

Other VA Research Programs

Research and Development Project on Advanced Orthotic Devices for Adult Paraplegics

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Prast Research Associates has completed all design modifications on PACO III and has started production on three new units for further testing by other paraplegics in the VA system.

This new system has adjustable capabilities so that the device can be adjusted to each patient's needs rather than building a custom-fit device for each patient.

Dr. Lawrence Carlson of the University of Colorado at Boulder has joined PRA as a co-principal investigator and is now redesigning the knee lock mechanisms to make these automatic.

Further testing by other paraplegic users will begin, with the next 6 months spent in determining any shortcomings of the new PACO III design.

SENSORY AIDS

Edited by

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Laser Cane Blind Mobility Aid

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A final report on this project is in progress and upon completion will appear in a future issue of the Bulletin.

Research on Audible Outputs of Reading Machines for the Blind

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Introduction

The objective of this research is the development of an audible output for a reading machine which can be readily understood. Speech is a medium of communication which functions at the required speed—possibly uniquely so. Therefore, the work is being concentrated on the generation of intelligible English speech by an automatic process.

During the 6-month period covered by this report, attention has been primarily focused on improving prosodic features of the synthesized speech, on introducing modifications and additions to an existing speech synthesis algorithm and preparing for a series of word intelligibility tests, and on the development of a set of print-to-sound rules for proper names. In addition, some further progress has been made on the preparation of a new synthesis system which will generate speech via either a hardware or programmed synthesizer.

Improvements to Synthesis Programs

The function of a synthesis-by-rule program is to convert a string of phonological symbols into an array of continuously varying parameters to drive a hardware synthesizer. One of the aims of the research is to realize the correct segmental durations in full-plus-weak syllable sequences and to superimpose an appropriate pitch contour. The proposed solution has been outlined and the preliminary stages to coding are under way.

Briefly, the algorithm hierarchically organizes vowels and consonants into clusters which are, in their turn, organized into syllables, phonological words, and phonological phrases. In a manner similar to that in which the realization of vowels and consonants varies with contexts, the algorithm will provide for variations to be introduced in the structure of larger units. Using this technique, we expect to introduce some of the more important features of "stress timing" into the synthetic speech output and to effect a significant improvement in intelligibility. A paper describing the technique was presented at the linguistics meeting held at the University of Kansas during October 1975.

While the basic rules for manipulating durations are now believed to be sufficiently well understood that programing can begin, the magnitudes of the adjustments that must be made are still a subject requiring empirical study. For this task, natural speech test phrases are being composed

and spoken by careful speakers. These data are then being measured and examined spectrographically with a Sonograph and the Digital Pattern Playback—a special instrument for analysis and manipulation of speech signals.

Extending the Speech Synthesis Program

Following the development of a synthesis-by-rule program for the OVE III synthesizer, a reorganization of the related program structure has been undertaken. This involves an extension of the phonetic symbol keyboard and display system to permit the addition of new phonetic categories, an expansion of the phoneme tables which are now in the form of 15 by 8 matrices, and the provision of a new program for creating allophone rules and naming them with a set of mnemonic symbols.

In addition, an extension of the allophone rule tables has been completed with the purpose of providing the synthesis-by-rule programs with the ability to search for a larger number of segmental environments. Specifically, the most important outcome is the ability to specify some immediately adjacent environments which were not previously available. We are now able to write allophone rules for additional prosodic contexts and for phones whose influence is felt at greater distances. As a result, the synthesis of certain complex rapid articulations (such as occur in consonant clusters) is more realistic.

Other technical improvements include a broadening of the synthesis program to permit the calculation of asymmetrical transitions flanking certain phonetic elements. This makes it possible to improve the effectiveness of the allophone rules and enhances the quality of coarticulation that can be realized by the program. Also, in related work concerned with the evaluation of a new set of phoneme rules that were formulated during midsummer 1975, some hitherto undiscovered computational errors were brought to light and eliminated. Following these developments, several sets of word lists have been synthesized in readiness for a series of tests scheduled for the college spring 1976 vacation. These tests include one involving many types of fricatives—a phonetic category whose intelligibility has always been relatively poor.

Print-to-Sound Rules for Proper Names

On another aspect of the contract work, progress is being made on the development of a print-to-sound algorithm which will generate the phonetic strings of words which are not found in the computer dictionary. This dictionary is used by the reading machine to convert orthography to phonetics and can contain only a limited number of proper names and surnames. Accordingly, a study has been made of the structure of several thousand names found in American telephone directories, and rules have been written to convert the majority of anglicized family names (Italian,

Polish, Spanish, etc., as well as those of Anglo-Germanic origin) to acceptably pronounced sounds.

The method that has been adopted depends on three factors: the actual spelling, local letter context (i.e., other letters and/or spaces lying immediately fore or aft of a letter or cluster of letters), and the stress grade of the syllables in which the letter (or letter sequence) appears. Approximately 200 different letter sequences are stored in order to convert conventional spellings to their most probable phonetic counterparts. Stress assignment, which is a subsequent operation, may modify the first phonetic transcription for vowels.

Stress is assigned on the basis of, a. the number of syllables, and b. the right-end syllable structure of the name, if the latter is significant. (Syllable boundaries are established automatically.) One of the four types of stress pattern is assigned by rule, each pattern exploiting a sequential portion of the syllable-to-syllable stress pattern series: High, Low, Mid, Low, (High, Low, etc.).

The rules have been successfully applied by hand to hundreds of randomly chosen names (with only an occasional poor outcome) and they are now being put into a form suitable for conversion into a computer program that will take over whenever the dictionary lacks an entry.

New Synthesis Methods

Work has begun on the programing of a new synthesis-by-rule program on the Laboratories' PDP-11/45 computer. It is intended that this program will optionally use either the OVE III synthesizer or a software synthesizer now being tested.

Conclusion

The work has proceeded over the past 6 months substantially as anticipated. During the next half year, it should be possible to reap the benefits of much of the groundwork laid during the period under review. Specifically, the improved synthesis-by-rule program should spur new efforts on the refinement of segmental cues, particularly for consonant clusters involving fricatives and nasal consonants, through comparative studies of synthetic and natural speech.

Research and Development in the Field of Reading Machines for the Blind Mauch Laboratories, Inc.

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In the period from July 1 to December 31, 1975, Mauch Laboratories concentrated on testing and improving the Cognodictor breadboard, building the hardware for a microprocessor-based interface between the

Cognodictor breadboard and a Model VS-6 Votrax vocal synthesizer, and designing and building circuit boards for Cognodictor prototypes.

The Recognition Matrix of the Cognodictor breadboard was expanded from a maximum capacity of 256 matrices (or templates) to 1024 maximum. Tests with a new series of type fonts and increasing numbers of templates showed that variations in the letter patterns produced by the pre-processing of the Two-Dimensional Multiple Snapshot process limited the effectiveness of adding templates to reduce error rates. A modification of the second part of this process was devised to greatly reduce these variations. The Cognodictor prototypes will use this modification, and a new set of templates, to produce a lower error rate over more type fonts than the breadboard currently achieves. A mini-computer (PDP-11 with floppy disk storage) was requested for Mauch Laboratories' use in preparing these templates. This equipment will allow many more letter patterns to be gathered for use in the design procedure than was practical with the remote computer service. The new design process will also require much less time and hand labor.

At the end of September it was decided to forego adding further improvements to the Cognodictor breadboard and to concentrate on building parts for the Cognodictor prototypes. By the end of December 1975, circuit boards for the Recognition Matrix and the Tone Generators had been completed. Boards for the Word Storage Unit and Template Comparison Logic had been designed. The design of the Cognodictor probe was started.

The Cognodictor-Votrax Interface unit will receive ASCII coded letters (grapheme strings) from the Cognodictor breadboard and produce appropriate control signals (phoneme strings) required by the Votrax vocal synthesizer which will produce acceptable speech for about 97 percent of English words (if the grapheme string is error-free). The hardware for this unit (a microprocessor, about 12,000 words of memory, several input-output circuits, power supplies, etc.) was completed by the end of December 1975. The software which will be used has been prepared by Dr. Scott Allen at the National Institutes of Health (NIH), Bethesda, Md., and furnished to Mauch Laboratories for use in this VA-sponsored program.

Clinical Study of Mobility Aids for the Blind

**Central Rehabilitation Section for Visually Impaired and Blinded Veterans
VA Hospital, Hines, Illinois 60141**

John D. Malamazian, Leicester W. Farmer, and James J. Whitehead

This report period has been characterized by the continuation of research and evaluation of electronic mobility aids, sensory systems, and minor instruments, and the admission of five blinded veterans for participation in the electronic mobility devices program. Of the five

veterans admitted, two completed training with the Sonicguide (Mark II Model), and two finished the C-5 Laser Cane course. Three veterans confined to wheelchairs were taught to employ the Lindsay Russell Pathsounder (E Model) to achieve mobility while undergoing blind rehabilitation training at VAH, Hines. It was found, during pre-course evaluation, that one veteran's basic orientation and mobility (O/M) cane and travel skills were inadequate for participation in the electronic mobility course. However, he was given a refresher course in the regular O/M program before returning to his home.

Remarkable among the four successful trainees was one veteran (trained with the Sonicguide), who had bilateral below-elbow amputations with Krukenberg reconstructive procedures. He had undergone plastic surgery operations on his right ear which presented a challenge for the Hines personnel in obtaining accurate fitting specifications, and for Tele-sensory Systems, Inc., Palo Alto, California, in assembling the spectacles to fit properly and comfortably. However, both agents met the challenge and the fitting of the aid was successful, as was the veteran's training experience and his use of the Sonicguide.

Three O/M staff members attended the Electronic Mobility Aids course at Western Michigan University, Kalamazoo, Michigan, and are certified to teach blinded persons to use electronic mobility devices. Virtually the entire O/M staff has completed the course at Western Michigan University, leaving only two specialists who will enroll in the devices course which begins on May 10, 1976.

Orientation and Mobility Research Specialists James J. Whitehead and Leicester W. Farmer participated in a workshop for teachers and/or administrators of programs for the visually impaired, "Optical and Electronic Aids for the Visually Impaired." The workshop was held August 11-13, 1975, at Northern Illinois University (NIU), DeKalb, Illinois.

At the end of August and the first of September, 1975, Mr. Farmer made a field trip to Des Moines, Iowa, for an evaluation visitation of one of the Sonicguide users.

In September 1975, Messrs. Farmer and Whitehead visited Western Michigan University to meet with Mr. Geoff C. Mowat, inventor of the Mowat Sonar Sensor, from Auckland, New Zealand. Mr. Mowat discussed some changes and modifications he has made in the aid, and demonstrated an accessory telemetry unit which may be used with the Sonar Sensor. Other topics covered concerned the manufacture and availability of the device, potential market and distribution, and strategies for the use of the aid.

A final draft version of a compendium of environmental sensing and behaviors has now been completed and received at Hines. The compendium has been developed by staff members of American Institutes for Research (AIR), Palo Alto, California, as an initial effort in

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developing a comprehensive and uniform evaluation procedure for the Veterans Administration. Periodically, throughout this reporting period, Dr. Robert A. Weisgerber and Mrs. Amanda Hall of AIR have contacted and interacted with the Veterans Administration O/M Research Specialists and obtained broad-based information which assisted them in completing the final draft.

On December 10, 1975, Mr. Whitehead and Mr. Farmer participated in a Department of Vocational Rehabilitation In-Service Workshop, "Low Vision and Electronic Aids for the Blind," held at Northern Illinois University. This workshop was sponsored by the Illinois Division of Vocational Rehabilitation with NIU College of Continuing Education and the Department of Special Education.

The December 1975 issue of "The New Outlook for the Blind" featured an article, "Travel in Adverse Weather Using Electronic Mobility Guidance Devices," by Leicester Farmer.

Mr. Arthur J. Snider, Science Editor for the Chicago Daily News and recipient of the American Medical Association's 1975 Journalism Award, has a special report, New "Eyes" for the Blind, in the 1976 World Book Science Annual. The staff at Hines was one of the resources Mr. Snider used in gathering technical information for his contribution to the World Book Yearbook.

Clinical Trials of Reading Machines for the Blind

**Central Rehabilitation Section for Visually Impaired and Blinded Veterans
VA Hospital, Hines, Illinois 60141**

John D. Malamazian and Harvey Lauer

This project consists of the clinical application and evaluation of ink-print reading machines and other new communication aids for the blind. Mr. Lauer engaged in four types of major activities during this reporting period.

Training

Eight persons were given assessment testing and familiarization experience with the reading aids. Two users were given followup training which included testing, advanced techniques, and speed-building practice. Recent students were also followed-up by correspondence and phone.

Stereotoner Evaluation

The Stereotoner Evaluation Project conducted by the American Institutes for Research was in its final phase. Mr. Lauer contributed to the

data gathering and the production of revised tape recorded training materials. The final report has been delivered to the VA, and the new training materials are soon to be delivered. Mr. Lauer also compiled and recorded a 70-minute user's manual for the new braille calculator modified and sold by the American Foundation for the Blind.

Lectures and Demonstrations

Mr. Lauer attended and participated in the convention of the American Council of the Blind, held in Mobile, Ala., July, 1975. He lectured, and demonstrated electronic and sensory aids at two workshops held at Northern Illinois University at DeKalb, Ill., and to students and professionals on detail to this facility. He sent tapes and articles about the reading aids to professionals and to prospective users.

Mr. Lauer began training a staff member to work part-time teaching the use of reading aids.

Information Gathering and Publishing

Through correspondence and interviews, Mr. Lauer gathered data on the development of optical character recognition machines for the blind. His article was reviewed by developers and colleagues in the field and will soon be published.

Three new models of speech compressing tape machines were studied by Mr. Lauer. He prepared a fact sheet on them for distribution to inquirers and colleagues.

Instruction in, and Evaluation of, Reading Machines for the Blind

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Two students were trained to use the Stereotoner during the period covered by this report. Both students were from countries outside the United States. The first student, from Canada, performed well in the auditory selection test and during the training was able to hear the code well. Performance, however, was poor so that the achieved reading speed at the end of the training period was two words per minute. It was obvious during the second week of training that "saturation" had occurred and this was reflected in the time test. This student has purchased a Stereotoner and is practicing with it in order to develop a higher reading speed. Followup will determine what progress is made.

The second student is associated with the Swedish Association for the Blind, Stockholm, Sweden. This organization has purchased a Stereo-

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toner and intends to set up a training program. The wife of this Swedish student also took some training in the use of the Stereotoner. It was a new experience to teach a sighted person who intended eventually to teach the blind. The reflex viewer was very useful in this part of the training.

The main thrust of the project during this period has been the collection of data in order to generate final reports of all the experience gained. Data were collected for the following purposes:

1. Toward a determination of the optimum duration of each student session, in order to develop teaching periods corresponding to student capacity.

2. Toward a determination of the parameters of saturation with the Stereotoner, in order to develop strategies to avoid and/or overcome this condition.

3. Toward the determination of graduates' continuation in self-directed training, and the development of strategies to assist this need.

Clinical Application Study of Reading and Mobility Aids for the Blind

Western Blind Rehabilitation Center

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Stereotoner Activity

With the VA—American Institutes for Research Stereotoner Evaluation Project completed, Mr. Richard Bennett trained one final project participant. This trainee, a 57-yr-old blinded veteran, received 92 hours of individual instruction. While his acquired reading skill with the Stereotoner was marginal, he expressed a strong desire to continue study at home and to remain in the project. Accordingly, he was issued a Stereotoner and accessories, along with the appropriate home-study materials and tapes.

Mr. Bennett worked with VA and AIR project personnel in final revisions of the preliminary Stereotoner Manual and the updating of the Home Study Units tape recordings. Master cassettes were prepared from the corrected open reel tapes. Another product of this period has been the revised and shortened Auditory Selection Tape and a final version of the Stereotoner Pre-Training Series.

Optacon Activity

Optacon instruction was requested by one 56-year-old veteran. Use of the Telesensory Systems screening materials indicated little potential for

reading proficiency with the Optacon and the Auditory Selection Test for the Stereotoner was even less favorable. After 60 hours of instruction, this veteran was reading with the Optacon at a very slow rate. In a decision mutually agreed to in conjunction with his instructors, he decided that there was little likelihood he would be able to incorporate the Optacon into his daily reading regimen. Further instruction was therefore not provided.

Electronic Mobility Aids

Two veterans have been trained at the Western Blind Rehabilitation Center in the utilization of electronic mobility devices; one on the Laser Cane and the other on the Sonicguide.

The Western Blind Rehabilitation Center has sent one mobility staff member to Western Michigan University at Kalamazoo, Michigan, to be trained on the electronic mobility devices.

CCTV Followup and Mobility

Since the last report in the Bulletin of Prosthetics Research, Nancy Darling has visited 28 veterans. These veterans were trained in the use of the Closed Circuit Television (CCTV) at the Eastern Blind Rehabilitation Center. An analysis of the data Miss Darling collected was prepared by Dr. Gregory L. Goodrich and is as follows:

Research on closed-circuit television (CCTV) systems began during 1972 with a study by Mehr, Frost, and Apple (1). That study utilized data on 40 veterans to provide initial estimates of performance with CCTV's and to provide some criteria for determining how much a CCTV would benefit individual veterans. In 28 of the 40 subjects, the following benefits of CCTV use were found:

1. Improved ability to write.
2. Reversed contrast (polarity).
3. Increased contrast enhancement.
4. Increased depth of focus.
5. Reduction of aberrations and distortions.
6. Reduced postural tension.
7. Reduced need for saccadic movements.
8. Binocularity with larger amounts of magnification.

The study was also one of the first done on CCTV systems to indicate increased duration resulting from use of CCTV's, as opposed to optical aids.

Subsequent experience in prescribing CCTV systems, and observations conducted at the Center and in the field, indicated that additional useful information might be attained by conducting a formal followup study of veterans using CCTV systems. Specific information which was to be

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gathered included reading speed and duration, amount and type of use of the CCTV, visual acuities, and relative value of the CCTV versus other types of low vision aids. The resulting study (2) indicated that the CCTV systems were used for a wide variety of tasks in addition to reading. These included home repairs, stamp and coin collections, and filling out forms. The mean age of the 27 veterans included in the study was 52; however, the range was 26 to 79 years of age indicating that CCTV's are beneficial to a wide range of veterans. In comparing data gathered on the followup to data taken at the Center, it was found that reading speeds had decreased from an average 115 wpm at the Center to an average 103 wpm at the followup. This is a statistically significant difference; however, it may be due to a number of factors including different reading materials, decreased visual acuity, and different motivational levels.

As in the Mehr, Frost, and Apple study, the veterans tended to use rather high magnification levels with relatively large viewing distances.

The average daily use of the CCTV systems reported by the veterans was 2.66 hours per day. Such high use rates probably contributed to the veterans' ranking of the CCTV as their single most important aid (this ranking includes both near and distance aids).

About one out of three veterans had had some mechanical or electrical malfunction with the CCTV. The majority of these malfunctions were minor, such as a sticking X-Y table, although some malfunctions included major failures to the camera and monitor. Such malfunctions might be expected in some of the CCTV systems because of their age (e.g., up to 3 yr); however, the malfunctions were not confined to the older sets alone.

A number of Pearson product-moment correlations were computed on the data in an attempt to isolate some of the factors correlated with reading speed. Of these correlations, the highest was between reading speed and visual acuity ($r = +0.46$). This particular correlation was of interest since it indicates that visual acuities account for only about 20 percent of the variance in reading speeds and that other factors may make equal or greater contributions.

Expanded Followup Study of CCTV Use

The high degree of cooperation from the veteran population encouraged the undertaking of an expanded followup study. Based on our previous experience, an improved and expanded questionnaire was developed. The new followup was designed to explore usage patterns of optical aids, as well as CCTV's, and to explore additional variables which appeared related to performance factors (e.g., reading speed and duration). From these factors, it was hoped to be able to improve training techniques for the low-vision programs and to improve selection procedures for veterans who might benefit from a CCTV system. The population for this study was selected from each of the three VA Blind

Rehabilitation Centers so that the results of the study would have the widest possible applicability. Additionally, by utilizing this larger population, the statistical validity of the study could be improved and more sophisticated statistical procedures used. An added advantage of this study was the use of one researcher for the followup visits, which minimized the variability of results.

This followup study is now being completed and a final report is expected to be written by March or April 1976. At the present time, 110 veterans have been asked to participate in the study. Of the 110, 41 could not be visited for a variety of reasons (28 percent could not be scheduled due to time conflicts, 3.5 percent had lost all remaining vision and returned their CCTV's to the VA, 2.5 percent had CCTV's being repaired, and 2.5 percent had died). Of the 69 veterans visited, 38 use the CCTV as their sole reading aid and 31 use both the CCTV and some optical aid. For this latter group, the CCTV is used for reading large amounts of material, while the optical aid is used to scan items or as a portable aid.

The mean age of the populations 46.9 yr (standard deviation = ± 13.9 yr) and with one exception is male. The average reading speed with the CCTV is 63.7 wpm (standard deviation = ± 38.1 wpm). The average duration is 102.7 min (standard deviation = ± 64.5 min). For those subjects using both CCTV's and optical aids, the mean reading speed with the CCTV is 81.8 wpm, and with an optical aid is 89.5 wpm. However, the mean duration with the CCTV is 119.8 min while with an optical aid it is only 42.7 min.

It is of interest that the population is relatively well educated, the average having completed 14 yrs of school. The standard deviation is about ± 3 yr; thus, most veterans in the study have completed between 11 and 17 yr of school.

In addition to the gathering of a great deal of research data, the study has had a number of other benefits. One fact mentioned by a large number of veterans was their appreciation that the VA was concerned enough about their well-being to send a representative. Also, some of the veterans were having some difficulty with their equipment and the researcher was often able to facilitate repairs or put the veteran into contact with someone who could arrange the repairs. Thus, the study has been very successful in producing valuable data, and in furthering the care provided to low-vision veterans.

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Development of Test Procedures for Evaluation of Binaural Hearing Aids
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Effects on Intelligibility of Speech of Filtering and Clipping

Introduction

Several investigators (e.g., Martin, 1950; Licklider and Pollack, 1948; Pollack and Pickett, 1959; and Thomas and Sparks, 1971) have shown that high pass filtering and peak clipping of the speech waveform do not substantially degrade intelligibility. Such a finding has implications for both hearing-aid design and use. Specifically, if the large moment-to-moment fluctuations in the intensity of speech could be limited without decreasing intelligibility, then this should benefit persons who have a hearing loss characterized by a limited dynamic range. In other words, by filtering and peak clipping speech, it might be possible to maintain intelligibility yet avoid large fluctuations in the intensity which might be disturbing to the listener. The research reported in this paper is a series of experiments aimed at determining the effects of filtering and peak clipping on the intelligibility of speech for both normal hearers and persons with sensorineural hearing impairment.

Technique of Filtering and Clipping

In the experiments reported here the speech was filtered and clipped in the following manner. The first step was to filter the speech in such a way that the spectrum of the filtered speech could be considered flat or "white." The speech was whitened by passing it through a multifilter (General Radio, #1925) which was set to the reciprocal of the speech spectrum. The rationale for whitening was to give each spectral component of the speech signal an equal chance of reaching the criterion voltage above which clipping would occur. Peak clipping was accomplished with a clipper constructed in our laboratories. The clipper was characterized by a (fixed) criterion input voltage and any signal exceeding this voltage was clipped. Consequently, the degree of clipping was set by varying the level of the input signal to the clipper. For example, 10 dB of clipping could be achieved by setting the level of the signal into the clipper 10 dB above the criterion voltage. Twenty dB of clipping required setting the level of the input signal 20 dB above the criterion voltage.

The magnitude of clipping for speech was defined in terms of a 1000Hz calibration tone recorded on magnetic tape at the same level on the vu meter as the frequent peaks of the speech signal recorded on that same tape. For one condition, the intensity of the tone was adjusted so that it

was just below the criterion clipping voltage. This point was termed the *minimal clipping* condition since just the peaks of speech above the level of the calibration tone were clipped. Clipping levels for speech greater than *minimal clipping* were defined in terms of the aforementioned procedure using the 1000Hz calibration tone. Finally, a 20kHz sinusoid was electrically mixed with the speech signal at a level 6 dB greater than the intensity of the background noise on the tape. This was done in order to prevent the tape noise from intruding into the silent periods between test words for the clipping conditions. The speech signals were passed through a 10kHz low-pass filter before presentation to the subjects, thus removing the 20 kHz tone.

First Experiment

The purpose of the first experiment was to determine whether the intelligibility of speech was affected when the speech signal underwent the filtering and clipping just described. Twenty normal-hearing young adults served as subjects in this experiment in which word discrimination functions were obtained under various filtering and clipping conditions. First, two spondee thresholds were determined for each subject. One threshold was obtained using unmodified spondees, the other employed spondees which were whitened in the manner described earlier. Then articulation functions were obtained using monosyllabic words of the CNC variety (Northwestern University Auditory Test No. 6) under the following six conditions: a. unmodified (not whitened and not clipped); b. whitened but not clipped; c. whitened and peak-clipped. In the latter instance, four degrees of peak clipping were used: minimal, 20 dB, 30 dB, and 40 dB.

The unmodified test words were presented at 4, 12, and 28 dB sensation levels in reference to the unmodified speech reception threshold. In the other conditions test words were presented at the same sensation levels but in reference to the filtered spondee threshold. Subjects listened monaurally via a TDH-39 earphone in an MS 41/AR cushion.

Results (Experiment 1)

The data yielded in this first experiment suggested that whitening and clipping the speech did not decrease intelligibility in any systematic way. At the +4 dB sensation level, the unmodified speech produced the lowest mean discrimination score (56.2 percent) and the whitened but unclipped speech yielded the highest mean discrimination (67.3 percent). The mean discrimination scores produced by the other types of signal processing fell between these two values. The differences among the mean scores became systematically smaller as sensation level was increased. At the highest sensation level (28 dB), the maximum difference was between the

mean score produced by the unmodified speech (99.1 percent) versus that yielded by 30 dB of clipping (97.2 percent). This difference is only 1.9 percent. Statistical analysis of the data (ANOVA) indicated that whitening and peak clipping did not significantly alter the intelligibility of the unprocessed speech. Thus, these data reaffirm the findings of earlier investigators.

The Second Experiment

The purpose of the second experiment was to determine whether the intelligibility of whitened and clipped speech remained high in the presence of a competing message for persons with normal hearing. In this experiment, articulation functions were obtained for the test materials, under several types of signal processing, for normal-hearing persons. A competing message composed of five talkers, each reading a separate passage, was electrically mixed with the target CNC words prior to the whitening and clipping. In order to generate the articulation functions, the target discrimination words were presented at a constant level of 85 dB SPL and the intensity of the competing message varied to yield five signal-to-competition ratios: -12, -8, 0, 8, and 12 dB. Consequently, the signal going to the filter and clipper was composed of the target words and the five-talker competition. It was this composite signal which was first whitened and peak clipped and then presented to the subjects.

There were three modes of signal processing for each of the five signal-to-competition ratios. These modes were: unmodified, whitened but not clipped, and whitening plus 30 dB of clipping.

The target discrimination words employed in this study were the ten Lehiste-Peterson (1962) word lists instead of the four lists of the NU No. 6 words used in the first study. This change was made so as to use the greater number of lists from Lehiste-Peterson, thereby minimizing learning effects. In addition, a hearing-aid receiver was employed in place of the high quality earphone in order to more appropriately reflect the transduction that would be used with an actual hearing aid. The receiver (Knowles BP) was used with 40mm of #13 tubing and was terminated in an EAR plug inserted in the subjects' ear. The EAR plug is a self-adjusting plug of foamed polymer which expands to full ear canal diameter. A hole was drilled through the EAR plug so that the #13 tubing could just be inserted through. Ten normal-hearing young adults served as subjects in this experiment.

Results (Experiment 2)

The results indicate that at the poorest signal-to-competition ratio (-12 dB), the subjects did equally poorly for the three types of signal processing. Specifically, the percent correct was 0.4, 1.0, and 0.0 percent for unmodified speech, whitened but not clipped, and whitened plus 30

dB clipping, respectively. However, as the signal-to-competition ratio was made more favorable, the unmodified and the whitened but not clipped speech yielded comparable discrimination scores, both of which were substantially better than the scores obtained with the whitened plus 30 dB clipping condition. At the +12 dB signal-to-competition ratio, the unmodified and the whitened but not clipped speech produced discrimination scores of 96.6 and 96.2 percent. This is contrasted to the discrimination score of 79.0 percent yielded by the whitened plus 30 dB of clipping at this signal-to-competition ratio. Consequently, these data would suggest that the intelligibility of speech is slightly degraded when whitened and clipped in the presence of competition and when transduced by a hearing-aid receiver.

Third Experiment

The reduced intelligibility shown in the second experiment was not sufficient to rule out the use of whitening and clipping for persons with hearing losses without further experimentation. Consequently, a third experiment was completed in which speech was whitened and peak clipped, and then presented to persons with sensorineural hearing loss. Basically, the experimental design of the third study was the same as that for the second experiment. Three conditions of speech processing (unmodified, whitened but not clipped, and whitened plus 30 dB clipping) were presented at five signal-to-competition ratios (-12, -8, 0, 8, and 12 dB) via the hearing-aid receiver. The intensity of the discrimination words (the Lehiste-Peterson lists) remained constant at 85 dB SPL. As in the second experiment, the transducer was the Knowles BP hearing-aid receiver. The subjects in this experiment, however, were persons with presbycusis hearing loss meeting the following criteria: first report of hearing loss at 60 years or older; speech reception threshold in better ear between 20 and 45 dB HL (re ANSI, 1969 standards); and discrimination greater than 70 percent in better ear.

Observations (Experiment 3)

The data from this third experiment have been collected but the analysis is not yet complete. The following observations, however, can be made on the basis of the preliminary analysis. For all three types of signal processing, the subjects obtained a score of 0 percent for the -12 dB signal-to-competition ratio. When the signal-to-competition ratio was +12, however, the mean percent correct was 81.8 percent for the unmodified speech. In contrast, when the speech was just whitened, the mean discrimination score was 69.8 percent at the +12 dB signal-to-competition ratio. Finally, at this same signal-to-competition ratio, the score obtained with the whitened and clipped speech was 45.0 percent.

These results suggest that the whitening, and whitening and clipping,

of speech do degrade its intelligibility. In addition, this degradation may be more pronounced for those persons having a hearing loss than for those having normal hearing. Specifically, at the +12 dB signal-to-competition ratio, the normal-hearing subjects in the second experiment obtained a mean discrimination score of 96.6 percent for the unmodified speech versus a score of 79.0 percent for the whitened and clipped speech. This is contrasted to scores of 81.4 percent versus 45.0 percent obtained by the hard-of-hearing subjects under the same experimental conditions. However, the differences between the results yielded by the normals and those obtained with the hearing-loss subjects have not been completely analyzed.

Additional data analysis is currently underway along with the planning of experiments to investigate further the effects of whitening and clipping on speech intelligibility when more than one talker is present.

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The Development of Improved Techniques for the Analysis of Hearing-Aid Performance

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Rank-Ordering of Aids by Clinical Audiologists

A study to determine if certain attributes of the hearing aids on VA contract could account for the rank-ordering of these same aids by clinical audiologists at 23 VA Centers has been completed. Twenty-two models had characteristics similar enough to permit them to be divided into the following eight categories on the basis of power and/or type of aid: 1. mild power over-the-ear aids, 2. mild power in-the-ear aids, 3. moderate power over-the-ear aids, 4. moderate power regular eyeglass aids, 5. strong power on-the-body aids, 6. CROS aids, 7. BICROS aids, and 8. hi-pass aids (minimum amplification below 1000 Hz).

The data for the study were based on questionnaire responses from 72

VA audiologists regarding: 1. their assessment of the acoustic quality of each aid, 2. the desirability of seven style and operational features of each aid, and 3. the rank-ordering of each model against the other models in a given power/type category. In addition, the number of each model issued by all VA Centers during 12 months of the fiscal year was tabulated.

Analysis by the chi square technique indicated that certain models were judged as having superior acoustic quality in the three categories of mild over-the-ear, moderate over-the-ear, and hi-pass over-the-ear (.05 level). The results of the styling and operational responses showed significance (.05 level) for six of the categories and indicated that the battery compartments and on/off switches were the major contributors to the desirability of these features. The final analysis of the data related the overall rank-ordering of the aids by the audiologists and the percentage of issue of each aid by category. In each category for which acoustic quality judgments showed a significant difference, the aid judged best was also ranked the highest and was issued at a higher rate than the competing instruments. In general, the same trend was maintained when rank-order, issue rate, and styling/operational features were compared, but not as rigidly.

Of particular significance to these findings is the fact that minimal contamination was present due to either original hearing-aid cost or maintenance costs to the hearing-impaired user. This contrasts with what would be expected with a civilian clinical population.

Current Studies and Investigations

Work was completed regarding the relative importance of *recovery time in compression hearing aids* for quiet listening of monosyllables. Both normal-hearing and impaired-hearing subjects performed more poorly when recovery time was excessively long or short. A substantial "middle" range on the order of 50 to 200ms appeared acceptable for the type of compression design studied.

Beginning study of measurement problems in evaluating intermodulation distortion in hearing aids was completed. A questionnaire provided to hearing-aid design engineers was of help in developing strategies for this work. No standardized method presently exists for measuring intermodulation distortion in hearing aids. Yet, there is some evidence that intermodulation distortion may be of greater significance than simple harmonic distortion in hearing-aided listening performance. Initial descriptive data on intermodulation distortion in representative hearing aids will be reported at the IEEE International Conference on Speech, Acoustics, and Signal Processing in Philadelphia in April 1976.

Investigation of hearing aid processing is currently underway. The

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technique involves the recording of the output of a hearing aid via a coupler simulating the characteristics of human ears, with subsequent playback under an earphone. This process is being studied as used with the 2cc coupler, the Zwislocki coupler, and the KEMAR manikin which itself houses the Zwislocki coupler. The response of these coupler systems, and their analogs in real ears under an earphone, are to be compared to the real ear response of the hearing aid under an earmold using probe tube measurements.

Preliminary results suggested that playback of the aided response via an earphone results in a significantly different response than that produced live by the hearing aid. Appropriate corrections are expected, as an outcome of this work, which will be applied in work on hearing-aid quality judgments, now in progress.

The Reading of Printed Materials by the Blind (Evaluation of an Ink Print Reading Aid: The Stereotoner) American Institutes for Research (AIR)

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Evaluation Procedures for Environmental Sensing, Orientation and Mobility by the Blind

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These contracts have been completed and the following are abstracts of final reports submitted as a requirement of the contract.

Evaluation of an Ink Print Reading Aid for the Blind

Background of Problem and Objectives of Project

The Veterans Administration has provided support for the development of new prosthetic aids for handicapped persons for many years. The Stereotoner is a chest worn, ink print reading aid for the blind developed by Mauch Laboratories under VA contract, and is an outgrowth of earlier exploratory research with direct optical-to-auditory conversion devices. The Stereotoner output, consisting of 10 separate tones, is activated according to the shape of the individual letters or numbers being sensed through a small moving camera or probe.

^aSpecial assistance was received from A. B. Chalupsky, M. N. Danoff, B. J. Rodabaugh, and C. Taylor.

The present study was designed to:

- a. Develop specialized instructional materials for the Stereotoner;
- b. Coordinate a program of instruction carried out by three VA and two non-VA instructors;
- c. Evaluate candidates for training, the process of training, and the outcomes of training in terms of attained reading performance (reading rate, accuracy, and variety); and,
- d. Make available multiple copies of basic course materials developed during the study.

Planning and Design of Project

The main study plan called for the provision of some 48 adult trainees from veteran and non-veteran referral services and for their instruction at three VA Blind Rehabilitation Centers (in Connecticut, Illinois, and California) and the Hadley School for the Blind, in Illinois. Additional exploratory instruction took place with a youngster in a public school in California.

Instructional materials were adapted from a prior AIR study in ink print reading for the blind and were substantially augmented by additional tapes and manuals. A new instrument (the Auditory Selection Test) was developed specifically to assess aptitude for Stereotoner training. Additional instruments were also developed to investigate the relationship of background and process variables to attained reading performance. Observational and interview data were collected throughout instruction, 1 month after training, and at least 4 months after training. Criterion tests were administered at the end of formal training (2-4 weeks) and again at the time of a final followup visit in the trainee's home or office.

Analyses of Results

Fifty trainees were admitted to training. The main study analyses were based on 30 trainees who completed at least the first criterion test; 17 persons dropped out for a variety of reasons, and 3 persons were classified as special cases and their performance was analyzed separately.

Results indicated that following formal training, covering about 54 hours of instruction, trainees' average reading rates were 4 wpm and they averaged 80 percent accuracy on isolated words. Following a period of home study covering about 87 hours, trainees' average reading rates increased to 7 wpm but accuracy decreased to 66 percent. Respectively, 13 wpm and 34 wpm represented the uppermost speeds attained in Criterion Tests A and B by the participants. However, one person not in the sample group was observed reading at 85 to 90 wpm with the Stereotoner. His technique was analyzed and translated into a strategy for more

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effective instruction in the future. It was also demonstrated in an exploratory effort that a 12-yr-old blind boy could learn to read with the Stereotoner.

Trainees found the auditory code difficult but possible to learn. They found the precise requirement of line tracking to be the most frustrating aspect of Stereotoner usage. They generally expressed pride in their modest new ability to independently perform personalized tasks such as reading of incoming mail and proofing of typing. However, their ability to read various difficult formats, typefaces, and applied numerals (prices, etc.) was quite limited.

The Auditory Selection Test used as a prediction measure was found to be significantly and positively correlated with Stereotoner reading performance. A revised and shortened form was produced for subsequent use by the training agencies including the VA. Age proved to be the most highly correlated background variable, with younger trainees doing better.

Both the instructional materials and the instructors' methods were favorably described by the trainees. It was established that instructors should place more emphasis on whole-word sound patterns and context recognition, in future training efforts. Trainees felt that home study is difficult without the availability of direct, periodic instructor intervention to counteract a possible loss of momentum. Even so, ample home study time was crucial.

Interpretation and Implications

It is clear that some blind persons, but by no means all, can learn to read ink print materials with the Stereotoner. Consequently, it can be added to the repertoire of devices and aids currently available at blind rehabilitation centers. Careful screening and selection procedures should be employed to avoid excessive frustration and failure. These procedures should include the newly developed Auditory Selection Test and a consideration of personal factors and individual commitment.

It is also clear that reading rates and accuracy are typically modest at the outset. Concerted and prolonged study are required of trainees if they are to achieve real proficiency. Personal priorities sometimes militate against such a level of commitment, and trainees should be realistically informed about this prior to training.

It was recommended that Stereotoner training programs continue, that recently developed adjunct aids (an automatic pacer and a tracking aid for books) be made available to trainees, and that the revised AIR instructional materials be utilized. It was further recommended that the training be dispersed more widely throughout the country to facilitate trainees' access to the centers, and that sessions be better spaced so as to avoid trainee fatigue.

Given the difficulties encountered and slow rates attained, it was recommended that further research and development be conducted with ink print reading devices having spelled-speech output or synthetic speech output. Hopefully, such efforts would lead to a simpler, more rapidly learned and more widely used aid for blind persons, whose independent access to printed materials *is* important to their personal and economic well-being.

Project Products

In addition to the Final Report, the project resulted in the preparation of multiple copies of: a. a taped Auditory Selection Test, with examiner's manual and score sheets, b. a series of pre-training orientation tapes, c. a basic Instructional Manual, with accompanying drill and practice tape and complete instructor's guide, and d. a Home Study Manual containing 48 lessons, with five accompanying instructional tapes.

Evaluation Procedures for Environmental Sensing, Orientation, and Mobility By the Blind

Background of Problem and Objectives of Project

The Veterans Administration offers blind veterans orientation and mobility training at Palo Alto, California; Hines, Illinois; and West Haven, Connecticut. Electronic sensing devices have been introduced into these training programs in recent years. Prior evaluation efforts, being locally developed and locally relevant, lacked generalizability and tended not to reveal the outcomes of training in terms which could be meaningfully related back to elements of that training or to particular devices being utilized.

The present study was designed to:

- a. Develop a conceptual framework (compendium) identifying the factors thought to be associated with environmental sensing skills and behaviors, and obtain critical reviews from expert and naive persons.
- b. Develop preliminary measures to assess trainees' skills before and after training, and try out those measures on a pilot basis relative to their feasibility and clarity.
- c. Develop an orientation/selection tape for trainees contemplating training with either the C-5 Laser Cane or the Sonicguide, two electronic sensing devices.

Planning and Design of Project

A number of potential factors to be considered in the conceptual framework were identified through a. interview and consultation, b. search of the literature, and c. direct observation of training. This information-

gathering stage culminated in a week-long working conference at AIR with VA and other consultants. Identified factors were then organized by AIR staff into a preliminary compendium of environmental sensing tasks and behaviors, and consultants were invited to review and make suggestions about the document.

Selected compendium entries were chosen (cooperatively with VA staff) for development as performance objectives and criterion exercises. Standard procedures were developed for specifying the conditions to be met in any given exercise, for administering the exercise and for scoring the exercise. Exercises were grouped according to whether the particular skill being assessed was preparatory (being needed before training), or mastery (to be assessed before and after training). A further distinction and grouping was made among mastery level exercises according to their setting and their complexity. Route exercises were also developed and included as a "summation" of the trainee's ability to reach a destination.

Pilot trials with the preliminary measures resulted in some modifications of the exercises, and enough copies of the preliminary measures were reproduced to permit subsequent field-testing on a more substantial basis by VA staff.

Separately from the development of the measures, project staff cooperated with VA staff to prepare preliminary versions of audio tapes describing typical ways two different electronic sensing devices might sound when encountering a variety of environmental stimuli, both indoors and outdoors.

Principal Products of the Study

All products of the study are considered to be preliminary, in that they should be revised at some future date when sufficient data are available from field testing at training centers: The products include:

a. *Environmental Sensing Skills and Behaviors: A Reference Compendium*. The preliminary reference compendium is a document over 95 pages in length, comprising some 16 topical areas with subordinate variables, and including a glossary of terms and an index to facilitate its use.

b. *Preparatory Skills and Behaviors for Orientation and Mobility Training: A Preliminary Inventory*. The inventory comprises approximately 30 pages. Full descriptions of administration procedures are given. It encompasses some 44 *criterion exercises* for evaluation of some 21 performance objectives. An extra scoring booklet is included.

c. *Mastery Skills and Behaviors for Orientation and Mobility Training: A Preliminary Performance Test*. The mastery performance test comprises approximately 150 pages. Complete descriptive explanations are given for its use. Relationships between the compendium entries and criterion exercises are shown in tabular form for reference purposes.

The mastery performance test is divided into two main sections. The first section contains some 126 *criterion exercises* for evaluation of some 59 performance objectives.

The second section of the mastery performance test presents four *route exercises*. Two are indoor and two outdoor: of the latter two, one is in a residential setting and one is in a business/commercial setting.

A separate scoring booklet accompanies the test and would be used to forward the outcomes of training (scores) to a centralized analysis center.

d. *Pre-training Orientation Tape for the C-5 Laser Cane and Sonic-guide Glasses*. This cassette runs less than one hour and enables the candidate to gain an impression of the effects of each device and to make initial judgments about the appropriateness of each device for his or her needs.

Implications of the Study

Inasmuch as the materials submitted await field-testing and revision, it is premature to speculate on their impact. Potentially, the use of this kind of systematic approach to evaluation should lead to more consistent and more comparable trainee performance data being accumulated at training centers than has been possible in the past. In turn, more reliable and interpretable information about outcomes should then be available to trainees, trainers, equipment designers, and evaluators than is presently the case.

**Clinical Application Study of Reading and Mobility Aids for the Blind
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Comprehension of Time-Compressed Speech

Data concerning Center research on blinded veterans' ability to comprehend time-compressed speech were presented at the Third Louisville Conference on Rate-Controlled Speech (4,6). Of the veterans sampled from clients having either vocational or avocational needs to process prerecorded verbal material in a rapid fashion ($n=99$), it was found that 86 percent were able to comprehend the test material at a presentation rate of approximately 485 words per minute (2.5 times the original spoken rate). A broader blinded veteran sample ($n=129$) showed an average percent correct comprehension score of 89.6 when the material was presented at normal rate, 87.9 when presented at 1.5 times

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the normal rate, 81.9 when presented at twice normal rate, and 67.6 when presented at 2.5 times the original spoken rate.

Linear regressions of the comprehension scores and veterans' ages ($n=84$) revealed a significant negative relationship. No significant relationships were found between comprehension scores and the Wechsler Adult Intelligence Scale verbal IQ ($n=65$) or educational level ($n=79$). The California Psychological Inventory ($n=68$) personality scales which were significantly related to successful comprehension of compressed speech included those that reflect positive socialization, maturity and responsibility, achievement potential, a sensitivity to psychological variables, and cognitive-behavioral adaptability. Depression, as measured by the Minnesota Multiphasic Personality Inventory ($n=63$), was found to be negatively related to performance. The finding that presence of "psychological health" is associated with positive sensory processing in the blind, both in regard to "natural" stimuli or the displays provided by sensory aids, is consistent with findings reported by this Center in previous communications and presentations during this reporting period (1,5,8). The staff is currently testing blinded veterans' comprehension and evaluating their needs prior to recommendation of speech compression devices. Speech compression systems from four different sources are also undergoing evaluation.

The Value of Prisms

Center research on the use of prismatically displaced images for veterans with visual field restrictions has resulted in the publication of a paper concerned primarily with the prism placement and training techniques used at EBRC (3). The results of a survey of veterans for whom prisms were prescribed is underway in an attempt to assess the long range usefulness of image displacement. An investigation of the roles played by visual pathology, type of field loss, personality characteristics, and demographic variables in the success or failure of prisms to meet the client's needs, is underway.

Low-Vision-Aid Survey

Preliminary data from the results of a survey of blinded veterans issued low-vision aids from the Center were presented at the August meeting of the Blinded Veterans Association (7). This information has allowed the low-vision clinic to establish much less arbitrary criteria for issuance of sophisticated reading devices. It was found that when a client was unable to use optical magnifiers of less than ten power, an increase in reading speed, average length of time at one sitting, and overall time spent reading was associated with CCTV use. Several specific aids were found to be much less useful when the client was in his home environment than

they had appeared to be during trials at the Center. The data are still being analyzed and results will be published in the near future.

The major devices and the extent of their deployment in the period covered by this report are shown in Table 1.

TABLE 1

Device	Number of veterans screened	Number of veterans trained	Number of devices issued
Sonicguide	a	5 ^b	5
Laser cane	a	2	2
Pathsounder	a	0	0
Stereotoner	8	2	0
Optacon	5	2 ^b	1
Speech compressor	22	15	14
CCTV	35	10	10

^aAll mobility students are shown the electronic devices and are screened at this time.

^bThis figure includes those veterans who have returned for additional training on the device.

Clients are now routinely evaluated in acoustic environmental assessment skills in the "notch" detection task described earlier (1). The task is now presented in a recently acquired audiometric test room by mobility instructors. Continued evaluation of the task's effectiveness as a predictive and teaching tool is underway, as is preliminary work on evaluation of its sampling of auditory skills possibly required of successful Binaural Sensory Aid users.

Papers and Publications

Papers published or presented in the period July 1 to December 31, 1975:

1. Gillispie, G., W. De l'Aune, P. Gadshaw, and C. Lewis: Clinical Trials of Reading Machines and Mobility Aids for the Blind. *Bull. Prosthetics Res.*, BPR 10-23:348-351, Spring 1975.

2. Needham, W., W. De l'Aune, and G. Fry: Patient's Expectations in a Residential Rehabilitation Center. *New Outlook for the Blind*, 69(9):399-406, November 1975.

3. Finn, W., P. Gadshaw, G. Kevorkian, and W. De l'Aune: Increased

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Field Accessibility Through Prismatically Displaced Images. New Outlook for the Blind (in press).

4. De l'Aune, W., C. Lewis, W. Needham, and J. Nelson: Correlations of Successful Speech Compression Use by Blinded Veterans. Proceedings of the Third Louisville Conference on Rate-Controlled Speech (in press).

5. De l'Aune, W.: Aids for the Visually Impaired: User Needs and Technological Promise. Connecticut Council of the Blind Meeting, Hartford, Conn., October 1975.

6. De l'Aune, W., C. Lewis, W. Needham, and J. Nelson: Correlates of Successful Speech Compression Use by Blinded Veterans. Third Louisville Conference on Rate-Controlled Speech, Louisville, Ky., November 1975.

7. Gadbow, P., and W. De l'Aune: Low Vision Needs of Blinded Veterans. Blinded Veterans Association Convention, New York, August 1975.

8. De l'Aune, W., C. Lewis, P. Gadbow, and M. Dolan: Prosthetic Device Needs of Blinded Veterans. Blinded Veterans Association, New York, August 1975.

Development of a Hearing-Aid System with Independently Adjustable Subranges of Its Spectrum Using Microprocessor Hardware

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During the second half of 1975, work on this project, which had started at the end of November 1974, was mainly concerned with the translation of the previous design into microprocessor hardware. This has involved construction of a microprocessor realization of an array of up to six very sharp cut-off (to minimize inter-band interaction) low pass and band pass digital filters, each of low order, on a double-word-length Intellec 8 Mod 80 microprocessor system. Since low processing speed is a major problem with this system, hardware multipliers were incorporated into the microprocessor system to increase multiplication speed by a factor of ten. The performance of this hardware realization has been shown to be comparable to that achieved with a large general purpose computer (CDC-6400) as reported earlier (BPR 10-23, 351-352 and BPR 10-24, 274-275), though computational speed is still below real-time requirements, especially when many low-pass elements are involved. The latter

problem can be overcome by using faster microprocessors and faster hardware multipliers which have already become commercially available.

Future work will involve efforts to speed up the digital filter, mainly by experimenting with faster hardware multipliers. Clinical testing should then be possible and meaningful.