

# Journal of Rehabilitation Research and Development

## Rehabilitation R & D Progress Reports 1987

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### XV. Sensory Aids

- A. Blindness and Low Vision
  - 1. General
  - 2. Mobility Aids
  - 3. Reading Aids
- B. Deafness and Hearing Impairment
- C. Speech Impairment
  - 1. Hearing Related
  - 2. Aphasia
  - 3. Other

# XV. Sensory Aids

## A. Blindness and Low Vision

### 1. General

#### The Use of the Electroretinogram to Predict Retinal Cell Activity \_\_\_\_\_

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—The objective of this research is the non-invasive prediction of retinal cell activity. More specifically, the goal is to assess the healthiness of discrete regions of the retina. The diagnosis of certain areas of the retina is sought via the use of the electroretinogram (ERG). Two protocols were developed, both theoretically and experimentally. The first involves multiple measurements of electrical and experimentally. The first involves multiple measurements of electrical potential over the cornea and sclera in response to a single flash stimulus. Using integral field theory and some simplifying assumptions as to the constitution of the intra- and extraocular region, a prediction of a retinal activity commensurate with a corneal potential scan is realized through a matrix inversion. The matrix is an embodiment of the link between the sources (which are jumps in electrical potential across the pigment epithelium) and the potential on the front of the eyeball, i.e., the cornea. The experimental procedures used to realize the multiple corneal potential

measurements along with the necessary circuitry and results are presented.

The second protocol involves a single potential measurement on the cornea as is commonly done clinically at present, but with multiple flash stimuli. The technique is ultimately dependent on the patient's ability to focus on the external flash stimulus pattern. The individual components of the ERG, which are directly associated with specific parts of the stimulus pattern (and thus, localized regions on the retina), are stripped from the composite ERG using signal correlation techniques. At the heart of this approach is the requirement that the isolated stimuli are each individually uncorrelated to one another, i.e., they are random in time. An analytical ERG is constructed to test the efficacy of the use of single and double kernel correlations for predicting retinal impulse responses. The theory is applied experimentally to a three-flash stimulus ERG setup with a large bullfrog.

#### Pupillary Function in Elderly Individuals with Impaired Night Driving Vision \_\_\_\_\_

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—The goal of this research is to determine the cause of poor night driving vision in elderly individuals. Age-related alteration of pupillary func-

tion is a variable which may impact on the adaptive visual ability of the elderly in situations where light intensity changes rapidly, as when driving at night

against oncoming traffic.

Many people over age 60 describe difficulty seeing when driving at night, to such an extent that they feel unsafe while driving. These people either continue to drive and pose a threat to their own safety and that of other drivers, or they restrict their driving to daylight hours and thus are limited in their mobility and ability to participate in social functions at dusk or at night. A significant proportion of the veteran population falls into this age category.

A solution to this problem is to identify the cause of impaired night driving vision by examining the physiology of vision as relates to night driving. Because night driving involves rapid changes in light intensity (as in driving against oncoming traffic),

and because alteration in pupil size is the physiologic means of regulating the amount of light entry into the eye, this study will establish whether changes in pupillary function are related to this problem. If this relationship exists, it may provide an impetus for better illumination of roads and highways to ensure the safety and improve the quality of life of the elderly. To date, 140 volunteers have been enlisted to participate in this study, as funding is made available for its implementation.

The tasks of this study are to quantify the prevalence of poor night driving vision and establish any relationship between this symptom and abnormal pupillary function.

## Predicting the Visual Abilities of Partially Sighted Persons

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—Clinicians prescribe aids and therapies for visually impaired persons on a daily basis. However, these prescriptions and therapies lack a sound theoretical foundation. It is generally accepted that psychophysical measures of visual function tell us something about how a person sees. However, there is little evidence that they tell us how well a person can perform various visually oriented tasks. Accordingly, a theoretical model is needed to guide the treatment and rehabilitation of persons with severely impaired vision.

There is no set of measures of visual function that accurately predicts people's ability to perform various tasks. Previous research has demonstrated that some measures (contrast sensitivity, visual acuity or visual fields) can be used to predict performance on some tasks. However, these predictions do not always hold for other tasks. The basic problem lies in reducing measures of visual function to a form that is a robust predictor of a person's ability to perform a wide variety of tasks.

**Progress**—I have attempted to solve this problem by reducing measures of visual function to a parametric form suitable for multivariate analysis. These data will be correlated with data on people's ability to perform various tasks that will be obtained by survey. By correlating the ability to perform a task

with variables in the feature set of measures of visual function, I hope to obtain a robust set of predictors that can be used by clinicians to prescribe the course of treatment for persons with severe visual impairments.

**Preliminary Results**—I have recently replicated earlier studies on the effect of contrast on letter detection and recognition. I subsequently extended these studies to determine the relationship of the contrast sensitivity function. In contrast to previous studies, I have found that the relationship depends on the letter's medium and high spatial frequency components rather than their fundamental spatial frequency components as reported by other studies. This finding has led me to develop protocols for additional studies to determine the precise band of spatial frequencies that affects people's abilities to identify letters. It has also led me to develop techniques for image enhancement that are based on expanding contrast rather than increasing the magnitude of certain spatial frequency components.

**Future Plans**—During the project's final year, I will conduct studies on persons with severely impaired vision to examine the relative importance of certain spatial frequencies in letter recognition and to test the efficacy of contrast enhancement techniques.

## Hearing Impaired Blind Veterans

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*Sponsor: VA Department of Medicine and Surgery Funding*

**Purpose**—The Eastern Blind Rehabilitation Center (EBRC) for the Veterans Administration is located at the VA Medical Center in West Haven and provides evaluation and training to patients from the entire Eastern Seaboard and Puerto Rico. Since 1983, all patients admitted for blindness or low vision rehabilitation have undergone audiologic evaluation. The purpose of this report is to present the results of the evaluations for the four-year time period, including hearing profiles and aural rehabilitative recommendations. Auditory needs of the visually-impaired veteran, and the role of audiologists in their care are discussed.

**Progress**—All patients admitted to EBRC from 1983-1987 were evaluated audiologically. As of this submission, the number of patients in the sample was 178 (approximately 250 are expected by the end of 1987). The data for the first 113 subjects is summarized below to provide insight into early trends.

The mean age of the present sample was 56.84 (SD = 13.72; range = 22-89). The predominant causes of blindness included: diabetic retinopathy; trauma; glaucoma; retinitis pigmentosa; macular degeneration; and glaucoma. Upon admission to EBRC, all patients were referred to Audiology. Procedures were standard audiometric evaluation, including: pure-tone air- and bone-conduction thresholds; spondee thresholds; speech discrimination for W-22 lists; site-of-lesion tests, when indi-

cated; and informational counseling regarding hearing loss. Patients were routinely asked if their hearing was an impediment to conversation, comprehension in the classroom setting, and orientation in mobility. Based on appropriate audiometric findings, referral for hearing aid evaluation was initiated. Means and standard deviations were calculated for audiometric thresholds, for pure tones and speech. Frequency counts of types of etiologies of blindness, reports of noise exposure, and hearing aid referrals were totalled. The percentage of the group was calculated for each of the latter factors.

**Preliminary Results**—The group was characterized by high frequency sensorineural hearing loss. Hearing loss was observed in 91 percent of the patients evaluated. The degree of loss was sufficient to warrant (new) aural rehabilitative intervention in 31 percent of the first 113 cases.

**Future Plans/Implications**—At the observed rate of need for new hearing aids (i.e., previously unfit with aids) and auditory training, a significant role for audiologists in programs of rehabilitation of the adult visually-impaired is readily seen. Furthermore, in view of the significant number of hearing impairments seen that were not amenable at this time for hearing aid use, the importance of education of the visually-impaired regarding audition and the effect of hearing loss on mobility is apparent.

## A Voice-Output Questionnaire Administrator

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*Sponsor: VA Rehabilitation Research and Development Center Core Funds*

**Purpose**—This project employs a computer-controlled DECTalk speech synthesizer to administer, score, display the results of, and maintain data from, a standard psychological test (POMS, the Profile of Mood States) for visually impaired and blind individuals.

**Progress**—To measure and compare the mental state of individuals, the Bipolar Form of the Profile of Mood States (POMS) has been developed by the Educational and Industrial Testing Service to quantify six selected bipolar subjective mood states. In this test, each mood consists of two extremes, one

represented by the positive aspects of the mood, the other by the negative aspects (such as happy-sad). Each of the six moods (composed-anxious, agreeable-hostile, elated-depressed, confident-un-sure, energetic-tired, and clearheaded-confused) are measured by analyzing the test-taker's level of agreement to positive and negative mood indicator phrases such as "cheerful" or "downhearted." While POMS was developed to evaluate established mood states and feelings reported by both normal and psychiatric patients, the principal contemplated use of this test at the Western Blind Rehabilitation Center is to evaluate the relative effectiveness of various training programs in reducing negative moods while enhancing the positive ones.

The POMS test cannot be administered in the traditional manner to patients who are blind or have visual impairments, since neither group has the visual acuity to read the individual phrases, nor the ability to indicate their choice on the answer sheet. Currently, a staff member reads the phrases to these individuals, queries them for their response, and then fills in the appropriate box on the answer sheet. Later, the answers are hand-scored and a profile produced. Although the time for a sighted person to take the test is only five minutes, the staff time required to administer the test to an in-patient is often double or triple this. Also, the current manual method of scoring and graphing the results is time-consuming. Other staff duties often interfere with these tasks, so the motivation exists to reduce the number of these tests given, rather than to increase their administration during the patients' course of therapy and training. The whole process is therefore a labor-intensive one, since it requires administering, scoring, and graphing the results.

The prototype system consists of an IBM XT-compatible computer with printer, a DECtalk speech synthesizer, and appropriate software. The DECtalk unit has been chosen because it produces speech which is readily understood by those who have no computer experience.

During test-taking using the DECtalk, the software first provides verbal instructions to the patient and then starts the test. Each mood phrase is presented in turn, and a response is solicited. Responses are made by the patient by either pressing keys on a standard keyboard or on a set of large mushroom-

shaped buttons. If, after a given time, no answer is received, the computer reissues the phrase. All patient responses are confirmed, and can be changed if a mistake is made.

At the completion of the test, the computer performs all the necessary scoring, collation, and computation required to produce a dated graph of the mood state profile. This result is then compared to others taken previously, and is eventually placed in the patient's medical record.

It is estimated that the verbal administration of this test would take fifteen minutes, while the computerized administration of the questionnaire will require just five minutes. Scoring and the printing of the results would take an additional minute or two; an appreciable saving over the five-minute manual method. In addition, more accurate results are anticipated, since any human bias in verbally asking the questions and recording the results of the questionnaire would be eliminated.

**Preliminary Results**—The initial software phase of this project has been completed. The first volunteers and test subjects have been selected and testing has begun. At this early stage, no conclusions can be made as to the accuracy or repeatability of this voice-output method of testing.

**Future Plans/Implications**—Two positive results are anticipated upon completion of the pilot phase of this project. First, the project will provide the Western Blind Rehabilitation Center with needed data concerning the effect of the courses and therapy it provides to its patients. Second, it will provide information on the utility of computer-based speech synthesizers in administering psychological tests to visually impaired and blind individuals. This data should also prove useful in the development of other systems that disseminate information to callers in a similar manner.

#### **Publications Resulting from This Research**

- Rehabilitation Applications of the DECtalk Speech Synthesizer.** Jaffe DL, *Computer Technology for Disabled Conference*, Palo Alto, March 1986.
- A Voice-Output Questionnaire Administrator.** Jaffe DL, *Voice I/O Systems Application Conference*, Alexandria, VA, September 1986.

## The Physical Correlates of Tactual Perception

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Sponsor: VA Rehabilitation Research and Development Center Core Funds

**Purpose**—Although tactual symbols are frequently used in materials for blind persons, there is no theoretical framework for developing symbols that are easily understood or recognized. Accordingly, most tactual symbology is designed by trial and error. Unfortunately, this has resulted in material that is not easily understood by many blind persons.

Before we can design meaningful tactual symbols, we must understand the physical features that affect how people recognize and interpret them. Although considerable research has been done on this problem, no one has yet determined the features that most significantly affect perception of tactual symbols.

We are attempting to solve this problem by describing tactual forms on the basis of the Fourier transform of a function describing the tangent angle to their boundaries at regularly spaced intervals. The transformation yields a set of variables called Fourier descriptors and it has been used successfully to solve many pattern recognition problems. We hypothesized that if the mechanisms of tactual perception are similar to algorithms for pattern recognition, then Fourier descriptors may be used to predict perceived qualities such as similarity or complexity. We believe that if our hypothesis is correct, Fourier descriptors may also be used to assess the identifiability or discriminability of existing or newly-developed tactual symbols.

**Progress**—We created a set of six tactual forms. The shape of each form was determined by a random process and the forms vary in the number of line segments that they contain. We then analyzed the forms to determine their Fourier descriptors.

We subsequently asked 30 subjects to rate the

complexity of each form and the similarity of all pairs of the six forms. The subjects examined the forms both tactually and visually. We found that certain bands of Fourier descriptors were highly correlated with the subjects' ratings of complexity and similarity. We found that complexity ratings were highly correlated with high-frequency bands of Fourier descriptors, regardless of how the forms were viewed. We also found that the band of Fourier descriptors that was most highly correlated with subjective ratings of similarity depended on whether the form was viewed tactually or visually. Visual similarity ratings were more highly correlated with high-frequency bands of Fourier descriptors and tactual similarity ratings were more highly correlated with low-frequency bands. We also found that tactual ratings of similarity were highly dependent on the form's area. Our data suggest that it is much more difficult to detect differences between small forms than large forms. Interestingly, this finding does not hold for forms that exceed a certain area which suggests that different perceptual mechanisms may be used for large forms.

**Future Plans**—Our next task is to repeat our studies, using subjects who are blind. This will tell us if prior tactual experience has any effect on similarity judgments and the relationship between Fourier descriptors and similarity ratings. After we have completed these studies, we will test the robustness of our measurement by using it to predict the perceived similarity of commonly used tactual symbols. This will give us an idea of how useful the technique is for making *a priori* judgments on the ease with which blind persons can perceive tactual symbols.

## Model-Based Image Enhancement for the Visually Impaired

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*Sponsor: National Eye Foundation*

**Purpose**—Image enhancements potentially provide elderly macular disease and cataract patients better use and enjoyment of printed photos and television. A variety of equipment and techniques exist for enhancements, but there is currently no systematic method of designing appropriate techniques.

Threshold and suprathreshold contrast sensitivity functions (CSF) provide more detailed description of pattern vision losses than standard acuity and visual field data. CSFs potentially provide a basis for image enhancements tailored to losses of disease classes or individuals. This potential will be investigated in the context of spatial frequency filter visual models. Image enhancements will be based on measurements of patients' threshold and suprathreshold CSFs. The value of filter models in

this context will be determined by measuring the patients' performance with the enhanced images. Patients with monocular cataract or monocular macular disease will be evaluated.

The patient's threshold CSF obtained with the good eye will be compared with that obtained with their other eye to determine a degradation transfer function. The inverse of this function will be applied as a filter to pre-emphasize spatial frequency bands in face photographs. Suprathreshold CSFs will be used similarly; in this case the specific enhancement filter applied will depend upon local contrast in the input image. Recognition of learned and familiar (celebrity) faces and discrimination tests will be used to evaluate the benefit of the various enhancement schemes.

## Functional Vision and Clinical Tests in Low Vision

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*Sponsor: National Eye Institute*

**Purpose**—Our broad objective is to improve the quality of low vision care. The clinician attempting to help the low vision patient needs to have clinical tests that can predict the patient's disability at functional tasks. In this project, a battery of clinical tests and a series of tests of functional vision will be assembled. These tests will be applied to two groups of subjects who show substantive changes in functional ability with changes in illumination. One group will have macular degeneration, the other retinitis pigmentosa. An added normal, age-matched control group will also be used. Controlling illumination will provide changes in the subjects' functional disabilities. The clinical test scores associated with particular levels of disability will be determined for each subject. The strength of the association between test scores and disability levels will provide the predictive power of the clinical tests.

The functional tasks to be tested are reading, face

recognition, and mobility. The clinical tests considered are of: 1) visual acuity: grating, single letters, letter charts, work reading, and low contrast letter charts; 2) contrast sensitivity: CSF's small and large field, edge detection, Arden gratings (with suitable controls), vistech VCTS and Bailey's contrast test; 3) visual fields: Dicon perimetry, Freidman field analyzer, Amsler Grid, and Reversed Contrast tangent screen; 4) color vision: with standard, desaturated, and large area panel D-15 tests; and, 5) as appropriate, there will be added testing to better define the extent and nature of the visual loss in cooperation with Professor Enoch's laboratory.

Correlations and multiple correlations between clinical test scores and functional abilities will be evaluated. Recommendations will be made advising clinicians which tests are most appropriate for predicting capabilities at the different functional tasks.

## Sonar Sensory Substitution—Spatial Behavior in the Blind

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*Sponsor: National Eye Institute*

**Purpose**—A program of investigation is outlined which will explore the effect of a new generation sonar sensory aid—the Trisensor—on blind people's ability to spatially "update" or keep track continually of their changing position relative to their surroundings during locomotion. In addition, the project will assess the extent to which the sonar sensory aid can substitute for vision in the control and regulation of balance and postural stability in blind people.

The major study will assess the ability of congenitally totally blind adults and school-age children to learn to use the Trisensor to locate targets in large scale space (5m arc). The subjects' ability to use the Trisensor will be compared to their ability to locate the targets when they are emitting sound. The effects of both Trisensor and natural sound localization training on more generalized tests of spatial cognition will also be determined. The prototype test entails familiarizing subjects with an array of targets by walking them to each target. Subjects would then be led to one of the targets and asked to indicate the direction and distance of

another target, the location of which they had not directly experienced from their new position.

Blind people experience difficulty with this task, presumably because they have not had past experience with dynamic visual information which is produced during locomotion and specifies an observer's changing perspective. Since the returning echoes of the Trisensor afford a moving observer acoustic flow patterns regarding the position of objects in the distal world, it is hypothesized that the use of the aid will enhance spatial updating ability.

It is now known that vision also plays a critical role in controlling human balance. Because blind people have well-documented difficulties with balance, it is important to determine whether the Trisensor can substitute for vision in this capacity. A battery of balance tests administered before and after Trisensor and natural sound localization training will permit the assessment of the effect of sonar sensory aid and natural sound on the control and regulation of balance and postural stability.

## Electronic Braille Page Output Device Using Nitinol SMA

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*Sponsor: National Eye Institute*

**Purpose**—The research objective is a page-format electronically controlled Braille output device for blind computer users. Each dot, six of which constitutes a Braille character, is actuated by a short length of fine-gauge wire. The wire is made of a shape-memory alloy: Nitinol. This method has been proved feasible for a single dot.

Further research will combine six dots into a standard size Braille character module and incor-

porate character modules into a multiple-line format. Methods of wire-drawing will be developed for producing the small-diameter Nitinol wire required. A printed circuit board for insertion into an IBM-PC (or alternatively for the Apple-2E) will be developed for driving the output device, along with appropriate software to demonstrate the capability of the system.

## Psychophysics of Reading—Normal and Low Vision

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*Sponsor: National Eye Institute*

**Purpose**—We will measure how reading by observers with normal and low vision depends on the stimulus properties of text. The stimulus properties of text that are necessary for normal observers to read are defined to be the visual requirements of reading. Our research has three primary goals: 1) to measure the visual requirements of reading under conditions that are relevant to low vision; 2) to develop simple tests of visual capacity that can predict reading performance of low-vision observers; and, 3) to discover the influence on reading performance of stimulus properties, ophthalmic disorder, acuity deficit and field loss for low-vision observers.

We will use psychophysical methods in five series of experiments. First, we will discover the visual requirements of normal reading, with special emphasis on contrast and spatial frequency. We will also measure the visual requirements of letter, word, and picture recognition. Secondly, we will seek to develop improved means for measuring contrast

sensitivity, based on recognition rather than detection, to quantify the visual capacities of low-vision observers. Thirdly, we will determine whether recognition tests of contrast sensitivity and knowledge of the visual requirements of normal reading can be used together to predict reading performance of low-vision observers. Fourthly, we will measure effects of several special factors of low-vision reading—glare, contrast reversal, wavelength, and ability to focus. Finally, we will test hypotheses that attempt to explain psychophysical properties of reading in terms of known properties of pattern vision.

The research will be useful in three ways: 1) improved understanding of the sensory constraints of normal reading; 2) the development of systematic techniques for testing low-vision capacity, with the aim of specifying image properties required of an appropriate reading aid; and, 3) in establishing necessary stimulus characteristics for new low-vision reading aids.

## Analysis of Navigation Without Sight

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*Sponsor: National Eye Institute*

**Purpose**—This research is concerned with non-visually guided navigation by blind and by blindfolded observers. All experimental tasks involve locomotion through a work area of 30m by 30m; some segments of travel will involve guidance by the experimenter while others will involve free locomotion.

The experiments will attempt to analyze navigation performance into two major components: 1) perception of distance and heading changes; and, 2) cognitive representation of surrounding space and transformations of this representation during locomotion. Precision of the first component will be assessed by simple tasks such as estimation, reproduction, and bisection of distances or angles.

The second component will be assessed by more complex tasks, such as having the observer: 1) return to the start point after being guided over two legs of a triangle; and, 2) proceed directly between two locations that are known previously by traveling between each and a common origin.

The research will evaluate the utility of a stereophonic auditory display as an interface to a digital map system. It will also add to our understanding of the apprehension of space without vision and will aid in the development of an effective display to be used in conjunction with those digital map/navigation systems which are coming into use and may some day prove useful for the visually impaired.

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## Profile of Visual Function in Low Vision Patients

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*Sponsor: National Eye Institute*

**Purpose**—One of the major problems associated with the management of the low vision patient is the lack of diagnostic tests that accurately reflect the impact of a vision loss. This study will address this problem by investigating the parameters involved in a specific vision task: recognition.

Facial recognition is one of the most commonly reported problems for the low vision patient, especially the older low vision patient. The objective of this research proposal is to develop a battery of clinical tests, the central vision performance profile (CVPP), which will provide the clinician with a more accurate description of the functional/performance

capabilities of the older low vision patient. Problems with recognition have been identified as being one of the major frustrations of individuals with visual impairment. Thus, recognition tasks will be used by the investigators to evaluate performance (or function).

The ultimate goal of this project is to gain a better understanding of visual impairment through the development of the vision profile concept, the study of the recognition task, better characterization of residual functional vision, and improved clinical diagnostic services.

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## Prediction of Symbol Recognition in Low Vision Patients

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*Sponsor: National Eye Institute*

**Purpose**—This study will correlate the results of clinical measures of contrast sensitivity, visual acuity, and visual fields with the ability of low vision patients to identify symbols correctly at intermediate distances. The study aims to develop these tests so that they correlate well with performance in visual tasks, and to determine the role of apparent size and contrast in the identification of objects by patients under several conditions of visual impairment.

The long-term benefits will be derived through improved diagnosis of visual disabilities and improved low vision therapy. Approximately 100 subjects ranging from 20 to 80 years in age will be used in the study, and will have lost sight to one of three diseases: retinitis pigmentosa, diabetic retinopathy, or maculopathy. Forty normally-sighted, age-matched control subjects will also participate in the study. Each subject will have his acuity measured, using the acuity chart employed in the Early Treatment Diabetic Retinopathy Study at a test distance of 2.4 meters, and a background luminance of 100 cd/m<sup>2</sup>.

The results will be recorded as log minimal angle of resolution (MAR). Visual fields will be measured using a Humphrey Model 610 automated perimeter. Threshold static fields will be determined for the central 40 degrees of vision, and the results will be recorded as log threshold sensitivity versus weighted eccentricity, the weighting function having been derived from previous studies. These points will be reduced to a measure of the mean slope, which will be normalized to the results from the normally sighted subjects.

Contrast sensitivity at five spatial frequencies will be determined through a two-alternative forced choice procedure at a distance of 1.5 meters, using the Nicolet Optronics CS 2000 system. The field tested will subtend 8.6 by 10.6 degrees visual angle, and the space averaged luminance will be 100 cd/m<sup>2</sup>. Symbol identification will be assessed using a four-alternative forced choice procedure to determine the probability of correct identification of four non-verbal symbols at each of seven sizes and two contrast levels. The test distance will be 1.5 meters

and the background luminance will be 100 cd/m<sup>2</sup>.

The results of all tests will be checked for multiple correlations and colinearities, and models of symbol

identification performance will be developed using the results of the clinical tests as predictor variables.

## Low Vision Reading: Optimizing Visuo-Motor Performance

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*Sponsor: National Eye Institute*

**Purpose**—A significant obstacle to the independence and rehabilitation of the visually handicapped is a loss of their ability to read text. Despite this, little is known about the retinal loci and retinal movements used in reading by our increasing population of elderly patients with macular disease.

Scanning laser ophthalmoscopy provides a unique means of obtaining this data since it permits determination of the retinal loci of visual defects, measurement of visual acuity profiles on the retina, and direct observation of retinal movements during reading. We propose to use scanning laser ophthalmos-

copy to obtain this information in a study: 1) to determine optimal retinal loci and movements for individuals with macular disease; 2) to analyze which combinations of text orientation, size, and movement are most effective for particular scotomata size and locations; and, 3) to investigate procedures for training patients to optimize residual retinal function. Additional long-term benefits from this study include the development of more efficient low vision aids and more effective text displays for the visually impaired.

## Visual Tests for Patients with Central Scotoma

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*Sponsor: National Eye Institute*

**Purpose**—The ultimate goal is the development of visual tests that can be used by practicing eye care specialists to evaluate the useful vision in patients with bilateral central scotoma. Patients with central scotomata, as a general rule, have adequate vision for mobility under ideal conditions. The factors that limit their residual vision include contrast and illumination levels.

The specific aims of this investigation are: 1) to determine whether the reductions in contrast sensitivity correlate with the severity of visual problems that patients experience in everyday situations; 2) to determine whether contrast sensitivity correlates better with the patients' experience than other visual measures, such as the size of the patients' scotoma;

and, 3) to determine whether the measurement of vision at different illumination levels contributes to the evaluation of the patients' ability to function in their environment.

**Progress**—The approach for evaluating the relative merits of different visual tests and illumination levels uses a multiple regression analysis. The patients' ability to function in everyday situations will be assessed by asking the patients to estimate (on a scale of 1 to 10) the degree of visual difficulty that they experience. A multiple regression (R<sup>2</sup>) value will be computed between the visual measures, such as contrast sensitivity, and the questionnaire responses.

## Expansion and Enhancement of the National Blindness and Low Vision Database

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*Sponsor: National Institute on Disability and Rehabilitation Research and Mississippi State University*

**Purpose**—The purpose of this project is (a) to expand the MSU RRTC National Blindness and Low Vision (NBLV) Database to approximately 1000 cases by adding recently closed cases and (b) to increase the national representativeness of the NBLV Database by expanding the geographic range of the states sampled. The NBLV Database is designed to provide extensive information abstracted directly from case files by a trained data collection team. The information on each case includes case service and demographic data such as that from the R-300 or R-911 form, running record information such as multiple disabilities, use of aids, mobility training, occupational history, facility and counselor proximities, and specific service expenditures and results in over 250 client variables for each case. The information can thus be analyzed in various ways to provide extensive descriptive information on client characteristics and service delivery patterns, and can be used to determine what factors and activities of state and private vocational rehabilitation agencies contribute most to the enhancement of employment outcomes of blind and visually impaired individuals,

as well as early prognostication of client outcome. The increased sample size will ensure that all statistical estimates will be more accurate than with a smaller sample. Also, more varied and larger special population subsamples will be available for statistical analysis. This specific project increases the database by adding proportional quota sampled cases from the states of New Jersey for FY's 1984, 1985, and 1986; and from Arizona, Mississippi, and Washington for FY's 1985 and 1986.

**Progress**—Site visits for data collection have been completed. Coding, cross-checking, supplemental coding of jobs and disabilities, unemployment rates, etc., and data entry tasks are in progress preliminary to entry of the new data into the NBLV database. Program documentation will be updated to accommodate the new cases. Summary frequencies and descriptive statistics will be produced to describe the database. A brief annotated index report and descriptive statistics in computer printout form will be available for dissemination.

## An Optimal, Inexpensive Text Entry System for the Orthopedically and Neurologically Disabled

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*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this project is to devise software to support design of user-device interfaces to optimize text-entry performance by disabled users of communication aids and computers.

**Progress**—Keyboard optimization has involved three approaches to the mapping of language menu items to the keyboard: 1) direct selection, i.e., assignment of each language item to a different key; 2) encoding, i.e., mapping onto fewer discrete signals than there are language items, with resultant increase in the

average length of the sequence of keys representing each item; and 3) mapping more items to fewer keys, as in number two, but requiring fewer key strikes per item, comparable to approach number one. This last approach, which has been the focus of recent work, utilizes additional software developed to disambiguate the output of ambiguous keyboards.

Optimization in all three cases makes use of models of motor performance derived from application of the Tufts-MIT Prescription Guide, devel-

oped by the P.I. and Dr. Michael J. Rosen at New England Medical Center and the Massachusetts Institute of Technology. In the case of approach number three, the optimization software predicts the error rate that each character-to-key assignment pattern will yield, and attempts to produce assignment patterns that minimize this rate. Investigation of the relationship between error rate (i.e., residual ambiguity) and number of keys is in progress.

**Preliminary Results**—Ambiguous keyboards have been shown to be potentially significantly more effective in increasing communication rate. This gain appears to be achievable without increasing mental load relative to direct selection keyboards.

**Future Plans/Implications**—Research is being planned

on determining optimal parameters of an ambiguous keyboard text entry system, including utilizing both single-strike and coding, investigation of editing procedures, and a range of language statistics bases.

#### Publications Resulting from This Research

**Adaptive Technique for Customized Interface Design with Application to Nonvocal Communication.** Levine SH, Goodenough-Trepagnier C, Rosen MJ, Getschow CO, *Proceedings of the 9th Annual RESNA Conference*, 399-401, Minneapolis, MN, June 1986.

**Multi-Character Key Text Entry Using Computer Disambiguation.** Levine SH, Goodenough-Trepagnier C, Getschow CO, Minneman SL, *Proceedings of the 10th Annual RESNA Conference*, 177-179, San Jose, CA, June 1987.

**Computer Disambiguation of Multi-Character Key Text Entry: An Adaptive Design Approach.** Levine SH, Minneman SL, Getschow CO, Goodenough-Trepagnier C, Rosen MJ, presented at Conference on Systems, Man & Cybernetics, 1986.

#### Time Use and Resource Allocations of People with Visual Disabilities: Assessment Instrumentation

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; American Foundation for the Blind; Mississippi State University*

**Purpose**—The aim of this project is the development of instrumentation and sampling methodology to assess the way that people with visual disabilities use time and how they allocate their resources.

**Progress**—Reviews of time use and resource allocation literature have been completed. A series of four telephone survey instruments has been developed to elicit the following information from blind and visually impaired persons: a) educational background; b) employment history; c) visual disability; d) reading; e) mobility; f) job modifications; g) living arrangements; and, h) income and expenditures.

The time diary methodology will be employed to assess time use information. Sighted, nondisabled cohorts identified by the blind and visually impaired individuals surveyed will provide comparison data. A sample of 120 (60 blind and visually impaired; 60 sighted, nondisabled) persons will be surveyed in three telephone interviews to evaluate the instrumentation and the methodology.

**Future Plans**—Pending the outcome of the evaluation of the telephone survey instruments and research methodology, a larger survey of blind and visually impaired persons will be conducted in 1988.

## Development and Validation of a Work Environment Visual Demands (WEVD) Protocol

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*Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of this study was the development of procedures to analyze the visual demands of a job held or desired by a visually impaired person. The information may be used by eyecare professionals in prescription of low vision aids which will facilitate performance of job tasks or in the modification of visual tasks in the job setting.

**Progress**—From a pool of patients referred to the Low Vision Clinic at the University of Mississippi Medical Center, 30 subjects were randomly assigned to experimental and control groups. The job tasks required by the employment position held by each subject were analyzed, and on-the-job comfort level was assessed. For the experimental group, the Low Vision Rehabilitation Team reviewed the results of the Work Environment Visual Characteristics Protocol prior to the low vision examination (prescription, fitting, and instruction). The control group received the same range of services as the experimental group; however, the Low Vision Rehabilitation Team did not have the WEVD information from this group. Follow-ups were conducted at six-month intervals.

**Results**—A. *Work Environment Visual Characteristics Protocol*. The WEVD was developed. It provides for the assessment of the jobs performed by the visually impaired person in terms of action, purpose, time present at activity, footcandles observed, IES illuminance category as well as other characteristics of the work environment. B. *Work Environment Visual Demands Protocol Software*. The WEVD (version 1.0) program is designed for the IBM-PC with 128K and an Epson FX-80, IBM Quietwriter, or a compatible printer connected to the line printer port 1. The user-friendly software produces as output a report generated for the low vision rehabilitation team. C. *WEVD Evaluation Results*. The experimental group was found to report greater frequency of use of their low vision aids on the job and higher levels of comfort using the low vision aids on the job than the control group. The experimental group was found to need significantly fewer follow-up visits to the low vision clinic than the control group. No significant between-group differences were found for the other dependent measures.

## A Robotic Hand Communication Aid for the Deaf-Blind

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*Sponsor: National Institute on Disability and Rehabilitation Research; VA Rehabilitation Research and Development Center Core Funds; The Smith-Kettlewell Eye Research Foundation*

**Purpose**—People who are both deaf and blind experience extreme social and informational isolation. Those deaf-blind individuals who use a tactile version of fingerspelling and/or sign language to “converse” with others enjoy some relief from this isolation. This tactile method is far from ideal, however, as it restricts interaction only with others who are both knowledgeable in sign language and are willing to engage in this “hands-on-hands”

communication technique. The problem is further exacerbated by the fatigue caused by this system of information exchange.

A potential solution to this problem is offered by “Dexter,” a computer-based pneumatically-powered, electro-mechanical fingerspelling hand. Dexter enables a deaf-blind user to receive tactile messages from the mechanical hand in response to keyboard input during person-to-person communication, as

well as gain access to local and remote computers and the information they contain.

**Progress**—A common communication technique used with and among deaf-blind people is simply a combined, hands-on version of fingerspelling and/or sign language. Instead of receiving communication visually as deaf people do, the deaf-blind person's hand (or hands) remain in contact with the hand (or hands) of the person who is fingerspelling or signing. Many of the motions present in sign language, where both hands and arms are employed to convey whole words and phrases cannot be employed in the tactile communication mode required by a deaf-blind individual. Instead, each word to be sent is typically spelled out, one letter at a time with the fingerspelling technique. Although many Usher's Syndrome patients can speak intelligibly or use sign language, others require a "hands-on" system for expressive communication.

The Rehabilitation Engineering Center of The Smith-Kettlewell Eye Research Foundation sponsored a class project conducted by four graduate students in the Department of Mechanical Engineering at Stanford University to design and fabricate a state-of-the-art fingerspelling hand. A major goal was to develop a system with controlled timing and easily modifiable finger positions. These qualities were realized in the completed project—a new robotic fingerspelling hand named "Dexter."

Dexter looks like a mechanical version of a rather large human hand projecting vertically out of a box. The four machined aluminum fingers and a thumb are joined together at a palm. All digits operate independently of each other and have a range of motion comparable to human fingers. The thumb is jointed so as to allow it to both sweep across the palm as well as move in a plane perpendicular to it. A pneumatic rotary actuator allows the palm to pivot in a rotary fashion around a vertical steel rod much the way a human hand can pivot from the wrist—except that a full 180 degrees can be achieved by Dexter.

All finger and thumb motions are actuated by drive cables. Pneumatic cylinders pull these cables, which flex the individual fingers and thumb, while spring-driven return cables open the finger joints to the extended position. The cylinders, in turn, are activated by air pressure directed through electrically controlled valves. These valves are controlled

by a microcomputer system. The actuating equipment and valving are housed in two separate assemblies below the hand.

In summary, the microcomputer and associated software control the opening and closing of a bank of valves which direct air pressure to specific pneumatic cylinders which pull on the drive cables which are the "tendons" of the fingers. As a message is typed on a keyboard (an Epson HX-20), each letter's ASCII value is used by the software as a pointer into an array of stored valve control values. Since 22 valves are controlled, three bytes are required to specify the state of each valve (open or closed). Two to six of these valve operations, each separated by a programmed pause, are needed to specify the finger movements corresponding to a single letter. Presently, the hand can produce approximately two letters per second, starting from and returning to a partially flexed neutral position.

Although the mechanical hand cannot exactly mimic the human hand in fingerspelling all the letters (such as the special wrist and arm motions required in J and Z), the fact that Dexter always produces the same motions for a given letter is an important factor in "understanding" its actions.

**Preliminary Results**—Deaf-blind clients of Lions Blind Center (Oakland, CA) served as subjects for the initial testing of Dexter. They were able to identify most of the letters presented by the robotic hand without any instructions, and in less than an hour were correctly interpreting sentences. Equally important was their positive emotional reaction to the hand. They seemed to really enjoy using it and to be intrigued by its novelty. There were no negative comments made concerning its mechanical nature or any other aspect of the system.

**Future Plans/Implications**—Additional testing will be conducted on the ability of deaf-blind people to use the robotic hand for extended periods of time, as well as on determining optimal configurations for the letters, and optimum rate of letter presentation. The possibility of modifying the one-hand manual alphabet to require only the thumb and first two fingers will also be investigated. Since the last two fingers are redundant for most letters of the manual alphabet, this may be a reasonable approach to reducing the size, weight, complexity, and expense of the system. In addition, it would make Dexter

more like typical robotic hands (i.e., those for manipulation of physical objects), which generally consist of three digits.

In the next software design iteration, a finger-position editing program will be written. This program will permit the interactive formation of letter-pair transitions. The valve control information resulting from this phase will be incorporated into the next evaluation of Dexter. The future implementation of a full 26 by 26 matrix of possible letter-pair transitions would eliminate the need for the neutral position and produce more natural fingerspelling. A faster and more intelligible fingerspelling device is anticipated.

Further test results will dictate the details of the hand positions for the various letter pairs and the rate of presentation. Modifications of the system to decrease its size and increase its portability will include replacing the pneumatic structure with stepper motors or some other efficient system.

Dexter is intended to serve deaf-blind users as a complete receptive communication system, not just a means of receiving information in face-to-face situations. Its ability to respond to computer input means it can be interfaced to a TDD to provide deaf-blind people with telephone communication. It can also be connected to computers to provide improved vocational and avocational potential to the deaf-blind community.

#### Publications Resulting from This Research

**Dexter—A Helping Hand for Communicating with the Deaf-Blind.** Gilden D, Jaffe DL, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology* 6:49-51, Minneapolis, MN, June 1986.

**A Robotic Hand as a Communication Aid for the Deaf-Blind.** Gilden D, *Proceedings of the Twentieth Hawaii International Conference on System Sciences*, 1987.

**A Robotic Hand Communication Aid for the Deaf-Blind.** Gilden D, Jaffe DL, *SOMA* (in press).

### The Evaluation of Low Vision Aids and Prediction of Visual Performance

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—The aim of this project is to determine figures of merit for low vision aids based on their modulation transfer functions (MTF) and other characteristics that may be correlated with vision, specifically, visual acuity and contrast sensitivity, through the aid. Coherent (aerial) image-forming low vision aids, such as telescopes and telemicroscopes, will be extensively evaluated. Their MTF's will be measured on and off-axis, through focus, and in sagittal and tangential orientations. In addition, we will completely measure their paraxial properties. Aids will be classified according to optical quality. Diffraction limited aids and aids with MTF's that are characteristically degraded at high, low, or all spatial frequencies, will be selected for the vision tests.

The contrast sensitivity functions and visual acuities of normal and low vision subjects, classified according to refraction optics defects or retinal and neural dysfunctions, will be measured with the selected aids. The experimental plan will enable us to systematically investigate vision through aids under controlled optical conditions of aid coupled

to eye. These conditions will range from diffraction limited to highly aberrated. The effect of pupil size on the aberrated systems will be studied.

Since the modulation transfer function measurements yield very large amounts of data, the analysis will concentrate on determining rather simple (unitary) figures of merit that correlate with the effect that the aid produces on contrast sensitivity functions measured through the aids. The long range goals of this research are to predict the interaction of vision with optical aids and to develop standards of optical performance for aids.

**Progress**—Optical bench tests and modulation transfer function measurements on more than 200 devices have been completed. Contrast sensitivity measurements are in progress.

**Results**—Angular magnification, resolving power, astigmatism, field of view, eye relief, and light transmittance of 157 low power telescopes comprising 25 models from seven manufacturers were meas-

ured. Roof-prism Keplerian telescopes provided about one-half the resolution, 30 percent lower transmittance and more objectionable image flare than Galilean designs. The roof-prism was responsible for producing overlapping doubled images that appeared astigmatic-like. The prism further compromised rotational symmetry by deviating the image in a direction along the roof edge. The Keplerian telescopes, however, had about twice the field of view of the Galilean telescopes. Notably, several Keplerian telescope models from different suppliers

were found to be optically identical, although they varied 50-100 percent in price.

**Future Plans/Implications**—To complete contrast sensitivity measurements and publish results on the interaction of vision through low vision devices.

#### **Publications Resulting from This Research**

**Optical Properties of Low Vision Telescopes.** Katz M, Citek K, Price I, *Journal of the American Optometric Association*, 58:320-321, 1987.

### **Sensory Aid Technology: A Career Development Intervention Strategy for Blind and Visually Impaired Persons**

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*Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of this study was to determine the effects of the use of sensory aid technology on the employability and career development of blind and visually impaired persons. "Sensory aids" refers to any specially adapted electronic or mechanical device used by a visually impaired person to replace sensory information lost through the effects of visual impairment. The output of these devices is usually in a tactile, auditory, or enhanced visual mode. The study explores the types of sensory aids being provided, the resources used to provide them, and the effects of their provision on various aspects of employability and career development.

**Progress**—A survey instrument was sent to a representative sample of rehabilitation counselors in both public and private agencies; 91 completed surveys were returned, from which the following results were obtained. Counselors were asked to describe their background and training, their caseloads, and certain agency characteristics. A wide variety of descriptions were obtained on all of these dimensions. They also gave information concerning the number of clients in their caseloads to whom sensory aids were provided, number of aids provided, types of aids, and the sources of funding for these aids. Correlations were found to exist between such "aid" variables and characteristics of the counselors and agencies.

Counselors also provided detailed background descriptions for a randomly selected subset of clients to whom a sensory aid had been provided, and assessed the extent to which the aid had impacted on eleven aspects of the client's career development. Sixty-seven males and 62 females ranging in age from 17 to 79 were described. About half of this sample were congenitally impaired; 75 percent had a single impairment; ten percent were hearing impaired; 88 percent were legally blind. These clients differed widely in terms of educational and employment backgrounds, but on average were better educated and/or more skilled than the norm for rehabilitation clients.

**Preliminary Results**—Counselor's impact assessments indicated that in general, the overall impact of career development was greater for younger clients, non-white clients, those with earlier onset of disability, those with a visual field loss, and non-homemakers. The aspect of career development which was impacted most by the receipt of a sensory aid was "performing a job satisfactorily," followed by subsequent aspects of career development such as economic independence, skill enhancement, and job advancement.

Sensory aids were categorized according to their modality of output (visual, auditory, tactile, and computer/misc.), and their presumed function (read-

ing, communication, mobility, math, living skills, work skills, and computer/misc.). The greater percentage of aids provided were visual in output, followed by the computer category. The most common function for aids was reading, followed by computer usage and then math.

Chi squares and related statistics indicated that relationships exist between aid categories and the extent of impact on the 11 different aspects of career development, and that these patterns of benefit differed somewhat for congenitally blind persons

and for the adventitiously impaired. Uncertainty coefficients were computed to determine that the functional category of an aid was more predictive of impact for most of the 11 aspects of career development than was the modality of the aid. Results are discussed in terms of implications for policy and practice within rehabilitation.

Copies of the technical report and an executive summary may be obtained from the Rehabilitation Research and Training Center.

### Learning Styles and Effective Teaching Technologies for Enhancing the Employment of Deaf-Blind Youth

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*Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—This field-based project is attempting to identify and evaluate instructional technologies which take into account the learning style or approach of individual deaf-blind youth and which facilitate the acquisition of independent living, community living, and vocational skills by multiply impaired deaf-blind youth.

**Progress**—Initial phases of the project consisted of: 1) the identification, compilation, and review of existing literature on both “learning styles” and “teaching technologies” relevant to deaf-blind education, and 2) surveying of special educators and instructional personnel of deaf-blind students about their methods and resources for assessing students’ learning styles and for determining effective teaching techniques in a variety of task areas such as perception, memory, concept formation, and problem solving. Results of these two subprojects will be available in technical reports from the RRTC/BLV in the near future.

**Preliminary Results**—The current phase of this 3-year project involves a multi-site qualitative investigation of programs which have gained national recognition for their high success rates of vocational placement and instructional programs. Aspects of each program to be explored include: 1) the interaction between teacher and student; 2) the program-

matic organization of the program; 3) the overall characteristics of the students in the program; 4) the instructional and personality style of the teachers; 5) the participation of families; 6) the retention and reinforcement strategies involved in the program; and, 7) administrative and community support. The investigation will include both higher functioning deaf-blind students (such as those with Usher’s Syndrome) and more severely involved multiply handicapped students (such as the Rubella student). Instructional observations will focus on a variety of skill areas, including the four cognitive domain areas mentioned above.

**Future Plans**—The four exemplary programs to be studied are the Helen Keller School at the Alabama Institute for Deaf and Blind in Talladega; the Helen Keller National Center for Deaf-Blind Youth and Adults in Sands Point, NY; Project Advance of the Perkins School for the Blind in Boston, MA, and the Texas Educational Service Center, Region XX Program in San Antonio, TX.

The project team has made arrangements to spend two weeks at each facility observing, interviewing and documenting the instructional and learning aspects of the program. The data will be compiled and compared to determine whether there are common characteristics or aspects of these exemplary programs which may be of value to other programs

concerned with developing effective instructional programs for deaf-blind youth in transition.

All site visits and an initial field test at Ellisville State School in Ellisville, MS are scheduled between

June, 1987 and February, 1988. Data analysis will be ongoing and is scheduled to be completed by March, 1988. A technical report on this subproject will be available in April, 1988.

### **Identification of Job Tasks and Management Practices Performed by Blind and Visually Impaired Persons in the Operation of the Business Enterprise Program**

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*Sponsor: National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The Randolph-Sheppard Act of 1936 (as amended) authorizes business programs operated by blind or visually impaired persons licensed by state agencies. This study addresses 1) the need to identify those job related duties actually performed by licensed business operators under this program, and 2) a review of existing training opportunities for licensed business operators through state licensing agencies. The results of the research project should provide state licensing agencies with information to assist in the design of upward mobility training programs for blind and severely visually impaired businessmen and women operating programs under the Randolph-Sheppard authority.

**Progress**—Following literature review, instrumen-

tation development and pilot testing, a telephone survey was conducted. Blind business operators in cafeteria locations, snack bar and other locations and in vending facility locations were asked 71 questions related to the operation of their business. Participants were licensed operators from five states in five different ED Federal Regions, and represented approximately 8 percent of all blind businessmen and women in the U.S. Participant states have submitted their training program curricula for review. All data and information is being coded for computer entry.

**Results**—Results from this study, a technical report and monograph, will be available after April 1, 1988.

### **Identification of Work Assessment Technology Needs**

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**Purpose**—The purpose of this project is to locate and describe currently available work assessment technologies which can be reliably and validly used in their present formats with blind and visually impaired persons. Recommendations will also be made to users and manufacturers on how existing work assessment devices can be modified to meet the needs of rehabilitation and educational professionals. Needs for norm development and reliability and validity studies will be identified. Career options for blind and visually impaired persons for which work assessment technology is not available and

specific career options for which there is a need for work assessment technologies will be outlined.

**Progress**—Research literature, work assessment manuals, and other manufacturer-supplied information was reviewed and organized to identify any reliability and validity studies available on samples of blind and visually impaired persons. The statistical results and other information about the work assessment devices were entered into a computerized data bank for rapid retrieval and comparison among the various assessment systems. A draft

report addressing the five issues outlined in the Purpose section (paragraph 5) will be circulated among ten experts in the subject area. These ten people will be asked to review and critique the draft report, offer suggestions for revisions, assist in identifying career options for blind and visually impaired persons for which there is not appropriate

work assessment technology, and identify career options for which work assessment technologies are needed.

**Results**—Results from this study, a technical report and monograph, will be available after January, 1988.

### **Identification and Classification of the Career Transition Problems of Blind and Visually Impaired Persons Employed as Professionals, Managers, or Technicians**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of this project is to describe the career phenomena associated with visually impaired people and to more specifically explain the relationship between disabilities and career attitudes, abilities, events, and outcomes. By identifying and classifying the career development problems, a taxonomy will be formulated to describe the range of career development problems with which visually impaired persons must cope during career development stages.

visually impaired individuals have encountered in their professional employment. A questionnaire is being revised and a sample of 200 blind and visually impaired adults who have been employed in some types of professional jobs is being readied for a telephone interview. Statistical analyses from this questionnaire will later be compared with intervention strategies used in career development transition problems.

**Progress**—Following a literature review, a taxonomy was developed describing the difficulties blind and

**Results**—Results from this study, a technical report and monograph, will be available after January, 1988.

### **Modification and Adaptation of the Vocational Education Readiness Test for Blind/Severely Visually Impaired Individuals**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of this project is to determine whether each of the Vocational Education Readiness Test (VERT) adapted for blind and visually impaired persons is an appropriate assessment tool for determining the aptitude of these persons to enter vocational education programs in Auto Mechanics, Basic Wiring, Quantity Foods, and Industrial Sewing.

sites and rehabilitation centers were administered the revised work samples. Demographic and visual information on these subjects were collected. The work samples were administered in a test-retest format and pertinent work or test data collected for reliability and validity analysis.

**Progress**—Randomly selected subjects for the visually impaired clients and work force of five work

**Results**—A technical report and work samples were published in August, 1986. Reliability and validity were calculated for each task within the four work samples. Descriptions of the norm groups and per-

centile charts were provided for each work sample.

The Auto Mechanics, Basic Wiring, and Quantity Foods work samples are reliable and valid measures for evaluating a client's readiness for entry into a

vocational education training program. The Industrial Sewing work sample should not be used for this same purpose.

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## Cutaneous Pattern Perception

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*Sponsor: National Institutes of Health*

**Purpose**—The proposed research will investigate the perception of tactile patterns by human subjects. The tactile patterns will be generated on arrays of stimulators that fit against the subject's fingertips. Each array consists of 144 stimulators arranged in a matrix 6 columns by 24 rows. Sets of patterns differing along such dimensions as location, intensity, number of line segments, and so forth will be generated and presented to subjects. Response measures will include identification, discrimination, reaction time, and pattern matching.

Three aspects of tactile pattern perception will be examined: masking, interactions among multiple sites of stimulation, and the role of experience. A temporal masking paradigm will be used to see how the perception of tactile patterns is interfered with by tactile maskers and how the nature of the interference changes with changes in the type of masker and in the temporal separation between target and masker. In the studies of interaction among multiple sites, patterns will be presented to as many as three sites on the fingertips and palm. This paradigm will

be used to assess the role of attention in tactile information processing. The role of short-term experience will be examined by measuring changes in pattern perception as subjects learn to identify and discriminate tactile patterns. The effect of long-term experience will be evaluated by comparing the performance of groups of subjects who differ in the amount and nature of their experience with complex tactile patterns. One group will be Optacon users, blind individuals who can read by means of a tactile array. The other groups will be blind individuals without Optacon experience and several groups of sighted subjects with varying amounts of tactile experience.

The proposed research will be concerned with drawing parallels between tactile processing and visual and auditory processing, with developing measures relevant to understanding the neural coding of tactile patterns, and with improving cutaneous communication systems for the blind, deaf, and deaf-blind.

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## Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation

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*Sponsor: Research Centre for the Education of the Visually Handicapped*

**Progress**—Nine hundred and ninety-one newly blinded and visually handicapped adults were tested with the Purdue Pegboard test of manual dexterity while they were undergoing vocational rehabilitation. Normative data were derived to enable comparisons to

be made among various subgroups of the population on the basis of degree of residual vision, which together with the gender of the subjects is shown to be a significant determining variable. The results are also discussed in terms of the magnitude of the

disparity between the performance of the visually impaired and the fully sighted adult subjects on whom the test was originally standardized.

#### Publication Resulting from This Research

**Normative Data for Assessing the Manual Dexterity of Visually Handicapped Adults in Vocational Rehabilitation.** Tobin MJ, Greenhalgh R, *Journal of Occupational Psychology*, The British Psychological Society, 60:73-80, 1987.

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## Sensory Aids for the Blind and Visually Impaired

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**Sponsor:** *The Smith-Kettlewell Eye Research Foundation; National Institute on Disability and Rehabilitation Research*

The following are summaries of the past year's projects of the Smith-Kettlewell Rehabilitation En-

gineering Center, with support from the National Institute on Disability and Rehabilitation Research.

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### An Improved Volatile Braille Display

**Purpose**—The Volatile Braille Display, consisting of a row of braille characters which can be manipulated electronically, is generally acknowledged to be among the most desirable forms of access to electronic data for blind individuals. To date, commercially available versions of these devices have often suffered from high expense or reliability problems. Consequently, the Smith-Kettlewell REC has developed an innovative concept for a new generation of refreshable braille displays, using inexpensive electromagnetic technology and elimination of most moving parts through a special proprietary

design.

**Progress**—This year, attention has focused on the development of a 20-cell prototype of the device. Initial tests of the completed mechanical unit revealed that the braille dots were prone to sticking in the down position, and a number of other problems were identified. A new 3-cell prototype incorporating the design improvements necessary to overcome these has now been built and in initial testing it appears to offer successful operation along with greater simplicity of design.

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### Universal Job Instrumentation System

**Purpose**—The Smith-Kettlewell Flexi-Meter is the universal measuring instrument which derives its philosophy from the original Talking Pressure Gauge completed earlier. It is intended that the current design will be the basis for a relatively economical and reproducible computer-based measuring instrument which will be easily programmable to fit a wide variety of occupational needs. Activity in this project has been proceeding toward the fabrication and testing of the first prototype.

**Progress**—Our experience with the microcomputer-based Talking Pressure Gauge System (now in use

by the refrigeration repair person who originally requested it) has proven valuable in refining our approach towards the more flexible design now being undertaken. The Pressure Gauge System, which allows the operator to measure the high-pressure, vacuum, and low-pressure ranges necessary in the testing and recharging of refrigeration and air conditioning equipment, was originally delivered in October of 1985—and has been tested and returned for minor modifications and repairs several times during this year. The device is now providing reliable service in the user's repair shop, allowing the operator to complete his work independently and much

more quickly than would be the case if he had to ask help of sighted technicians who are less experienced than this blind worker.

A questionnaire describing the main features of the proposed design and requesting four categories of information was sent to one hundred recipients, taken from the mailing list of those who receive our Annual Reports. Besides the vocational rehabilitation services of all fifty states, other educational centers and training programs were targeted. The responses were used to finalize the specifications for the first prototype.

**Preliminary Results**—As a result of the evaluation of our refrigeration pressure gauge system, the preliminary results of our market survey, research into available equipment and components, and intensive design discussions within our staff and with other experts in hardware and software design, the specifications of the Flexi-Meter were delineated. In general, both the input and the output systems are expandable to add additional functions (such as those which were required by the user of the refrigeration pressure gauge system). The first prototype is now complete and is being tested prior to field evaluation.

## Specialized Vocational Aids and Devices

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**Progress**—Many specialized vocational sensory aids have been developed during the year, including the following:

**Auditory Breakout Boxes.** After receiving requests from such agencies as the Kentucky Bureau for the Blind, the Veterans Administration Western Blind Rehabilitation Center, and the National Federation of the Blind's Committee on Research and Development, we developed a prototype Auditory Breakout Box to simplify the interfacing of computers and peripherals by blind users. Sighted individuals have access to breakout boxes which can be connected between the computer input/output port and a peripheral. Each input signal line can be connected, through the use of jumpers, to any output line, and the device will indicate (through activation of LEDs) when the correct connections have been made. To make this ability available to blind individuals, we have developed an Auditory Breakout Box that provides a similar convenient means of trying different connection combinations, and utilizes a tonal sound coding system to indicate whether any selected line is grounded, high, low, or open.

This device has been successfully field-tested by several users. As a result of these field evaluations, it was found that there were possible improvements to be made on the jumper connection panel. One user complained that the protruding pins tended to retract into the panel when fitted with jumper wires. A temporary solution to this problem is to deposit a bead of epoxy over the connections on the panel's underside. Better quality pin "headers" are available which would constitute a permanent solution.

The amphenol sockets which are used on the jumper wires loosen up with constant use. While these can be tightened with needle-nosed pliers, a better solution would be to find new connectors. Several options for the production of this device are currently being explored.

**Computer Interface Aids.** To enhance computer accessibility for the blind, an auditory data-flow indicator was developed at the request of the Kentucky Bureau for the Blind. They have now made it commercially available for \$17 as the "Tweedle Dump." This device was designed to provide an indication to the blind user when data transfer is in progress in an RS-232 serial interface, aiding him in knowing whether the interface to printers and other peripherals is operating normally and when the computer is free to receive other input. It is especially useful with modem operations in alerting the user when a long data transmission has finished. The device consists of a simple audio transducer built into a standard interface cable, and is driven directly from the data signals.

**Computerized Court Stenographic Equipment—Adapting the Position of Court Reporting for the Blind.** The Rehabilitation Engineering Center was approached by the Sensory Aids Foundation (SAF) to determine whether suitable technology can be found or developed to enable several blind clients who are currently undergoing training as court stenographers to obtain employment in actual courtroom settings in this field. Many more blind individuals would be interested in this vocation if suitable means were available to accomplish all of the

sub-tasks required of court stenographers. Our findings from these investigations should have a practical impact on others by providing a summary of the

“state of the art” and the available practical options—most of which we or members of our collaborative team have tested or observed.

## The Note-a-Braille

**Purpose**—The Smith-Kettlewell Note-a-Braille is a portable electronic note-taking device with a braille keyboard for input, a memory capable of storing about eight pages of braille text, and a means of sending the stored notes in ASCII format to a receiving device (computer, printer, synthetic speech device, etc.). Once in the computer, the text can be edited or otherwise manipulated as required.

The philosophy of the Note-a-Braille is to allow rapid keying-in of notes from meetings, classes, etc., with little heed being paid to errors. The unit can then be taken home for accessing or editing the notes on one of the accessible computer systems now being used by an increasing number of blind individuals. By taking advantage of this mode of operation, the user of the inexpensive portable device is not forced to pay for another editor or read-out system. (Concurrently with the development of the Smith-Kettlewell Note-a-Braille, the Kentucky Bureau for the Blind has recently been engaged in the development of another braille note-taking unit with a slightly different emphasis. The philosophy behind the Kentucky unit is to incorporate a speech synthesizer output and controls for text review within the unit itself, making for a more sophisticated and expensive system.) Furthermore, the compact nature of the braille keyboard as compared with a conventional “qwerty” keyboard gives the blind user an advantage over his sighted counterpart, since the braille note taker can be made considerably more compactly than any comparable device could be made for note-taking by the sighted.

**Progress**—During this reporting period we completed testing of the bench model Note-a-Braille, and designed, built, and tested a portable prototype.

We are now in the process of exploring a further reduction in overall size of the design, for a second model.

Another area of activity was the acquisition and evaluation of a number of parallel-to-serial converters. This type of converter is needed if the receiving computer or device does not have a parallel input port. As a result of this evaluation, we were able to specify two commercially available devices suitable, without qualification, for this function. The cost of these devices is in the \$50 to \$100 range. An additional feature of the Note-a-Braille is that besides storing entries in its memory, it also sends this data immediately to the output connector. This makes possible the use of the Note-a-Braille as a braille keyboard.

**Results**—The prototype unit has been used extensively by members of our staff and by blind visitors and students, and has elicited enthusiastic comments from all who have tried it. It has seen use in taking notes during several meetings, and it was used to write portions of this report. A number of requests have been received for documentation for this design—from individuals not wishing to wait until the device goes into production. Accordingly, the original design has been fully documented and published, and at least one unit has been fabricated to our plans by a blind user in England. The May 1986 issue of *Technology Update* published by the Sensory Aids Foundation described the device, and the Summer 1986 issue of *The Smith-Kettlewell Technical File* contained complete information for construction of the unit. This documentation is now available directly from the REC. Commercial production is scheduled for late 1987.

## Dotless Braille Reader

**Purpose**—Dotless braille is a new concept and is intended for blind and deaf-blind people who are no longer able to read braille due to decreased tactile

sensitivity, as sometimes happens in those suffering from peripheral neuropathy associated with diabetic retinopathy or even from carpal tunnel syndrome.

It is based on the fact that braille is a code for reading, with raised dots being merely one of several possible methods of displaying the code.

Dotless braille is intended to be produced by a device with keys arranged like those of a braille writer; i.e., three keys for the left hand, three for the right, and a space bar, but it is designed to produce 8-dot rather than 6-dot braille. Instead of serving as a vehicle for sending information by the user's pressing the keys, however, in this system the user passively rests his fingers on the keys and "reads" via the combinations of keys which move upward from a resting point. The keys will be activated by ASCII input from a computer, or by a camera with optical character recognition capabilities, letter by letter. Each letter will be represented by the same key combinations which would be depressed to emboss that particular letter in standard braille. Favorable reactions to this concept have been obtained from rehabilitation professionals as well as blind consumers.

**Progress**—Research has been conducted to compare the use of dotless braille keys pressing upward against the underside of the user's fingers with their dropping down away from the user's fingers. This evaluation was conducted on a test unit we fabricated which has one upward-bound and one down-

ward-bound key. There has been a consensus among blind braille readers that the upward excursion seems to be more "intelligible." Another possible advantage of the up-moving keys is that this motion would preclude possible confusion between reading and writing in the ultimate device which could serve both functions. In other words, if downward-moving keys were used to both read and write, a user might question whether he pushed them down or the input device activated them.

**Future Plans/Implications**—The next dotless braille prototype unit, now completed, has the full complement of eight keys and a space bar. It will be evaluated with blind and deaf-blind subjects as a reading/communication machine.

Dotless braille is aimed at a relatively small target population, but if it proves to be useful as intended, it could have a tremendous impact on the lives of this group. Former braille users rendered functionally illiterate by peripheral neuropathy will instantly have their reading capabilities restored. The potential impact this device may have on the lives of certain deaf-blind individuals is even more dramatic, as in addition to allowing them to read again, it could restore a major input channel for communication.

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### **Dexter: A Mechanical Hand for the Deaf-Blind**

**Purpose**—The Smith-Kettlewell REC sponsored a rehabilitation engineering class project for four mechanical engineering graduate students at Stanford. Based on the original hand developed by the SouthWest Research Institute nearly a decade ago, the students designed and fabricated a more state-of-the-art mechanical hand which fingerspells information into the hand of a deaf-blind user. The hand ("Dexter"), completed in June 1985, is computer-controlled and keyboard-activated, and provides for input for both face-to-face and remote communication. Preliminary evaluation at the Lions Blind Center, Oakland, California, demonstrated that deaf-blind people could "read" information transmitted via Dexter.

**Progress**—During the past year, initial steps have been taken to simplify and refine the Dexter system. In addition, we have also undertaken development aimed at making it more portable. The large IBM computer which had been activating the hand has been replaced with a 3-lb. Epson HX-20 lap computer. Both the computer and the controller now have their own memories, and their software is called up the moment each device is turned on. It will be possible to use this as an authoring system, so that the user can specify hand shapes and speed of letter presentation as desired. Another improvement made to the Dexter system this year was the replacement of a prototype hand-wired printed circuit board with two commercially available boards which can easily be replaced as needed.

## Pediatric Research

**Progress**—The primary goal of the Pediatric REC for the past year has been to develop, refine, and field test a method of mass screening for ocular disorders in young children and infants. To this end, we have continued engineering development of a photographic method for determining refractive error, strabismic angle and media clarity. The device we have used initially is based upon commercially available 35mm cameras and strobe flashes. We are also in the process of modifying a commercially available Polaroid camera for use as a screening device. The design we plan for the Polaroid camera is intended, with some modification, to be generally applicable to any camera with a flash unit. We have conducted several laboratory studies intended to support the practical application of the photographic screening device. A major clinical concern which we have addressed in the past year is the detection of the presence of significant astigmatic errors. We have conducted a series of bench tests which have led us to the understanding of the utility of our device for astigmatic error screening.

In our collaborative field screening programs evaluating the photographic screener, we have identified a number of infants with significant astigmatic errors and with other undetected refractive error differences between the two eyes. Several of these infants are currently wearing glasses as the result of our early detection of their eye problems. We are continuing our own demonstration mass-screening effort and will be conducting follow-up visual assessment of infants found to have significant refractive errors.

We have conducted a series of laboratory studies of the changes in the appearance of the red-reflex which is also documented by our photographic screener. We have found that most of these changes are due to reflection of light from the optic nerve head. Our clinical database is presently limited to mainly esotropic cases (eyes turned in). During the remainder of the year we will screen a group of exotropic infants and children to determine if our hypothesis regarding the imaging of the optic nerve head is correct.

## Applications of Evoked Potential in Rehabilitation

**Progress**—Dr. Erich Sutter, of our REC staff, has carried out two projects during the past year under separate funding from the National Eye Institute and The Smith-Kettlewell Eye Research Foundation.

**Vision-Based Communication Aid.** The eye-gaze-directed communication system for the handicapped, based on visually evoked potentials, has seen considerable advances in its development and practical implementation. A special high-speed process board has been developed, and the use of color stimuli has been explored. Two methods of reducing noise due to muscle artifacts are being investigated, and a new method of coupling electrodes to the scalp without requiring "wet contact" is being explored. A practical prototype system has been developed for long-term evaluation in the field. It permits the user to access commercial software such as word processors, and will assist in the development of the concept towards a marketable product.

**Objective Perimetry.** A second project conducted by Dr. Sutter during the past year has been the

development of a novel method of visual field assessment utilizing the electroretinogram (ERG). This new concept involves the visual stimulation of 256 retinal locations simultaneously, while recording signals from a conventional ERG electrode pair on the eyeball. The technique allows objective assessment of local retinal function in recording times of approximately fifteen minutes, and shows potential for improved detection of retinal defects associated with visual disorders. Improved information of this type has the potential to make a major impact on both medical treatment and low vision rehabilitation.

### Publications Resulting from This Research

**Assistive Devices for the Blind and Visually Impaired.** Brabyn JA, *Wiley Encyclopedia of Medical Devices and Technology* (in press).

**Photographic Detection of Amblyogenic Factors.** Day S, Norcia AM, *Ophthalmology* 93(1):25-28, January 1986.

**Technology to Overcome Obstacles.** Gilden D, *The Deaf-Blind American* 24(3):80-90, American Association of the Deaf-Blind, March 1986.

**Dexter—A Helping Hand for Communicating With the Deaf-Blind.** Gilden D, Jaffe D, *Proceedings, Ninth Annual*

Conference, RESNA 6:49-52, Minneapolis, MN, June 1986.  
**A New Device for Measurement of Visual Adaptation.** Haegerstrom-Portnoy G, Adams AJ, Jampolsky A, *Proceedings, Ninth Annual Conference, RESNA 6:35-37*, Minneapolis, MN, June 1986.  
**Talking Signs—An Accessibility Solution for the Blind and Visually Impaired.** Loughborough W, *Proceedings, 12th*

*C.M.B.E.C./1st Pan-Pacific Symposium*, Vancouver, BC, July 18-26, 1986.  
**Photorefraction with a Catadioptric Lens.** Norcia AM, Zadnik K, Day S, *Acta Ophthalmologica* (in press).  
**Vestibulo-Ocular Reflexes of Adventitiously and Congenitally Blind Adults.** Sherman KR, Keller EL, *Investigative Ophthalmology and Visual Science 27:1154-1159*, 1986.

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## Automatic Lens Focusing for the Visually Impaired

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**Sponsor:** U.S. Department of Education, Office of Special Education and Rehabilitation Services; National Institutes of Health

**Purpose**—Many visually impaired individuals use special telescopic lenses as visual aids. Focusing and refocusing these lenses due to changes in object distance not only becomes tedious and monotonous for individuals, but is difficult for the aged or multi-handicapped. This report describes the progress of an automatic lens focusing system design and development effort. The system is intended to be practical, portable, and affordable. The level of performance in terms of quickness and quality of focus is intended to be as good as that of the currently available hand-held movie/tape recorders equipped with autofocusing.

**Progress**—There are two autofocusing systems under investigation. They are identified by the type of sensor: 1) an active sensor using ultrasonics; and, 2) a passive sensor using an array of photo detectors.

In the ultrasonic system, the computer control and lens motor drive subsystem vary slightly depending on the front end sensor. However, they essentially perform the same relative functions. The system contains a distance measuring device, computer control, and motor drive lens systems. These three subsystems work together to provide the basic operations that a normal, healthy human vision system goes through: imaging, quality evaluation, and action to improve. The system's digital computer not only generates and processes the various signals, it also monitors all the functions and provides an overall system control.

**Results**—The ultrasonic type autofocusing lens system was designed and constructed. It is currently fully operational. Initially, an Apple IIe computer

with five power supplies were used to drive the autofocusing lens system. The system has been further developed and currently uses a Macintosh computer and requires only two power supplies.

The investigation of the passive array of photo detectors as a sensor for the autofocusing lens system has also made progress. A development system including sensor, interface chips, and microprocessor controller have been integrated with a telescopic lens. System focusing investigations are in progress as of this writing. Preliminary results indicate that this system works.

**Future Plans**—The plan is to continue working with both of the autofocusing lens systems, but with slightly different purposes in each case. The ultrasonic version will be used to evaluate system-related operations, including human/algorithm relationships. In the case of the photo array, we will seek to integrate this sensor into a fully operational system.

The reason is that the photo detector array system is the more promising in terms of performance, as well as being light in weight. We expect to be able to design and implement a realistic, portable device employing a photodetector array.

This research investigation has been aided significantly by the Pennsylvania College of Optometry. Drs. Anthony DiStefano and Richard Brilliant of the William Feinbloom Rehabilitation Center provided invaluable insight into the problem. Mr. Robert Ellis not only provided the telescopic lenses, but also personally fabricated the necessary parts to allow the motor and unique drive train to focus the lenses.

## A. Blindness and Low Vision

### 2. Mobility Aids

#### Evaluation of Electronic Travel Aids (ETAs) for Visually Impaired Individuals \_\_\_\_\_

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—This is a 2-year study of Electronic Travel Aids (ETAs) which will closely examine the performance of existing ETAs and the travel needs of visually impaired people. Although research and development of ETAs has been ongoing since World War II at a cost of millions of dollars, only four devices have made it to the production stage, with approximately 3,000-3,500 purchased (Blasch, 1985). Preliminary data indicates that visually impaired persons own nearly 1,000 of the ETAs, while the remaining 2,000-2,500 are used for training, are in stock, or have been abandoned.

The four commercially available ETAs are the Pathsounder, the Mowat Sensor, the SonicGuide, and the Laser Cane. This study will determine the strengths and weaknesses of existing ETAs, reveal which types of individuals can benefit from ETAs, and provide recommendations of performance characteristics for future ETAs. The data will answer the questions: 1) How many people are using each

device? 2) What is the profile of the visually impaired person that will most likely benefit from an ETA? 3) What are the strengths and weaknesses of the devices? 4) What situations are most appropriate for using the device? and, 5) What are the directions and needs for future ETA development?

**Progress**—The steps involved in this project consist of locating ETA consumers, developing the telephone interview, writing a computer program for direct data entry by the interviewer, training the interviewers, conducting the survey, and analyzing the results.

At this time, a database has been organized which contains approximately 400 names and addresses of current and former ETA users. The written survey and computer program are in the final phase of development and training of interviewers will be starting in the near future.

#### Clinical Application Study of Training Techniques and Devices for the Blind \_\_\_\_\_

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—The measurement of mobility performance has been a difficult challenge to scientists. The difficulties have been caused most often by problems in determining what variables to measure (i.e., stride length, body posture, total time, straight line of travel). Previous work by the investigators has demonstrated that mobility instructors can reliably measure client performance with a behavioral checklist of critical events, such as bumping, stumbling,

or poor street crossings. This approach, while reliable, is of limited experimental or practical use as the results showed a low frequency of critical mobility events. This makes it difficult to demonstrate the effectiveness of mobility instruction. To increase the amount of obtainable data, without increasing the environmental complexity and compromising subject safety, a secondary task methodology was coupled with the checklist approach. The objective

of this study was to generate multiple performance measures for the assessment of mobility performance prior to, and following, mobility instruction.

**Progress**—Blind and visually impaired subjects who agreed to participate in the study were requested to complete three different experimental conditions on two separate occasions. The three conditions were: 1) seated while responding to an auditory tone; 2) walking sighted guide while responding to an auditory tone; and, 3) walking independently while responding to an auditory tone. The independent walk consisted of a 7-block route in a residential and small business environment. Each of these conditions was completed sometime during the first 10 mobility lessons (pre-test) and repeated during the last 10 mobility sessions (post-test). Therefore, each subject provided data on six separate occasions.

A hand-held Tandy PC-6 pocket scientific computer was programmed to generate a randomly timed, high pitched tone (beep). Modifications were made to the computer so that the subject would respond by squeezing the computer, which produced a response tone. The subject wore a set of Sony earphones which permitted the computer-generated and response tones to be heard in environments with ambient sounds. The computer provided data on the number of samples, the number of responses, the mean reaction time and the standard deviation.

## Measuring the Mobility of Blind Travelers

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The objective of this study was to create a scale for measuring the gait-related aspects of mobility: to measure these aspects and the travel activity of blind travelers before and after training; and to determine the relationship between travel activity and gait-related mobility.

**Progress**—Twenty subjects, half of them totally blind and half with low vision, volunteered for this training at the Hines Blind Rehabilitation Center.

Travel activities of the patients were measured using a self-report, guided interview. Each person

The subjects for this experiment were veterans assigned to the Eastern Blind Rehabilitation Center in West Haven, CT. This population is primarily male, over 50 years of age, adventitiously visually-impaired, partially-sighted, and with additional physical or cognitive impairments. As of the writing of this abstract, 16 subjects have completed the experiment.

**Preliminary Results**—Results of the experiment at this time demonstrate that reaction time is a stable measure with test retest reliability coefficient of  $r = 0.975$ ,  $df = 14$ . Additional results indicate that when walking sighted guide, a two-fold decrease in performance occurs. When required to walk independently, a four-fold decrease in performance occurs. These results are all statistically significant.

**Future Plans/Implications**—This study demonstrates the efficacy of the secondary task approach to describing mobility performance. This approach minimizes the need to expose subjects to difficult environments to assess critical events by increasing the complexity of the task through the introduction of the secondary measure. The results also suggest that the effectiveness of mobility instruction may be captured with this technique and can serve as one approach to documenting improvements in travel through systematic instruction.

estimated how often they performed 19 particular activities; how often they did the activity alone; and how difficult it was to do the activity. Easiest activities involved behaviors that can be done at home or close to home. Activities that involve travel a greater distance from home and/or may require transport are more difficult. The most difficult items concern activities that may not be completely determined by travel skills, such as interest or motivation, to be involved in such activities.

The gait characteristics of each patient were assessed before and after training using a gait-

measuring system during several types of circumstances. Step length and step time were measured at each event. Step length during simple tasks is longer than when the person is doing a more difficult task; inversely, step time is shorter during simple tasks and longer when doing more difficult tasks. The ratio of step length to step time gives a measure of walking speed at each of the events measured. The walking speed data were scaled to produce an instrument that provides an overall measure of the gait-related aspects of mobility.

**Results**—It was hypothesized that travel activity and skills as measured by gait parameters would not be highly correlated because travel activity was thought to depend upon a number of variables such as mood,

interests, family attitudes, and cognitive skills that are not related to travel skill. The correlations between travel activity and gait parameters support this hypothesis.

Blind and low vision patients were assessed in the study and the differing effects of training on these two groups were measured. Travel activity reported by blind patients was significantly lower before training than that of low vision patients. At the end of training there was not a significant difference between them. Blind subjects did significantly poorer than low vision patients on pre-training gait measures but made a noticeable improvement as a consequence of training. The improvement did not, however, bring them up to level of the low vision patients.

### Measuring the Spatial Layout Knowledge of Visually Impaired Adults

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—In order to create better aids and techniques for orientation training for visually impaired travelers, it is necessary to fully understand the spatial knowledge of these travelers. At present we do not even know much about such knowledge of sighted adults and it is not obvious how much we can generalize from the latter to the former. In particular, the three level distinction among landmark, route and global layout knowledge, while reasonable, is still unproven.

The orientation skills of visually impaired persons cannot be assessed without a reliable and valid instrument. With such an instrument we can establish the effects of both individual differences and environmental factors on the successful orientation of visually impaired travelers. Thus, goals of this project include: 1) The development of a reliable and valid response measure; and, 2) a description of the spatial representations of blind travelers at a level of detail sufficient to guide the creation of optimally compatible spatial displays and training

programs for these travelers.

**Progress**—The first step in this project is to establish a reliable and valid measure of spatial knowledge in both sighted and visually impaired persons. Seven such measures are being tested against each other, using a variety of psychophysical and psychometric criteria. The best measure will then be used for further studies. The measures of spatial layout are being created and tested.

We then will focus on the variables associated with various types and sizes of scenes and environments that are frequently encountered by travelers. In addition, we will assess the effects of a traveler's interactions with a scene (e.g., passive guidance versus active search), the effects of formal training in orientation and mobility skills, and the effect of specific training on spatial layout knowledge. Finally, an assessment of the effects of individual differences on spatial knowledge using a multiple regression analysis will be made.

## Digital Techniques for Objective Analysis of Aural Acoustic Immittance

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The current one-year project concludes the evaluation and implementation of a digital (“programmable”) acoustic-immittance instrument interfaced to a personal computer (IBM).

**Progress**—Emphasis was on completion of research-oriented software (Summit software; BetterBASIC) to utilize the programmable instrument and on development of limited routines (Microsoft; C) for a new digital instrument. Interface routines were written to calibrate the new instrument and to allow acquisition, scaling, and storage of tympanometric and acoustic reflex data. Stored data can be analyzed using software developed for the original instrument. The analysis software supports reduction of tympanometric data, determination of acoustic reflex thresholds, and measurement of amplitude and temporal characteristics of single acoustic reflex responses.

**Results**—Summary data is derived from raw immittance data and displayed in admittance units ( $Y_a$  and phase angle, or  $B_a$  and  $G_a$ ). Summary data for a given test are displayed on a single screen and can be saved to disk or printed out.

### Publication Resulting from This Research

**Digital Instrument for Measurement of Aural Acoustic Immittance: A Preliminary Report.** Robinette LN, Thompson DJ, *Journal of Rehabilitation Research and Development* 23(2):34-47, April 1986.

### Presentations

**Southern Audiological Society**, September, 1985. Robinette LN, Thompson DJ. **Association for Research in Otolaryngology**, 1986. Thompson DJ, Robinette LN.  
**Southern Biomedical Engineering Conference**, Gupta S, Robinette LN, Thompson DJ, 1986.

## Establishing Design/Operational Features for Portable Blind Reading Aids

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—This project has four goals: 1) to establish, via questionnaires, what are the demonstrable, unmet needs for reading aids among blind persons; 2) to determine, via technology surveys and follow-up contacts, where new components and systems are appearing to help meet those needs; 3) to establish experimentally, using a flexible reading aid testbed assembled at our Center, together with information from the previous steps, the design and operational specifications for the next-generation reading aid; and, 4) to utilize and disseminate the information acquired promptly and usefully, to those who need it either professionally or personally. The two unifying purposes of these coordinated activities are: a) to provide the information needed to ensure that the next-generation reading aid is yet more useful, affordable, and widely accepted than currently avail-

able devices; and, b) to prepare the ground thoroughly for the design, construction, and preliminary evaluation of a next-generation reading aid prototype, which will use specific components, techniques, and knowledge gained in this project.

**Progress**—In the past year and a half, the investigators have moved ahead purposefully in each of the areas. 1) To reach the first goal of establishing unmet needs, they have employed questionnaires and interviews. A “general user questionnaire” has been completed and administered by telephone to approximately 150 blind and visually impaired individuals in three groups—veterans (of working or retirement age), non-veterans (on the same age groups), and students (primarily around the college ages of 17-22). In addition, an “expert user ques-

tionnaire" has been written and is being administered to blind individuals with special experience and expertise in the use of technology to compensate for their disabilities. 2) The survey of current technology has led to the identification of several specific components that appear well suited for a next-generation reading aid, and discussions with the developers of those components have led to cooperative arrangements that hold promise for their eventual inclusion. 3) A series of human performance tests using our Center's reading aid simulator has been completed on blind, low-vision, and fully sighted individuals (the latter to provide baseline measurements). The tests allowed researchers to measure accuracy versus speed under several candidate feedback conditions (audio, tactile, and combined) while hand-tracking a camera over lines of text for optical capture. 4) Dissemination of results is underway: several abstracts are already published in conference proceedings (reflecting talks, posters, and demonstrations presented to the public), while lengthier, more detailed articles are being prepared for submission to the journals.

**Preliminary Results**—Each of the areas of activity has yielded important results. The user questionnaires have provided a detailed look at comparative usage patterns of existing reading aids (Optacons, KRMs), identified perceived needs which are currently going unmet, and helped us better characterize users' likes, dislikes, biases, and future expectations. The technology surveys and follow-up contacts have allowed the investigators to establish valuable cooperative arrangements with those developing promising technologies for our future device. The human performance studies, using our flexibly configurable reading aid simulator, has allowed the investigators to select the best feedback to blind people who are hand-tracking a camera

across lines of text on a page. Dissemination activities have elicited considerable interest among researchers elsewhere who are working on related questions.

**Future Plans/Implications**—With the completion of the expert user survey administration, with comprehensive data analysis from each activity area, and with the full publication of results, the investigators conclude their activities under the current project. They will incorporate the knowledge gained, the contacts established, and the components acquired into a follow-up Merit Review submission, in which they will propose to construct a portable, computer-based reading aid prototype for initial evaluation. This aid will be designed to support, additionally, the peripherals of an employment-or-home-based workstation for blind individuals.

#### **Publications Resulting from This Research**

- Survey of Potential Users: Design/Operational Features for Blind Reading Aids.** McKinley J, Goodrich GL, Steele RD, Hennies D, *Proceedings of the 10th Annual RESNA Conference*, 451-453, San Jose, CA, June 1987.
- Experienced Technology User Survey: Design/Operational Features for Blind Reading Aids.** Goodrich GL, McKinley J, Steele RD, Hennies D, Duluk J, *Proceedings of the 10th Annual RESNA Conference*, 443-445, San Jose, CA, June 1987.
- Audio and Tactile Feedback Strategies for Tracking.** Lasko-Harvill A, Harvill Y, Steele RD, Verplank W, Hennies D, *Proceedings of the 10th Annual RESNA Conference*, 459-461, San Jose, CA, June 1987.
- Development of a Portable Text Communication Environment for the Visually Impaired Community.** Hennies D, Steele RD, Goodrich GL, and McKinley J, *Proceedings of the 10th Annual RESNA Conference*, 431-433, San Jose, CA June 1987.
- A Multibus-Compatible Interface to Selected Reading Displays for the Blind.** Steele RD, Miranda RF, *IEEE Transactions on Biomedical Engineering*, 33(9): 896-898, 1986.
- Software Modules for a Hand-Scanned Reading Aid for the Blind.** Steele RD, Hennies D, Duluk J, Vogel E, McMillan K, *Proceedings of the 9th Annual RESNA Conference*, 43-45, Minneapolis, MN, June 1986.

#### **A Portable Navigational Aid for Blind Persons**

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**Sponsor:** *Rehabilitation Research and Development Center Core Funds*

**Purpose**—Blind persons travel by memorizing routes. In unfamiliar environments they frequently depend on other persons for assistance. This situation not

only increases their dependence on others, but also limits the extent to which they can travel, since it is difficult to memorize many routes. Although some

blind persons are satisfied with this degree of independence, many would like the ability to independently travel unfamiliar environments.

Devices that have been designed to help blind persons travel unfamiliar routes are not widely used. Assistive devices like "talking signs," audio cassettes, or the Sonic Orientation and Navigation Aid have limited scope. Tactual maps are cumbersome and not generally available for many places.

**Progress**—We have developed a device that will allow blind persons to independently travel unfamiliar routes. The device senses the direction and speed that the person travels each segment of the route. These data are processed by a microcomputer and stored in digital memory. When a person wishes to travel a route, they must first teach it to the device. This is done by simply walking the route. Thereafter, whenever they wish to retrace the route,

they simply command the device to replay the instructions for traveling. The device conveys instructions for traveling the route through tactile stimulators attached to the waist. The device also warns the person that they are deviating from the desired route by signaling them with appropriate tactile stimuli.

**Results**—A prototype device has been constructed and tested for accuracy and susceptibility to interference from ferromagnetic objects. The results of these bench tests suggest that the device will operate satisfactorily in most environments, even those that have a preponderance of large metallic objects. The prototype device will soon be tested under actual conditions in a dense, urban environment. If this test is successful, we will seek a company to produce pre-manufacturing prototypes for evaluation.

## A. Blindness and Low Vision

### 3. Reading Aids

#### Computer Vision to Guide the Blind

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**Sponsor:** VA Rehabilitation Research and Development Service; Pacific International Center for High Technology Research (PICHTR)

**Purpose**—This project deals with the development of a novel computer vision approach for guiding the blind. The principal goal in applying computer vision is to provide the blind with efficient and reliable guidance, improving their mobility needs and bettering their lives in the process. To this end, we exploit in an optimal fashion, and in harmony with the visual features used by humans, the rich information acquired by the camera to yield descriptions of the viewed environment which are most suitable to the blind. In this research direction, we identify and address four important problems: 1) the vision system design; 2) establishing the mapping principles between the two-dimensional (2-D) camera images

(the domain of the computer) and the three-dimensional (3-D) real world (the domain of the blind); 3) development of the appropriate imaging techniques for the interpretation of the 2-D images; and, 4) information integration and output coding in order to establish the proper communication link between the vision system and the blind.

**Progress**—In the design of the vision system, we are presently assessing the various design aspects, with strong emphasis placed on the current advances in Application Specific Integrated Circuits (ASIC) fabrication and in Very Large Scale Integration (VLSI) technology. The main issues here are that

the vision system should be portable and must operate in real time. Our present vision system is bulky and tethered.

To establish mapping between the 2-D images and the 3-D world, the depth information must be recovered from the 2-D images. To this end, we have devoted a great deal of our research efforts to two distinct methods, motion vision and stereo vision. Good results have been obtained under certain constraints. With the considerable work we have already done on these methods, we have developed significant insight into this problem, and are confident that one of these methods can be adapted to our vision system.

We have developed and implemented successfully the following image interpretation techniques: 1) planning a safe path for the blind to follow. (In this task, we can demonstrate, using our vision system, the whole procedure of providing guidance cues to the blind from image taking to image analysis and interpretation followed by results being displayed on the monitor for visual appreciation); 2) detecting

depressions or drop-offs, for they constitute the type of obstacles most feared by the blind; 3) discriminating upright objects from flat-lying objects, in view of the fact that upright objects may be either obstacles which should be avoided, or landmarks which could be used as necessary cues in the guidance process; 4) identifying shadows, for shadows cast on the path of travel can be mistaken by the vision system for actual objects leading to false alarms; and, 5) identifying, when necessary, those objects which could be important to the blind—such as stairs, crosswalks, curbs, and doorways.

**Preliminary Results**—Encouraging preliminary results have been obtained for all the imaging techniques mentioned above.

**Future Plans/Implications**—In the future, we will work on the output interface unit which will consist of an audio unit and a tactile unit. Also, we shall integrate the various imaging techniques to yield an integrated system.

## The Human Factors Design of a Large Print Display

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—The study was a design project to develop a device to format large print displays (LPD) for use by persons with limited usable vision. The objective of the project was to determine the display values which enhanced the readability of the LPDs.

**Progress/Methodology**—The approach taken in this project was to determine the text and display characteristics preferred by the low vision reader and to determine the relationship between these characteristics and the reader's sustained reading performance. The sample subject population consisted of low vision students ( $n = 10$ ) from local high schools.

A Voyager XL Visualtek closed circuit television system (CCTV) was used to obtain the initial assessment of font style and size preference. Several parameters of the LPD were investigated with the CCTV: font style; character size or magnification; and, achromatic polarity of the background/letters. Font styles were varied relative to the stroke width,

the presence of serifs, and the size of descenders. Character size was adjusted to accommodate the individual reader's needs.

The LPDs were generated on two different computer systems: a Hewlett-Packard Model 9000, Series 300 system; and, an Apple IIe with an 80 column card and 64K RAM. The Hewlett-Packard system permitted high resolution font generation, precise manipulation of character and line spacing, and extensive control of letter and background color. The Apple IIe provided an LPD (with some constraint to character size) and, additionally, offered text scrolling capability. The display for the Apple IIe was a standard green monitor.

Each subject participated in two experimental sessions. In the first session, each subject's description of visual impairment and reading behaviors were obtained through a brief biographical inventory. A set of fonts was presented on the CCTV for ratings of readability, desired magnification, and

general preference. Each participant then read passages of the "Timed Readings Test" containing 400 words of factual information. Reading speed and comprehension were assessed for the standardized font used. In the second experimental session, the subject was provided with his/her preferred LPD font styles and sizes on the Apple IIe. The text appeared in a single line in the middle of the monitor screen. The scroll rate of the text could be adjusted by the subject using keyboard input to cursor keys. New passages of the reading comprehension test, displayed in both the standard and the subject's preferred font were presented. Again, the subject's reading speed and comprehension were recorded.

**Results**—Significant differences were found in the ability to read an optotype (Landolt ring) depending upon the color combination of text and background; however, the ranking of color preference was not related to the ranking of optotype reading performance. Although there were strong preferences in font style, the use of these fonts in the reading of sustained passages was not associated with improved reading performance over the standard font

(Times Roman). The use of computer generated text provided no improvement in reading level over that obtained with the CCTV when the standard font was used.

**Future Plans/Implications**—One of the major implications of this research for the design of large print displays is that reader preferences for certain textual characteristics (e.g., font style or letter color) may not be sufficient to predict improvements in reading performance. Actual testing of the reading performance (*vis.*, reading speed and comprehension) must be done to confirm the effectiveness of design features in a large print display. Although there are no specific plans for future investigations in this area, the Rehabilitation R&D Unit continues to support related studies in low vision.

#### **Publications Resulting from This Research**

**Human Factors Considerations in the Design of Large Print Displays for Persons with Visual Impairments.** Amerson T, McNeal L, Ross D. *Proceedings of the 10th Annual Conference on Rehabilitation Technology* 7:419-421, San Jose, CA, June 1987.

### **Adaptation of the Amiga Personal Computer to the Visually-Impaired User** \_\_\_\_\_

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**Sponsor:** *Veterans Administration Core Money*

**Purpose**—The Commodore Amiga is a relatively new personal computer which offers the potential of addressing some of the common problems faced by visually-impaired users. Features of particular interest are: relatively low cost, high speed, built-in sound and advanced graphics capabilities. To take advantage of these features, appropriate software must be developed which provides large print and/or speech.

**Progress**—Utilizing Manx C and the documentation

available, a primitive text editor has been developed. Large fonts can be used, but thus far, only one has been designed.

**Preliminary Results**—Our work has shown that it is technically feasible to adapt the Amiga to the visually-impaired user.

**Future Plans/Implications**—Future progress will depend on achieving adequate documentation and manufacturer support.

## Braille Teaching Aid with Synthetic Speech

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Sponsor: VA Rehabilitation Research and Development Center Core Funds

**Purpose**—Although only 10 percent of blind people regularly use braille, it has many uses for which there is no substitute. Braille is still the only medium by which blind persons can easily take notes and label items. Additionally, accessibility codes mandate braille symbols in many public places. Accordingly, it is a useful language to know. However, few people bother because it is a difficult language to learn, especially for adults.

Traditional methods for teaching braille rely heavily on assistance from braille instructors or sighted persons. This not only reduces the extent to which students can study independently but also affects the instructor's ability to give personal attention to students who need it. Some instructors have attempted to solve this problem by providing audio cassettes to accompany braille material. Although these are helpful, they require the student to expend considerable effort in relating verbal instructions with braille materials.

**Progress**—We have developed a product that will make it easier to learn braille and give students the freedom to study independently. Our product is a book that combines braille and Talking Tracks™ bar code (Texas Instruments Incorporated). The Talking Tracks produce synthetic speech when read with an inexpensive bar code reader. This design gives students the opportunity to obtain verbal reinforcement whenever they need it, without having to refer

to passages on audio cassettes. Accordingly, they may study without the assistance of a braille instructor or sighted person.

**Results**—A prototype book has been developed after extensive testing. Twenty books were recently printed using a process that allows embossed materials to be printed with conventional presses. These books have been evaluated by braille instructors at the VA Hines Central Blind Rehabilitation Center, Hadley School for the Blind, Illinois Visually Handicapped Institute, Library of Congress, and the Perkins School for the Blind. The results of these evaluations were generally favorable. Instructors liked the idea but had problems with the design, embossed printing, and bar code reader.

The book's design has been changed to make it easier to locate and scan the bar code. The printer has been contacted regarding changing the formulation of ink to enable printing of braille material that meets existing standards. Additionally, the bar code reader has been modified to make it easier to handle.

**Future Plans**—We will determine the impact of these changes by printing new books using microcapsule, xerographic paper. We will then re-evaluate the altered books and reader. If the evaluation is favorable, we will reprint the books using the re-formulated ink and test the design on a larger population.

## Enhancing the Reading Skills of Low Vision Individuals with Macular Loss

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—This overall project is an applied research effort designed to quantify measures of visual and reading skills and to develop computerized training protocols and software that assist low vision instructors in the vision rehabilitation of the target population. The present report represents the work done

during the final year of this 3-year study and a brief summary of results from previous years.

**Progress**—*Part I. Development of Measures of Visual and Reading Skills.* The Pepper Visual Skills for Reading Test (VSRT) is an instrument designed

to quickly assess the visual skills required for reading. Developed and described in a previous project, it has been refined and revised in the course of the present study. Data has been presented regarding the reliability of the test. Fifty individuals with age-related maculopathy were tested on two forms of the test. The correlation coefficient between the two accuracy scores was 0.90 and between the two reading rate scores was 0.97. In terms of the validity of the test as an assessment of reading ability, assessments with the VSRT were compared with those made on the basis of the Gray Oral Reading Test. Data from 38 subjects with central field losses resulted in a Pearson-product moment correlation of 0.82. The validity data and a discussion of appropriate usage of the instrument is presented in a paper in press (Watson et al., 1987).

*Part II. Expert System for Training Eccentric Viewing and Reading.* The results of a national survey of 80 clinics providing eccentric viewing and reading training were incorporated into the framework of a computerized system to assist low vision professionals in this area. The resulting three-disk package includes the following modules: Training Flow, Pepper VSRT Scoring Module, Text Difficulty Assessment Module, Text Formatting, Psychological Testing, Training Exercises, Referral Database,

Lighting Advisor, and General Report Generator. The information gathered through the use of the modules is recorded on an accompanying data disk for future research. The documentation and final beta-testing of the system is currently under way.

**Future Plans/Implications**—The most interesting and potentially powerful aspect of the computerized system has been the psychological testing module. A proposal to extend this module and develop normative data for the client population and attempt to use this data to generate models which might prove helpful in developing optimum training strategies has been submitted to the National Institute on Disability and Rehabilitation Research.

#### Publications Resulting from This Research

**The Pepper Visual Skills for Reading Test.** Watson G, Whittaker S, Steciw M, Pennsylvania College of Optometry, Philadelphia, 1986.

**The Development and Evaluation of a Reading Test for Low Vision Individuals with Macular Loss.** Baldasare J, Watson G, Whittaker S, Miller-Shaffer H, *Journal of Visual Impairment and Blindness*, June 1986.

**Observations from the Psychology of Reading Relevant to Low Vision Research.** Baldasare J and Watson G, in *Low Vision Principles and Applications*, G. Woo (Ed.), Springer Verlag, 1986.

## Software Development: Blissbook

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**Purpose**—Blissbook is designed to provide an introduction to the reading of words for the student who communicates with Blissymbolics. The primary objective of the program is to facilitate the learning of traditional orthography through acquiring skills in the processes of writing, editing, and reading within the medium of Blissymbolics. The secondary objective is that the student direct the pace and content of this learning.

**Progress**—Blissbook requires a 512K ICON computer. Although it is a scanning program for students who use a single switch, direct keyboard access is also possible. Blissbook consists of four sections: Write, Read, Activities, and Utilities. The student

first composes a story in Blissymbols. At a pace set by the student, the Blissymbols may be converted to traditional orthography. Blissbook provides a variety of functions (e.g., insert, delete, gloss on/off, scan time) which enable the student to edit his/her stories and to control the screen environment. A special function, *Transform*, allows the student to convert the Blissymbol gloss to an approximation of standard English syntax. Through the *Utilities* section, the instructor, along with the student, may set up various program parameters according to the student's needs. Communication will be achieved through the video screen, synthetic speech and hard copy printout.

## B. Deafness and Hearing Impairment

### Electroacoustical and Clinical Protocols for Evaluating Assistive Listening Devices \_\_\_\_\_

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #C944-PA)

**Purpose**—People who suffer from hearing loss do not receive adequate help from hearing aids in situations where there is background noise or where the speaker is some distance away. Hearing aids amplify all wanted and unwanted signals in their range, both the interfering background noise and the speech. Examples of distance listening where hearing aids are of limited benefit include attending church services, going to a movie or play, and watching television at home.

Assistive listening devices are very useful in both noisy and distance listening situations because they use special microphones which are placed close to the speaker and transmit the signal directly to the hearing impaired listener. In this way the important message is transmitted without picking up the interfering background noise or losing the intensity of the signal because the speaker is a great distance away.

The purpose of this pilot project is to develop methods for the evaluation of these assistive listening devices to determine which of the many devices meets the needs of the particular hearing impaired individual. The audiologist must have reliable infor-

mation about how the device amplifies sound and how to evaluate the device on the patient. An electroacoustic protocol will be developed to determine how the device amplifies sound. Technical specifications will be developed that describe how much amplification is provided in the various pitch ranges and how effective the microphone and amplifier are in reproducing the signal effectively.

A clinical protocol will be developed that will measure the effectiveness of the assistive listening device while it is worn by the hearing impaired person. The measures will include determination that the required amount of amplification is present by measuring the amount of sound in the ear canal with a miniature microphone. The ability to understand speech while wearing the device will be measured by having the person listen to words in a background of interfering noise and repeat the words heard. Patients wearing the device will also report how much they understand by judging whether or not they feel the words are intelligible. They will also judge whether or not the quality of the device is good by reporting on how pleasant the speech sounds.

### Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II \_\_\_\_\_

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—The purpose of this research is to develop a new hearing assessment and hearing aid fitting procedure in which a new digital hearing aid concept plays a key role.

**Progress**—A digital hearing aid is under development that can provide the flexibility and control of audi-

tory signal processing required to match the patient's hearing deficiency along with an automated hearing test facility that measures the patient's hearing and that programs the hearing aid to provide an optimum setting for the patient. The incorporation of the final hearing instrument as an integral part of the hearing aid evaluation is a key feature of the approach and

represents a radical departure from traditional hearing aid evaluations. The hearing instrument used during testing is the same unit that will be worn home by the patient and includes the acoustic plumbing and earmold configuration specific to that patient. An obvious advantage is that instrument characteristics that vary from patient to patient are taken into account during the hearing evaluation. Fitting errors that arise due to assumptions about calibration with standard cavities are minimized. In addition, the hearing evaluation and fitting procedure can be simplified and shortened with concomitant benefits to the patient.

Work this year has been concentrated in three research areas. They are: 1) development of an adaptive feedback equalization algorithm; 2) comparison of digital hearing aid and conventional hearing aid performance through psychoacoustic studies and clinical field trials; and 3) development of full-custom Very Large Scale Integrated (VLSI) circuitry which operates at low power consumption levels. Progress in each area is described below.

**Preliminary Results**—Major parts of the feedback equalization study have been completed. Experimental ear modules have been fabricated and used to measure the characteristics of typical feedback conditions using a KEMAR manikin. A TMS320-based system has been programmed to implement the Widrow adaptive cancellation algorithm which has been implemented to constantly measure the feedback characteristics and to equalize the overall system. This program runs in real time and has been evaluated under various conditions of ear-mold seal, signal, and noise. The algorithm is simple and suitable for implementation in VLSI form.

Our preliminary results in the laboratory with the above system have been very promising. The algorithm is stable over a wide range of adaptation rates. The algorithm appears to equalize the acoustic feedback so that significantly greater system gains can be achieved with equalization than without. Finally, the quality of the sound through the equalized system is good.

**Future Plans/Implications**—In anticipation of field trials with the wearable digital hearing aid, several patients from the clinic have been identified as potential research subjects and were asked to re-

spond to questionnaires and to keep a log of specific information (environment condition, difficulty in understanding speech, changes in volume control, reasons for changes in volume control, etc.) while wearing a conventional hearing aid. Information from the logs indicated that this group of patients readjusted their aids on the order of 2-10 times per day under a variety of conditions. The predominant reason given for changing the volume control was to increase understanding of speech. We have also started a series of experiments with hearing-impaired subjects that are designed to provide additional information regarding: 1) differences between the digital hearing aid and conventional aids; and, 2) appropriate overall gain functions. In these experiments, speech intelligibility is measured as a function of signal-to-noise-ratio, overall noise level, and hearing aid parameters.

During the current year several milestones have been reached with regard to VLSI development. At the beginning of the year we received our first full-custom integrated circuit from the fabricator. The chip performs a multiply-accumulate operation on logarithmically-encoded data with a log base of  $D=0.908$ . This log multiply-accumulate (LMA) cell is the elementary function block required to carry out the linear filtering operations of the digital hearing aid. The LMA cell performs the equivalent of one tap in a Finite Impulse Response (FIR) filter and the four-channel, instantaneous-compression, digital hearing aid requires 256 such FIR taps. Eight chips were received and were tested to verify functionality and power dissipation. All eight circuits passed the functional tests and the measured power consumption was as predicted.

The basic LMA cell design was modified to execute eight FIR filter taps by incorporating multiplexing for the filter coefficients and sampled data. This multiplexed log multiply-accumulate cell (MLMAC) was submitted for fabrication and chips are expected to be received and tested before this year ends.

Our goal of achieving 256 FIR taps on a single chip is being pursued further by combining eight of the MLMAC's into a Systolic Array of Logarithmic Multiply-Accumulate cells (SALMA-8) which will be able to perform all taps needed for one of the four channels in the aid. This design has just recently been submitted for fabrication and chips are expected in late December. Future plans call for

combining four of the SALMA-8 arrays into a single chip to complete the evolution of the Digital Signal

Processing chip component of the digital hearing aid.

## Perception of Reverberation by the Hearing Impaired

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**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—The overall objectives of this research are to determine which aspects of the microstructure of reverberation are important for normal-hearing listeners and which are important for the hearing-impaired and to use this information for the development of signal-processing techniques for enhancing the intelligibility of speech in reverberant conditions for hearing aid users. For these studies, reverberation will be specified in terms of its important microstructure (e.g., density of reflections, spectrum ripple, early versus late reflections). Of particular interest are the effects of between critical-band and within critical-band spectrum ripple on the perception of complex sounds and, in particular, on the intelligibility of speech.

**Progress**—At the present time, the program is in its initial stage, which is devoted to the generation of test stimuli. Recordings of short bursts of white noise and recordings of speech will be made in two sets of test rooms. One set will consist of real rooms, with reverberation times that range from 80 ms to at least 500 ms. The second set will consist of rooms whose reverberation characteristics will be simulated on a computer. By use of computer simulation it will be possible to manipulate the received reflections so as to examine the effects of early (<10 ms), late (>60 ms), and midrange arrival times of reflections of the directly received sounds.

## Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans

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**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—To determine the feasibility of using direct magnitude-scaling procedures for the measurement of loudness in a clinical setting, a systematic study of the relation among power-function exponents for individuals with normal- and impaired-hearing was undertaken. Two assumptions underlie this methodological approach. First, individual sensation-magnitude functions are described by a power function in the form  $\psi = K\phi^\theta$ , where  $\theta$  is the exponent of the power function. Second, the matching behavior of individuals exhibits the basic mathematical property of transitivity. Thus, from the equal-sensation functions obtained for any two pairs of sensory continua with one continuum in common, the function for the third pair can be predicted.

was designed to measure, assess, and predict the loudness exponent for individuals. Three different psychophysical procedures were studied: absolute magnitude estimation (AME), absolute magnitude production (AMP), and cross-modality matching (CMM). The measurements involved two sensory continua, perceived length and loudness. They generated four sensation-magnitude functions for each participant. In addition, since the last progress report, a more precise procedure for data analysis was developed. This revised procedure was used to reevaluate the data obtained in normal hearing; it was applied to the results obtained in impaired hearing. To date, 51 people with normal hearing and 50 people with sensorineural impairment have been tested.

**Progress**—A battery of psychophysical procedures

**Preliminary Results—Normal Hearing ( $N=51$ ):** From these procedures, individual and group measured and predicted loudness exponents were obtained. The results show that both the group means and the individual distributions of loudness exponents measured directly by AME and AMP of loudness closely agree with the predicted values derived from CMM. The differences between the predicted and measured exponents range from  $-0.43$  to  $+0.37$  with a mean (and median) difference of  $0.0$ . More than half of the differences range from  $-0.07$  to  $+0.09$ , giving measured deviations that extend from  $12.5$  to  $16$  percent. Of primary importance, the results demonstrate that transitivity can be achieved for individuals, meaning that CMM can be used successfully to determine the exponent for loudness.

**Impaired Hearing ( $N=50$ ):** The results for 32 people were completely analyzed; those for 18 people are currently undergoing analysis. Both the individual and group results show that loudness functions derived from CMM are steeper for the 32 people with bilateral noise-induced cochlear losses than for the 51 people with normal hearing. Over the stimulus range where the impaired loudness functions exhibit loudness recruitment, most of the individual exponents lie between  $1.2$  and  $2.2$  with a mean value of  $1.72$ . This value is about three times larger than the mean of  $0.56$  obtained for the normal-hearing group; only one person with normal hearing lies within the hearing-impaired range. The results also show that, on the average, the slope of the loudness function depends on the severity of the hearing loss. The more severe the loss, the steeper is the loudness function. For threshold shifts from  $40$  to  $70$  dB, the slope increases by a ratio of  $1.7:1$ , in agreement with the increase in slope measured for the loudness of tones masked by broadband

noise.

**Future Plans/Implications—**The findings imply that CMM offers much promise as a clinical tool for the measurement of loudness in impaired hearing. Future experiments are planned with a larger and more diverse population of people with sensorineural impairment. The proposed research program is expected to improve the hearing aid evaluation and selection process.

#### Publications Resulting from This Research

- Perceived Magnitude of Noise-Tone Complexes: Relation to Loudness and Masking.** Hellman R, *Proceedings of Inter-Noise '85*, Munich, Germany 2:929-932, 1985.
- Group Estimation of Loudness in Sound Fields.** Canevet G, Hellman R, Scharf B, *Acustica* 60:277-282, 1986.
- Is High-Frequency Hearing Necessary for Normal Loudness Growth at Low Frequencies?** Hellman R, Meiselman C, (invited paper) *Proceedings of the 12th International Congress on Acoustics*, Toronto, Canada 1:B11-5, 1986.
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- On the Relation Between the Growth of Loudness and the Discrimination of Intensity for Pure Tones.** Hellman R, Scharf B, Teghtsoonian M, *Journal of the Acoustical Society of America* (in press).
- Measured and Calculated Loudness of Complex Sounds.** Hellman R, Zwicker E, (invited paper) *Proceedings of Inter-Noise '87*, Beijing, China (in press).
- Loudness Relations Among Broadband Noises with Different Spectral Shapes.** Hellman W, Hellman R, *Proceedings of Inter-Noise '87*, Beijing, China (in press).
- Can a Decrease in dB(A) Produce an Increase in Loudness?** Hellman R, and Zwicker E, *Journal of the Acoustical Society of America*. Accepted for publication.
- On the Growth of Loudness in Noise-Induced Hearing Loss.** Hellman R, *The 5th International Congress on Noise as a Public Health Problem*, Stockholm, Sweden (in preparation).

### Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans (Project Extension)

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Sponsor: VA Rehabilitation Research and Development Service (Project #XC296-2RA)

**Purpose—**Despite recent advances made in loudness-measurement procedures, these advances have not been translated into a viable clinical procedure. The work proposed will continue and extend the

work accomplished. A continuation of the current work will enable the further development, testing, and standardization of a direct psychophysical scaling procedure designed to measure loudness in

sensorineural impairment. This procedure is ideally suitable for the measurement of loudness in bilateral impairment, regardless of the underlying etiology of the hearing loss or the person's age. The primary goal is to systematically study the relations among sensation-magnitude functions in impaired hearing. To achieve this goal, the following experimental studies of a large and diverse population of people with sensorineural impairments will be carried out: 1) determination of the relations among four sensation-magnitude functions for each person; 2) determination of a possible relation between the shape of the audiogram and the pattern of loudness growth; and, 3) measurement of loudness, annoyance, and noisiness functions measured for the same people is planned so that the usable dynamic range for loudness can be defined and specified. The possibility that annoyance increases with signal level at a faster rate than loudness, exceeding loudness at high levels will also be explored.

The subjects for the proposed studies, all with a diagnosis of sensorineural impairment, will be volunteers recruited mainly from the adult veteran population. They will be obtained from both the Audiology Unit and the Normative Aging Study located at the Veterans Administration Outpatient Clinic. Two hundred and thirty-two people with sensorineural impairment of different presumed causes (e.g., aging and noise-induced) will be tested. Three difference psychophysical procedures will be studied: magnitude estimation, magnitude production, and cross-modality matching. The measurements

will involve two sensory continua, perceived length and loudness. In addition, a limited number of loudness balances, either ABLB or MLB, will be performed.

The information obtained from the proposed continuation and extension of the project is essential for the differential diagnosis of auditory pathology, for determination of the degree of recruitment and the consequent dynamic range for loudness, for assessment of the tolerable loudness-growth range, and for hearing aid evaluations. Especially important is the potential to distinguish better between cochlear and retrocochlear impairments. In the process, some light may be shed on the complex disorder associated with aging known as presbycusis. Furthermore, the results may be germane to the known, but little understood phenomenon of over-recruitment, as well as to loudness-comfort levels of pure tones. Knowledge of the loudness-growth range will be of immense value to the audiologist who must individually adjust hearing aid mechanisms such as the acoustic-gain and amplitude-compression controls for a maximum usage and minimum discomfort. This procedure is usually long and tedious. Thus, access to more detailed and precise loudness-growth information will not only facilitate diagnosis, but it will also improve the overall quality of care of the hearing-impaired veteran.

The long-term objective of the project is to determine how best to implement the newly developed procedure into the routine clinical evaluation process.

## Rabbit ERG Responses to White-Noise Modulated Stimuli

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—During the past 2 years, we have developed the necessary equipment and computer programs to characterize the Electroretinogram (ERG) response to simultaneous white-noise modulated stimuli of visible light and electric current. We have tested the programs on simulated data and verified that there are no errors in the hardware or software. We have also constructed special contact lenses for our proposed rabbit protocol, with platinum electrodes fabricated and installed into the contact lenses

by the Huntington Institute in Pasadena, CA.

**Progress/Methodology**—The vertebrate retina is comprised of organized layers of different cell types that presumably interact in a deterministic nonlinear manner. An electrical potential applied across the retina polarizes all of the cells oriented parallel to the potential gradient, i.e., predominantly receptors, bipolars, and Mueller cells. However, the investigators have demonstrated that the induced polari-

zation is greater for the cells which penetrate the R-membrane, i.e., receptors and Muellers. It is thus possible to produce a visual response that is initiated at the same time in the receptor and Mueller layers. The resulting perception of an electrical stimulus is a uniform field of white light, consistent with a rod-initiated response.

When a light stimulus is superimposed onto the electrical stimulus, the two stimuli will interfere with each other. For example, if the light stimulus occurs first, then all of the retinal cells will be refractory for different periods of time following the light stimulus and will not respond to the electrical stimulus for a brief period of time. This interference effect would be no different than two sequential light stimuli, if it were not for the fact that all of the vertically oriented cells are affected by the electrical stimulus at the same time. Hence, we have hypothesized that it is possible for the electrical stimulus to occur later and still reach the Mueller cells first. The resulting ERG would contain an A-wave produced by the light stimulus.

**Preliminary Results**—If the two stimuli are white-

noise (i.e., quasi-random) modulated, then the first-order kernels indicate the expected impulse (i.e., flash) response to each separate stimulus. In all eight experiments thus far conducted, the first-order kernels for the light stimulus have both the A- and B-waves suppressed. This evidence may indicate that the electrical stimulus triggers both the receptors and Muellers before the light stimulus has a chance to elicit a photochemical response. The first-order kernels for the electrical stimulus all seem to be unaffected by the light stimulus, consistent with the above hypothesis.

**Future Plans/Implications**—The second-order cross kernels indicate how (mathematically) the two independent stimuli interfere with each other. The main diagnostic value of this information will be to reveal how the Mueller cells interact with other retinal cells and to quantify changes in these interactions associated with different retinal diseases. We are hoping to determine the normal interference characteristics in this study, and then propose a continuation study of the effects of selected pathologies on first- and second-order kernels.

## Development of Materials for Computer-Assisted Instruction in Lipreading

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—The goal of this program is an examination of the effects of supplementary drill and practice with an auditory-visual laser videodisc interactive system (ALVIS) on the development of lipreading skill. A computer system has been designed and software has been written for ALVIS and is being used for drill and practice in computer-assisted interactive video (CAIV) instruction in lipreading. The system includes: a laser videodisc player, microcomputer, keyboard, video monitor, two micro floppy disk drives, dot-matrix printer, external amplifier and attenuator, programmable attenuator with associated accessories, and earphones.

**Progress**—Twelve lists of 25 sentences each have been standardized and arranged in order of difficulty as lipreading stimuli. These five- to eight-word

sentences were recorded on 1-inch videotape and then pressed on videodisc. Presentation of the 300 sentences is under software control by ALVIS in each of two conditions. In the first condition, no sound is given; the *word clues* (ALVIS/word) are presented on the video monitor for a maximum of five trials. In the second condition, *auditory clues* (ALVIS/hear) accompany the visual stimulus (0dB, 5dB, 10dB, and 15dB re the subject's binaural speech noise detection threshold) for a maximum of five trials. Student response data are recorded on microfloppy disk.

ALVIS has been used experimentally with post-lingually hearing-impaired adults in a program of aural rehabilitation that includes lipreading instruction. Six subjects received group lipreading lessons twice each week for 6 weeks. On days following

group instruction, each of two subjects received lipreading drill and practice in one of three conditions: 1) with ALVIS/word; 2) with ALVIS/hear; and, 3) face-to-face with the lipreading instructor. Thirty-six subjects have participated in group lipreading instruction: 12 have received drill and practice with ALVIS word clues, 12 with auditory clues, and 12 have received face-to-face practice with the lipreading instructor.

Data have been analyzed to determine the effects of CAIV instruction on the development of lipreading performance and the effects of group instruction on the degree of self-perceived hearing handicap.

**Preliminary Results**—The results are summarized as follows: 1) for the 36 subjects in the three groups, pre-test and post-test results of the Utley Lipreading Test and the Denver Quick Test of Lipreading are significantly correlated ( $r_s$  range from 0.81 to 0.91); 2) significant improvement in lipreading scores (Utley and Denver) occurred during the 6-week period of group lipreading instruction; 3) there were no significant differences between the amount of improvement in lipreading scores across the three groups (ALVIS/word, ALVIS/hear, and face-to-face); 4) pre-test and post-test section scores on the Hearing Performance Inventory (HPI) revealed no significant differences, indicating that the subjects' self-perceived degree of hearing handicap had not changed as a result of the intervention (the implications of

anecdotal information indicating that communication function has improved for almost all of the subjects are being examined); and, 5) the HPI section scores of the subjects' spouses ( $n = 20$ ) tended to indicate that spouses perceived their husbands/wives as having more difficulty hearing in a variety of listening situations than the subjects did.

**Future Plans**—The 36 subjects who participated in the group lipreading instruction and in lipreading drill and practice sessions are returning for an annual reevaluation of the status of their communication function. The long-term effects of the aural rehabilitation program they received will be summarized as data become available.

#### Publications and Awards Resulting from This Research

**Development of Sentences Graded in Difficulty for Lipreading Practice.** Kopra LL, Kopra MA, Abrahamson JE, Dunlop RJ, *Journal of the Academy of Rehabilitative Audiology* 19:71-86, 1986.

**Lipreading Drill and Practice Software for an Auditory-Visual Laser Videodisc Interactive System (ALVIS).** Kopra LL, Kopra MA, Abrahamson JE, Dunlop RJ, *Journal for Computer Users in Speech and Hearing* 3:58-68, 1987.

**A Survey of Microcomputer Applications in Aural Rehabilitation.** Sims DG, Kopra LL, Dunlop RJ, Kopra MA, *Journal of the Academy of Rehabilitative Audiology* 18:9-26, 1985.

**Second Award for Scientific Merit.** *Scientific exhibit: Laser videodisc interactive system for computer-assisted instruction in speechreading*, American Speech-Language-Hearing Association National Convention, Washington, DC, 1985.

#### Personal Computer System for Acoustic Measurements

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—The purpose of this research program is to study variables which influence the measurement or prediction of an individual's performance with a hearing aid. The purpose of this report is to describe progress made to date in developing a system, based on a personal computer, which may be used to evaluate experimental models of the *in-situ* hearing aid.

**Progress**—The system developed is a general purpose acoustic measurement system, but is specifically configured to make magnitude and phase meas-

urements of the performance of earphones on ears and acoustic couplers. Three routines for estimating the acoustic impedance of transducers have been completed and routines (which are based on a "two-load" method) are nearly completed for estimating acoustic impedance at a defined location in the ear canal.

The software package developed for this purpose consists of a combination of dBASE III Plus (Ash-ton-Tate, Inc.) and Lattice C (Lattice, Inc.). The dBASE portion provides a convenient user-interface while the C portion provides the detailed operations

and control of sampling hardware. Four user options lie at the root of a dBASE menu: reading or making spectral acquisition set-ups, acquiring spectral data, manipulating the data (individual and group) and filing the data. The dBASE programs associated with the menus call C routines to do the specific procedures.

#### Publications Resulting from This Research

Personal Computer System to Acquire and Display Ear Canal

**Spectra: An Exhibit.** Larson VD, Ahlstrom CJ, Egolf DP, Cooper WA, Talbott RE, *ASHA*, 19, 1987.

**A System for the Acquisition and Analysis of EEG Signals Evoked by Audio Stimuli.** Brown BD, Gowdy JN, Larson VD, *Proceedings of the IEEE Southeast Conf 85*, 272-276, 1985.

**The Acquisition of Tympanometric Spectra on the IBM PC-XT.** Larson VD, Ahlstrom CJ, Schwartz DM, DeChicchis AD, Raevsky PF, Harrell DA, *ASHF Computer Conference*, 46, 1986.

**The Constant-Volume-Velocity Nature of Hearing Aids: Conclusions Based on Computer Simulations.** Egolf DP, Haley BT, Larson VD, *Journal of the Acoustical Society of America*, 79(5):1592-1602, 1986.

### Threshold Sound Pressure Levels (SPLs) for the ER-3A Insert Earphone

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The purpose of this research program is to study variables which influence the measurement or prediction of an individual's performance with a hearing aid. The purpose of this report is to describe the results of a project designed to compare auditory thresholds produced by a standard earphone and a hearing-aid-like earphone (the ER-3A).

**Progress**—Auditory thresholds for tonal stimuli (125 to 8000 Hz) were obtained from 90 normal subjects and 25 subjects with middle ear pathology. Test-retest studies were conducted on thirty normal subjects. All thresholds were expressed in terms of the sound pressure level (SPL) developed in couplers meeting the requirements for the NBS-9A and an HA-1 coupler for the TDH-50 and ER-3A earphones respectively.

**Results**—The results demonstrated that the ER-3A

earphone, when coupled to the ear canal with a rubber eartip, produces estimates of auditory threshold in normal observers as reliable as those produced with a standard earphone, but it provides a different estimate of minimum audible pressure (MAP) at the eardrum for lower frequencies. The differences in MAP are most likely attributable to effects related to changes in the dimensions of the residual ear canal. For the subjects with middle ear pathology, preliminary analysis of the air-conduction thresholds suggested that factors other than normal inter-test variability contributed to the differences observed with the two earphones.

#### Publications Resulting from This Research

**Insert Earphones and Conductive Hearing Loss.** Larson VD, Cooper WA, Talbott RE, Schwartz DM, Ahlstrom CJ, DeChicchis AD, *ASHA*, 28, 1986.

**A Comparison of HA-1 2-ml Couplers.** Larson VD, Ahlstrom CJ, Cooper WA, Rainbolt HB, *ASHA*, 29, 1987.

### Effects of Manipulation of the Impedance of the Ear of Normal Subjects on Selected Indices of Auditory Function

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The studies reported herein are part of an ongoing program devoted to delineating the inter-

action of the acoustic impedance of the source (earphone, hearing aid, etc.) and the impedance of

the load, as represented by the ear canal and middle ear, on the spectra of acoustic signals in the ear canal and the subsequent transfer of acoustic information through the middle ear.

**Progress**—Several procedures were used to alter driving point impedance: changes in external ear canal air pressure; elicitation of the middle ear muscle reflex; inversion of the subject; and delivery of the signal through hearing aid earmolds of varying insertion depth in order to change the ear canal volume. Indices of performance included ear canal spectral measures, pure tone thresholds, word recognition ability, and median plane localization ability.

**Results**—While the effects of trans-tympanic air pressure differences and of the acoustic reflex on auditory thresholds are similar, the effects on word recognition are markedly dissimilar. In a group of normal listeners ( $N=30$ ), as the ear canal air pressure was changed from ambient to  $-200$  or  $+400$  daPa, word recognition ability was systematically and dramatically reduced with performance being directly related to presentation level and the magnitude of pressure change.

Using a reflex activating stimulus, which was unlikely to interfere with word recognition by producing masking, by either central or contralateral-direct mechanisms, and in an adaptive procedure used to determine presentation levels at which 30 percent and 70 percent correct scores were obtained, a group of normal listeners required a presentation level 4 to 8 dB less intense when the reflex was activated.

Reasoning that, because of the similar effect on auditory threshold, spectral shaping was not a sufficient explanation for the decrease in word recognition observed, it was speculated that stiffening the ossicular chain by air pressure changes may have produced other forms of distortion. Accordingly, an experiment was designed to determine the possible

effect of trans-tympanic pressure differences on median plane localization. The results indicated that the ear with the air pressure changes lags the other by 47.6 and 59.5 degrees at  $+200$  and  $+400$  daPa respectively. Therefore, the role of phase shifts through the middle ear is currently under study.

Studies of the relationship of ear canal volume and auditory threshold and ear canal sound pressure levels (SPLs) have been completed. The results obtained show that the SPLs in the ear canal associated with the smaller volume are greater than that associated with the larger volume. Conversely, the thresholds obtained with smaller volumes required less (coupler) SPL than those obtained when the volume was larger.

The changes in both the canal SPLs and the threshold SPLs were greater in the low frequencies and negligible above 1000 Hz. The changes are greater than would be predicted by the simple ratio of the volume differences or by the ratio of driving point impedances. These data are currently being considered in the context of a model of aural acoustic impedance.

Finally, an experiment was completed in which an attempt was made to simulate the effects of increased cochlear impedance by noting the changes in ear canal SPL observed when subjects were studied in both an upright and in a body-inverted position. When a companion effect of body inversion and increased middle-ear pressure was controlled, there was a slight increase in sound pressure for frequencies below the middle ear's resonance. For frequencies above resonance, the changes were sometimes large and varied extensively across subjects. Clearly, the change in terminating impedance influenced the ear canal sound pressures.

#### **Publications Resulting from This Research**

**Relationships Among Admittance, Ear Canal Spectra and Body Position.** Cooper WA, Larson VD and Ahlstrom CJ, *Abstracts of the XVIIIth International Congress of Audiology*, Prague, Czechoslovakia, 46, 1986.

## Voice and Speech Findings in Prospective Cochlear Implant Candidates

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**Purpose**—This research project has studied the effects of adventitious profound hearing impairment on speech and voice production. Emphasis was placed on the acoustical and perceptual investigation of fundamental frequency, intensity, and duration. Previous studies showed that adventitious profound hearing impairment resulted in both acoustical and perceptual changes in speech and voice quality. Specifically, fundamental frequency became significantly higher and intensity became significantly greater in the speech of adventitiously profoundly deaf subjects. The purpose of the present study is to examine rate and duration in the speech of the adventitious profoundly hearing impaired. The factors of length of time since onset of hearing impairment and history of hearing aid use were also considered.

**Progress**—The sample consisted of 25 adventitiously (post-lingually) profoundly hearing-impaired male experimental subjects and 10 adult male control subjects. Unaided three-frequency (500, 1000, and 2000 Hz) pure-tone averages in the better ear ranged from 90–125 + dB Hearing Level (ANSI, 1969) for the experimental subjects. Hearing acuity was within normal limits bilaterally for the control subjects.

The stimuli consisted of the first paragraph of the Rainbow Passage (Fairbanks, 1960). All stimuli were read once and recorded at the subject's normal rate in a single-walled audiometric room. The onset and offset of each recorded sentence was identified on a storage screen, and absolute durations (sec) obtained (Kay Visi-Pitch, 6087DS). Total paragraph duration was determined by adding the times for the six individual sentences, thereby excluding pauses between sentences. Syllables per second were determined by dividing the number of syllables in each sentence and the paragraph by the time required to produce the stimuli.

**Preliminary Results**—The adventitiously profoundly hearing-impaired group exhibited significantly longer

( $p < 0.01$ ) speaking duration values and significantly fewer ( $p < 0.01$ ) syllables per second than the normal-hearing group for both sentences and the paragraph. The time needed for the hearing-impaired group to read the paragraph was 35 percent longer than the time required by the normal-hearing group. No significant differences were observed for subject groups with profound hearing loss of less than 10 years versus greater than 10 years, or for subject groups currently wearing a hearing aid versus not wearing a hearing aid.

Adventitious profound hearing loss had a negative effect on speaking rate. The observed decrease in speaking rate and corresponding increase in speaking duration were similar to results obtained in prelingually deaf subjects.

**Future Plans/Implications**—It has been shown that teaching appropriate duration patterns of speech improved speech rhythm, which enhanced speech intelligibility. Similarly, appropriate rate of speech should be stressed during aural rehabilitation with adventitiously profoundly hearing-impaired speakers who exhibit speaking rate abnormalities. Therapy directed at decreasing phonation time, thereby increasing syllable rate, should focus on utilizing the intact visual, tactile, and kinesthetic sensory feedback channels, due to the paucity of available auditory input.

Speech tracking, although originally designed to increase speechreading efficiency, is a technique that can be adapted to increase speaking rate. In this technique, the incoming message determines rate of speech production, allowing for a range of increasing speaking rates. Self-monitoring of speech output is required by the subject in order to match the rate, sound, feel, and look of the incoming message. The present application of aural rehabilitation has the dual purpose of improving the hearing-impaired speaker's speech rhythm and making speech more natural sounding.

## Basic Mechanisms and Rehabilitative Strategies for Presbycusis

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*Sponsor: VA Rehabilitation Research and Development Service (Project #XC251-2RA)*

**Purpose**—We have shown, through experiments using pure tone acoustic trauma, that the frequency organization of the cochlea changes during early and post-natal development. Further electrophysiological studies have confirmed that the cochlear response to various frequency stimulation is dynamic and mutable in early life. Whether this mutability continues in later life is still unknown. The consequences of such mutability are many. Changes in cochlear frequency organizations as we propose could define one of the basic mechanisms of hearing loss in old age. Once this mechanism has been defined the potential for reversal or prevention exists. Further, a changing frequency organization could result in altered perception of loudness and/or pitch in the elderly thus changing their preference for gain and frequency response characteristics in hearing aids and other amplification devices.

The purpose of the proposed experiments is: 1) to further explore the possibility of a changing frequency organization at the cochlear level with aging; and, 2) to examine the possibility of an altered preference for frequency and/or gain characteristics in amplification devices that might correlate with

this altered frequency organization. Pure tone acoustic over-stimulation has been used to define frequency organization in the mammalian cochlea. We have shown that it can be used with similar specificity for frequency organization during development. In the proposed experiments pure tone acoustic over-stimulation is used to create discrete, localized regions of sensory cell loss. The location of sensory cell loss is used to define frequency organization during aging.

In a recent study using probe microphone measurements comparing real ear insertion gain in young and old experienced hearing aid users we found that less gain was preferred, especially for the lower frequencies, in the older group. The proposed set of experiments are considered likely to provide insight into at least one of the basic mechanics involved in the deterioration of hearing during aging. By concurrently analyzing the rehabilitative process in the elderly these experiments will apply our theoretical concepts at the soonest possible time so that the best auditory rehabilitative process can be provided at the earliest possible time.

## Changes in Frequency Organization of the Cochlea During Aging

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*Sponsor: VA Rehabilitation Research and Development Service*

**Purpose**—The purpose of the current project is: 1) to determine the normal auditory morphological and electrophysiological profile within one species (Coturnix Quail) during its entire predicted lifespan in order to use this as a model for further study of mechanisms in presbycusis; and, 2) to determine if shifts in frequency organization at the cochlea, such as we have seen in early development, are also seen in the later declining years of life. These studies are expected to yield important information regarding the basic mechanisms of presbycusis.

**Progress**—Using plastic embedded serial sections, we have performed qualitative and quantitative light microscope analysis of the hair cells of the basilar papilla (cochlea) as well as the ganglion cells of the VIII nerve. Quails from age 3 months to 7 years (actuarial lifespan = 2 years) have been examined.

**Preliminary Results**—Very little difference in total hair cell number has been found over the actuarial lifespan of the quail (3 percent). Qualitatively, the accumulation of inclusion bodies, probably lipofus-

cin, was noted in the supporting cells as well as in the hair cells. Lipofuscin accumulation has also been noted in the hair cells and supporting cells of aged humans. Even at 150 percent of predicted lifespan (6-7 years) very little total hair cell loss was seen (6 percent). Ganglion cell loss, on the other hand, was much greater as a function of aging. A 25 percent reduction in the number of ganglion cells was seen over actuarial lifespan. By 6-7 years of age approximately 61 percent of ganglion cells are lost.

Far-field compound VIII nerve action potentials (AP) have been recorded in quail from 3 months to 3 years of age. The average AP threshold for tonebursts from 250Hz to 6000Hz in young adult quail (3 months) are very similar to those reported for other, non-passerine birds. No change in AP thresholds was seen up to 1 year of age. At 2 years of age some loss of sensitivity was seen across all frequencies and by 3 years of age (100 percent of actuarial lifespan) a 20dB hearing loss was noted for most frequencies. Because of the relatively flat nature of the hearing loss an examination of click evoked AP latency was performed. No difference in Wave I latency was seen between young and old quail. Anatomical analysis showed no evidence of infection or blockage, therefore, the hearing loss was presumed to be of a non-conductive nature. Finally, analysis of absolute and interpeak latencies

of the click evoked AP was performed. A significant prolongation of Wave III was seen in older birds. Since the hearing loss was not conductive, this latency delay was interpreted as a delay in neural conduction time.

**Future Plans/Implications**—These results are in good agreement with previous quantitative studies in mammals and suggest that a loss of spiral ganglion cells may be a generalized response to aging in both mammals and non-mammals. Further, the delay in neural conduction time seen in the early component waves of the AP correlate well with the decrease in ganglion cell number. This delay in neural conduction time deserves further study in humans in that it may be an early indicator of neural presbycusis.

#### Publications Resulting from This Research

**Ganglion Cell and Hair Cell Loss in Coturnix Quail Associated with Aging.** Ryals BM, Westbrook EW, *Assoc. for Research in Otolaryngology Abstract* 151:119, 1987.

**Development of the Place Principle.** Lippe WR, Ryals BM, Rubel EW, *Advances in Neural and Behavioral Development*, Volume II, R.N. Aslin (Ed.), Ablex Publishing Co., Norwood, NJ, 1986.

**Ontogenetic Changes in the Position of Hair Cell Loss after Acoustic Overstimulation in Avian Basilar Papilla.** Ryals BM, Rubel EW, *Hearing Research* 19:135-142, 1985.

**Differential Susceptibility of Avian Hair Cells to Acoustic Trauma.** Ryals BM, Rubel EW, *Hearing Research* 19:73-84, 1985.

## An Auditory Prosthesis for Sensorineural Hearing Loss

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #XDC054-3RA)

**Purpose**—The object of the proposed research is to determine optimal design parameters and fitting procedures for a new multichannel compression hearing aid for patients with sensorineural hearing loss (SNHL). During the past six years, the initial 8-channel version of the new aid has been developed and tested in the laboratory on over 20 SNHL patients. This 8-channel compression hearing aid proved very effective in helping the patients to recognize speech sounds in the presence of noise—a key problem for individuals with SNHL. The new 8-channel aid not only produced better speech recognition performance than an individually best fit

conventional hearing aid in most patients, but in 20 percent of the patients tested, the 8-channel compression hearing aid produced essentially normal speech recognition in noise even when the speech itself was no louder than the noise. The conventional hearing aid did not produce such a high level of performance in any of these patients. This high degree of success of the initial version of the new aid mandates further work on a compression hearing aid of the same general design. Some aspects of the design of the initial aid suggest that the aid can be improved, while aspects of the results suggest that, in many subjects, even the initial 8-channel

multichannel version of the aid may be more effective than our present results indicate.

The complexity of our multichannel compression hearing aid precluded any attempt to determine optimal design parameters or fitting procedures in the initial experiments. Indeed, all research on multichannel compression hearing aids is limited by the complexity of multichannel compression systems. In response to this problem, the proposed research will begin with the already highly successful preliminary model and concentrate primarily on those parameters of the hearing aid that impact most

heavily upon improved performance, production costs and the length and complexity of the procedures required to fit the aid to the patient. On the basis of the previous results, we expect the proposed research to determine the specifications for a multichannel compression hearing aid that will yield near-normal hearing performance in appreciably more than 20 percent of the SNHL population and that will yield better performance than other hearing aids in the remainder of the SNHL population, as well.

### Transition Study of Persons with Hearing Impairments

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*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—Little is known about the movement of persons with hearing impairments from the school to the community, a process that has come to be called “transition.” The purpose of this 3-year project is to examine the transition from school to the community for students who are hard of hearing, deaf, or have hearing impairments and secondary disabilities (e.g., deaf-blindness).

**Progress**—There are four major research thrusts of this project. First, to learn about the transition processes of persons with hearing impairments, an intensive study is being conducted of these students who have left school systems/programs in the Northwest. Longitudinal follow-up and follow-along designs are employed. The follow-up design allows for contact with respondents once, 3 years after they have left the educational setting. The follow-along design differs in that initial contact is made at school exit, and annual contact is continued with these students throughout the project. Both designs utilize multiple data sources to provide a large database.

In addition to the data collection efforts undertaken for the targeted groups, we are also gathering data on comparable groups of students without handicaps from the participating sites, as a control. Second, a national survey of transition-planning mechanisms for the target population has been conducted, and a profile of the service structure is being finalized. Third, an investigation will be con-

ducted in the second project year that will include educators, rehabilitationists, parents of students with hearing impairments, and persons with hearing impairments, to identify weaknesses in existing transition systems. Fourth, variables associated with successful transition mechanisms have been identified via a review of the literature and analysis of exemplary transition linkages. Model transition programs will be summarized and described.

**Preliminary Results**—All first-year data have been collected for the first objective (follow-up and follow-along studies). These data have been coded and are currently being analyzed. With the addition of second and third year data, the number of subjects included in the study will increase. It is anticipated that by the end of the project a total of 400-500 students with hearing impairments, and an equal number of students without handicaps, will be involved.

The second objective, the national survey of transition planning, has been completed. We have obtained matched pairs of vocational rehabilitation and education surveys from 34 states. (An article has been submitted for publication on the results of this survey.)

**Future Plans/Implications**—Both follow-up and follow-along studies will continue during the next two years of the project. The investigation to identify

weaknesses in existing transition plans was scheduled to begin in the fall of 1987 and be completed in the fall of 1988.

Variables associated with successful transition are continually being gathered via our different data collection efforts. This information will be disseminated through publications and presentations by project staff. Our overall objective continues to be to improve the transition into the community of youth with hearing impairments. Project outcomes, based on the empirical evidence gathered, will serve to suggest new and innovative ways to assist in the transition processes of secondary students with hearing impairments.

## Technology for Sensory Devices for Deaf and Severely Hard of Hearing People

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*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—Many people with severe or profound hearing losses make extensive use of devices that take advantage of alternate senses, particularly vision and tactition. Despite the proven usefulness of devices such as Telecommunication Devices for the Deaf, visual and tactile signalling systems, and captioning devices and systems, relatively little government-supported development of these devices has been undertaken.

This study is part of a 2-year research and demonstration project for NIDRR on: 1) the need for devices in this category; 2) emerging technologies that should be exploited for this purpose; 3) financing mechanisms to assist consumers in acquiring devices in this category; and, 4) how government might best work with businesses to achieve a greater variety of useful devices.

**Progress**—During the first year of the project, we conducted 15 focus-group discussions with hearing impaired people about their current uses of technology, opinions about the devices they are now using, and hopes for future devices. An annotated bibliography was created on devices in this category.

Technology-assessment papers were prepared on three areas which seem to hold promise for future development of devices: speech recognition technology for captioning speech; image-processing

## Publications Resulting from This Research

**Research on the Community Transition of Adolescents and Young Adults with Hearing Impairments: An Annotated Bibliography.** Bull B, Bullis M, Sendelbaugh J, Teaching Research Division, Oregon State System of Higher Education, Monmouth, OR (in press).

**Review of Research on the Community Transition of Adolescents and Adults with Hearing Impairments.** Bullis M, Bull B, Sendelbaugh J, Freeburg J, The Catholic University, National Rehabilitation Center, Washington, DC (in press).

**Adolescents and Young Adults with Hearing Impairments.** Bullis M, Freeburg J, Bull B, Sendelbaugh J, *Issues and Research in Special Education*, Vol. 1 (Invited chapter), R. Gaylord-Ross (Ed.), Teacher's College Press, New York, NY (in press).

technology for telecommunication of sign language and/or lipreading; and signal processing for detection of acoustic signals in noise.

Mail and telephone surveys were conducted with the goal of identifying financing programs that help consumers to acquire sensory-substitution devices. A directory of sources of financing will be one outcome of the project.

Manufacturers and distributors of sensory devices were interviewed to ascertain whether they used the research or technical assistance available from rehabilitation engineering facilities. Their suggestions were sought on ways that government-supported programs might stimulate development in their industry.

**Preliminary Results**—A 30-page report available from our program describes the results of our discussions with consumers. Some basic findings: hearing impaired consumers find text output very useful in receiving communication from the environment. They expressed a desire for increased captioning of spoken communication—more captioning of television, including local programming, and of movies. For the future, consumers repeatedly mentioned the potential of speech recognition technology for automated captioning of any and all speech. Despite the existence of visible and tactile signalling systems

for alerting and paging the hearing impaired person, many particular environmental sounds go undetected. Troublesome areas included knowing when something is still on (oven fans, cars, running water) and emergency sirens (in traffic, in case of environmental hazard, in case of natural disaster). Preliminary results from interviews with 14 manufacturers and distributors indicate that this industry has not received much advantage from government-supported research on devices. Many were unaware of the existence of rehabilitation engineering centers. A few were aware of the Trace Center. (These

results do not include the National Captioning Institute.)

**Future Plans**—In the second year of the project, the technology-assessment reports will be completed and compiled into a volume on emerging technologies that hold promise in this class of devices. A volume of sources of financing for sensory devices will be completed and disseminated. A demonstration activity will be conducted on making sirens of emergency vehicles accessible to hearing impaired people.

### Project PALS (Places with Assistive Listening Systems)

**Selig Starr and Carolyn Rossick**

Self Help for Hard of Hearing People, Inc., Bethesda, MD 20814

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The goals of this project are to maintain a current inventory of all places in the United States that have assistive listening systems (ALS) and to provide lists of sites with ALS in specific locales in response to requests from hard of hearing people and others with a legitimate interest. The sites include cultural, religious, and community activities.

ALS help hard of hearing people to hear better and understand more in large areas that are subject to interference such as background noise, reverberation, and distance between the speaker and listener. Used with microphones or coupled to an existing public address system, ALS deliver sound directly to the listener's ear at a consistent volume, despite any interference (noise). There are five major ALS types in use: infrared, audio induction loop, FM, AM, and hardwired.

**Progress**—The project has been publicized widely. Organizations and publications that are concerned with hearing impaired people have been informed of the project. The SHHH chapters and groups (over 200) have been encouraged to help locate ALS sites.

A corps of SHHH volunteers are actively involved. The manufacturers of ALS are providing data on past installations and will provide data on new installations.

The inventory of ALS is maintained in a database on a microcomputer. This allows the data to be searched quickly and organized in a variety of useful ways. The project is in the preliminary stages. There are an estimated 15,000 to 20,000 ALS in the United States; as of September 1, 1987, we have information on about 5,500.

**Future Plans/Implications**—The plan is to bring the ALS inventory up to date and keep it current through additions and revisions. Depending on resources, the project will be expanded to include an inventory of sites (e.g., hotels) with assistive listening devices to accommodate the communication access needs of hearing impaired people. This would include, for example, telephone amplification devices, TDD's telecaptioning TV decoders, and visual alert systems to alert a hearing impaired person of smoke, fire, knock on the door, telephone call, etc.

## AKL Spatiotemporal Representation in a Tactile Aid for the Deaf

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**Grayson D. Abbott**

Creare, Inc., Hanover, NH 03755

*Sponsor: National Institutes of Health*

**Purpose**—The objectives of this contract are the conduct of a series of studies to evaluate the spatiotemporal pattern recognition capabilities of the skin for conveying speech information to deaf, deaf-blind, and severely hearing-impaired persons. Phase I will consist of an evaluation of the effectiveness of the Auditory/Karhunen-Loeve (AKL) represen-

tation, a Principal Components Analysis of English speech, in conveying the speech code to the skin and the development of a "real-time" AKL system. Phase II will include the determination of the optimum configuration of AKL parameters and the development of a breadboard system of the AKL processor.

## Speech Perception Studies—Bimodal and Developmental

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**Lynne E. Bernstein**

Johns Hopkins University, Baltimore, MD 21218

*Sponsor: National Institutes of Health*

**Purpose**—The research is concerned with speech perception in normal adults and children and profoundly deaf children. A research theme will be perceptual learning, both in terms of development and during periods of training. Bimodal speech perception will be a focus of many of the proposed experiments. Combinations of stimulation to two out of the three senses, audition, vision, and somesthesia, will be used to examine basic constraints on bimodal speech perception as well as to evaluate schemes that may have practical significance in the design of aids for the profoundly deaf.

**Progress**—Project I is a systematic study of candidate transformations between voice FO and single channel vibrotactile stimulation. Results will be incorporated in a long-term evaluation of aided lipreading by hearing, "artificially deafened," young adults. Project II is a series of experiments on coding cues to segmental phonetic distinctions. Audio-visual and tactile-visual stimulus presentation will be used in a standard procedure that allows for comparison across coding schemes. Project III is

concerned with normal development of speech perception between ages 3-4 years and early adolescence. Experiments will be used to study whether there is a developmental hierarchy of phonetic segmental cues. Project IV continues current work on tactile sensitivity thresholds as a function of age and stimulus waveshape. Prelingually, profoundly deaf children will be tested to determine whether vibrotactile perception is affected by auditory experience. Work on Project IV will also include development of training and testing protocols using computer graphics. Protocols will be developed to train and test children on bimodal speech perception schemes. The proposed research is particularly important for individuals whose hearing loss is such that they are unable to derive significant speech information from the auditory channel. Electrical stimulation of the cochlea (implant) is gaining increasing attention as an aid for the deaf. At this time, as young children are having this expensive and traumatic implant operation, it is important that progress be made in devising wearable vibrotactile aids as a reasonable alternative.

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## Tactile Communication of Speech

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**Nathaniel I. Durlach**

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*Sponsor: National Institutes of Health*

**Purpose**—The ultimate goal of our research program is to develop tactile aids for the deaf and deaf-blind that can serve as substitutes for hearing in speech communication. To the extent that this research is successful, it will enable people who are deaf to achieve substantially improved speech perception, speech production, and overall language competence. In addition, it will provide increased knowledge about the basic nature of speech communication, about the general capabilities of the tactile sense, about underlying principles for the design of displays, and about sensory substitution and human plasticity.

**Progress**—The research proposed in the application is divided into four parts. The first concerns methods of tactile communication that have evolved within the deaf-blind community and includes study of the Tadoma method, in which speech is perceived by placing a hand on the face of the talker, and also

Tactile Signing and Tactile Fingerspelling. The second includes study of Augmented Tadoma, in which the remarkable performance achieved with Tadoma is improved by adding an auxiliary tactile display of information on tongue position, and Synthetic Tadoma, in which a simulation of Tadoma that uses an artificial talking face is used as a research tool to dissect Tadoma and evaluate its components. The third compares artificial speech-reception aids that present short-term spectral information by means of homogeneous arrays of tactile stimulators. A variety of such aids are evaluated using common experimental procedures and subjects, and attempts are made to interpret results in terms of speech-parameter resolution and tactile psychophysics. The fourth involves basic study of encoding and display problems and is directed towards improved information transmission through the use of more effective encoding schemes and perceptually richer display systems.

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## Cutaneous Communication Aids for the Deaf

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**Moise H. Goldstein, Jr.**

Johns Hopkins University, Baltimore, MD 21218

*Sponsor: National Institutes of Health*

**Purpose**—The goal of the research is to provide a wearable vibrotactile speech communication aid for prelingually, profoundly deaf children. The proposed work aims to achieve a design which uses a single or a few channels. A primary function of these aids shall be acquisition and enhancement of lipreading skills.

Three projects are proposed. Project I is a systematic study of candidate transformations between FO and single channel vibrotactile stimulation. Results will be incorporated in a long-term evaluation of aided lipreading by hearing, "artificially deafened," young adults. In Project II, current microprocessor technology will be used to achieve a several-channel aid that presents FO and additional segmental information, with again, evaluation of

aided lipreading. Project III is a model of the auditory periphery that will be a basis for design of a superior acoustic signal processor for aids for the deaf. The model is a computer simulation of the auditory periphery, from acoustic input to representation of temporal-spatial characteristics of neural firing by the population of auditory nerve fibers. It will include the neural coding of speech sounds as revealed in experimental work at this University.

The proposed research is important for individuals whose hearing loss is such that they are unable to derive significant speech information from the auditory channel. Electrical stimulation of the cochlea (implant) is gaining increasing attention as an aid for this population. For the post-lingually deaf adult, an implant is often beneficial; although only in very

rare cases does it provide reception without lipreading. It is critical at this time (as young children are having the expensive and traumatic implant opera-

tion), that progress be made in devising wearable vibrotactile aids that provide a reasonable alternative.

## Rehabilitation Strategies for the Hearing Impaired ---

**Harry Levitt; Nancy M. McGarr; Arthur Boothroyd**  
CUNY Graduate School, New York, NY 10036

*Sponsor: National Institutes of Health*

**Purpose**—Rehabilitation strategies for the hearing impaired will be developed and evaluated. Strategies for speech and auditory training of hearing impaired children and adults will be considered. The impact of tactile and visual sensory aids on learning rates will be investigated and new types of sensory aids will be developed including computer-simulated experimental hearing aids and wearable multichannel

tactile displays. Methods of rehabilitation training for cochlear implant recipients will be developed and evaluated. Analytic and global methods of training will be compared. Comparisons with tactile aids and conventional hearing aids will also be undertaken. The proposed research should result in improved rehabilitation techniques for a wide range of hearing impairments and methods of intervention.

## Reading and Writing Skills in the Congenitally Deaf ---

**Donald F. Moores and Ann E. Geers**

Gallaudet College, Washington, DC 20002 and Central Institute for the Deaf, St. Louis, MO 63110

*Sponsor: National Institutes of Health*

**Purpose**—The purpose of this procurement is to study two different groups of congenitally deaf individuals: those trained via Total Communication; and those exposed to American Sign Language from early development. The contractor has access to a large number of congenitally deaf adolescents who received their early language training through one of these two approaches. Collaboration will occur between the National Institute of Neurological and

Communicative Disorders and Stroke (NINCDS), the contractor, and another institution chosen to study the Oral Approach. The institution will select, design, and construct standardized and experimental test procedures. The main objective of this project is to identify the factors related to the outcome of reading and writing training within each of the three approaches.

## Factors Predictive of Reading and Writing Skills in the Congenitally Deaf ---

**R.F. Raubertas**

National Institute for Neurological and Communicative Disorders and Stroke, National Institutes of Health, Bethesda, MD 20892

*Sponsor: National Institutes of Health*

**Purpose**—This project consists of the statistical and data management aspects of a Communicative Disorders Program contract. Tasks include design of data collection and monitoring procedures, and statistical analysis of study data. The study will examine factors that may be associated with development of

reading and writing skills in the congenitally deaf. Study subjects will comprise three groups of deaf 16- to 17-year-olds, with 65 subjects in each group. Each group will include only subjects who received their preschool language training through one of three approaches: aural-oral, total communication,

and American Sign Language. Data will be collected on the audiologic, familial, and educational background of the subjects, and on their present language skills. These data will be examined for their asso-

ciation with present reading and writing skills of the subjects. A pilot study has been completed and the main data collection phase is now in progress.

## Development of a Wearable Vibrotactile Aid—Phase II

**Brian L. Scott**

Scott Instruments Corporation, Denton, TX 76205

*Sponsor: National Institutes of Health*

**Progress**—The major concern of the Phase I feasibility study was the design of a wearable vibrotactile array. The proposed design consists of seven piezoelectric vibrators with all electronics and vibrators in one package, and the power supply in a second package. Each package measures approximately 2 1/4 inches × 6 1/2 inches × 3/4 inch and is designed to be worn on the forearm of an adult or on the thigh of a small child. Each vibrator will have a separate filter and driving circuit associated with it to allow for the investigation of various coding schemes. Phase II development is divided into four stages: 1) construct breadboard devices with three

different coding schemes; 2) evaluate the bench models on four functionally deafened and four profoundly deaf adult subjects and select one of the coding techniques; 3) construct twelve wearable units (engineering prototypes); and, 4) field test the wearable units on six additional profoundly hearing impaired adults and contrast their performance with six non-aided control subjects. It is anticipated that Phase II development will result in a production ready vibrotactile aid for the profoundly hearing impaired with enough inherent flexibility to support alternative speech coding strategies.

## The Role of the Haptic System in Communication

**Carl E. Sherrick**

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*Sponsor: National Institutes of Health*

**Purpose**—In continuing the study of the conditions under which tactile patterns are most accurately and speedily recognized, this project is aimed at problems of both a basic and applied character. On the basic side, the problem of suitability of different skin areas for information processing persists, and this will be taken up in the grant period by direct attack. Selected body sites will be examined in both hearing and deaf populations for standard psychophysical functions, including, but not restricted to, absolute and differential thresholds for intensity and rate, spatial and temporal limens for pulses, magnitude estimation for intensity, and pattern recognition at various levels of complexity.

Further work on the problems of pattern recognition will be done using the locally constructed tactile matrices for the palm and thigh, and the

Optacon fingertip display recently acquired. Comparisons among these areas for a variety of processing capabilities are now possible, including growth of loudness with increasing number of vibrators, and the problem of pattern discrimination with increasing communality of elements between pairs.

There will continue to be an analysis of the saltation effect, discovered in this laboratory. Of special interest is the variation of the apparent position of the saltatory phantom with repeated exposure found in the visual system, and to be searched for in the cutaneous sense. In addition, the primary determinants of the degree of saltatory leap, viz., locus, time, and intensity, will be examined for their relative influence on saltation in selected body sites.

For some time, it has been the orientation of the

Princeton Cutaneous Project to attempt to balance the basic and applied aspects of empirical inquiry. The comparative fidelity of transmission of speech information by single- and multi-channel vibrators is an applied research effort of the laboratory that serves to supply information to developers and other investigators, while at the same time presenting the investigators of this project with questions that may

lead to basic research work. The aim and hope of this approach is to serve the medical sciences with two hands, so to speak: providing the basic information on normal mechanisms of information processing by the skin, while suggesting means by which the mechanisms may replace those in other senses that are undeveloped or lost.

### Development of a Cochlear Prosthesis ---

**Blair F. Simmons**

Division of Otolaryngology, Stanford Medical Center, Stanford, CA 94305

*Sponsor: National Institutes of Health*

**Purpose**—The objective of this project is to create hearing and at least limited speech comprehension in totally deaf persons by electrical stimulation of the auditory nerve. Deaf human volunteers receive multi-electrode implants within the inner ear. Basic psychophysical stimulation experiments measure the range of auditory percepts for each electrode and this data is then used as design criteria for the

development of computer-generated “speech processors” or acoustic feature detectors. The processors so developed are used to code speech sounds for electrical stimulation. Concomitant with this human research are animal experiments verifying the safety, tissue tolerance, and other features helpful and necessary for the human research.

### Wearable Multipoint Opto-Tactile Transducer for the Deaf or Blind ---

**Javier A. Valenzuela**

Creare, Inc., Hanover, NH 03755

*Sponsor: National Institutes of Health*

**Purpose**—The purpose of the work is to assess the feasibility of developing a wearable multipoint opto-tactile transducer for the deaf or blind by building and evaluating a desk-top, laboratory version of the transducer. The objectives will be accomplished by: 1) reviewing technical literature on opto-tactile perception; 2) designing and fabricating a laboratory

laser-tactile transducer; 3) characterizing and testing the response of the skin to the transducer stimulation; 4) identifying the technical developments needed to fabricate the transducer (if the tests show that optical stimulation is feasible); and, 5) reporting all results of the work in a final report.

### Basic and Applied Studies of Tactile Perception ---

**Janet M. Weisenberger**

Central Institute for the Deaf, Research Department, St Louis, MO 63110

*Sponsor: National Institutes of Health*

**Purpose**—The proposed research combines basic and applied laboratory studies with clinical and educational approaches to provide new information about the basic abilities of the tactile system and

the design and evaluation of tactile aids for speech perception of deaf persons.

In basic studies, the temporal properties of the tactile system are outlined using amplitude-modu-

lated stimuli and masking paradigms with vibratory stimulus presentation. Knowledge of these temporal abilities, in addition to their basic research interest, should prove useful for the design of effective tactile aids.

In applied laboratory, clinical and educational trials, three different types of experimental tactile aids will be evaluated. First, studies will continue with a single-channel vibrotactile aid worn on the chest by very young deaf children, to determine whether the aid will improve their ability to attend to and produce sounds. Second, a binaural two-

channel earmold vibratory stimulator will be tested with adults for its potential as a speech aid, both alone and as part of a hybrid auditory-tactile aid. Finally, the effectiveness of multichannel (16 or more) vibratory aids in improving the understanding of speech and the accuracy of a child's own speaking will be evaluated with deaf children enrolled in the CID school. Information from these studies should determine the situations in which each type of aid might be useful, and also point out needed improvements in the design of each kind of aid.

## C. Speech Impairment

### 1. Hearing Related

#### Measurement and Prediction of Benefit from Amplification

Robyn M. Cox, Ph.D.; Kay M. Pusakulich, M.A.; Genevieve C. Alexander, M.A.; Christine Gilmore, M.A.  
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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The objective of this 2-year project is to develop and validate a test of intelligibility of everyday speech called the Connected Speech Test (CST). The project plan calls for four major experimental phases: 1) investigation of the intelligibility characteristics of a typical talker and selection of a typical talker to record the initial pool of test items; 2) generation and evaluation of the initial pool of CST test items; 3) generation of final CST test forms; and, 4) evaluation of final CST test forms.

**Progress**—In the past year, phases 2 and 3 have been completed. In phase 2, 72 passages of connected speech were audio-visually recorded on optical disk by the talker selected in phase 1. Twenty-five key words in each passage, five in each of five categories of difficulty, were empirically determined. In accomplishing this, the number of test passages was reduced to 57. In phase 3, 40 hearing-impaired subjects, divided into four groups according to hearing loss, provided intelligibility data for the key words in each of the 57 test passages.

**Preliminary Results**—A version of the CST for nor-

mal hearers was defined. This test consists of 48 test passages of equal intelligibility. The performance-intensity slope is 12 rationalized arcsine units (rau)/dB signal-to-babble ratio. For pairs of scores, each based on mean performance across four randomly-chosen passages, the 95 percent critical difference is about 14 rau.

Intelligibility data from the hearing-impaired subjects were analyzed to determine whether scores obtained for a passage were significantly related to the proportion of particular phonetic categories (e.g., voiced plosives) in the key words. Results indicated that some groups of subjects did reveal significant relationships. Consequently, the 48 passages were divided into 24 pairs with all pairs equalized in the proportion of sounds (in scoring words) in the affected categories. The resulting test consists of 24 sets of 2 passages each. On average, all sets are equally intelligible for hearing-impaired listeners. For pairs of scores, each based on mean performance across three randomly-chosen sets of passages, the 95 percent critical difference is about 15 rau.

**Future Plans/Implications**—In phase 4, 24 additional

hearing-impaired subjects will audit the final form of the CST. Scores will be analyzed to determine equivalence and reliability data and the performance-intensity function for the final test.

#### Publications Resulting from This Research

**Intelligibility of Average Talkers in Typical Listening Environments.** Cox RM, Alexander GC, Gilmore C, *Journal of the Acoustical Society of America* 81:1598-1608, 1987.

**Development of the Connected Speech Test (CST).** Cox RM,

Alexander GC, Gilmore C, *Ear and Hearing*, 1987 (in press).

**Composite Speech Spectrum for Hearing Aid Gain Prescriptions.** Cox RM, Moore JN, *Journal of Speech and Hearing Research*, 1987 (in press).

**Intelligibility of Average Talkers in Typical Listening Environments.** Cox RM, Alexander GC, Gilmore C, Pusakulich KM, presented at the National Convention of the American Speech-Language-Hearing Association, 1986.

**Development of the CST for Measuring Hearing Aid Benefit.** Cox RM, Alexander GC, Gilmore C, Pusakulich KM, accepted for presentation at the National Convention of the American Speech-Language-Hearing Association, 1987.

## Computerized Treatment of Acquired Reading Disorders: Treatment of Alexia and Agraphia

**Leslie J. Gonzalez Rothi, Ph.D.**

Audiology and Speech Pathology, Veterans Administration Medical Center, Gainesville, FL 32602

**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—The purpose of this project is threefold. First, to develop therapy tasks that are suitable to improve deficient reading strategies associated with the lexical or phonological routes of single word reading: to computerize these tasks and assess the efficacy of the treatment protocols for patients with alexia with agraphia. Second, to develop a second level of tasks utilizing stimuli of greater than one-word length and assess the efficacy of using both level 1 and 2 tasks for cases of alexia without agraphia. Third, to develop therapy tasks suitable to improve deficient spelling strategies associated with lexical or phonological routes of spelling: to computerize these tasks, and assess the efficacy of the treatment protocols for patients with agraphia.

**Progress**—All treatment tasks have been designed and reading levels 1 and 2 treatment tasks have been computerized. As of August 1987, computerization of the spelling tasks were completed. We have thus far completed treatment protocols on 20 patients on level 1 reading and three patients on level 2 reading tasks. Treatment protocols for the spelling tasks were begun in August 1987.

**Preliminary Results**—No group data will be analyzed until all subjects have completed the projects. However, a number of single case studies have been reported as part of, or adjunct to, this research program (see below).

**Future Plans/Implications**—As our knowledge of normal reading and spelling expands, the models change as to the corresponding predictions about reading and spelling abnormality. The distinctions between lexically-derived and nonlexically-derived phonology, as well as nonlexically-derived meanings of written material, allow for expansion of our model from a dual route to a 3-route model. New treatment tasks will need to be developed to follow these distinctions for more specific remediation.

#### Publications Resulting from This Research

**Isolated Lexical Agraphia.** Rothi LJG, Roeltgen DP, Kooistra C, *Brain and Language* 30:181-190, 1987.

**Phonological Alexia with Optic and Tactile Anomia: A Neuropsychological and Anatomical Study.** Rapcsak SZ, Rothi LJG, Heilman KM, *Brain and Language* (in press).

**Treating Surface Dyslexia in A CHI Patient.** Moss SM, Rothi LJG, *Journal of Clinical and Experimental Neuropsychology* (in press).

#### Presentations

**Deep Dyslexia in a Wernicke's Aphasia.** Fleet WS, Raade A, Rothi LJG, Heilman KM, *Academy of Aphasia*, Nashville, TN, 1986.

**A Neuropsychological Approach to Aphasia Rehabilitation.** Rothi LJG, *The 12th Annual Course in Behavioral Neurology and Neuropsychology*. The Florida Society of Neurology, Orlando, FL, 1986.

**Treatment of Alexia and Agraphia in Adult Brain Damaged Patients.** Rothi LJG, *The 12th Annual Course in Behavioral Neurology and Neuropsychology*. The Florida Society of Neurology, Orlando, FL, 1986.

**Hemispheric Specialization for Writing in Right-Handers.** Mack

L, Heilman KM, Rothi LJG, *International Neuropsychological Society*. Washington, DC, 1987 (Abstract, *JCEN*, 9:31, 1987).

**Computerized Treatment of Alexia Without Agraphia: A Case Report.** Moss SE, Rothi LJG, *International Neuropsychological Society*, Washington, DC, 1987 (Abstract, *JCEN*,

9:39, 1987).

**A Six-year Follow-up Study of Language and Cognitive Development After a Left Hemisphere Infarct in a 9-Year-old-Girl.** Voeller K, Rothi LJG, Arnus J, *International Neuropsychological Society*, Washington, DC, 1987 (Abstract, *JCEN*, 9:40, 1987).

## Acoustic Vowel Measures Following Radiation Therapy to the Larynx

**Richard W. Trullinger, Ph.D. and Dean C. Elliott, M.D.**  
Veterans Administration Medical Center, Augusta, GA 30910

**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—Often patients who have undergone radiation therapy (XRT) for laryngeal carcinoma confined to the true vocal folds, in the absence of positive neck nodes and/or metastases, are referred for voice therapy because of a residual hoarse voice. Generally the hoarseness diminished over time, following the completion of XRT, but the time, course, and degree of voice change have not been documented thoroughly. The overall objective of this study, therefore, is to compare perceptual, acoustic, and physical data of such cancer patients to normal-speaking controls as a function of time.

The study will ideally investigate the following questions: 1) What is the mean spectral noise level, jitter, shimmer, and fundamental frequency associated with the sustained production of five different test vowels for each data collection, i.e., baseline, once each week for 6 to 8 weeks, and at one month intervals for one year for both groups? 2) Do the data obtained for the pathologic group differ from those obtained for the normal-speaking group? 3) Are there differences between pre- and one-year post-XRT acoustic measurements, and apparent success of the XRT as evaluated visually by the surgeon who first identified the laryngeal pathology

and perceptually by a panel of speech pathologists who often provide post-XRT management to improve voice quality? 4) Do the test vowels differ with regard to the acoustic and perceptual measures? and, 5) Can a relationship be shown among acoustic and perceptual measures and alcohol consumption, smoking behavior, dry mouth, and/or amount of radiation received?

**Preliminary Results**—Procurement of software necessary to the collection of the proposed acoustic vowel measurements has begun. To date, the software to retrieve spectral noise level measurements has been written. Because funding for the study was just received, only partial data have been collected on three cancer patients.

**Future Plans/Implications**—Completion of this study will be realized with the collection and analyses of data for 20 pathologic and 20 normal-speaking individuals. The findings will aid our decision-making process regarding voice management care of patients with small laryngeal cancers that have been treated with XRT.

## Language Performance in Cleft Palate Adolescents

**K. McCann (Student), B.Sc.(C.D.)**  
Hugh MacMillan Medical Centre, Toronto, Ontario, Canada M4G 1R8

**Sponsor:** Hugh MacMillan Medical Centre Student Research Award

**Purpose**—This research project is an extension of a pilot study investigating the receptive and expressive language skills of adolescents with cleft lip and/or cleft palate. Results of the pilot study indicate that

the language abilities of cleft palate adolescents differ significantly from age-matched adolescents in the normative population. These results support the majority of research demonstrating a delay in the

language skills of cleft palate individuals. However, a larger sample size is necessary in order to effectively examine the nature of the language deficit and to investigate further those variables which serve as early predictors of later language functioning in the cleft palate population.

**Progress**—Twenty male and female individuals aged

11 to 20 years old inclusive with a repaired congenital cleft lip and/or palate will participate in this study. Each subject will complete the *Test of Adolescent Language*, the "Sentence Combining" subtest of the *Test of Language Development—Intermediate* and the *Test of Nonverbal Intelligence*. Subject scores will be compared with data from the normative population.

### The Use of Microcomputers in Diagnosis and Rehabilitation of Adult Aphasic Individuals

**Katharine Odell, M.S.; Michael Collins, Ph.D.; Charles C. Lee, M.S.; Gregg C. Vanderheiden, Ph.D.**  
Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This project involves a series of studies to investigate the feasibility of using microcomputers in the diagnosis and treatment of adult aphasic individuals. The first study compared the performance of aphasic subjects on a computerized and standard version of the Colored Progressive Matrices (CPM), a visual, non-verbal problem-solving task. The second study examined the relative efficiency with which aphasic adults use different computer input systems (i.e., keyboard, long range light pen, stylus, touch-sensitive screen, and joystick); performance on a measure of reading comprehension was compared across all interface systems. Results of that work will assist in the selection of appropriate input systems for aphasic users. Further, analysis of response characteristics using each of the interface systems will address the theoretical question of competition for cognitive resources: i.e., the degree of cognitive ability required of aphasic users to both operate the device and proceed with the test.

Another study in the series will investigate computer strategies for recognizing perseveration and self-correction attempts and will develop software to both interrupt perseveration and facilitate self-correction tendencies. The behavioral tool for this study is a computerized version of the Revised Token Test (McNeil and Prescott, 1978), a measure of auditory comprehension on which aphasic subjects are likely to display perseveration or self-correction tendencies.

**Progress**—*Study 1:* Comparisons of performance on

the standard and computerized version of the CPM has shown that quality of performance in terms of percentage correct and response time does not vary significantly across test versions for our samples of severely, moderately, and mildly-impaired subjects (Odell, Collins, Dirkxs and Kelso, 1985), "A Computerized Version of the Colored Progressive Matrices," in *Clinical Aphasiology Conference Proceedings 1985*, R. Brookshire (Ed.), BRK Publishers, Minneapolis, MN.

*Study 2:* The reading measure for this project is a multiple choice synonym-identification test, with two levels of difficulty. A different test was developed for each interface system; all tests were designed to be equivalent in grade level. Algorithms for scoring and response time data collection were devised. A Latin Square (complex) design was used for the study. Ten of the 12 subjects have been tested.

*Study 3:* The software routine developed for the Revised Token Test has been completed, including token movement, scoring, data collection, and speech generation algorithms. Programming algorithms for perseveration interruption and self-correction facilitation are being completed. A series of single-subject design studies using a multiple-treatments design is planned. One portion of the test will focus on perseveration and will initially involve two subjects; the second portion will focus on self-correction and also initially involve two subjects.

**Future Plans**—Extension of Study 2 to compare the mouse device and other access systems is being considered.

## The Acquisition of Morphological Processes in American Sign Language (ASL)

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*Sponsor: National Institutes of Health*

**Purpose**—The general objective of our research is to study the human capacity for language. We aim to investigate to what extent the overall form and organization of language is determined by the articulatory and perceptual modality in which it has developed, and to what extent these represent more fundamental aspects of human cognition. As a research tool, we study American Sign Language (ASL), the system of hand signs developed by deaf people in the absence of speech. We find that ASL differs dramatically from English and other spoken languages in some of the mechanisms by which its lexical units are modified. For the form of its inflectional and derivational processes, the mode in which the language develops makes a crucial difference.

In this grant we propose to study the acquisition of three contrasting subsystems of ASL: 1) The system of morphological processes which operate on signs, simultaneously changing or adding specifications for dimensions of movement to the root form of the sign; 2) compounding processes which

are essentially sequential combinations of signs, bound together by particular rhythmic properties which differentiate them from phrases; and, 3) spatial indexing, a system which includes the establishment of loci for non-present referents in the signing space between signer and addressee, and anaphoric reference by pointing or by inflection of verb. Detailed longitudinal studies of spontaneous mother/child interactions on videotape are augmented with experimental interventions. We have chosen to investigate the acquisition of specific aspects of the grammar, selected so that some are most like and some are most unlike comparable processes in spoken language. In the process, we investigate the acquisition of some of the most distinctive aspects of signed languages: its conflation, its simultaneity and its structured use of space. The comparison of the acquisition of signed and spoken languages becomes a privileged ground for testing hypotheses about the mechanisms that determine language structure.

## Electrically Controlled Talking Tracheostomy Systems

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*Sponsor: Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation, University of Michigan*

**Purpose**—An individual can become ventilator-dependent due to neuromuscular disease, high-level spinal cord injury, or any other condition that seriously reduces respiratory function. For those requiring long-term ventilation, a tracheostomy tube is surgically implanted into the trachea below the larynx. Cuffed tracheostomy tubes are used to insure that adequate ventilation parameters are maintained and to protect the inner airways. Providing a means of communication for these patients is crucial to their medical as well as their psychological well-being.

A commonly-used method to provide verbal expression for patients using a tracheostomy tube,

is to partially deflate the cuff, allowing air to flow up across the vocal cords. Another method employs a specially-designed "talking tracheostomy" tube which has an additional small gauge air line running along its curved surface and ending just above the cuff. The external end of this air line is connected to a source of compressed air that is regulated to produce audible speech (approximately 5 liters/minute). A "tee" in the air line provides a port to control the air flow to the vocal cords. Air flow escapes out of the control port until covered by a finger to direct air through the air line to the vocal cords. It is the inability to close this control port that prevents quadriplegics from being able to in-

dependently actuate their voice. Several systems for independent actuation of the talking tracheostomy systems have been developed.

**Progress**—Two basic designs have been developed to allow independent voice control: 1) an electro-mechanical solenoid to control flow from a compressed air source; and, 2) an air compressor which can be turned on and off to supply regulated air to a talking tracheostomy tube. These systems have been designed for either bedside use or in a portable wheelchair-based arrangement.

The compressed air system consists of a 110 VAC normally closed solenoid valve placed directly in-line with a compressed air source (such as a hospital room wall outlet). A humidifier bottle is placed in the line to moisten the air before it enters the trachea. The air control port is eliminated as air passage only occurs when the valve is activated by a switch. The solenoid valve can be activated through a momentary switch (non-latched, time-latched, or latched), or an environmental control unit.

The solenoid system has been made transportable through the use of a small pressurized air tank and a 12 VDC solenoid valve powered by ventilator or wheelchair batteries. Designs for mounting tanks, ventilator, and battery to either a manual or electric wheelchair have been developed. One drawback of pressurized tanks is that they must be refilled. A 12 VDC compressor has been used in place of an air tank but produces considerable noise. Containers with high density foam and filters on the inlet port have been designed for noise reduction. A humidifier bottle on the outlet port further reduces noise.

**Preliminary Results**—The solenoid valve systems have worked with good success in both bedside and portable configurations. Regulation of air pressure from hospital wall outlets (to 25 psi) has been required, because pressures over 50 psi damage the flow meters controlling air flow to the vocal cords. In addition to its applicability to wheelchair-portable systems, the compressor-based system has been used in a home bedside unit. Minor electronic modifications were required: in this case, to permit activation of the system through an environmental control unit. The ECU provided the 12 VDC and the latching switch functions needed to operate the system.

**Future Plans/Implications**—These systems have been extremely successful in allowing patients to independently control their talking tracheostomy systems. Independent voice control has greatly enhanced communication for these individuals. Future options will include improved mounting systems, air compressors, and other system components. Options for more automatic control of these talking tracheostomy systems (i.e., one that senses speech initiation) are also being considered.

#### **Publications Resulting from This Research**

- Independently Activated Talking Tracheostomy Systems for Quadriplegics.** Levine SP, Koester DJ, Kett RL, *Archives of Physical Medicine and Rehabilitation*, 1987 (in press).
- Self-Activated Talking Tracheostomy Systems for Quadriplegics.** Koester DJ, Levine SP, Kett RL, Kluin KJ, *Proceedings of the 9th Annual RESNA Conference* 6:299-301, Minneapolis, MN, June 1986.

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## **Speech Transmission Laboratory Reports**

### **The Royal Institute of Technology**

Department of Speech Communication and Music Acoustics, S-100 44 Stockholm, Sweden

**Sponsor:** *Swedish Board for Technical Development; The Bank of Sweden Tercentenary Foundation; The Swedish Natural Science Research Council; The Swedish Council for Research in the Humanities and Social Sciences; The Swedish Telecom; The Swedish Ministry for Social Affairs; The Swedish Institute for the Handicapped; The Swedish Council for Planning and Coordination of Research; Knut och Alice Wallenbergs Stiftelse; Nordiska Nämnden för Handikappfrågor; Stiftelsen Tysta Skolan; Telefonaktiebolaget L M Ericsson*

The following reports summarize work conducted at the Speech Transmission Laboratory in the areas

of speech production, speech synthesis, musical acoustics, and speech and hearing defects.

## Nonlinear Interaction in Voice Production

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Qiguang Lin

**Progress**—A source model taking the acoustic interaction into account was developed. As an integrated component, the approach to deriving a lumped-parameter representation of the VT load is also outlined. To evaluate the model, a selective-inverse-filtering technique is utilized. A comparison is made between interactive and linear source conditions. We find that the interactive source model can, to a certain extent, reproduce the effect that higher

formant amplitude maxima tend to synchronize with F1 amplitude maxima, viz., indicating an F1/F0 dependency. We have also studied the skewing of glottal flow and its overlaid ripples. All of these aspects are known to occur in human speech. Thus, the present model is closer to the mechanism of true speech production and should accordingly contribute to the development of high quality synthesis.

## Glottal Source—Vocal Tract Acoustic Interaction

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Gunnar Fant and Qiguang Lin

**Progress**—Recent developments within our group of voice source—vocal tract acoustic interaction placed special emphasis on non-linear superposition phenomena, i.e., how the excitation within a period is dependent on the past history of vocal tract oscillations and their residual components within

the transglottal pressure. A study of breathy phonation shows that constant leakage affects the voice source slope less than does the dynamic leakage in terms of a residual closing phase. A simulation of a female voice source is attempted.

## Speech Technology for the Visually Impaired: The Swedish Perspective

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Björn Granström

**Progress**—Fundamental speech research at the Department of Speech Communication and Music Acoustics, KTH, has led to a multilingual text-to-speech system and a speech recognition device. Both are presently put to use by the visually impaired.

To date, over five hundred text-to-speech systems have been delivered, most of them to applications for the visually impaired. Some of these applications

include software for screen access, reading machines and a radio-distributed daily newspaper experiment. In some applications, simple speech coding techniques suffice, as in a cuing system that recently has been successfully introduced.

Work on present and future research topics, that will lead to improved speech technology aids for visually impaired persons, is planned.

## Relationship Between Changes in Voice Pitch and Loudness

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Patricia Gramming; Johan Sundberg; Sten Ternström; Rolf Leanderson; William H. Perkins

**Progress**—The change in mean fundamental frequency accompanying changes in loudness of phonation during reading was analyzed in nine professional singers, nine nonsingers, and in ten male and ten female patients suffering from vocal fatigue and/

or functional dysfunction. The subjects read discursive texts with LP-filtered noise in earphones, and some also voluntarily varied vocal loudness. Also, the healthy voice subjects phonated as softly and as loudly as possible at various fundamental fre-

quencies throughout their pitch ranges, and the resulting mean phonetograms were compared. The mean fundamental frequency was found to increase by between 0.2 and 0.6 semitones per dB equivalent sound level. No great differences were found between these subject groups, although the singers

were found to vary their mean fundamental frequency more than the nonsingers. It is possible to explain the voice pitch changes as the passive results of the changes of subglottal pressure applied in order to vary sound level of phonation.

### **Long-Term-Average Spectrum Analysis of Phonatory Effects of Noise and Filtered Auditory Feedback**

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Johan Sundberg; Sten Ternström; William H. Perkins; Patricia Gramming

**Progress**—Using long-term-spectrum (LTAS) analysis of fluent speech, the effects of speaking in noise and of speaking with differently filtered auditory feedback as well as of voluntarily changing vocal intensity were analyzed in nine male adult singers and nonsingers. Three values in the LTAS were analyzed: the level of the main peak near 500 Hz, of a secondary peak near 2000 Hz and at the average fundamental frequency. The level at 500 Hz was highly correlated with the equivalent sound level, with the average fundamental frequency and with the level of the peak near 2000 Hz. The singers were found to produce a higher sound level than the

nonsingers under all conditions, and their voices contained stronger high-frequency components. Also, unlike the nonsingers they reduced vocal intensity when reading in silence with enhanced high-frequency components in the auditory feedback. The LTAS effects of noise and of auditory feedback filtering was found to be similar to those of the voluntary changes of vocal intensity for both singers and nonsingers. When the high-frequency components of the auditory feedback was enhanced during reading in noise, both subject groups reduced vocal intensity.

### **Some Effects of Cochlear Implantation on Speech Production**

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Anne-Marie Öster

**Progress**—A new method for the treatment of acquired total deafness in adults has been under probation in Sweden since 1983. The Vienna Cochlear Prosthesis is an extra-cochlear system comprising a single-channel implant with its active electrode placed in the round-window niche. The device functions on the basis of electrical stimulation of the cochlear nerve.

The present study involved acoustical analyses of fundamental frequency of two patients' recorded readings of a familiar text consisting of 89 words and an unfamiliar text of 56 words. The recordings

were made pre-implant and post-implant after 1, 3, 6, 12, and 24 months. We have also made recordings of the patients when they read the text without and with the implant.

The analyses made included the speech rate, phonation time as well as the mean and the standard deviation of the fundamental frequency. The results were shown in forms of FO-histograms. The main effect found was an improvement in FO-control, which means a lowering in mean FO and a more normal FO-distribution. A shift towards a more normal rate of articulation was also found.

## C. Speech Impairment

### 2. Aphasia

#### Promoting Generalized Language Use: An Analysis of Treatment Strategies

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—The challenge in the rehabilitation of the adult with acquired aphasia is to provide interventions that reliably and efficiently result in the acquisition of functional communication skills that endure over time and are performed across the variety of conditions imposed by the natural environment. Thus, the concept of generalization or transfer of treatment effects is a fundamental concern of the clinical aphasiologists.

Traditionally, the process of generalization of learned behaviors was expected to occur as a natural consequence of the acquisition process. This may account for the relatively few studies in which programming was specifically designed to promote generalization. Unfortunately, many intervention programs that produce excellent effects under treatment conditions often fail to result in similar behavioral changes under more natural conditions. The purpose of our program of research is to identify treatment variables that will enhance the ability of aphasic adults to generalize learned language behaviors to natural conversational contexts.

**Progress**—In a recently completed study, four neurologically stable adults with Broca's aphasia were trained to use the communicative function of requesting information. The treatment program employed five variables which we hypothesized would enhance generalization. These were: 1) the use of multiple trainers; 2) selection of the target behavior based upon communicative function rather than structural form; 3) reinforcement and shaping of subject-initiated utterances; 4) reinforcement of relevant variations of the target response; and, 5) systematic manipulation of the stimulus conditions employed during training to approximate those en-

countered in natural conversational contexts. As our dependent measure, each subject had 36 5-minute conversations with unfamiliar peer volunteers who were blind with regard to the purpose of the study and the target behavior under investigation. The effects of treatment were evaluated by employing the single case experimental design of a multiple baseline across behaviors and subjects. This design allows one to examine changes in the level of responding of treated and untreated behaviors across baseline, treatment, and maintenance phases of the study, while inherently controlling for threats to internal validity.

**Results**—The results of this investigation revealed that all subjects acquired the target behavior under training conditions and that three of the four subjects were able to use the behavior in conversational interactions with unfamiliar peer volunteers at levels well above their baseline performance. These results indicate that aphasic adults, similar to those described in this study, can generalize learned language behaviors to extratherapy contexts and that the manner in which language responses are trained will effect the degree to which generalization occurs.

**Future Plans/Implications**—Our future research will focus on the identification of those variables that are both necessary and sufficient for the process of generalization of treatment effects in aphasic adults.

#### Publication Resulting from This Research

**Experimental Analysis of Syntax Training in Broca's Aphasia: A Generalization and Social Validation Study.** Doyle PJ, Goldstein H, Bourgeois MS, *Journal of Speech and Hearing Disorders*, 52:143-155, 1987.

## An Experimental Analysis of Response Elaboration Training in Aphasia

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**Purpose**—The primary purpose of this project is to examine the effectiveness and generality of Response Elaboration Training for aphasia (Kearns, 1985). This procedure is a form of divergent semantic language intervention designed to facilitate an increase in the quantity and variety of verbal responses produced by patients with nonfluent aphasia. The emphasis in Response Elaboration Training (RET) is on facilitating an increase in the amount of information contained in patients' verbalizations. Unlike more didactic training programs, specific lexical items are not targeted for intervention during RET. Rather, spontaneous, patient-initiated utterances are systematically chained together to elicit more elaborate verbal responding.

A within-subject experimental design (i.e., multiple baseline across behaviors and subjects) was used to explore two key questions: 1) Will RET facilitate an increase in the amount of information (number of content words) produced by nonfluent aphasic subjects within the treatment setting? and, 2) Will RET result in generalization of more elaborate responding to untrained stimuli, settings, and individuals?

**Progress**—To date, four nonfluent aphasic subjects have completed the training protocol and social

validation data have been collected on ten age-matched normal subjects. The results for three experimental subjects replicated our initial findings. RET facilitated an increase in the number of content words produced in response to training and generalization stimuli. Generalization of training effects to spontaneous interactions, novel settings, and individuals, although somewhat variable, was also found.

The generality of RET was further explored by using the procedure with a nonverbal aphasic-apraxic patient in an attempt to train him to communicate through drawing. This cross-modality replication was successful. The patient developed an elaborate nonverbal (drawing) communication system on structured tasks and generalization occurred to untrained stimuli, settings, and people.

**Preliminary Results**—Our preliminary data support the contention that RET is an effective procedure for facilitating increased production of informational content for nonfluent aphasic patients. The results of generalization testing have also been encouraging. Additional data are being collected on RET and future efforts will compare the results of this procedure to more didactic training approaches.

## Drawing: Its Use as a Communicative Aid with Aphasic and Normal Adults

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Sponsor: VA Rehabilitation Research and Development Service

**Purpose**—For adults who incur a cerebral stroke that results in the loss of speech due to a linguistic deficit (aphasia), approximately one-half will never reacquire adequate verbal skills to communicate their daily needs. That is, although they may understand simple requests, statements, or commands and appear to know the basic concepts to be expressed, they are unable to retrieve and order the necessary verbal symbols to do so. The purpose of

this investigation was to determine whether drawing might serve as an alternative form of expression which, in combination with existing communicative skills, would permit the successful completion of such communiques. In addition, a control group of normal adults was included to determine how readily nonbrain-damaged adults could draw communicatively when restricted to comparable levels of verbal and handedness use.

**Progress**—Eight chronic, severe, Broca's aphasic adults and eight, normal non-brain-damaged adults were studied for their ability to communicate a variety of information (objects, actions, sequences, questions, and solutions to simple problems) to a naive interactant. For aphasic adults, baseline measures were obtained for their ability to communicate such information to a naive interactant within a three minute period using drawing and, on a separate occasion, without the use of drawing. Thereafter, they were enrolled in a three month "drawing" treatment program which stressed two facets: 1) refinement of drawing skills needed to augment communication; and, 2) instruction of interactants in how to extract information from drawings. Following the treatment period, baseline measures were re-administered. Performance on baseline measures were judged on an eight-point ordinal scale which delineated accuracy, completeness, and promptness of response. Normal adults did not require a treatment period in that they drew and communicated beyond predetermined criteria levels on initial baseline measures whether using dominant or nondominant hand and being restricted to a verbal "yes or no" with interactants.

**Results**—Aphasic adults communicated information significantly better to interactants when drawing

was used than when it was not used even prior to treatment. Further significant gains occurred for these subjects following the three-month treatment period.

**Future Plans/Implications**—These findings support the premise that drawing does serve as an effective communicative alternative for expressively restricted aphasic adults. Based on these findings, the current investigator is completing a Merit Review submission to look at the use of drawing in acute, expressively restricted aphasic adults when compared to traditional treatment (pantomime) techniques in four separate VA Medical Centers.

#### **Publications and Presentations Resulting from This Research**

- Drawing: Its Communicative Significance for Aphasic Adults.** Lyon JG, Helm-Estabrooks N, In C. Hagen (Ed.), *Topics in Language*, Rockville, Maryland, Aspen Systems Corp., Oct. 1987.
- Drawing: Its Value as a Communicative Aid for Aphasic and Normal Adults.** Lyon JG, Sims E, *Journal of Speech and Hearing Disorders*, (in press).
- Drawing: Evaluation of Its Use as a Communicative Aid with Aphasic and Normal Adults.** Lyon JG, Sims E, Second International Aphasia Rehabilitation Congress, Goteborg, Sweden, June 1986.
- Drawing: A Communicative Aid for Aphasic and Normal Adults.** Lyon JG, Sims E, *American Speech-Language-Hearing Convention*, New Orleans, LA, November 1987.

### **Computer-Aided Visual Communication for Severely Impaired Aphasics**

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—The purpose of this project is to research and develop a graphically oriented, computer-based alternative communication system for chronic, severely aphasic individuals. It is called the C-VIC (for Computer-Aided Visual Communication) system. It is to draw on selected subjects' demonstrated abilities to identify graphic objects, arrange them according to specified conventions, assign meanings to the resulting structures, and use them reliably to support performance and communicate about many conventional transactions in activities of daily living. Four major questions will be answered by this project. 1) Specifically, which aphasic individuals and populations can benefit from the device, when,

and how? 2) What graphically encoded communicative abilities can be tapped or developed to help our severely aphasic patients, and what is their relationship to natural language? 3) Which activities of daily living can benefit from such communicative support, and how? 4) Can artificial intelligence modules assist aphasic individuals in using this assistive device, and how?

**Progress**—Investigators have pursued several mutually reinforcing lines of activity. These include:

1) Designing, implementing, and modifying successive versions of the C-VIC interface on the Macintosh computer, and gaining experience in

patient training on successive interface versions as they become available.

2) Selecting candidate users from a population of severely aphasic individuals of differing etiologies and deficit profiles; providing them training in the use of the system and monitoring their progress; and periodically assessing their communicative abilities in different modalities using standard assessment tools or their modifications (when necessary).

3) Designing and conducting single-subject controlled experiments with aphasic subjects, in order to: a) analyze effects of C-VIC training versus effects from equivalent speech therapy training; b) characterize patient learning, generalization, and retention on the system, and, c) probe the effect of differing types of graphic representations on user performance.

4) Exploring the potential for a modified C-VIC interface to be used in other promising ways, for example, as a cognitive orthosis to help aphasic persons perform new and/or complex tasks without immediate human supervision.

**Results**—Progress can be reported in each of the four areas identified above:

1) In interface work, we completed the programming of C-VIC Version 1.0 (card metaphor) in December, 1986, and have been using it in patient training since completion; we anticipate finishing Version 2.0 (high graphic interactivity) in December, 1987, and Version 3.0 (artificial intelligence capabilities) the following year.

2) In training, we have gained extensive experience with three globally aphasic individuals and two subjects with severe Broca's aphasia, plus some additional experience with other subjects. This training has shown several things: a) that mastery of the fundamentals of the system is within the capability of all our subjects; b) that their performance in communicative transactions using C-VIC is significantly better and more reliable than in comparable transactions using natural language; and, c) that the subjects are enthusiastic about using the system, and perform better on the computer than on the original VIC cards, despite several novel cognitive demands by the computer.

3) In controlled experimental studies, we have: a) shown circumstances under which C-VIC training produces superior results to equivalent traditional speech therapy; b) demonstrated the efficacy of

components in C-VIC training; and, c) begun answering questions on the proper representation of "verbs" within the system.

4) Finally, we have begun pilot studies to explore the potential of C-VIC type communications for guiding subjects through complex, multi-step tasks, such as baking a cake, with promising (e.g., edible) results.

**Future Plans/Implications**—Work is scheduled to proceed apace on each of the four fronts. Version 2.0 of the interface should be ready by the end of 1987, and we will begin training with it soon thereafter. We are already making arrangements to increase our patient pool, to gain training experience with larger numbers and types of patients. We are expanding the number and type of controlled experimental studies, as these both guide specific project decisions, and help us to document and report the efficacy of the approach. Finally, we are actively working on identifying and producing pilot data on other promising C-VIC applications to help language-impaired individuals.

#### **Publications and Award Resulting from This Research**

- Representations of 'verbs' in a Computerized Visual Communication System.** Weinrich M, Steele RD, Kleczewska MK, Carlson GS, Baker E, *Proceedings of the 10th Annual RESNA Conference*, 7:162-164, San Jose, CA, June 1987.
- Designing a Computerized Visual Communication System for Global Aphasics,** Carlson GS, Kleczewska M, Steele RD, Weinrich M, *Proceedings of the 10th Annual RESNA Conference*, 7:94-96, San Jose, CA, June 1987.
- Patterns of Learning in Aphasics Trained on a Computer-Based Visual Communication System.** Kleczewska M, Carlson GS, Steele, RD, Weinrich M, *Proceedings of the 10th Annual RESNA Conference*, 7:157-159, San Jose, CA, June 1987.
- Evaluating Performance of Severely Aphasic Patients on a Computer-Aided Visual Communication System.** Steele RD, Weinrich M, Wertz RT, Kleczewska M, and Carlson GS, forthcoming in *Clinical Aphasiology*, 1987.
- Prospects for a Cognitive Orthosis.** Weinrich M, Steele RD, forthcoming chapter in *Advances in Neurology*, "Functional Recovery in Neurological Disease," Stephen G. Waxman (Ed.), 47:583-600, New York: Raven Press, 1988.
- A Microcomputer-Based Visual Communication System for Treating Severe Aphasia.** Steele RD, Weinrich M, Wertz RT, Carlson GS, and Kleczewska M, *Abstracts of the Academy of Aphasia*, 7-8, 1986.
- Training Severely Impaired Aphasics on a Computerized Visual Communication System.** Steele RD, Weinrich M, *Proceedings of the 9th Annual RESNA Conference*, 6:348-350, Minneapolis, MN, June 1986.
- Computerized Icon-Based Communication for Aphasics.** Steele RD, Weinrich M, *Proceedings of the 39th Annual Confer-*

ence on Engineering in Medicine and Biology, Baltimore, MD, 1986.

**Computerized Visual Communication for Severely Impaired Aphasics.** Steele RD, Illes J, Weinrich M, *Journal of Clinical and Experimental Neuropsychology*, 7(6):609, 1986.

**Implementation of a Visual Communication System for Aphasic Patients on a Microcomputer.** Weinrich M, Steele RD, Illes

J, and Lakin F, *Annals of Neurology*, 18(48), 1985.

**1987 Special Award for Creative/Innovative Application of Information Resources Management,** US Government Inter-agency Committee on Information Resources Management (IAC/IRM) Annual Competition, awarded to RD Steele and M Weinrich.

## Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands

**Richard D. Steele, Ph.D.**

Various Institutes in Stockholm, Sweden; Warsaw, Poland; and Delft, Hoensbroek, Leersum, Eindhoven, Nijmegen, The Netherlands

*Sponsor: VA Rehabilitation Research and Development Service; International Exchange of Experts and Information in Rehabilitation, World Rehabilitation Fund, Inc., New York*

**Purpose**—The purpose of the trip was to study and report on current and upcoming uses of contemporary technology for aphasia research and rehabilitation in three European countries of differing political systems, economic situations, and cultural mores—Sweden, Poland, and The Netherlands—and to draw out the implications of the findings for aphasia researchers and clinicians in the United States.

**Progress**—The investigator used preparatory study, site visits to relevant institutions, indepth researcher/clinician interviews, and content analysis to prepare his report. Interviews aimed at establishing and assessing the particulars both of previously reported work, and as of yet unreported projects. The existence of local contacts allowed for meetings, under local sponsorship, with aphasia researchers and clinicians in a variety of settings (e.g., the Swedish Aphasia Association Headquarters, the Polish Psychoneurological Institute, the Dutch Institute of Rehabilitation Research, among others). Altogether, some 40 individuals in 15 institutional settings were interviewed, with information gathered on 16 special projects of relevance in aphasia research and treatment.

The topic of technology applications to aphasia studies merits attention. In general, aphasia researchers and clinicians are not aggressively exploiting potentially useful, but still relatively novel, technologies. In this regard, they are rather focusing their attention primarily on a single one: computer-based tomography. The contents of two 1986 U.S. conference—the Academy of Aphasia, and the Clin-

ical Aphasiology Conference—are illustrative. Of 87 papers in those proceedings, only 12 (14 percent) involve innovative technological approaches, and of those 75 percent (9 papers) report on computer-aided tomography (CT, PET). While these papers make invaluable contributions to our knowledge, they also show that some available tools are being left under-utilized (e.g., database tools, statistical package tools, expert system tools, evaluation tools, and more). Given the magnitude of the tasks in aphasia research and the limited manpower, the field can ill afford such neglect.

**Results**—The overseas study revealed several ongoing projects that deserve the attention of aphasiologists in the United States. While many of them are aimed directly at the problems of aphasic deficits and their rehabilitation, others are not. These latter focus on research in relevant ancillary fields—problems of communication, or learning behaviors, or of device development and evaluation. Their value lies in methodologies which are being elaborated, subsequently available for adaptation and transfer to aphasia research projects. Three examples follow:

1) In Delft (Netherlands), researchers and clinicians have developed a System for Training Aphasic Patients (STAP), which is being evaluated in a three-stage, longitudinal single-subject experimental design, with some positive results.

2) In Hoensbroek (Netherlands), a psycholinguist is developing computer-based tools to analyze communicative transactions between young, language-disordered children and their caregivers.

3) In Stockholm (Sweden), the Swedish National

Board for Technical Development (STU) is funding two computer-based projects to develop therapeutic and alternative communication systems for aphasic individuals.

**Future Plans/Implications**—Observations from the study suggest several things. Researchers must learn more about advanced tools under development elsewhere and should establish networks for ongoing communication and mutual support. They can benefit from broadening their contacts with ancillary fields, and may have lessons to learn from foreign models for organizing, supporting and conducting

research, development and evaluation. An important practical observation is that much of the current work is tied rather closely to clinical activities: both theoretical and clinical aphasiologists can benefit from more extensive interaction and collaboration in developing, using, and evaluating contemporary technology in their projects.

#### **Publications Resulting from This Research**

**Technology Applications for Aphasia Rehabilitation: Lessons from Sweden, Poland, and The Netherlands.** Steele RD, *Fellowship Report to the International Exchange of Experts and Information in Rehabilitation Program*, World Rehabilitation Fund, Inc., New York, NY, May 1987.

### **Efficacy of Remote Treatment of Aphasia by TEL-Communicology**

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—Four Veterans Administration Medical Centers participated in an investigation designed to compare the efficacy of remote treatment of aphasia by TEL-Communicology (TEL-C) with traditional Face-to-Face treatment. Those patients who met selection criteria were assigned randomly to either the traditional treatment program delivered Face-to-Face, or to the treatment program delivered by TEL-C. The patients who rejected randomized group placements were given the option of entering self-selected groups in order to receive treatment by the other delivery system. This option resulted in four groups—two randomized and two self-selected.

**Progress**—An evaluation battery of language measures was administered at entry, eight, sixteen, and twenty-four weeks. Neurological evaluations were given upon entry and upon completion of twenty-four weeks of treatment. All subjects received five hours of treatment a week for six months, or for as long as they remained in the study. Two groups received treatment delivered Face-to-Face; two groups had treatment delivered by TEL-C. The latter consisted of two-thirds clinician-assisted TEL-C and one-third REMATE computer-assisted TEL-C. (REMATE is an acronym for Remote Machine-Assisted Treatment Evaluation.)

**Clinical data analyses.** The data showed no differ-

ences between the Face-to-Face and the TEL-C groups, nor between the randomized and self-selected groups, in regard to age, education, or initial severity levels. All groups improved during the treatment period. There were few significant differences (as many as would be expected by chance), and they were all in favor of TEL-C. It appeared that Face-to-Face and TEL-C delivery of treatment were equally effective. On the Porch Index of Communicative Ability (PICA), there was a tendency for randomized subjects to approximate the estimated target levels at six months post-onset more closely than did the self-selected subjects.

**Cost comparison.** The cost of the delivery of the Face-to-Face treatment on this project was 191.4 percent more costly than the combined TEL-C clinician and TEL-C REMATE delivery. These costs included direct and indirect costs, telephones, and facility/patient travel costs.

**Results**—This project demonstrated that the combined TEL-C clinician-assisted and TEL-C REMATE-assisted delivery of a remote aphasia treatment program was as effective as that delivered by the traditional Face-to-Face delivery system. This study also showed that, on a national basis, the Veterans Administration traditional Face-to-Face delivery system in speech pathology in 1985, was

148.6 percent more costly than TEL-C clinician-assisted delivery, and 344.9 percent more costly than TEL-C REMATE-assisted delivery.

**Future Plans/Implications**—Because of the careful selection of subjects for the study, the size of the sample obtained was smaller than desirable. Many of the group differences failed to meet statistical significance, although the differences appeared to be clinically significant. Future studies, therefore, should be planned to increase the size of the sample. This could be done in several ways: (1) by making

the subject selection criteria less stringent; (2) by increasing the number of centers participating in the study; or (3) by increasing the length of the study. Clinical experience during the study also suggested the usefulness of TEL-C for providing information, guidance, support, and treatment information to the families of aphasia patients.

#### **Publication Resulting from This Research**

**Efficacy of Remote Treatment of Aphasia by TEL-Communication**, VA Rehabilitation Research and Development Project, Audiology-Speech Pathology Service, Veterans Administration Medical Center, Birmingham, AL, September 1986.

### **The Influence of Mode of Stimulation on Naming Performance in Aphasia** \_\_\_\_\_

**Sarah E. Williams, Ph.D.**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Pilot Proposal #C943-PA)*

**Purpose**—Naming is a language behavior of special interest to aphasiologists, since a reduction of the capacity to name seems to be almost universal in aphasia. Four major variables appear to influence the naming performance of aphasic patients: 1) the characteristics of the referent to be named; 2) the characteristics of the referent's name; 3) the type of stimulus presentation; and, 4) the situation in which naming occurs. Only recently have attempts been made to study the last variable.

The purpose of the proposed pilot study is to examine the influence of situational context (confrontation naming versus running speech) on the recall of nouns and verbs by aphasic patients when the stimuli are videotaped, rather than depicted by line drawings as in previous investigations. It is hypothesized that, with more realistic portrayals of objects and actions on videotape, results obtained will differ from those obtained in previous studies using line drawings.

The following goals will be accomplished: 1) determine the extent to which performance in confrontation naming is predictive of naming perform-

ance during connected speech for both objects and actions; 2) determine whether object and/or action naming performance is significantly different during confrontation naming versus connected speech for any syndrome(s) of aphasia; 3) determine whether performance is significantly different for any syndrome(s) of aphasia when naming objects versus actions; 4) determine the patterns of naming errors produced by each syndrome of aphasia for object and action naming; and, 5) compare the results obtained in this investigation with those obtained in earlier studies using line drawings as stimuli.

Results of this investigation will be compared to previous research findings using line drawings as stimuli to determine if the number and type of errors produced by aphasic patients varies according to the mode of stimulus presentation. In addition, the specific syndrome(s) influenced the most by mode of stimulus presentation will be identified. This will provide important information for Speech-Language pathologists who are routinely involved in the diagnosis and treatment of aphasia.

## Recovery from Aphasia in Stroke

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Sponsor: *National Institutes of Health*

**Purpose**—The project proposes to obtain systematic evaluation of the course of recovery from aphasia in a population of stroke patients. The study has three specific goals. First, this project will provide extensive information on the demographic, neuroanatomical, medical, and neurolinguistic correlates of the recovery of specific language functions in aphasia. This information about prognostic factors can be used as a database for the development of on-line, computer assisted decision aids that would be of use to the neurologist in deciding questions of patient management. Second, the proposed study will evaluate the hypothesis that some language functions recover better than others. Experimental tests will be administered that allow relatively selective evaluation of distinct aspects of language comprehension (such as phoneme discrimination) and of speech production (such as syntactic complexity). Scores obtained on these measures will be used to evaluate the possibility that there are different recovery rates for particular aspects of gross

language functions such as comprehension and production. In addition to their considerable theoretical importance, the results of such an evaluation would have significant implications for the design of therapies and communication aids for the aphasic patient. Third, the study proposed here will furnish data for testing hypotheses concerning the functional components that underlie the major aphasic syndromes.

Specific issues to be addressed include the incidence of linguistically-defined symptoms (e.g., agrammatism) within the classical syndromes (e.g., Broca's aphasia), and the extent to which the phenomenon of evolution of syndromes during recovery reflects substantive changes in language capacities. This third goal reflects an attempt to join the theories and methods developed in recent neurolinguistic studies of language impairment with the more traditional approach to the study of recovery from aphasia.

## Communication in Aphasia and Other Organic Disorders

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Sponsor: *National Institutes of Health*

**Purpose**—The goal of the research is to investigate how communicative capacities are organized in the brain and to arrive at neurologically interpretable analyses of such capabilities. The hypothesis is that the effects of focal damage in the left and right hemispheres serves to disentangle cognitive systems that normally interact in the exercise of language-based communication.

The research encompasses three levels of communication: 1) a linguistically-specific embodied as the capacity to carry out syntactic analysis; 2) a lexical-semantic component based upon a lexical inventory and upon categories of extralinguistic knowledge that serve to structure word meanings; and, 3) a discourse component comprising the ca-

capacity to process meanings involved in stories, jokes, arguments, and other supra-sentential entities.

The specific investigations at the syntactic level will focus on thematic and surface structure contributions to sentence processing in aphasia. These studies make use of grammatical judgments and reaction time methodologies for the assessment of comprehension as it unfolds over time. Such "on-line" methods will also be used in the studies of lexical semantics; the foci at this second level will include denotative and connotative forms of knowledge in left hemisphere damaged aphasic and right hemisphere damaged patients.

Studies at the discourse level will examine the

effects of right brain damage, probing the nature of limitations in integrating textual material and in comprehending non-literal forms of language. This program should yield a fuller picture of communi-

cative capacity in aphasic and right hemisphere damaged patients, and provide a basis for implementing appropriate forms of language remediation.

## Reorganization of Brain Function in Recovery from Aphasia

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Sponsor: *The University of Texas Medical Branch; U.S. Department of Education*

**Purpose**—Most aphasic patients sustaining focal left hemisphere lesions recover at least partially their linguistic capabilities within about a year following injury or stroke. Among the mechanisms postulated to account for this phenomenon of spontaneous restitution of language is functional reorganization of the brain involving a hemispheric dominance shift or increasing involvement of the relatively intact right hemisphere in mediating language.

**Progress**—During the past year, we have explored this hypothesis using two physiological measures of hemispheric activation, evoked potentials (EPs) and regional cerebral blood flow (rCBF) along with a measure of shift in ear advantage using a dichotic listening procedure.

**Preliminary Results**—Consistent patterns of task-specific hemispheric activation have been obtained with the use of cortical EPs in the context of a probe paradigm. This consists of recording EPs to an irrelevant probe stimulus (a click or tone) from the left and right hemispheres during performance of various cognitive tasks. When the task is linguistic the amplitude of the probe EPs is attenuated more in the left hemisphere. This asymmetric attenuation is considered as an index of greater left hemisphere involvement in the language tasks. This pattern of greater left hemisphere involvement has been consistently obtained with normal subjects, and right hemisphere stroke patients. In contrast, the majority of the 22 left hemisphere stroke recovering aphasics we have examined thus far show the opposite pattern of greater right hemisphere engagement during verbal memory, shadowing, phonological, and semantic target detection tasks.

Similar indications of increased right hemisphere

participation in recovery from aphasia have been obtained from 11 of these patients using rCBF. This noninvasive procedure allows for indirect assessment of local metabolic rates (thus degree of activation) of various cortical regions. Unlike normal controls and right hemisphere stroke patients, the majority of recovering aphasics showed greater right temporal activation during a phonological target detection task. Moreover, 11 of the recovering aphasic patients were given a dichotic listening test which involves simultaneous presentation of a pair of different speech syllables to each ear and requires the subject to respond with the syllable they heard. Most normal subjects, as well as right hemisphere lesion patients, report most often the syllable presented in the right ear, thus showing a left hemisphere advantage for language. However, the majority of the recovered aphasics (eight of the 11) showed a left ear (therefore, right hemisphere) superiority.

**Future Plans/Implications**—Although the interpretation of the results obtained with each procedure cannot be considered definitive, the general concordance of the electrophysiologic, blood flow and dichotic listening data supports strongly the hypothesis that restitution of language following left hemisphere stroke is due to increasing involvement of the intact right hemisphere in many patients.

It is hoped that further investigation will elucidate the conditions and extent of this functional reorganization. Moreover, it is expected that the results of such investigations will be of value in designing appropriate language retraining strategies that would enhance the process of language rehabilitation among stroke victims.

### Publications Resulting from This Research

**Habituation of Auditory Event-Related Potentials: A Comparison of Self-Initiated and Automated Stimulus Trains.** Bourbon WT, Will KW, Gary Jr. HE, Papanicolaou AC, *Electroencephalography and Clinical Neurophysiology*, 66:160-166, 1987.

**Memory Assessment in Neuropsychology.** Loring DW, Papanicolaou AC, *Journal of Clinical Experimental Neuropsychology*, 9:340-358, 1987.

**Electrophysiologic Methods for the Study of Attentional Deficits in Head Injury.** Papanicolaou AC, *Neurobehavioral Recovery from Head Injury*, Levin, HS, Eisenberg HM, Grafman J, (Eds.), New York: Oxford University Press, 1987.

**Convergent Evoked Potential and Cerebral Blood Flow Evidence of Task-Specific Hemispheric Differences.** Papanicolaou AC,

Deutsch G, Bourbon WT, Will KW, Eisenberg HM, *Electroencephalography and Clinical Neurophysiology*, 66:515-520, 1987.

**Evoked Potential Correlates of Right Hemisphere Involvement in Language Recovery Following Stroke.** Papanicolaou AC, Moore BD, Levin HS, Eisenberg HM, *Archives of Neurology*, 44:521-524, 1987.

**Cerebral Blood Flow Evidence of Right Frontal Activation in Attention Demanding Tasks.** Deutsch G, Papanicolaou AC, Bourbon WT, Eisenberg HM, *International Journal of Neuroscience* (in press).

**Dichotic Listening Evidence of Right Hemisphere Involvement in Recovery from Aphasia Following Stroke.** Moore BD, Papanicolaou AC, *Journal of Clinical and Experimental Neuropsychology* (in press).

## C. Speech Impairment

### 3. Other

#### Effects of Real-Time Biofeedback on Dysarthric Speech

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**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—This research program is devoted to developing and testing the effectiveness of computer-controlled visual biofeedback in inducing changes in speech breathing and speech rate in normal and dysarthric subjects. Of particular interest are changes in speech intelligibility that may occur with changes in speech rate and speech breathing patterns. Cerebellar ataxic and Parkinson subjects are being studied and compared with normal control subjects.

**Progress**—The normative and procedural validation experiments have been completed. We have devel-

oped an algorithm which provides a real-time metric highly correlated with speech rate and are presently applying this technique to both normal and disordered subjects. Speech breathing patterns for both normal and disordered subjects have been identified. Our results thus far suggest that this technique can successfully induce changes in speech rate and speech breathing. The remainder of this grant period will be aimed at determining the effect of such changes on speech intelligibility and other related speech parameters.

#### Perceptual and Acoustical Characteristics of Tracheoesophageal Voice

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Proposal #C941-PA)

**Purpose**—Tracheoesophageal puncture is the newest procedure available for voice restoration of laryngectomy patients. It involves the use of a one-way

valve prosthesis inserted through a fistula in the posterior wall of the trachea into the esophagus. When air is expired from the lungs it may be diverted

into the esophagus by occlusion of the tracheostoma, and hence, produce vibration of the esophageal tissue resulting in voice. Only recently have attempts been made to study the characteristics of speech produced by patients following tracheoesophageal puncture. Our study attempts to fill voids which exist in current descriptions of tracheoesophageal speech.

The purpose of the present study is to examine perceptual and acoustical characteristics of tracheoesophageal speech. Different types of voice prostheses, as well as different methods of occluding the tracheostoma to divert air into the esophagus, will be used to determine if these factors influence perceptual and acoustical characteristics of tracheoesophageal speech. We hypothesize that speech characteristics will be influenced by systematic variation of these factors.

The projected goals are: 1) determine if speech

produced using various combinations of voice prostheses and methods of tracheostomal occlusion can be discriminated on the basis of specified perceptual and acoustical characteristics; and, 2) determine which combinations of voice prostheses and method of tracheostoma occlusion yields speech most similar to that of laryngeal speakers with normal voices on both perceptual and acoustical measures.

The results will indicate specific voice characteristics which may need attention in speech treatment following tracheoesophageal puncture. In addition, this investigation will provide information regarding which combination(s) of voice prostheses and method of stomal occlusion yields the most "normal" audible speech. It is hoped that this will assist tracheoesophageal puncture patients and speech pathologists in making a more informed decision regarding tracheoesophageal speech.

## Transparent Access to Sources of Computer-Based Information

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**Sponsor:** VA Research and Development Core Funds; Digital Equipment Corporation

**Purpose**—A software program, KIOSK, has been developed that demonstrates how the barriers to obtaining computer-based information can be reduced, benefiting both able-bodied and disabled people.

**Progress**—The KIOSK software has been designed to run on both 8-bit and IBM-PC compatible computer systems. A DECTalk Speech Synthesizer completes the hardware system and provides a friendly interface between the computer and its data and individuals requesting information.

In operation, the user uses his/her home or business Touch-Tone telephone to dial the telephone number of the DECTalk Speech Synthesizer. The equipment answers the telephone and KIOSK then mediates the interaction between the caller and the computer. The software: 1) permits the DECTalk to speak computer-based text files; 2) receives data from the DECTalk on which Touch-Tone keys are pressed by the caller; and, 3) works with a knowledge of a structure for presenting the text files.

In the current implementation, the interaction

between the caller and the computer is accomplished through a series of computer-initiated speech output and caller responses. The user is presented with either instructions, information, or choices. The caller's response to a choice is made by pressing the Touch-Tone key corresponding to his/her selection. The DECTalk recognizes the keypress and causes the program branches in an appropriate manner based upon the response. This process is continued, with the computer sending information from text files to the DECTalk which are spoken over the telephone and the user making choices on how the interaction is to proceed.

For example, a typical choice might be: *Press 1* for information on recreational devices; *Press 2* for information on robotic applications; *Press 3* for information on new wheelchair developments.

KIOSK has been developed as a general-purpose program. It operates by structuring disk-based text files, presenting them verbally to the caller at the proper time, when the right sequence of choices has been made. The information provider designs this structure and provides the text files to be spoken

by the program. As such, KIOSK is a flexible Authoring System for the DECTalk Speech Synthesizer and can be used to disseminate a variety of information.

**Preliminary Results**—One current application being demonstrated at this facility is a voice-output version of this Center's 1986 Progress Reports, which are descriptions of the operation of this Center and its projects.

When called, the system welcomes the user and briefly describes its operation. The caller is first asked to press any Touch-Tone key to continue and subsequently asked to press the 0 key. After a short introduction to the Center, the user is asked to indicate in which of the three groups within the Center (Orthopaedic Biomechanics, Neuromuscular Systems, or Human-Machine Interface) he/she is interested. The user responds with a Touch-Tone keypress and the program branches to the information and projects of the chosen group. The title of a project is then presented and the caller is given the choice of whether to hear the text of the project, go on to the next project, or return to the previous menu of choices.

The KIOSK software has recently been used to create an information system serving blind athletes at their 1987 World Series of Beep Baseball at Ithaca College in Ithaca, New York. Competitors used their telephones to hear team scores and standings as well as information on how to get around campus and the immediate area. Listings of restaurants, shopping areas, bus schedules, and tourist sights were all included.

An unexplored application of KIOSK is the voice output dissemination of information that would normally be presented in traditional printed newsletter format or general consumer type information.

**Future Plans/Implications**—KIOSK makes it possi-

ble for individuals without access to or knowledge of computers to obtain computer-based information. Information requesters simply employ their Touch-Tone telephone, a device already in their home or business and one which they know how to use. The substantial barriers of having to buy and learn how to use a computer for obtaining computer-based information are eliminated. Visually-impaired people could benefit from this type of access, and it serves able-bodied individuals equally well. In addition, modem communication could be added to supply the same information to people who have computer systems, including hearing-impaired individuals. In summary, a system based on KIOSK serves persons who are disabled because of their lack of information and those that are disabled because they lack the funds and motivation to buy and learn how to use a computer to access sources of computer-based information.

The next extension of this work will allow a computer system to mediate the exchange of information between the caller and the information contained in a remote database such as CompuServe or computer-based bulletin board systems. This would be accomplished by first engaging in a dialog with the caller to determine the information required and then connecting to the appropriate information source. Next, the computer would send the required commands in the proper syntax to obtain the information from the remote system and present it to the user as synthesized speech. An electronic librarian would thus be created to transparently search multiple databases of electronic information for the caller.

#### **Current Publications Resulting from This Research**

- Human-Machine Interfaces.** Jaffe DL, *IEEE Short Course on Rehabilitation Engineering*, Palo Alto, CA, February, 1986.  
**Rehabilitation Applications of the DECTalk Speech Synthesizer.** Jaffe DL, *Computer Technology for Disabled Conference*, Palo Alto, CA, March, 1986.

## **Neuropathophysiology of Speech Motor Impairments**

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**Sponsor:** *National Institutes of Health*

**Purpose**—The overall goal of this clinical research center is to advance our understanding and treatment

of motor speech disorders. We are in the process of achieving this objective through an integrated

series of investigations involving perceptual, acoustic, aerodynamic, electromyographic, movement and force analyses, in many cases conducted simultaneously and/or on the same subjects for critical comparative interpretations. Specifically, our research program involves four major areas of concurrent activity: 1) intelligibility and acoustic and aerodynamic analyses of dysarthric speech; 2) de-

velopment of motor control impairment profiles for speech mechanism subsystems; 3) system physiology-based investigations directed at the neural substrates of speech motor function and dysfunction; and, 4) development, evaluation, and refinement of improved techniques for rehabilitation of motor speech disorders.

## Structure and Acquisition of American Sign Language

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**Sponsor:** *National Institutes of Health*

**Purpose**—This research will investigate the structure and acquisition of American Sign Language (ASL), a natural language of the deaf of North America. ASL may be acquired as a primary language either early or late in life, and either from native signers or from signers who themselves acquired the language late in life. Its study therefore provides an unusual opportunity to investigate the consequences of early versus late experience, and of wide variations in input environment, on the process by which a language is acquired and the ultimate character of its user's knowledge. Eight experiments are proposed, to test adult users of ASL as well as children who are in the process of acquiring ASL, with a test battery of ASL phonology, morphology, and syntax which we will devise.

Given our previous results, these experiments are expected to demonstrate: 1) that there are striking

differences in the knowledge of a language that users attain as a function of when they began to learn that language; and, 2) that there is striking uniformity in the knowledge of a language that users attain when they begin learning the language in infancy, despite wide variations in input environments. In addition, the experiments should reveal whether these phenomena are due to the nature of the acquisition process, to hitherto unnoticed details of the input, or to interference (or the lack of interference) from English.

The results should contribute to our understanding of the importance of early experience for language acquisition, and to the character of learning in childhood versus adulthood. In addition, they should contribute to decisions regarding language exposure, whether spoken or signed, in deaf education and parent counseling.