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SENSORY AIDS FOR THE HANDICAPPED:
A CHALLENGE FOR MODERN ENGINEERING TECHNOLOGY

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ABSTRACT

The search for sensory aids for the blind and deaf has revealed many possibilities, but at present there is no aid which to any great degree replaces the defective sensory channel. This paper summarizes the major developments in sensory aids in an attempt to stimulate interest in this problem among engineers and scientists.

INTRODUCTION

It is estimated that in the United States there are ten million persons who are totally or partially deaf. Another one-half to one million are blind, and approximately two million more have seriously impaired vision. It is also estimated that there are approximately 6,000 persons both blind and deaf.

The partially impaired can sometimes make effective use of basic devices such as eye glasses and common hearing aids. However, modern technology has yet to make available aids which significantly compensate for serious impairment of visual and auditory sensory channels. Some progress has been made and as one views the present state-of-the-art in sensory aid development and in technology in general he gets the impression that we could be on the threshold of some "break-throughs". Such "break-throughs" will require a coordinated effort and exchange of information among many disciplines. Part of the lack of progress is due to insufficient attention to the problem. Private enterprise has not met the need because of low profit potential. Government and Foundation support has been minimal.

Recognizing the challenge for the application of modern technology to the problems of the deaf and blind, the National Academy of Engineering has recently formed a sub-committee on Sensory Aids as part of the Academy's Committee on the Interplay of Engineering with Biology and Medicine. This committee will attempt to foster a national program to apply the modern developments in engineering, science, medicine, and psychology to the deaf, blind and the deaf-blind. The Institute of Electrical and Electronics Engineers' Group on Audio and Electroacoustics has recently formed a Committee on Speech Processing which will consider aids for the visually and aurally handicapped as part of its speech related

interest. These are long needed developments, since, unlike many European countries, the United States has very little coordinated effort in the development of aids for the sensory handicapped person.

The purpose of this paper is to stimulate interest in sensory aids among engineers and scientists. First, several devices are discussed in an attempt to illustrate how widely the search for effective aids has ranged. Then, the progress will be summarized and suggestions made for the direction of future investigations.

Aids For The Blind

The two main categories of sensory devices for the blind are reading aids and travel aids. The purpose of a reading aid is to make ordinary printed material available to the blind via hearing or the sense of touch. Such a device was the Optophone (1), invented in 1912. Since then development of similar devices has continued in the United States (2). With this approach, a small hand-held device is passed over the printed page and the shape of each letter is recoded into a specific sound pattern. The speed and accuracy of such "reading" depends on the ability of the user to learn the code. Many codes have been investigated, but reading speeds of only a few words per minute have been achieved after months of training by the user.

Many investigators, believing that there is no audible letter-by-letter code which will allow reading speeds approaching the rate of spoken language, have directed their attention to the development of reading machines which could convert printed text into connected speech (3), (4). Such a machine must recognize the printed material, recode the printed symbols into speech symbols, and then synthesize connected speech according to these symbols. This approach presents many significant problems, including the necessity of a significant amount of computing facility. However, some progress is being made toward a feasible system. One class of systems permits speech rates much faster than normal without loss in intelligibility. This is an attractive feature, because many blind people consider normal speech rates too slow for general information acquisition.

Another type reading machine converts ordinary

printed material into a tactile presentation (5). A hand-held optical system focuses an image of the printed material onto a rectangular array of photocells. An electronic system then converts this electrical image into a rectangular array of vibrating pins which produce a tactile facsimile of the original printed image. The tactile image is "read" by placing the finger tips of one hand on the vibrating pin array. Several years of development and the use of integrated circuit technology have produced a small portable unit which is quite effective and which requires only one and one-half watts of electrical power. One blind operator has achieved reading speeds of 50 words per minute using this device.

Travel aids which detect obstacles, stair steps, curbs, holes, changes in level of terrain, etc., have been developed for the blind (6). Most of these aids operate on the principle of radiating sound or electromagnetic energy and then detecting the signal reflected by the obstacles in the path. Warning signals are communicated to the user via an aural or tactual stimulus. The tactual stimulus is often preferred because most environments are quite noisy. Also, this stimulus does not interfere with normal auditory reception. These devices do not usually communicate enough information so that the obstacles can be identified.

Systems that do allow the blind to "see" shapes have been considered. Drs. Paul Bach-y-Rita and Carter Collins of San Francisco's Pacific Medical Center have developed a system which consists of a TV camera used to pick up the image and an electronic system which reproduces the image on a 20 by 20 matrix of vibrating cones placed against the back of the user. It is reported that with a few hours of training, blind subjects can accurately identify simple objects. The system is quite bulky in its present state of development. Miniaturization is planned, including the use of electrical impulses for tactual stimulators.

Aids For The Deaf

Severe hearing impairment at birth or with onset in the first few years of life generally means that the person will never develop normal speech communication. With seriously limited ability to distinguish speech patterns, a person not only has great difficulty in understanding speech by others but has equal difficulty in developing speech that the normal hearing can understand. This lack of speech communication retards the normal development of an understanding of language. Specialized education is required, particularly in the primary school grades if this deficiency is to be overcome. Even with an intensive educational program, the severely deaf child has great difficulty with speech production and speech recognition, and consequently, is quite retarded in vocabulary development, grammar, and reading skills compared to normal children. The plight of the young deaf student has motivated

many investigators to look for speech recognition aids.

The most common form of severe hearing loss involves an impairment of the cochlea, the signal analyzing portion of the ear. This type of loss generally leaves very little amplitude sensitivity in the frequency range of speech signals and also produces a "discrimination loss" which greatly reduces the ability of the ear to differentiate speech sounds.

A great amount of research has been directed toward methods of efficiently using the auditory capacity still available to the severely deaf. Direct amplification by a common hearing aid, although of limited value, is greatly preferred over no aid, since it provides the deaf with information on gross speech patterns. Carefully designed prescription hearing aids fitted to the loss characteristic of the individual have produced remarkable results in many cases.

A type of special hearing aids is called a "frequency transposer", "speech analyzing aid", or "coding amplifier". These devices process the speech signal in such a way that the resulting frequency spectrum is in the range of 100Hz to 1000Hz, the region of maximum amplitude sensitivity of the impaired ear. The main purpose of these aids is to recode the high frequency energy in the speech signal to lower frequency energy that can be detected by residual hearing. Many designs for this type of aid have been suggested and implemented (7). However, at least one rather intensive testing program has failed to show that training with type of aid produces significantly better results than training with ordinary amplification (8).

The possibility of recoding the speech signal into a visual pattern has been explored for many years. Lip reading (or face reading as it might be more properly termed) is a form of visual code as displayed by the speech production mechanism. However, a large portion of the production mechanism is invisible to the lip reader and therefore many significant speech patterns cannot be detected.

In the mid-1940's, a device called the Visible Speech Translator was developed by the Bell Telephone Laboratories. This device displayed, by means of a moving cathode ray tube and multiple band-pass filters, the frequency characteristics of speech as a function of time. These patterns, called spectrograms, were investigated for many years as a possible vehicle for "visible speech" for the deaf (9). However, only a few individuals were able to develop significant proficiency with this device. A later version of the Visible Speech Translator incorporates modern circuitry and a storage oscilloscope (10). This new system has been found useful for displaying speech patterns in programs stressing speech correction for the deaf. The general problem of finding suitable visual codes for displaying speech has

been investigated (11), but an effective method for visually displaying speech to the deaf has eluded investigators. However, several devices useful in speech teaching and correction have been developed (12).

Recoding speech into a form for tactual reception (12) was investigated at the Massachusetts Institute of Technology in 1949 and the investigation continued at the Speech Transmission Laboratory of the Royal Institute of Technology, Stockholm, Sweden, and at the Norwegian Technical University, Trendheim. The Swedish tactual aid measures the energy in ten frequency bands covering the speech spectrum and modulates the intensity of ten 300Hz vibrators proportionally to the instantaneous energy in the bands. An individual with his ten fingers placed on the vibrators receives a spatial tactual pattern which is characteristic of the spectral energy distribution of the speech signal. A Norwegian system is based on cascaded bistable multivibrators which perform successive frequency division. The output of each stage drives one of five vibrators, one for each finger of the hand. Since the frequency range of the skin's vibratory sensitivity is mainly from 200-400Hz, each finger "feels" a signal proportional to a specific frequency band in the speech signal spectrum. Tests indicate that these systems are useful as supplements to lip reading and as aids in speech teaching and correction.

DISCUSSION

The preceding outline, although very brief and incomplete, shows a fairly accurate picture of the general progress in developing sensory aids for the blind and deaf. A few devices, useful in a limited sense, have been developed, but no aid comes close to replacing the defective sensory mechanism.

The unsatisfactory progress is not due to lack of creative use of modern device technology, but it is due to the lack of knowledge (or lack of using the knowledge we have) of the mechanisms of human information processing. The human sensory systems of most interest in this study are the visual, auditory, and tactual information processing channels. As we have seen, a large majority of the aids involve cross-modality applications; that is, the information normally processed by the human in one modality, or sensing mode, is processed into a form perceivable by another modality.

As an example, consider the problem of developing speech recognition aids for the deaf. The normal modality for speech processing, the auditory channel, is a highly efficient decoder of the speech information contained in the acoustic speech signal. This channel and the speech production mechanism have developed a mutually suitable code. Applying this same code to a substitute modality which has evolved in response to an entirely different code could not be expected to produce high information processing rates.

The frequency spectrum of an electrical signal which is proportional to the acoustic pressure of speech has a bandwidth of approximately 3000Hz. To transmit this signal with a signal to noise ratio of 20 db (similar to a conventional telephone channel) requires, according to Shannon's relation for channel capacity, an information rate of 40,000 bits per second. However, if we consider that the human uses approximately 40 basic sounds in producing speech and that in normal speech he produces these at an average rate of 10 per second, speech has an information rate between 50 and 60 bits per second. This figure is approximately that which is estimated to be the maximum rate of perceptual intake of information by the human. Therefore, the auditory channel performs the task of information reduction by extracting those features of the speech signal which define the speech code. Since normal speech is quite redundant, the channel can also take the time to extract features which identify the speaker without overloading the input rate capacity of the brain.

Presenting the speech signal directly to another modality, such as vision or touch, is not likely to produce satisfactory feature extraction since the substitute modality has evolved in response to an entirely different need and thus uses another type of code. Also, it is unlikely that retaining could be accomplished in a reasonable length of time. Therefore, a speech recognition aid must perform the majority of the feature extraction (information reduction) before the signal is presented to the substitute modality. Also, the signal processing capability of the substitute modality must be considered in order to choose an optimum method of presentation.

An example of an approach which fits this description has been reported by Stewart (13). Here, a speech to touch conversion code was sought by studying the touch sensations which accompany the act of speaking. These sensations are a "natural code" since they are associated with the articulatory mechanism which produces the acoustic speech signal. Several investigators, including those studying machine recognition and production of speech, have recognized the possibilities of a code based on the configuration of the vocal tract. Such a code may be very efficient, because it is conjectured that the brain accomplishes speech recognition by the association of the speech signal with a motor control program that would produce the same signal by the articulatory mechanism. In other words, we recognize words by comparing the acoustic signal with a stored program that would cause us to produce the same signal. Stewart and his group were interested in developing a tactile code for communicating speech to normal hearing persons who have already developed language. However, the same code should be highly efficient as an aid for the deaf, both in terms of speech recognition and speech correction.

Aids for the blind which use substitute modalities need to perform feature extraction also, since this is the way the eye analyzes data. Again, after

feature extraction, the proper code for the substitute modality must be developed.

CONCLUSIONS

Development of sensory aids for the blind and deaf has advanced to the point where a coordinated effort between engineering, science, medicine, and psychology is necessary before the last crucial problems are solved. The engineers must apply their latest developments in information and communication theory, pattern recognition techniques, bandwidth reduction techniques, machine speech recognition, device miniaturization, etc. Equally important, they must combine this technology with applicable studies in medicine and psychology. Such team effort is capable of producing useful aids for the sensory handicapped.

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