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ABSTRACT

Described is a program of research into sensory aids for the deaf, emphasizing research on factors involved in the effective use of sensory aids rather than evaluation of particular devices. Aspects of the program are the development of a programed testing and training unit, the control of fundamental voice frequency using visual feedback, and tactile stimulation using a wearable hearing aid. The experiments conducted in each of these three areas are detailed. (KW)

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SENSORY AIDS RESEARCH PROJECT - CLARKE SCHOOL FOR THE DEAF

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SPEECH COMMUNICATION ABILITY AND PROFOUND DEAFNESS

For inclusion in Technical equipments or Conventional systems and speech analyzing systems.

SENSORY AIDS RESEARCH PROJECT--CLARKE SCHOOL FOR THE DEAF

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In the Hudgins Diagnostic and Research Center at Clarke School, we have begun a program of research into the application of sensory aids for the deaf. These we define as "devices which accept an acoustic input and introduce modifications before presenting an output to the auditory, visual or tactile sensors of the deaf subject." This definition includes the conventional amplifier. Our aim is not so much to evaluate particular devices as to research some of the factors involved in their effective use.

To date our work has covered three areas. Firstly, the design of a binary choice programmed teaching and training unit. This is controlled by modular programming equipment (Grason-Stadler 1200 Series) and can be operated in the classroom, with remote control from the research laboratory. In a preliminary auditory discrimination study, using 30 deaf children, we found that younger children (6 years or younger) did not react well to the machine, but older children were interested and well motivated.

Our second area of interest has been in the use of a pitch display for instantaneous visible feedback of fundamental voice frequency. A study with 60 deaf children showed that very few of them were able to exercise voluntary pitch control. Performance on the task given was not found to be related to sex, hearing loss, habitual pitch, or speech intelligibility. It was found, however, that there was a significant improvement with age. We have since extended this work by teaching control of fundamental voice frequency to a group of children both with and without the instantaneous feedback.

Our third interest has been the use of tactile stimulation for those children whom we feel to have no residual hearing. We have designed special mittens which permits the children to wear a bone conduction oscillator in the hand. This is driven by a high power hearing aid and gives a 20 to 30 dB improvement in sound sensitivity over the conventional aid. We hope to learn more of the information handling capacity of this system and to establish reliable means of deciding which children are most likely to benefit from it.

It is my opinion that development in this area is limited not by technical factors but by insufficient knowledge of the way in which children learn to perceive complex coded signals.

SENSORY AIDS RESEARCH PROJECT - CLARKE SCHOOL FOR THE DEAF by: A. Boothroyd

I. Introduction

This paper will describe a program of research into sensory aids for the deaf which has been initiated in the Hudgins Diagnostic and Research Center at Clarke School.

A sensory aid for the deaf may be defined as any device which takes an acoustic input and modifies it in some way before presenting it to the deaf individual. The modification may involve amplification, analysis, frequency transposition, recoding or some combination of these. The output may be sound, light or mechanical vibration, the appropriate sensory modalities being hearing, vision and touch. Such devices may be of value in the perception of sound stimuli, or as feedback links in the control of speech.

In considering the potential use of sensory aids, there are several questions to be considered. For example, one needs to know the information handling capacity of the sensory modality used for perception and to ensure that the device presents its output in a suitable form. One also has to decide whether the device is to become a permanent extension of the subject's sensory apparatus, in which case it must be wearable. If not wearable, then it must be considered as a temporary aid in the acquisition of skills which are to be taken over by some other system. For example, a pitch extractor can be used to enable the deaf subject to exercise voluntary control of pitch. If it is wearable, it may become the permanent means of providing feedback information. Alternatively, it may be used as an aid in learning kinesthetic control of pitch.

The purpose of this research program is to find ways of answering these questions and to develop methods of evaluating sensory aids. Where a device or technique is found to have educational value, it is hoped also to determine ways of incorporating it into the school curriculum. During the first year of the project, we have worked on the development of a programmed testing and training unit, the control of fundamental voice frequency using visual feedback, and tactile stimulation using a wearable hearing aid.

II. Programmed Training and Testing

Rationale

Controlled research into the effectiveness of a teaching method, or device, is complicated by the teacher variable. Machine instruction offers the possibility of removing this variable, and also provides for reproducible test conditions (Cf. Risberg and Spens, 1967). It was felt that such techniques should be used in the evaluation of sensory aids where possible, and the necessary facilities were established.

Equipment

A student console was constructed, containing a twin channel tape recorder (for stimuli and control data), a slide projector and rear projection screen (for visual presentation of response alternatives), student response buttons, and indicator lights. This is shown in Figure 1. Also shown in Figure 1 is the Grason-Stadler modular programming equipment (1200 Series) used to control the console.

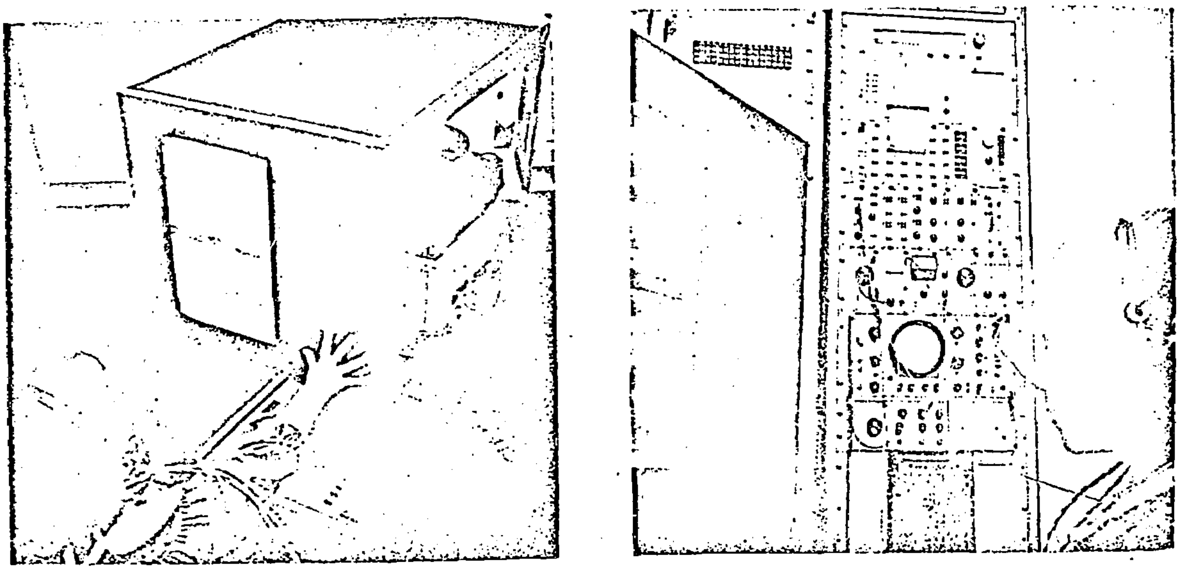

Figure 1. Student console for programmed testing and training (left) and control equipment (right). With the installation of multichannel audio circuits, the console can be operated in the classrooms by remote control from the research laboratory.

Preliminary Study

In order to evaluate the system and to assess student reaction, a binary choice word and vowel discrimination test was recorded, and given to 30 Clarke School students. Each student was tested on two occasions, separated by several days.

Subjects

There were 10 subjects from each school division, age ranges being:

Lower School, 5 years 1 month to 7 years 0 months

Middle School, 11 years 7 months to 14 years 0 months

Upper School, 14 years 9 months to 17 years 6 months

Hearing levels ranged from 70 dB I.S.O. (three frequency average in better ear) to levels in excess of 110 dB.

Test Program

The program involved a forced binary choice between pairs of words or vowels differing in terms of number of syllables, duration, first formant frequency, and second formant frequency. Any response advanced the program to the next stimulus. A correct response also caused the indicator lights to come on for one second, this being the only reward for a correct response.

There were 12 trials for each stimulus pair and a subject was considered to have discriminated successfully if he made 10 or more correct responses in 12 trials or 6 correct responses in the last 6 trials.

Results

Table I shows the number of subjects in each group who were able to discriminate between members of each test pair.

Effect of Test Repetition

It will be seen from Table I that there were more instances of success during the second test session. In the Upper School group, 13 of the 23 instances of failure on the first test became successes on the second. The corresponding proportions in middle and lower school were 6 out of 18, and 15 out of 75. All these proportions are significantly different from zero at the 1% level.

Table I. Number of Subjects Attaining Criterion on the Discrimination Tasks
(10 or more correct responses in 12 trials, or 6 correct responses in the last 6 trials)

Major Distinguishing Feature	Word or Vowel Pair	Lower School n=10		Middle School n=10		Upper School n=10	
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Number of Syllables	clock/Santa Claus	2	4	9	9	9	10
	stick/Christmas tree	2	4	9	9	10	10
	ball/baby	3	5	9	9	9	9
	pig/monkey	3	2	9	9	8	10
Duration	moon/stick	3	1	9	9	9	10
	room/clock	3	3	9	10	7	8
First Formant Freq. (F1)	too/tar	3	3	8	9	7	9
	u:/a:	3	5	8	8	8	9
	u:/ɔ	1	3	8	10	8	8
F2	u:/i:	2	1	4	5	2	4
	Totals	25	31	82	87	77	87

Effect of Age and Discrimination Task

The hardest discrimination task was the one involving second formant differences, i.e. u:/i:. On this task all groups did equally badly. On the other tasks, the lower school children did significantly less well* than either the middle or upper school children, these two groups showing no significant differences.

Effect of Hearing Loss

Among the upper and middle school children there were 11 whose hearing levels at 2000 Hz were in excess of 110 dB. Only one of these passed the u:/i: discrimination on the first trial, though four passed it on the second trial as shown in Table I.

* Probabilities of all sample proportion differences less than 5%.

Table II. Performance of upper and middle school children on the u:/i: discrimination in relation to hearing loss at 2000 Hz

	Sample Proportion Attaining Criterion	
	Hearing Level at 2 KHz 110 dB or less	Hearing Level at 2 KHZ in excess of 110 dB
Test 1	5/9	1/11
Test 2	5/9	4/11

Calculation of probability values showed that those children with less hearing at 2000 Hz did significantly less well on the first test ($p < .05$), but that a significantly greater proportion of them improved between tests ($p < .05$).

Discussion

The poorer performance of the lower school children was not necessarily related to discrimination, but could have been due to limited vocabulary, poorer reading skills, and low attention motivation. It was observed during testing that the middle and upper school children were highly motivated, very attentive, and very careful to make as few errors as possible. By contrast the lower school children became bored with the procedure and did not enjoy interacting with a machine.

The only task which appeared to present any major difficulty to the older children was the one involving second formant differences. As expected, those subjects with more high frequency hearing did better on this task at the first test. However, the ones with less hearing showed greater improvement so that at the second test there was no difference of performance. This could point to a basic weakness of the binary choice task--namely that there may be fine differences between the pairs other than the one which has been deliberately introduced. Thus the particular utterances of u: and i: used in this study may have had differences of pitch, duration, intensity, intonation, etc., sufficiently large for children with only low frequency hearing to learn to make correct decisions. Such learning would not be expected to offer any help in the recognition of phonemic categories, since these differences are not based on consistent features.

Conclusions Based on this Study

1. It was felt that results of this study demonstrated the validity of the programmed approach to testing and training with older children, but that different response alternatives and reinforcements should be tried with younger children (i.e. below age 7 years).

2. If the results of training on binary choice discrimination tasks are to have relevance to recognition, it may be necessary to modify the program so that correct decisions cannot be made on the basis of secondary and inconsistent features. This might involve the randomization of secondary features, or the use of one "target" stimulus with various alternatives (Cf. Schultz and Kraat, 1970).

III. Control of Fundamental Voice Frequency Using Visual Feedback

Background

Two investigations have been carried out using an instantaneous visible display of fundamental voice frequency. The first was designed to assess the extent to which a group of deaf students were able to exercise voluntary control of pitch, and the second to find out how easily this skill could be taught both with and without the visual feedback.

Absence of adequate pitch control is one of the more obvious features of the speech of the deaf. According to Haycock (1933) pitch control can be taught using non-instrumental techniques, though the time involved would be more than could be afforded in a classroom situation. More recently Woodward (1967) has stated that one reason for the failure of teachers of the deaf to teach pitch control is inadequate application of knowledge of the essential features of normal intonation patterns. Considerable interest has been shown in the development of visible displays c. pitch (Coyne 1938, Dolansky 1955, Plant 1960, Anderson 1960, Tjernlund 1964, Risberg 1968), and it has been shown that pitch control can be taught with such devices (Martony 1966, 1968, Dolansky and others 1965, 1966, 1969, Phillips and others 1968). However, it has not generally been found that such control results in improved intelligibility, nor has the crucial question of the superiority of instrumental over non-instrumental techniques been investigated.

Equipment

Grason-Stadler modular programming equipment was again used in the construction of the pitch indicator. A low pass filter was used to extract fundamental frequency, and a pulse generated for each cycle of the resulting sine wave. The time interval between pulses was measured using a discharging condenser, and its reciprocal displayed on a storage oscilloscope screen. Figure 2 shows the oscilloscope and control system, and a typical pitch trace.

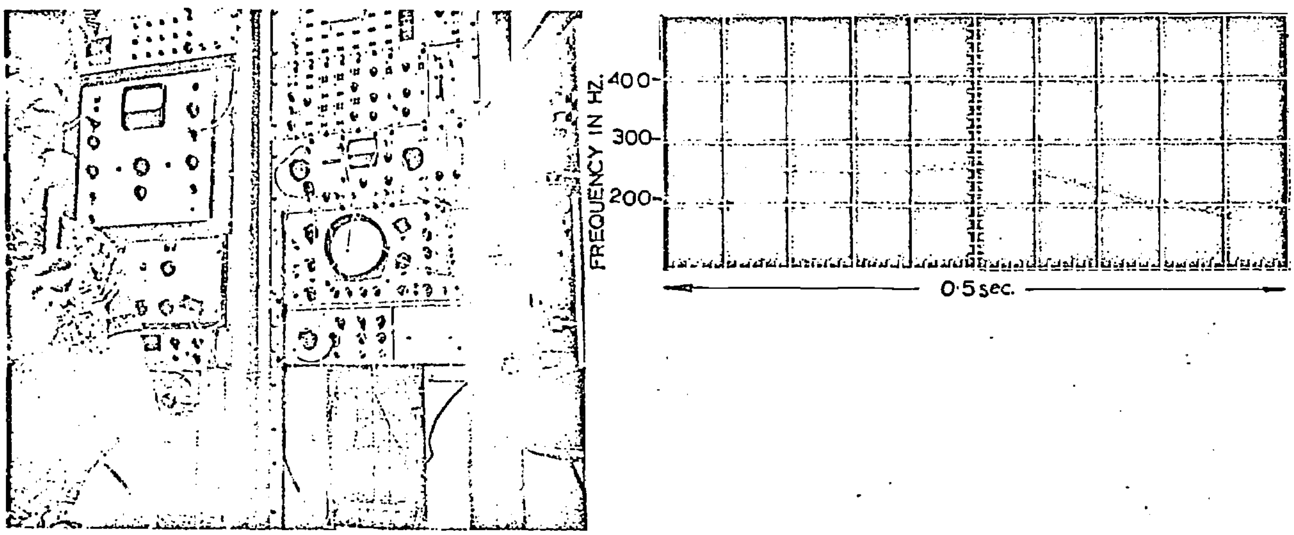

Figure 2. Subject observing pitch pattern on oscilloscope screen (left), and a pitch trace from an utterance of the word "today" (right). The vertical position of each spot depends on the interval between consecutive vibrations of the vocal cords.

First Study

Sixty students of Clarke School (20 from each school division) were given a pitch matching task in which they were required to generate fundamental voice frequency at three different levels (200± 10 Hz, 300± 15 Hz, 400± 20 Hz). All had losses in excess of 80 dB I.S.O. (better ear average at 500, 1000 and 2000 Hz).

Twenty-three of the children were unable to produce any voluntary control of pitch. Nine succeeded in generating three different frequencies though these were not generally close to the targets.

It was found that there were significant differences of performance between the three age groups, older children showing more pitch control than younger ones. Performance on the pitch matching task was not found to be related to sex, hearing loss, habitual pitch, or speech intelligibility.

Second Study

Twenty subjects (10 from middle school and 10 from lower school) were given 10 minutes per day instruction in pitch control for a period of four weeks. Half of the subjects used the visible display, the other half were taught with non-instrumental methods. The groups then changed over and were taught for a further four weeks. All subjects were assessed on four occasions:

1. Before instruction began
2. After four weeks of instruction by one method
3. After four weeks of instruction by the second method
4. After a period of six weeks without instruction

The tests given required the subjects to match two pitch levels (250 Hz and 350 Hz) and to produce rising and falling patterns of pitch between these two levels. They were also required to read two sentences which were later assessed for intelligibility.

The results showed that both methods were effective in teaching pitch control and that the older children performed better than the younger ones. After the six week period without instruction there was no deterioration of performance. There were some improvements in speech intelligibility during the experiment, but these bore no relation to improved pitch control.

It thus appears that for the simple pitch matching tasks used in this study instantaneous visual feedback offers no advantages over non-instrumental techniques. There remains the possibility, however, that tasks requiring more sophisticated pitch control might be learned faster and better with instantaneous visual feedback, and this possibility will be investigated.

The absence of an association between pitch control and overall speech intelligibility appearing in this study and others suggests that the teaching of pitch control should be given less priority than some other aspects of speech production.

IV. Wearable Hearing Aids with Tactile Output.

Rationale

There are many profoundly deaf children whose responses to low frequency sound represent tactile rather than auditory sensitivity (Nober 1963, 1967, Boothroyd and Cawkwell 1970).

The use of hearing aids by such children has some justification, but the hearing aid receiver is not the most efficient generator of mechanical vibrations nor is the ear the most sensitive place for feeling them. It was hypothesized that the totally deaf child, with only tactile sensitivity to sound would benefit more from a hearing aid if it were fitted with a bone conduction oscillator worn in the hand.

Equipment

A high power hearing aid with extended low frequency response was fitted with a bone conduction oscillator and an air conduction receiver on the two arms of a

Y-cord. A patch of "Velcro" was glued to the back of the oscillator so that it could be attached to a simple mit to be worn on the hand (see Figure 5).

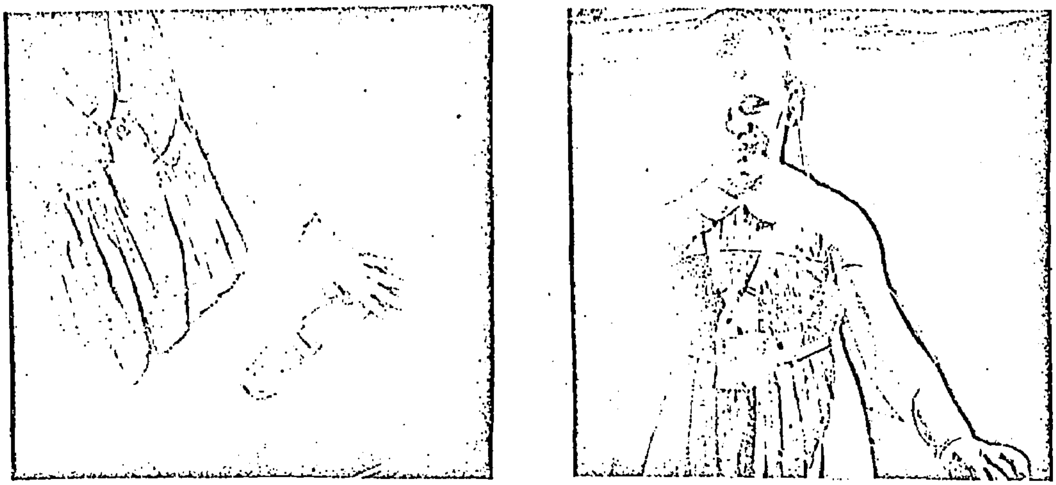

Figure 5. Showing the addition of a hand worn bone conduction oscillator to a high power hearing aid.

Subjects

This arrangement was fitted on a group of young children, all of whom appeared to be obtaining no benefit from a standard hearing aid and who gave little or no response to sound in audiometric testing.

Evaluation

Free field pure tone tests showed an average of 25 dB increase in sensitivity when the children wore their vibrators and air conduction receivers as opposed to the air conduction receivers only. They were also able to distinguish syllabic patterns and voicing using the vibrator. In addition, the teachers of many of the children have noted improved voice control--an improvement which is lost if the special hearing aid is out of action for more than a few days.

VI. Conclusion

The work described here represents the beginning of a continuing study, and much of it has been of necessity exploratory. It is my opinion that the most difficult problems involved in the use of sensory aids with the deaf are not technical but are concerned with the ways in which the human perceptual systems process the complex coding in speech and other sounds, and how such processing is learned. With more information on this subject it might be possible to design machines which are tailored to the needs of the human perceptual systems.

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