences between the discrimination scores obtained by groups of subjects assigned to the three conditions of amplification. It was also designed to explore the use of programmed instruction with stimulus words in which consonants, but not vowels differed within sets. The purpose was to assess the relative efficiency of the amplification conditions by comparing differences between (a) subjects' discrimination scores at crude limits of learning and (b) the rate at which these limits were reached.

Method

Subjects

Twenty-four children of French speaking parentage, aged between seven and eleven years, were selected from pupils attending the Montreal Institut des Sourds. All were profoundly deaf from birth or early infancy. The selection of subjects was based on age, hearing level for pure tones as measured immediately prior to training*, use of audition and teachers' ratings. Data on these subjects are presented in Tables 4.1 - 4.4.

Children excluded were those who showed no ability to use their residual hearing in the pre-training test of speech discrimination and those who were rated by their teachers as below average in school achievement.

Apparatus

A Uher Universal 5000 tape recorder was used to record and present the words which were spoken by a female of French speaking origin. For pre- and post-training tests with conventional amplification, the tape

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* Audiograms repeated immediately after training were not significantly different for any subject.

Table 4.1

Age, Teachers' Rating and Hearing Levels of Subjects in Group 1, Trained with Direct Amplification to Both Ears

Subject	Age	Teachers' Rating		Hearing Levels (I.S.O.) 250	500	1000	2000	4000
1	8	A	L	75	90	100	100	110
			R	55	75	90	95	100
2	9	B	L	80	90	95	95	110
			R	75	80	90	100	110
3	10	C	L	65	85	95	85	95
			R	80	85	90	95	95
4	9	B	L	85	90	105	105	110
			R	90	95	95	85	110
5	10	B	L	70	75	80	95	105
			R	65	70	75	85	105
6	9	A	L	70	65	65	80	70
			R	85	80	80	70	80

Table 4.2

Age, Teachers' Rating and Hearing Levels of Subjects in Group 2, Trained with Direct Amplification to the Left Ear and Coded Speech to the Right.

Subject	Age	Teachers' Rating	Hearing Levels (I.S.O.)	250	500	1000	2000	4000
1	7	B	L	90	100	110	110	*
			R	85	90	100	*	*
2	10	B	L	90	95	110	*	*
			R	90	100	110	*	*
3	8	B	L	55	80	90	105	*
			R	75	95	85	100	*
4	10	A	L	60	80	90	105	105
			R	30	60	60	80	105
5	8	C	L	85	95	100	105	*
			R	80	95	105	110	*
6	10	B	L	70	85	100	105	*
			R	65	80	95	100	*

* No response at 110 dB

Table 4.3

Age, Teachers' Rating and Hearing Levels of Subjects in Group 3, Trained with Coded Speech to Both Ears.

Subject	Age	Teachers' Rating	Hearing Levels (I.S.O.)	250	500	1000	2000	4000
1	10	B	L	90	95	95	85	110
			R	90	105	*	*	*
2	10	A	L	60	70	85	80	80
			R	40	65	85	80	80
3	9	B	L	70	75	90	105	*
			R	65	85	100	110	*
4	7	B	L	65	85	100	110	*
			R	55	75	80	95	95
5	10	B	L	90	100	110	110	110
			R	90	100	100	90	80
6	9	C	L	85	95	105	110	*
			R	80	100	100	110	*

* No response at 110 dB

Table 4.4

Age, Teachers' Ratings and Hearing Levels of Subjects in Group 4, Trained without Audition.

Subject	Age	Teachers' Rating	Hearing Levels (I.S.O.)	250	500	1000	2000	4000
1	11	B	L	70	80	80	75	70
			R	55	70	80	100	105
2	10	A	L	90	110	105	*	*
			R	90	105	105	*	*
3	9	B	L	90	90	100	90	80
			R	90	95	95	85	85
4	10	A	L	90	105	110	*	*
			R	85	90	95	100	105
5	8	A	L	80	95	105	*	*
			R	90	100	110	*	*
6	7	B	L	90	100	95	80	90
			R	75	85	100	100	90

* No response at 110 dB

recorder was used with Sharpe HA-8 earphones. For all other conditions of testing and training a vocoder (coding amplifier) with one linear and ten analog channels was employed. A VU meter permitted the control of output levels under all conditions.

Adjustment of the amplification system. The output levels of the analog channels of the vocoder could be adjusted in relation to each other and the total coded output could be adjusted in relation to the linear channel. For this experiment the signal input to the analog channels was emphasized with a 6 dB/octave slope. The total coded output was balanced with the output of the direct channel by means of the VU meter. The vocoder was used with TDH-39 earphones.

Programmed instruction system. In the training programme, pictures were presented by a Kodak Carousel Projector Model 550 which included a Davis Scientific Instrument Model DP-152 Projector Programmer. The pictures were rear projected onto a viewing area containing three windows each measuring 2.5 by 4 inches.

A microswitch was placed behind each window so that pressure on any part of the window would close the contacts. Each slide was made from three pictures in such a way that each was projected on one of the windows. The correct window for a given trial, the one containing the picture corresponding to the word, was coded by a hole punched in the slide mount. Light from the projector lamp through this hole activated a photo-electric cell in the Projector Programmer.

The sequence of events produced by correct or incorrect window pressing was controlled by DigiBits solid-state programming modules. If the correct window was pressed following the presentation of a word, the tape and the projector automatically advanced to the next trial. If an incorrect window was pressed a shutter occluded the image projected on the windows for the duration of that trial after which the tape rewound and the trial was repeated. The trial was similarly repeated if no response was made.

Rewinds, slide changes and the beginning of new trials were initiated by inaudible pulses recorded and played back through a Uher Diapilot. These pulses were spaced at eight-second intervals. Words followed the pulses initiating each trial after three seconds. A period of at least four seconds following each word was available for the subjects' response.

Materials

Pictures representing the tape-recorded words, obtained from flash cards, magazines and catalogues, were used for both testing and training.

Pre- and post-training tests. For the pre- and post-training tests, seven groups of six pictures corresponding to common words having the same syllabic count were glued to separate pages to form a booklet so that the child could respond without speech by pointing. A list of these words is presented as Appendix 1. Four series of this test were prepared. The initial six words of each series, which were reserved for practice, and the remaining thirty-six test items were tape-recorded in randomly ordered blocks of six to correspond with the pictures on each page.

Training series. For training, 108 pictures were selected. These were arranged and photographed in sets of three. Each set contained words with the same vowels and syllabic structure so that consonant features were the only means by which the words in each set could be discriminated, e.g. la mouche, la bouche, la douche; les avions, les camions, les papillons. Each set contained nouns of the same gender so that no vowel cues were provided by the article which preceded each word.

Each set of three was photographed in all six possible orders. Six different sets constituted one series, which comprised thirty-six slides. Six series were constructed as shown in Appendix 2. The order in which the sets appeared in a series, in which a stimulus word was chosen from a set and the position of the picture corresponding to the stimulus word were randomly arranged to make it difficult for subjects to memorize the sequence of visual presentations.

Procedure

The work was carried out in a quiet, distraction free room in the school.

Pre- and post-training speech discrimination tests. Each subject was tested on one of the four series, first with linear amplification and then with transposition. Because delivery of the vocoder was delayed, the orders of amplification conditions could not be counterbalanced. Subjects were randomly assigned to series.

Each subject was seated at a table, the headphones fitted and the output level adjusted to approximately 125 dB SPL. Subjects were instructed by gesture if necessary, to point to the picture corresponding to the tape recorded word heard and to guess if not sure. Six practice items were provided.

The assignment of subjects in groups to experimental conditions. On completion of the pre-testing, the subjects were arranged in four groups of six. Groups were matched as well as possible for age, hearing level for pure tones, teachers' ratings and scores on the pre-test with linear amplification. As the cause of hearing loss was unknown in nineteen cases, this variable could not be considered in matching groups.

Each group was assigned to a different condition of training as follows:

Group 1. Linear amplification to both ears.

Group 2. Linear amplification to the left ear and coded speech to the right ear.

Group 3. Coded speech to both ears.

Group 4. No auditory cues (control).

The task for subjects in Group 4 was to learn to memorize and identify the correct picture from position and sequence cues.

Since groups could not be equally matched on all variables, the sources of bias that were evident were taken into account in assigning the groups to the training conditions. Specifically, the group in which all subjects had hearing to 4 KHz were trained with linear amplification and the group with the best teachers' ratings acted as controls.

Training procedures. In training, the subjects were seated in front of the viewing response device. For the first three groups, the headphones were fitted and the output adjusted to deliver approximately 125 dB SPL. Only on the first few trials of the first series was it necessary for the experimenter to intervene by giving guidance or reassurance to any subject. All quickly learned that pressing the correct window made a new picture appear and pressing the incorrect window resulted in a temporary darkening of the viewing-response device.

The time taken to complete the thirty-six trials depended on the accuracy and latency of the subjects' responses. If the correct picture was the last of three to be pressed in every trial, an unlikely event and one which did not occur, a series could take about fourteen minutes. If the first choice in each series was correct, the series would take three minutes. Thus, with fifteen minutes daily training assigned for each subject, there was usually time for one series on initial sessions and two in later sessions. Subjects were given a candy for each series completed during a session.

Learning criteria. Each of the six subjects within a group was assigned to a different series of words and pictures at the beginning of training. Thus the first subject in each group was trained on Series 1, the second subject in each group on Series 2, and so on.

Each series was repeated until the subject had reached a crude limit of learning (Ferguson, 1956). This limit may be regarded as the point beyond which little or no increase in discrimination score occurs with further training. For the purpose of this experiment, this limit was defined as any one of the following:

a. Twenty sessions without achieving a score of 20/36.
b. Fifteen sessions achieving over 20 but less than 25/36.
c. Ten sessions achieving over 25 but less than 30/36.
d. Five sessions achieving over 30 but less than 34/36.
e. Two sessions achieving scores of 34 or more.

When a crude limit of learning had been reached, subjects began the next series. Thus the first subjects in each group would move from Series 1 through to Series 6, the second from Series 2 through Series 6 to Series 1 and so on. By counterbalancing the order in which subjects were assigned to series, possible differences in the level of difficulty of each list could be controlled.

Results

The data comprised (1) results on the pre- and post-training tests, (2) scores at each subject's crude limit of learning for each training series, (3) the number of repetitions of series by each subject to asymptote, and (4) matrices of confusions made by each group at asymptote.

Pre- and post-training tests. Scores for these tests are presented in Table 4.5. Scores for all four groups were similar. Few subjects scored better finally than initially. Scores achieved with linear amplification on both tests were superior to those for coded speech.

Analysis of variance, summarised in Table 4.6, showed that there was no significant difference between groups or between final and initial scores averaged over groups and amplification conditions. Scores for linear amplification, averaged across groups and pre- and post-training tests, were better than those for coded speech ($F = 10.52$ with 20 and 1 df). This difference was significant beyond the .01 level.

Scores at each subject's crude limit of learning. Subjects in Group 4, trained without audition, were unable to complete all series. Two of the six scored no better

Table 4.5 Pre- and Post-Training Scores for All Subjects on a 36-Item Test (a) with Linear Amplification to Both Ears and (b) with Coded Speech to Both Ears.

Group*	Subject	Pre-Training Scores (a) Linear	Pre-Training Scores (b) Coded	Post-Training Scores (a) Linear	Post-Training Scores (b) Coded
1	1	23	11	16	6
	2	5	4	9	7
	3	13	7	8	8
	4	8	8	10	5
	5	17	6	7	5
	6	11	7	10	4
	Sum	77	43	60	35
2	1	16	5	9	7
	2	9	7	5	1
	3	13	7	9	9
	4	30	10	33	4
	5	9	5	2	3
	6	3	6	8	7
	Sum	80	40	66	31
3	1	16	5	12	8
	2	23	12	27	9
	3	15	7	7	9
	4	9	6	10	8
	5	8	4	4	6
	6	3	4	5	7
	Sum	74	38	65	47
4	1	31	8	31	13
	2	7	7	3	17
	3	11	14	15	7
	4	13	8	14	6
	5	8	8	5	3
	6	8	9	8	8
	Sum	78	54	76	54

* Group 1 trained with linear amplification to both ears.
Group 2 trained with linear amplification to one ear and coded speech to the other.
Group 3 trained with coded speech to both ears.
Group 4 trained without audition.

Table 4.6

Summary of Analysis of Variance for Data Presented in Table 4.5

	SS	df	MS	F
Between Subjects	1,754.13	23		
Between Groups (G)	60.54	3	20.18	
Subjects within Groups	1,693.58	20	84.68	
Within Subjects	2,123.50	72		
Amplification Conditions (A)	570.38	1	570.38	10.52**
G x A	18.71	3	6.24	
A x Subjects within Groups	1,084.41	20	54.22	
Tests, Pre- & Post-training (T)	26.04	1	26.04	3.35NS
G x T	22.21	3	7.40	
T x Subjects within Groups	155.25	20	7.76	
A x T	12.04	1	12.04	
G x A x T	18.08	3	6.03	
A x T x S's within Groups	228.42	20	11.42	

** Significant beyond the .01 level

than chance after the first series had been repeated thirty times. They were too upset by the difficulty of the task to continue. The remaining four subjects achieved crude limits of learning, each scoring 20 with a mean of 28 repetitions in their first series and 20 with a mean of 26 repetitions on their second series. Since the scores were significantly poorer than those of the other three groups on their second series, the training of this control group was terminated.

Scores at crude limits of learning for Groups 1 - 3 were analysed to determine whether the six series differed in difficulty. The series were found to be equivalent (F = 0.33 with 75 and 5 df).

Scores for each series in the order learned are presented in Table 4.7. Scores were similar for each group and appeared to stabilize at a relatively high level from Series 2 onwards. A summary of the analysis of variance for these data is presented in Table 4.8. Differences between scores on successived series were significant

Table 4.7 Scores at Asymptote for Each of the Six 36-Item Series.

		Series					
Group*	Subject	1st	2nd	3rd	4th	5th	6th
1	1	30	30	30	30	30	30
	2	15	30	30	30	30	30
	3	30	30	30	34	34	34
	4	15	30	30	30	30	30
	5	25	30	30	30	30	34
	6	15	30	30	30	30	30
	Sum	130	180	180	184	184	188
2	1	15	25	30	34	30	30
	2	20	30	25	25	30	30
	3	30	30	30	30	30	34
	4	34	34	30	30	34	34
	5	15	30	30	30	34	30
	6	30	34	30	30	34	30
	Sum	144	183	175	179	192	188
3	1	25	30	30	30	34	30
	2	34	34	30	34	30	34
	3	25	30	30	34	30	30
	4	15	30	30	30	30	34
	5	20	25	30	30	30	30
	6	25	30	30	30	30	30
	Sum	144	179	180	188	184	188

* Group 1 trained with linear amplification to both ears.
Group 2 trained with linear amplification to one ear and coded speech to the other.
Group 3 trained with coded speech to both ears.

Table 4.8

Summary of Analysis of Variance for Data Presented in Table 4.7

	ss	df	MS	F
Between Subjects	381.61	17		
Between Groups	4.78	2	2.39	
Subjects within Groups	376.83	15	25.12	
Within Subjects	1,642.99	90		
Series	844.07	5	188.82	18.54**
Groups x Series	35.09	10	3.51	
Series x Subjects within groups	763.82	75	10.18	

** Significant beyond the .01 level.

beyond the .01 level (F = 18.54 with 75 and 5 df). The greatest difference in scores was between the first and the second series learned.

<u>Series repetitions to asymptote: Groups 1 - 3.</u> The number of repetitions required by each subject to reach a crude limit of learning on each series was examined to see if series differed in difficulty. No significant difference between series was found (F = 0.65 with 75 and 5 df).

The number of repetitions to a crude limit of learning on each series for each subject is presented in Table 4.9. The data are similar for each group. The number of repetitions required to reach asymptote appears to drop sharply from the first to the second series, moreso for Group 1 than for Groups 2 and 3. There is an apparent trend for repetitions to decrease over successive series.

Analysis of variance for these data, summarized in Table 4.10, confirms that there was no significant difference between groups, but that the trend for repetitions to decrease for successive asymptotes was significant

Table 4.9 Number of Repetitions Required by Each Subject to Reach a Crude Limit of Learning on Each Series.

Group*	Subject	1st	2nd	3rd	4th	5th	6th
1	1	21	15	11	12	9	8
	2	33	16	19	14	15	16
	3	18	12	14	8	7	7
	4	26	15	12	9	15	16
	5	23	13	15	9	9	6
	6	21	16	13	12	11	7
	Sum	142	87	84	64	66	60
2	1	21	35	24	32	29	8
	2	34	30	29	20	15	17
	3	30	14	11	10	9	10
	4	6	4	8	9	6	7
	5	30	19	17	14	11	12
	6	19	13	9	15	11	11
	Sum	140	115	98	100	81	65
3	1	22	16	8	13	6	12
	2	19	11	9	9	8	7
	3	25	23	24	19	13	14
	4	28	28	17	11	15	14
	5	21	27	9	16	10	21
	6	33	15	13	13	15	12
	Sum	148	120	80	81	67	80

* Group 1 trained with linear amplification to both ears. Group 2 trained with linear amplification to one ear and coded speech to the other. Group 3 trained with coded speech to both ears.

Table 4.10

Summary of Analysis of Variance for Data Presented in Table 4.9.

	ss	df	MS	F
Between Subjects	2,221.85	17		
Between Groups	139.57	2	69.79	
Subjects within Groups	2,082.28	15	138.82	
Within Subjects	3,587.00	90		
Repetitions	1,988.52	5	397.70	20.87**
Groups x Repetitions	169.09	10	16.90	
Repetitions x Subjects within Groups	1,429.39	75	19.06	

** Significant beyond the .01 level

beyond the .01 level (F = 20.87 with 75 and 5 df). Both the linear and the quadratic components of this trend reached a .01 level (F = 10.23 with 75 and 1 df for the linear regression and F = 12.95 with 75 and 1 df for the quadratic).

Confusions made at crude limits of learning. Matrices of confusions made by each group are presented in Appendix 2. The data comprise subjects' incorrect responses over the final three training sessions for each series. Repeated errors were not included.

Errors tended to occur with similar frequency for particular sets. In Series 1, for example, all groups made most errors on Set 1, [la mouche, la bouche, la douche] and Set 5, [le verre, le fer, le père], but none for Set 4 [le sapin, le lapin, le patin]. In Series 2 most errors are made by all groups on Set 4, [la brosse, la cloche, la poche], and fewest on Set 3, [le sel, le lait, le bec]. The trend was maintained in all series with only five exceptions among the 36 sets. The five sets in which the total errors differed between groups to a significant level ($Chi^2 > 5.99$) were as follows:

1. Series 2, Set 6 in which the words le dragon, le ballon, le wagon were confused least often by Group 3.
2. Series 4, Set 2 in which la boîte, la noix, la poire were confused less often by Group 2 than by other groups.
3. Series 5, Set 5 in which the words la jambe, la dent, la lampe were confused less often by Group 1 than by Groups 2 and 3.
4. Series 6, Set 2 in which the words la grange, la manche, la tente were confused more often by Group 1 than by Groups 2 and 3.
5. Series 6, Set 3 in which the words le bouton, le bouchon, le mouton were confused most often by Group 2 and least often by Group 3.

There were also five sets in which types of confusions for particular words differed between groups to a significant level ($Chi^2 > 5.99$). These were:

1. Series 1, Set 1 in which la mouche and la bouche were confused with la douche most often by Group 1 and least often by Group 2.
2. Series 1, Set 3 in which les rideaux was confused with les ciseaux most frequently by Group 3.
3. Series 2, Set 6 in which le wagon was confused with

le ballon most often by Group 2.

4. Series 4, Set 2 in which la boîte was confused with la poire most often by Group 1 and least often by Group 2.

5. Series 6, Set 3 in which le mouton was confused with le bouton most frequently by Group 2 and least frequently by Group 3.

Results in relation to age, teachers' ratings, hearing levels for pure tones and the pre-training speech test of hearing. Scores at crude limits of learning and repetitions to asymptote were analysed in relation to each of the above variables. Results were as follows:

1. There was no significant difference between the nine youngest and the nine oldest subjects ranked by date of birth.

2. There was no significant difference between subjects rated as A, B or C in relation to scores at asymptote. But in relation to the number of repetitions required to learn each series, differences were significant ($F = 4.04$ with 15 and 2 df). Subjects rated as A required fewer repetitions than the others.

3. Results for subjects with hearing up to 2000 Hz and for subjects with hearing beyond 2000 Hz were compared. Their attainments were not significantly different.

4. Subjects with equivalent pure tone hearing levels and teachers' ratings (Subjects 1, 2, and 4 from Group 1;

Subjects 3, 4, and 6 from Group 2; and Subjects 2, 4, and 5 from Group 3) were compared. Scores at asymptote were similar for subjects in the three groups but subjects from Group 2 required fewer repetitions of series to reach crude limits of learning. This difference between groups was not significant (F = 1.16 with 6 and 2 df).

5. Subjects above and below the median for the pre-training test were compared. Scores at asymptote were similar for the two groups but fewer repetitions of series were required by the group whose pre-training test results were superior. Analysis of variance showed that this difference was not significant (F = 1.2 with 15 and 2 df).

Discussion

Results did not favour any of the three conditions of amplification but indicated that deaf children may be trained to discriminate coded speech as effectively as linearly amplified speech. Differences between groups in the confusions made at crude limits of learning suggest that each condition of amplification offers minor advantages for the discrimination of certain sets of words, but that these are offset by equal disadvantages in the discrimination of other sets.

Pre- and post-training tests. Differences between scores on the pre-training test favouring linear amplification were to be expected since coded speech was initially unfamiliar to all subjects. That this difference remained after training may be similarly explained for Groups 1 and 4. The final scores of Groups 2 and 3, which also were poorer for coded speech than for linear amplification, probably reflect the fact that the stimulus words, which did not occur in the training series, were less familiar in their coded form and that there was no generalization from the words in which specific training was given.

Results of training. Subjects in Group 4, trained without audition, were unable to identify the correct picture as effectively as subjects in other groups. This indicates that scores at crude limits of learning and the number of series repetitions to asymptote for Groups 1 - 3 reflected auditory discrimination ability rather than artefacts of the training procedures.

The similar scores at asymptote for the third and subsequent series suggest that the series should have been made slightly more difficult. More difficult series might have resulted in greater differences between scores. It is, however, impossible to use sets of more than three minimally different French words. They do not exist in the language. Difficulty could be increased in this training paradigm by using more sets and having each picture in a set named three times instead of twice in a series.

The number of repetitions required by subjects in Groups 1 - 3 to reach asymptote was considerably more varied than their scores at asymptote. Nevertheless, the three groups learned successive series at an equivalent rate. This similarity between groups was not expected. Subjects in Group 1 had had previous experience of linear amplification whereas subjects in Groups 2 and 3 met with coded patterns for the first time in this training. A greater difference than that obtained between groups for the first, second and third series might therefore have been predicted.

The significant reduction in the number of repetitions to crude limits of learning and the higher scores at asymptote for successive series indicated that the programmed instruction was a very efficient method of teaching under each of the experimental conditions.

Results were better than expected for Group 1, who were trained with linear amplification. Discrimination between consonants had proved difficult for subjects under any amplification condition in Experiments I - III. This group had slightly better hearing than subjects in the earlier experiments and their task in this experiment (discrimination between sets of three words rather than four) was somewhat simpler. Nevertheless, their scores at crude limits of learning were surprisingly high and the repetitions they required to reach asymptote relatively few. Rosen (1962, Pp. 514-515), who studied phoneme identification with subjects having sensorineural hearing loss stated:

> "Some consonant cues which are considered important to normal listeners either are unavailable or are distorted for subjects

> with sensorineural hearing impairment. Nevertheless, although the absence or distortion of cues impaired phoneme recognition, subjects identified most consonants better than might have been expected. Apparently, subjects with sensorineural hearing loss can use the remaining cues effectively or can find cue values in dimensions which ordinarily are not considered to be important to consonant discrimination in normal hearers."

Apparently Group 1 subjects in this study also made use of minimal auditory cues in the same way.

Scores at asymptote and repetitions required to reach crude limits of learning for Groups 2 and 3 were equivalent to those for Group 1. These results are similar to those of Experiments I - III but are superior to results reported by Oeken (1964) whose subjects' scores for transposed speech were poorer than those for linear amplification.

Subjects in Group 2, who received both conventional and coded cues, did not achieve better results than subjects in either Group 1 or Group 3. This finding contrasts with that of Raymond and Proud (1962), who reported that certain subjects' scores for linearly amplified speech to one ear and transposed speech to the other were superior to their scores for either condition separately. However, their subjects had more hearing, and speech was frequency shifted less than the coded speech in the present study. That separate speech cues arriving at each ear were apparently integrated by subjects in both studies supports the work of Matzker, (1962) who regards "binaural fusion" as indicative that hearing loss is peripheral rather than central.

Errors and confusions. Differences between groups in relation to the quantity of errors and the type of confusion made within sets proved not to be significantly related to either (a) the possible preferences for response window position, (b) the vowels used within sets or (c) the subjects' relative familiarity with the words. Differences in errors and confusions between groups therefore appear to reflect relationships between amplification conditions and discrimination. But these differences are few, and explanation of them would be highly speculative.

For example, it may be conjectured that Group 1, in discriminating la jambe, la dent and la lampe better than other groups, were relying on differences in the manner of production of the initial consonants. All three of these consonants were voiced and had strong low frequency components which would render them audible, but the first was a fricative, the second, a plosive and the third, a lateral. However, this Group confused la grange and la manche more frequently than other groups and these words, too, have initial consonants with strong low frequency components produced in a quite different manner. The final consonant in either set had comparable voiced-unvoiced contrasts.

Similarly, Group 2 confused la mouche and la bouche less frequently and le mouton with le bouton more frequently than other groups. Apparently the initial consonants [m] and [b] were more discriminable following the feminine article la than when following the masculine article le; but in other sets such a vowel related effect does not seem to occur.

Group 3 made fewer errors than other groups on two sets le dragon, le wagon, le ballon and le bouton, *le bouchon*, *le mouton*; but then confused *les rideaux* and *les ciseaux* more frequently. As the sonograms presented as Figure 4.1 show, *les rideaux* and *les ciseaux* in their coded forms were quite dissimilar. While all but one of the profoundly deaf subjects in this group confused these words, adults with normal hearing were able to discriminate between them in their coded form without difficulty. Confusions in this case were evidently related to the impaired discrimination capacity of subjects rather than to possible limitations of the coding process.

In summary, it appears that each condition of amplification tended to yield equivalent results; and confusions indicated that relative discrimination gains for certain sets were offset by comparable discrimination loss for other sets. Results do not suggest that speech coding could substantially improve the discrimination of words by deaf subjects. Nor do the results indicate that a combination of coding and conventional amplification

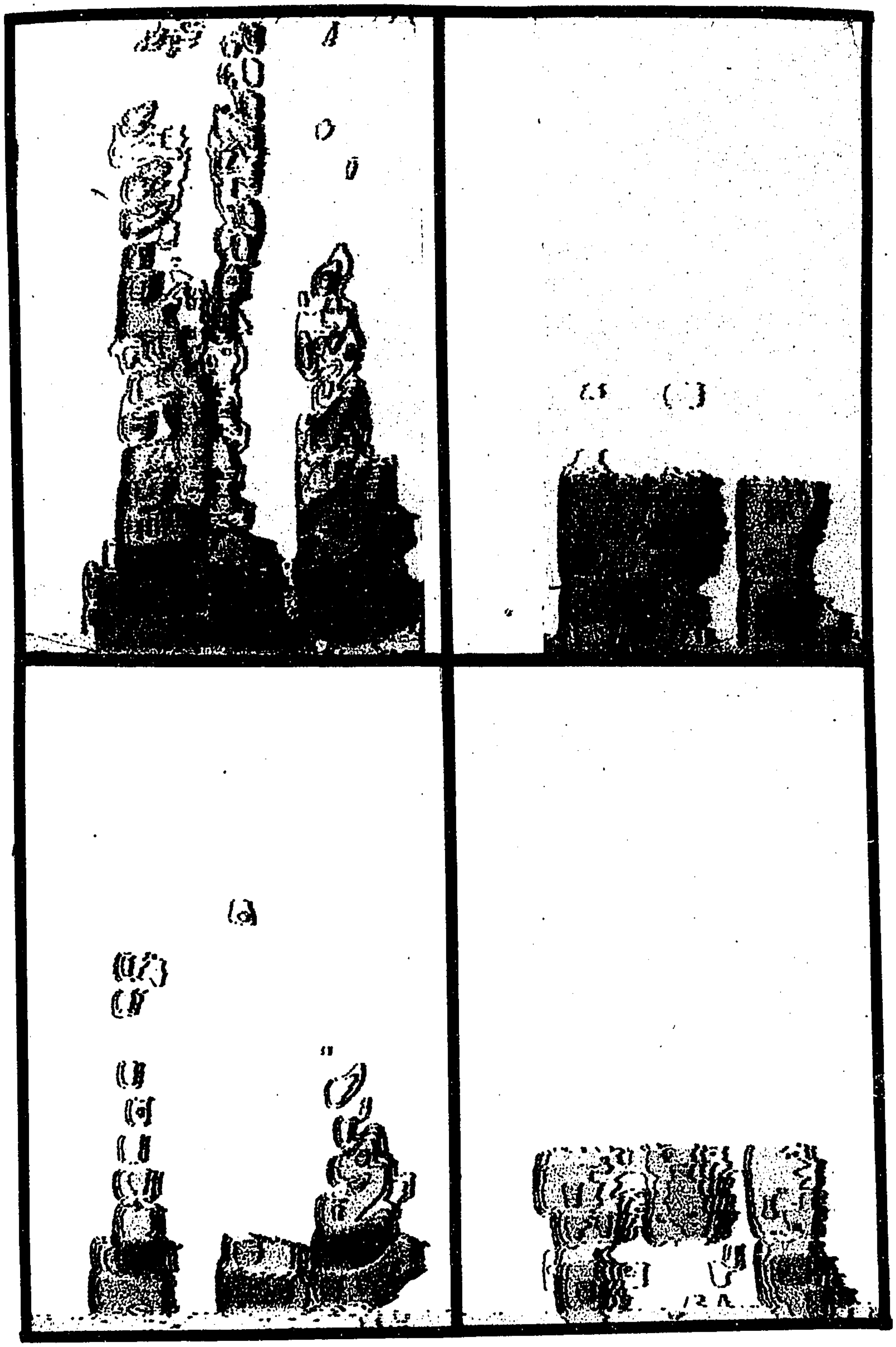

Figure 4.1 Sonagrams of the words <u>les rideaux</u> (above) and <u>les ciseaux</u> (below) as reproduced by linear amplification (left) and by coding (right).

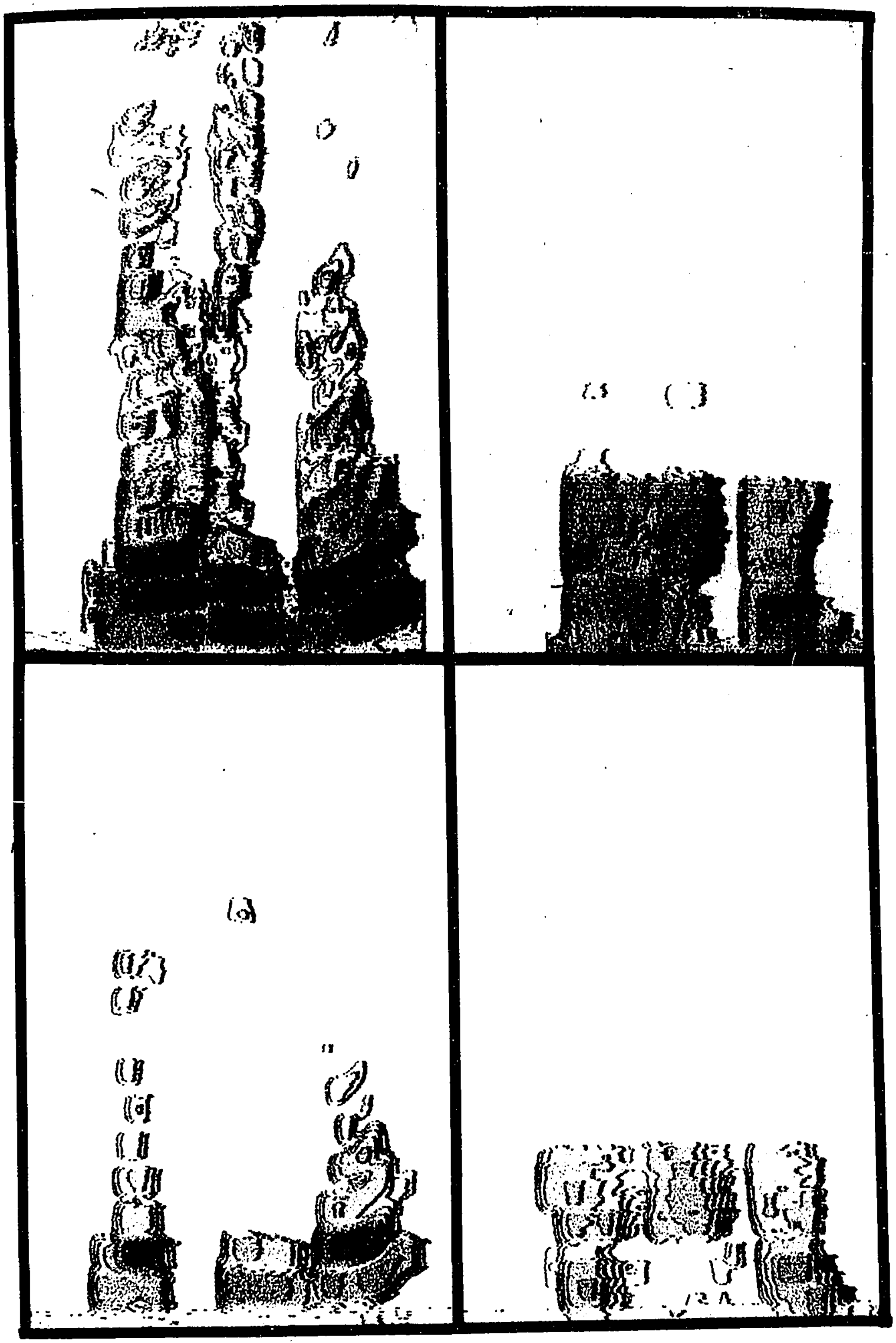

Figure 4.1 Sonagrams of the words <u>les rideaux</u> (above) and <u>les ciseaux</u> (below) as reproduced by linear amplification (left) and by coding (right).

could lead to better results than either alone.

Results of all four experiments serve to indicate the need for basic studies on the nature of the cues profoundly deaf subjects can use in making auditory discriminations, both monaurally and binaurally. The ability of such subjects to perceive differences in duration, intensity and frequency of speech or speech-like sounds has received little attention (Pickett and Martin, 1968). Interaction effects of these factors has received none. These and other variables, such as rate and temporal order (Hirsh, 1959) and their relationship to the subjects' own motor speech production require intensive study. The extent to which discrimination of running speech can be predicted from the discrimination of isolated syllables or words by such subjects also requires investigation. Results suggest that discrimination of coded speech by profoundly deaf children is unlikely to be more efficient than in the present experiments unless the method of coding is designed on the basis of knowledge derived from such fundamental studies.

GENERAL CONCLUSIONS

In the four studies which constitute this series of experiments, profoundly deaf children were trained to discriminate linearly amplified speech and speech coded by three different processes. The purpose of the experiments was to determine whether frequency transposition (coding) could improve such subjects' speech discrimination skills. The experiments, which were more exhaustive and systematic than any others undertaken in relation to this problem, and which involved intensive training, led to the following conclusions:

1. Profoundly deaf children's discrimination of coded speech was not superior to their discrimination of speech amplified by conventional linear systems.
2. Coded speech to the right ear and linearly amplified speech to the left did not lead to better results than either form of amplification presented binaurally.
3. Results suggest the need for further study on the nature of cues that profoundly deaf subjects can use in making auditory discriminations.

SUMMARY

Four experiments on the discrimination of coded speech by profoundly deaf subjects are reported.

In the first experiment speech components from 2000 - 3000 Hz were coded and presented as analog signals over the frequency range 750 - 1000 Hz, adjacent to a linearly amplified bass-band from 70 - 700 Hz. Comparison of discrimination scores obtained after subjects had been trained with this form of coding and with conventional linear amplification were not significantly different.

In the second experiment, two coding processes were compared, one as described above and the other as described by Johansson, (1966). Subjects' discrimination scores for either form of coded speech were not significantly different from those obtained with the linearly amplified bass band provided by each instrument.

The third experiment was a partial replication of the second. In this study the Johansson transposer was used over an extended period to provide further training for four of the subjects who had participated in

Experiment 2. The purpose was to determine whether adequate time had been allowed in Experiment 2 for an improvement in the discrimination of coded speech as compared with linear amplification. Results were similar to those of Experiment 2.

In the fourth experiment, speech components from 1000 - 4000 Hz were transposed by means of a spectrum channel vocoder and presented over the range 100 - 1000 Hz. Three groups of profoundly deaf subjects were trained to crude limits of learning by the use of programmed instruction: the first, with linear amplification to both ears, the second, with linear amplification to one ear and coded speech to the other, the third with coded speech to both ears. No significant differences between groups resulted.

It was concluded that discrimination of coded speech by profoundly deaf children was not superior to their discrimination of speech amplified by conventional linear systems.

REFERENCES

Ahlstrom, K.G., Risberg, A. and Lindhe, V. Experiment in Learning to Discriminate Frequency Transposed Speech. Report #36. Institute of Education, Uppsala University, Sweden, 1968.

Bennett, D.N. and Byers, V.W. Increased Intelligibility in the Hypacusic by Slow-played Frequency Transposition. J. Aud. Res. 7, 1967, 107-118.

Bouillon, J-P. Resultats de Réeducations Auditives Effectué par des Professeurs de l'Institut de Jeunes Sourds de Paris. Proc. Colloque Internat. Paris, Octobre 1967. Paris, L'Assoc. des Communautes d'Enfants. Pp 12-14.

Clarke, B.R. Use of Group Hearing Aids by Profoundly Deaf Children: in Educational Guidance and the Deaf Child. [A.W.G. Ewing, Ed.] Manchester University Press, 1957.

Cornett, R.O. Cued Speech. Amer. Annals of the Deaf. 112, 1967, 3-13.

Davis, H. and Silverman, S.R. Hearing and Deafness. [2nd Edition] New York: Holt-Rinehart, 1960.

DiCarlo, L.M. The Deaf. New Jersey: Prentice Hall, 1964.

Doehring, D.G. Validity of Intelligence Tests for Evaluating Deaf Children. J. Speech & Hearing Dis. 30, 1965, 299-300.

Doehring, D.G. Picture-Sound Association in Deaf Children. J. Speech & Hearing Res. 11, 1968, 49-62.

Dudley, H. The Vocoder. Bell Labs Record. 18, 1939, 122-126.

Ferguson, G.A. On Learning and Human Ability. Can. J. Psychol. 10(3), 1956, 121-131.

Fletcher, H. Speech and Hearing in Communication. [2nd Edition] New York: Van Nostrand, 1953.

Foulke, E. and Sticht, T.G. Listening Rate Preferences of College Students for Literary Material of Moderate Difficulty. J. Aud. Res. 6. 1966, 397-401.

Gauron, E.F. and Becher, W.C. The Effects of Early Sensory Deprivation on Adult Rat Behaviour Under Competition Stress: An Attempt at a Replication of a Study by Alexander Wolf. J. Comp. Physiol. Psychol., 52, 1959, 689-693.

Guttman, N. and van Bergeijk, W.A. Frequency Division in Real Time as a Means of Counteracting High Frequency Hearing Loss. Padua, Italy. Proc. 4th Int. Aud. Conf. October 2-4, 1958.

Guttman, N. and Nelson, J.R. An Instrument that Creates Some Artificial Speech Spectra for the Severely Hard of Hearing. Amer. Annals of the Deaf. 113, 1968, 295-302.

Hartley, R.V.L. Transmission of Information. Bell System Tech. J. 7, 1928, 535.

Hebb, D.O. Organization of Behaviour. New York: Wiley, 1949.

Hirsh, I.J. The Measurement of Hearing. New York: McGraw-Hill, 1952.

Hirsh, I.J. Auditory Perception of Temporal Order. J. Acoust. Soc. Amer. 31, 1959, 759-767.

Hubel, D.H. and Wiesel, T. Effects of Visual Deprivation on Morphology and Physiology of Cells in the Cat's Lateral Geniculate Body. J. Neurophysiol. 26, 1963a, 978-993.

Hubel, D.H. and Wiesel, T. Single-Cell Responses in Striate Cortex of Kittens Deprived of Vision in One Eye. J. Neurophysiol. 26, 1963b, 1003-1017.

Hudgins, C.V. Auditory Training: Its Possibilities and Limitations. Volta Review. 56, 1954, 339-343.

Huizing, H.C. Deaf Mutism: Modern Trends in Treatment and Prevention. Annals Oto-Rhino-Laryng. 5, 1959, 74-106.

Jakobson, R., Fant, C.G. and Halle, M. Preliminaries to Speech Analysis. Cambridge: M.I.T. Press, 1965.

Johansson, B. A New Coding Amplifier System for the Severely Hard of Hearing. Proc. 3rd. Internat. Congr. on Acoustics. Amsterdam, Elsevier. 2, 1961, 655-657.

Johansson, B. The Use of the Transposer for the Management of the Deaf Child. J. Internat Audiol. 5(3), 1966, 362-371.

Klumpp, R. and Webster, J. Intelligibility of Time-C Compressed Speech. J. Acoust. Soc. Amer. 33, 1961, 265-267.

König, G. und Eichler, H. Ein Nues Verfahren zur Hörverbesserung bei Hochgradiger Perzeptionsschwerhörigkeit durch Hörapparate. Arch. Ohr. Nas. Kehlkopfhk., 165, 1954, 326-331.

Krech, D. Recent Experiments on Effects of Differential Experience on Brain Acetylcholinesterase and Cholinesterase Activities. Paper presented at Amer. Psychol. Assoc. Symposium, 1964.

Kringlebotn, M. Experiments with Some Visual and Vibro-tactile Aids for the Deaf. Amer. Annals of the Deaf. 113, 1968, 311-317.

LaBenz, P.J. Potentialities of Auditory Perception for Various Levels of Hearing Loss. Volta Review. 58(9), 1956, 397-402.

Lafon, J-C. Appareil Amplificateur a Compensation pour la Surdite Profonde. J. Internat. Audiol. 6, 1967, 343-345.

Ling, D. The Education and Background of Children with Defective Hearing in Reading. Unpubl. Res. Associateship Thesis, Cambridge University Institute of Education, 1959.

Ling, D. An Auditory Approach to the Education of the Deaf Children. Audecibel. 13, 1964a, 96-101.

Ling, D. Implications of Hearing Aid Amplification Below 300 cps. Volta Review. 66, 1964b, 723-729.

Ling, D. The Use of Residual Hearing in Profoundly Deaf Children. M.Sc. Thesis, School of Human Communication Disorders, McGill University, 1966.

Ling, D. Three Experiments on Frequency Transposition. Amer. Annals of the Deaf. 113, 1968, 283-294.

Ling, D. and Druz, W.S. Transposition of High Frequency Speech Sounds by Partial Vocoding of the Speech Spectrum: Its Use by Deaf Children. J. Aud. Res. 7, 1967, 133-144.

Ling, D. and Ling, A.H. Speech and Hearing Problems in the Pre-school Child. Proc. C.P.H.A. Conf. Saskatchewan, April 1967.

Matzker, J. The Binaural Test. J. Internat. Audiol. 1, 1962, 209-211.

Mazéus, R. Hearing Capacity, Its Measurement and Calculation. Amer. Annals of the Deaf. 113, 1968, 268-274.

Melzack, R. Effects of Early Perceptual Restriction on Simple Visual Discrimination. Science. 137, 1962, 978-979,

Miller, G.A. The Perception of Speech: in "For Roland Jakobson" 353-360. Harvard Psycho-Acoustic Laboratory Report PNR 180, 1956.

Mykelbust, H.R. The Psychology of Deafness. [2nd Edition] New York: Gruen & Stratton, 1964.

Ochiai, Y., Saito, S. and Sakai, Y. Articulation Study of Speech Qualities in Rotational Synchronous Distortion. Mem.Fac. Eng. Nagoya, 7, 1955, 40-48.

Oeken, F.W. Can the Hearing of Patients Suffering from High Tone Perceptive Deafness be Improved by Frequency Transposition? J. Inter. Audiol. 2, 1963, 263-266.

Oeken, F.W. Untersuchungen über das Sprach und Sprachlautverständnis bei Frequenztransponierung. Phonetica 10, 1964, 92-109.

Perwitzschy, E. Ein Nuess Prinzip der Hörverbesserung. Zschr. Hals. Nas. Ohrenhk. 12, 1925, 593-602.

Pickett, J.M. Transmitting Speech Sounds by Tactual Vocoder and Lipreading. Royal Inst. of Technol., Stockholm. Report #27, 1963.

Pickett, J.M. and Martin, E.S. Some Comparative Measurements of Impaired Discrimination for Sound Spectral Differences. Amer. Annals of the Deaf. 113, 1968, 259-267.

Pickett, J.M. and Mártony, J. Low Frequency Single Formant Discrimination in Deaf Listeners. Paper contrib. 75th Meeting Acoust. Soc. Amer., Ottawa, May 1968.

Pimonow, L. The Application of Synthetic Speech to Aural Rehabilitation. J. Aud. Res. 3, 1963, 73-82.

Pimonow, L. La Parole Synthétique et Son Application dans la Correction Auditive. Cahiers d'Acoustique. 133 and 134, 1965, 151-187.

Potter, R.K., Kopp, G.A. and Green, H.C. Visible Speech. New York: Van Nostrand, 1947.

Raymond, T. and Proud, G.O. Audiofrequency Conversion. Arch. Otolaryngol., 76, 1962, 436-446.

Rosen, J. Phoneme Identification in Sensorineural Deafness. Ph.D. Thesis, Stanford University, Palo Alto, California, 1962.

Rosenthal, R. Experimenter Effects in Behavioural Research. New York: Appleton-Century-Crofts, 1966.

Sakai, T., Doshita, S., Niimi, Y. and Tabata, K. Fundamental Studies of Speech Analysis and Synthesis. Amer. Annals of the Deaf. 113, 1968, 156-167.

Schroeder, M.R. Vocoders: Analysis and Synthesis of Speech. Proc. I.E.E.E. 54, 1966, 720-734.

Schubert, K. Theorie und Praxis der Hörgerätanpassung. Thieme, Stuttgart, 1960.

Springer, A.M. Lässt Sich Das Restgehör für Tiefe Frequenzen dazu Verwenden, Das Durch Frequenz-transposition der Hörbereicherweitert Wird? Zschr. Laryng. 41, 1962, 420-422.

Sterritt, G.M. and Robertson, D.G. Pathology Resulting from Chronic Paraffin Ear Plugs: Methodological Problems in Auditory Research. Percep. & Motor Skills. 19, 1964, 662.

Stevens, S.S. and Davis, H. Hearing: Its Psychology and Physiology. New York: John Wiley, 1938.

Strizver, G.L. Frequency Discrimination of Deaf Children and Its Relationship to Their Achievement in Auditory Training. Volta Review. 60, 1958, 304-308.

Tervoort, B. Development of Language. in: Identification and Management of the Young Deaf Child. [H. Davis, Ed.] Acta-Oto-Laryngologica Supplement 206, 1964.

Tiffany, W. and Bennett, D. Intelligibility of Slow-played Speech. J. Speech & Hearing Res. 4, 1961, 248-258.

Upton, H.W. Wearable Eyeglass Speech Reading. Amer. Annals of the Deaf. 113, 1968, 222-229.

Van Uden, A. A Sound Perception Method: in Educational Guidance and the Deaf Child. [A.W.G. Ewing, Ed.] Manchester University Press, 1957.

Völz, H. Frequenztransponierung Durch Rotierende Magnettonköpfe. Bild und Ton 14, 1961, 384-390.

Watson, T.J. Speech Audiometry for Deaf Children: in Educational Guidance and the Deaf Child. [A.W.G. Ewing, Ed.] Manchester University Press, 1957, 278-296.

Watson, T.J. The Use of Residual Hearing in the Education of Deaf Children. Volta Review. 63, 1961, 238-334.

Wedenberg, E. Auditory Training of the Severely Hard of Hearing Using a Coding Amplifier. Proc. 3rd. Internat. Congr. on Acoustics. Amsterdam, Elsevier. 2, 1961, 658-660.

Whetnall, E. Benefits from Amplified Sound: in Identification and Management of the Young Deaf Child. [H. Davis, Ed.] Acta-Oto-Laryngol. Supplement 206, 1964.

APPENDIX 1

Pre- and Post-training Tests Administered to All Subjects in Experiment 4

Appendix 1

Pre- and Post-training Tests Administered to all Subjects in Experiment 4

Practice Items	maison	soleil	feuille	garçon	Blé d'Inde	chien
Set 1	un	deux	trois	quatre	cinq	six
Set 2	coude	doigt	oeil	pouce	front	dos
Set 3	jaune	vert	bleu	rouge	blanc	gris
Set 4	fleurs	cloche	livre	clé	oeuf	montre
Set 5	sept	huit	neuf	dix ou	onze	douze
Set 6	tortue	oiseau	girafe	canard	poisson	souris

Note. Four series of these stimulus words were recorded. For each series, a different order of all words within sets were used. Each set of words corresponded with a separate set of coloured pictures or symbols arranged to permit the subjects to respond by pointing rather than speech.

A P P E N D I X 2

Confusion Matrices of Stimulus Words Presented in Experiment 4

SERIES 1: INCORRECT RESPONSES AT ASYMPTOTE

Sets	Stimulus Words	Group 1			Group 2			Group 3		
		mouche	bouche	douche	mouche	bouche	douche	mouche	bouche	douche
1	mouche	x	0	10	x	1	2	x	1	5
	bouche	2	x	10	2	x	2	1	x	7
	douche	3	5	x	0	8	x	5	3	x
		chou	cou	loup	chou	cou	loup	chou	cou	loup
2	chou	x	0	1	x	0	0	x	0	1
	cou	1	x	0	0	x	2	0	x	0
	loup	0	1	x	2	3	x	0	1	x
		ciseaux	stylos	rideaux	ciseaux	stylos	rideaux	ciseaux	stylos	rideaux
3	ciseaux	x	1	1	x	0	7	x	2	4
	stylos	3	x	2	2	x	1	3	x	0
	rideaux	7	1	x	5	3	x	15	0	x
		sapin	lapin	patin	sapin	lapin	patin	sapin	lapin	patin
4	sapin	x	0	0	x	0	0	x	0	0
	lapin	0	x	0	0	x	0	0	x	0
	patin	0	0	x	0	0	x	0	0	x
		verre	fer	père	verre	fer	père	verre	fer	père
5	verre	x	5	5	x	4	8	x	1	14
	fer	5	x	2	2	x	3	4	x	3
	père	10	6	x	10	6	x	8	4	x
		niche	vis	pipe	niche	vis	pipe	niche	vis	pipe
6	niche	x	1	0	x	2	0	x	5	0
	vis	2	x	0	7	x	3	2	x	0
	pipe	0	0	x	0	0	x	0	0	x

SERIES 2: INCORRECT RESPONSES AT ASYMPTOTE

Sets	Stimulus Words	Group 1			Group 2			Group 3		
		femme	malle	nappe	femme	malle	nappe	femme	malle	nappe
1	femme	x	2	4	x	0	5	x	1	3
	malle	3	x	1	1	x	1	4	x	0
	nappe	0	4	x	1	5	x	2	2	x
		seau	veau	pot	seau	veau	pot	seau	veau	pot
2	seau	x	9	2	x	2	1	x	3	1
	veau	0	x	3	3	x	0	4	x	2
	pot	6	2	x	4	0	x	2	4	x
		sel	lait	bec	sel	lait	bec	sel	lait	bec
3	sel	x	0	0	x	0	0	x	0	0
	lait	0	x	0	0	x	0	0	x	0
	bec	0	1	x	0	1	x	0	0	x
		brosse	cloche	poche	brosse	cloche	poche	brosse	cloche	poche
4	brosse	x	4	3	x	3	7	x	5	3
	cloche	3	x	2	6	x	7	2	x	0
	poche	2	3	x	1	6	x	3	8	x
		chaise	fraise	mer	chaise	fraise	mer	chaise	fraise	mer
5	chaise	x	0	0	x	0	0	x	0	0
	fraise	0	x	2	0	x	3	0	x	2
	mer	0	3	x	0	7	x	0	4	x
		dragon	ballon	wagon	dragon	ballon	wagon	dragon	ballon	wagon
6	dragon	x	3	2	x	1	2	x	1	2
	ballon	1	x	1	4	x	3	0	x	0
	wagon	10	0	x	5	11	x	4	1	x

SERIES 3: INCORRECT RESPONSES AT ASYMPTOTE

Sets	Stimulus Words	Group 1			Group 2			Group 3		
		blé	néz	dé	blé	néz	dé	blé	nez	dé
1	blé	x	1	5	x	0	2	x	0	1
	nez	0	x	0	2	x	3	2	x	3
	dé	8	3	x	2	1	x	11	0	x
		chat	mât	bas	chat	mât	bas	chat	mât	bas
2	chat	x	0	0	x	0	0	x	0	0
	mât	0	x	2	0	x	0	0	x	0
	bas	1	2	x	0	0	x	0	0	x
		plant	gant	banc	plant	gant	banc	plant	gant	banc
3	plant	x	1	6	x	1	6	x	0	5
	gant	0	x	0	0	x	0	0	x	0
	banc	3	0	x	1	2	x	8	0	x
		cravate	carafe	banane	cravate	carafe	banane	cravate	carafe	banane
4	cravate	x	3	3	x	3	1	x	3	1
	carafe	1	x	5	2	x	3	2	x	2
	banane	4	2	x	2	4	x	5	5	x
		pêche	chèvre	pelle	pêche	chèvre	pelle	pêche	chèvre	pelle
5	pêche	x	1	1	x	6	0	x	3	1
	chèvre	3	x	0	1	x	0	1	x	0
	pelle	0	1	x	0	1	x	0	0	x
		nid	fil	lit	nid	fil	lit	nid	fil	lit
6	nid	x	6	8	x	2	3	x	0	5
	fil	2	x	1	1	x	1	2	x	4
	lit	7	0	x	5	2	x	6	2	x

SERIES 4: INCORRECT RESPONSES AT ASYMPTOTE

SETS	Stimulus Words	Group 1			Group 2			Group 3		
		balle	table	palme	balle	table	palme	balle	table	palme
1	balle	x	0	0	x	0	0	x	0	0
	table	1	x	4	1	x	6	0	x	11
	palme	1	2	x	1	7	x	0	5	x
		noix	poire	boîte	noix	poire	boîte	noix	poire	boîte
2	noix	x	1	1	x	1	3	x	0	3
	poire	4	x	2	2	x	0	3	x	4
	boîte	2	9	x	2	1	x	5	6	x
		pain	singe	train	pain	singe	train	pain	singe	train
3	pain	x	5	2	x	0	2	x	2	3
	singe	0	x	0	2	x	0	1	x	2
	train	4	1	x	1	1	x	4	0	x
		feu	pneu	noeud	feu	pneu	noeud	feu	pneu	noeud
4	feu	x	1	7	x	0	1	x	1	4
	pneu	4	x	4	2	x	0	4	x	0
	noeud	2	3	x	1	5	x	2	4	x
		cadre	arbre	phare	cadre	arbre	phare	cadre	arbre	phare
5	cadre	x	7	1	x	6	0	x	6	3
	arbre	1	x	0	2	x	2	1	x	6
	phare	0	0	x	1	2	x	0	4	x
		poule	coupe	soupe	poule	coupe	soupe	poule	coupe	soupe
6	poule	x	1	5	x	0	5	x	1	4
	coupe	0	x	0	0	x	6	0	x	0
	soupe	4	0	x	0	0	x	3	0	x

SERIES 5: INCORRECT RESPONSES AT ASYMPTOTE

Sets	Stimulus Words	Group 1			Group 2			Group 3		
		bague	cage	plage	bague	cage	plage	bague	cage	plage
1	bague	x	5	0	x	3	0	x	4	0
	cage	6	x	4	2	x	11	5	x	4
	plage	3	2	x	3	3	x	0	1	x
		drapeau	gâteau	marteau	drapeau	gâteau	marteau	drapeau	gâteau	marteau
2	drapeau	x	4	2	x	1	12	x	1	7
	gâteau	5	x	0	3	x	3	1	x	0
	marteau	1	3	x	7	1	x	5	0	x
		avions	camions	papillons	avions	camions	papillons	avions	camions	papillons
3	avions	x	6	0	x	2	0	x	1	0
	camions	3	x	5	8	x	3	2	x	6
	papillons	9	3	x	0	2	x	1	2	x
		tasse	vache	page	tasse	vache	page	tasse	vache	page
4	tasse	x	4	1	x	5	3	x	2	0
	vache	1	x	0	3	x	2	0	x	0
	page	0	0	x	0	4	x	1	4	x
		jambe	dent	lampe	jambe	dent	lampe	jambe	dent	lampe
5	jambe	x	0	2	x	1	10	x	0	5
	dent	0	x	0	0	x	0	0	x	0
	lampe	0	1	x	6	2	x	12	0	x
		pigeon	lion	citron	pigeon	lion	citron	pigeon	lion	citron
6	pigeon	x	0	1	x	0	1	x	2	1
	lion	0	x	0	0	x	0	0	x	0
	citron	1	0	x	0	0	x	2	1	x

SERIES 6: INCORRECT RESPONSES AT ASYMPTOTE

Sets	Stimulus Words	Group 1			Group 2			Group 3		
		botte	pomme	robe	botte	pomme	robe	botte	pomme	robe
1	botte	x	3	0	x	3	1	x	2	2
	pomme	2	x	4	4	x	4	4	x	3
	robe	4	3	x	3	2	x	1	8	x
		grange	manche	tente	grange	manche	tente	grange	manche	tente
2	grange	x	4	2	x	2	0	x	0	0
	manche	6	x	0	1	x	0	3	x	2
	tente	1	3	x	0	0	x	0	0	x
		bouton	bouchon	mouton	bouton	bouchon	mouton	bouton	bouchon	mouton
3	bouton	x	7	8	x	1	7	x	5	3
	bouchon	3	x	4	0	x	4	1	x	1
	mouton	4	5	x	10	1	x	1	0	x
		trèfle	cerf	zèbre	trèfle	cerf	zèbre	trèfle	cerf	zèbre
4	trèfle	x	1	0	x	0	1	x	0	0
	cerf	1	x	5	4	x	1	0	x	3
	zèbre	1	4	x	1	3	x	0	8	x
		plume	lune	mule	plume	lune	mule	plume	lune	mule
5	plume	x	1	6	x	1	3	x	2	3
	lune	1	x	1	1	x	2	4	x	4
	mule	9	5	x	6	5	x	9	2	x
		chameau	chapeau	bateau	chameau	chapeau	bateau	chameau	chapeau	bateau
6	chameau	x	1	0	x	3	1	x	5	2
	chapeau	4	x	1	0	x	3	1	x	1
	bateau	0	1	x	0	1	x	1	3	x