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Sensory Aids for the Blind.

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The problems of providing sensory aids for the blind are presented and a report on the present status of aids discusses direct translation and recognition reading machines as well as mobility aids. Aspects of required research considered are the following: assessment of needs; vision, audition, taction, and multimodal communication; reading aids, including individual devices and service centers; and mobility aids. The evaluation of reading machines and mobility devices; the introduction or deployment of new devices or techniques, and recommendations for a long range program are also considered. (RJ)

SENSORY AIDS FOR THE BLIND

NATIONAL ACADEMY OF SCIENCES

SENSORY AIDS FOR THE BLIND

Report of a Conference Held at the
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FOREWORD

Involvement of the National Academy of Sciences (NAS) in improvement and development of sensory aids for the blind began in 1945. Stimulated by the needs of those who lost their sight as a result of World War II, and by a desire to apply newly developed technology to solving some of their problems, the Committee on Sensory Devices (CSD) already had been established by Dr. Vannevar Bush in 1944 as a part of the wartime Office of Scientific Research and Development (OSRD). Shortly before termination of its activities OSRD transferred the CSD, with the same membership and research contracts, to the National Research Council (NRC) in October 1945. The existing Committee on Prosthetic Devices--predecessor of the present Committee on Prosthetics Research and Development (CPRD)--and the CSD reported to the Board for Prosthetic and Sensory Devices. Fiscal support after November 1, 1945, was provided for the balance of FY 1946 by The Office of the Surgeon General of the Army, and for FY 1947 jointly by the Army and the Veterans Administration (VA); thereafter the remaining CSD program was sponsored financially by the Veterans Administration alone.

A convenient description of this early work and tabulations of the later programs sponsored by the Vocational Rehabilitation Administration, the National Institute of Neurological Diseases and Blindness, the National Institute of Mental Health, the U.S. Office of Education, and the Veterans Administration may be found in *Blindness 1964*,* first of an annual series published by the American Association of Workers for the Blind.

As an NRC function, CSD established a central laboratory for both research and evaluation at Haskins Laboratories. Work was done on development of ultrasonic guidance devices at the Hoover Co., Stromberg-Carlson Co., and Brush Development Co. RCA developed several types of

* Connor, Gordon B., editor, *Blindness 1964*, Annual of the American Association of Workers for the Blind, Inc., 1511 K St., N.W., Washington, D.C. 20005, 175 pp., c. August 1964.

reading machines with audible outputs. Radio Inventions built an improved Visagraph for tactile replicas, and Dartmouth Eye Institute, Franklin Institute, and Perkins performed research on magnifiers for the partially sighted. Franklin Institute also studied the relative merits of various types of obstacle detectors.

The CSD was reorganized in 1947 on its own recommendation because the members felt that developments had caught up with existing technology and more emphasis was necessary in psychological and human-engineering areas. Appropriately CSD was then transferred to the Division of Anthropology and Psychology of NRC. The Kellogg Foundation took over sponsorship of the Franklin Institute projects on magnifiers and mobility aids and made a grant to CSD for support as an advisory group.

With the reduction of field and laboratory work, efforts were concentrated on a masterful volume compiled under the editorship of Paul A. Zahl.* This book not only served as a summary report of CSD activities but also as a review of time-tested aids. The CSD was discontinued June 30, 1954.**

Despite its limited budget, the VA continued to support evaluation and further development of those segments of the CSD program that seemed to promise useful results. The RCA direct-translating "Reading Pencil," the Model A-2, was evaluated by psychologists at the University of Michigan, including study of training methods. The University of Rochester evaluated 21 optical aids for the partially sighted. Somewhat later, Haverford College evaluated a guidance device designed by Cranberg of the Signal Corps and produced by RCA.

* Zahl, Paul A., editor, *Blindness: Modern Approaches to the Unseen Environment,* Princeton University Press, 576 pp., 1950. (Reprinted 1962 with bibliographic additions, Hafner Publishing Co., New York, N.Y.)

** Kappauf, William E., "Final Report of the Committee on Sensory Devices" to the Division of Anthropology and Psychology, National Research Council, 18 pp. mimeo., 38-item biblio., June 30, 1954.

Out of this evaluation came recommendations for further development that the VA has supported at Haverford College and Bionic Instruments, Inc. This in turn has led to a three-laser cane now in clinical trials.

In 1954 the VA initiated a series of technical conferences on reading machines for the blind. In response to ideas developed at these conferences, the VA sponsored work on audible outputs for reading machines at Metfessel Laboratories (spelled speech) and Haskins Laboratories (compiled speech and synthesized speech). Work on home-type portable reading machines was begun by Mauch Laboratories. Results of all these efforts are now reaching clinical trials.

In 1964, after several years of informal discussions, Dr. Robert E. Stewart, Director of the VA Prosthetic and Sensory Aids Service, requested NAS to establish an advisory group on research in aids for the blind. Accordingly, the Subcommittee on Sensory Aids was established under the CPRD with Prof. Robert W. Mann, already a member of CPRD, as chairman. Out of the work of the Subcommittee came the recommendation for a conference to survey the status of aids for the blind, review current research, and assess possibilities for future action. The VA offered to support such a conference. It was held at Washington, D.C., March 30-31, 1967. This document is a report of that conference.

HERBERT ELFTMAN
Chairman, CPRD

PREFACE

The purpose of this report is to outline the current state of the art of sensory aids for the blind; to cite inadequacies in past efforts and funding to provide technological supplements; and to document areas of research, development, evaluation, and deployment, which are required to meet more satisfactorily the requirements of the blind. Reflecting on past experience, we formulate plans for a greater effort to provide rehabilitation for the blind at the individual, vocational, industrial, and national levels. We are convinced that such an effort is warranted on a humanitarian basis, but we do not overlook the ultimate compensation of program costs through the increased earning power of the rehabilitated blind and visually impaired.

Specific recommendations define an effective, sustained, integrated, long-range program:

1. The scientific, technological, rehabilitation, and economic resources of the nation must be mobilized to provide an effective program to meet the needs of the blind. Such a program should embrace research, development, and evaluation of blind aids, their eventual deployment, and training in their use.

2. The major thrusts of basic research that are required include: assessment of information requirements of the blind, assessment of human perceptual and sensory capabilities, and technological studies on the acquisition, processing, and display of information.

3. The systematic evaluation of sensory aids to determine utility, to guide further research, to feed back information for redesign, and to establish valid training procedures is mandatory and must be carried out in close liaison with research efforts.

4. The developmental facilities and costs associated with the production of small, experimental lots of promising devices must be recognized and provided for, as must the ultimate production engineering, operational, and maintainence aspects of deployed devices and systems. Concurrent demographic and economic studies must explore the

cost-benefit prospects of planned devices and systems so that adequate provision for deployment costs and organization can be made.

Assessing the present state of the art, we recommend program priorities:

1. Emphasis should be placed on the reading problem because of the present promise of early significant results that will require substantial developmental efforts.

2. A concerted attack on the mobility problem should proceed concurrently with that on the reading problem, but owing to our ignorance of human mobility (compared with reading) and the need for experience with man-device interaction, research and small-scale evaluation should be emphasized.

3. A strong effort should be made to provide various technological aids that can widen the vocational horizons of the blind.

To implement the program we propose three specific actions:

1. A committee on sensory aids providing connective structure between federal agencies and scientific and technical communities should be appointed. A suggested vehicle is the National Academy of Sciences-National Academy of Engineering-National Research Council, because that organization is well-placed to recruit advisory panels to formulate long-range plans, review proposals, and advise on funding.

2. An information center on blindness, providing a primary channel for dissemination of information to workers, users, and other interested individuals, should be created. Suggested responsible agencies are the National Institute for Neurological Diseases and Blindness and the American Foundation for the Blind.

3. Several research centers combining the mutually beneficial resources of university and industrial organizations capable of making contributions to fundamental and applied research and development should be established.

This report results from the discussions at a meeting of the Subcommittee on Sensory Aids of the Committee on Prosthetics Research and Development held at the National Academy of Sciences in Washington, D.C., on 30 and 31 March 1967.

CONTENTS

THE PROBLEM

Vision in the normal human accounts for the bulk of all input information. This enormous channel of communication between the individual and his environment provides the major proportion of his utilitarian input and a considerable part of his aesthetic input.

The classic problem of providing practical substitutes for vision is concerned primarily with access to the printed page and unhampered mobility in a normal environment. These objectives constitute the primary subject matter for our present consideration. It is worth noting, however, that many other applications of visual communication are also quite important; these range from sign reading to gesture observation, from graphic and pictorial instruction to scenic and artistic enjoyment.

The tasks of providing a blind person with sensory aids that equip him for reading text or for moving effectively in unfamiliar surroundings are formidable. Such aids must extract complex information from the environment and present the pertinent aspects to the user through one or more of his remaining sensory channels. The contrast between about a million nerve fibres from the eye to the brain and some 40,000 from the ear to the brain emphasizes the relative disadvantage of the ear, while a comparison of the 525-line visual video-image with the perhaps six-line resolution of the fingertip stresses the inadequacy of touch relative to vision. Adequate sensory-aid replacement of the functions of the complex neural networks of the visual systems obviously requires extensive fundamental knowledge and extremely sophisticated system design.

The present state of the art in reading and mobility prostheses has developed from research and development efforts spanning several decades. The Committee on Sensory Devices of the National Research Council under the chairmanship of Dr. George W. Corner flourished from 1944 to 1948 (1). This group coordinated the work of several laboratories but suffered untimely disestablishment when interest lagged during the postwar years because dramatic accomplishments akin to radar or atomic-fission devices did not materialize from sensory-aids researchers. The Veterans Administration held six technical conferences on reading machines for the blind between 1954 and 1966 (2, 3), the minutes from which have been distributed to interested workers and placed in reference centers. Other sessions that similarly provided for voluntary co-ordination of effort and exchange of information were the Human Factors Society Sensory Extensions Symposium, Cambridge, Massachusetts, September 12, 1960 (4); the ONR-NBS Symposium on Optical Character Recognition, Washington, D.C., January 15-17, 1962 (5); the International Congress on Technology and Blindness, New York, June 18-22, 1962 (6); the Rotterdam Mobility Research Conference, August 3-7, 1964 (7); and the International Conference on Sensory Devices for the Blind, London, June 13-17, 1966 (8).

Although these conferences have provided some measure of coordination, the efforts of private inventors and organizations, though frequently displaying individual ingenuity and commitment, have been largely uncoordinated, narrowly structured, and inadequately funded. As a result of these factors and the inherent difficulties of the problem, the existing arsenal of sensory aids is relatively small and falls short of meeting even the basic requirements of blind users. Talking books, Braille, and sighted readers are still used instead of an automatic text reading system, and the guide dog and the long cane remain more effective than any mobility device yet produced.

These shortcomings arise from several sources that are symptoms of a general lack of support in both magnitude and co-ordination. Besides the fact that the sparse research effort is limited to a few narrow and isolated fields of interest, there is often so little common ground among individual researchers that effective intercommunication is rarely achieved, even when the opportunity exists. Another difficulty is that the directions of research and development have not been guided by systematic assessments of needs and projections of cost. With such lack of explicit guidelines and coordinated thrust, results have been ineffectual. Yet another problem has been that of striking a satisfactory balance between technological development and fundamental research. Development projects have often been undertaken without sufficient preliminary basic study of user capabilities. The evaluation of the utility of devices or processes by behavioral scientists and iterative and concurrent engineering development (or reconsideration), extensive field trials, and the development of training procedures have been virtually nonexistent. The absence of any widely deployed device, coupled with the indeterminacy of the market (demographic and economic) represented by potential blind "customers," has isolated the field from manufacturing, marketing, and "sales," the very fields in which this nation excels. And finally, the organizational and funding resources that will be necessary when truly useful devices and processes are demanded by the blind have yet to be estimated, planned for, and mobilized.

Two brief, necessarily oversimplified illustrations can dramatize the national need and opportunity. Estimated federal support of research on several selected aspects of human rehabilitation arranged on a "per potential patient affected" basis would yield:*

$220.00	per cancer patient
76.00	per cardiovascular patient
1.25	per legally blind patient
0.50	per visually handicapped patient

Considering benefits accruing from a sensory-aids program in crass monetary terms, if sensory supplements enable one blind youth to become a competent computer programmer, he moves from dependency on marginal income for a lifetime, to a taxpayer who returns many

* Cancer and cardiovascular data from News Report of NAS-NAE-NRC, December 1966; blind and visually handicapped data from AAWB Annual Reports, Society for the Prevention of Blindness, and National Center for Health Statistics.

times over to the U.S. Treasury the investment his government made in his rehabilitation.

Given the difficult and unique goals implied by a sensory-aid prosthesis, an integrated and coordinated program responsive to the needs and capabilities of the blind is essential if substantial progress is to be achieved. The succeeding discussion includes technological, organizational, and support aspects. It is in part a review and in part a commentary on the direction and scope of visual-prosthesis research and development. The major objective is to show how a comprehensive, determined program can and should produce truly useful substitutes for vision.

PRESENT STATUS

Historically, the development of aids for the blind has always taken its impetus from some new technical development. Innovators usually have tacitly assumed that almost any method that achieves the translation of visual information into a tactile or audible signal will lead to success. We now know that this is not the case.

READING

Direct Translation

Since familiarity with photoelectric effects was obtained, there have been repeated efforts not only to provide light-sensitive probes but, more ambitiously, to translate graphic patterns into other modalities for use by the blind (6, 21). One class of device consists of a vertical, linear array of photocells directed at a slit narrower than the letter to be scanned. The presence of ink produces patterns of tones, or tactile or electrical stimuli with durations dependent on the times involved in scanning successive portions of letters. Another class of direct-translation device transforms the optical signals into enlarged replicas embossed in metal foil.

Some of these devices have been carried to reasonably workable models, then evaluated by prolonged clinical experience or by psychologists interested primarily in problems of selecting and training users. However, even after prolonged training, speeds with these devices are very slow (5-30 wpm), compared with visual reading or even with human speech. Thus direct-translation devices generally have not reached usable reading speeds for long articles and books. They may prove valuable for short-term, personal use--for reading labels, checks, short letters, and the like, thus providing a useful supplement to more sophisticated reading systems.

Recognition Reading Machines

There has also been great interest, over several decades, in more elaborate machines to recognize individual characters and produce some form of output assimilable by the blind user. Generally this means an auditory or tactile signal. This implies two quite different technological problems; one is character scanning and recognition, and the other is the generation of a new corresponding symbol or other linguistic signal in another sensory modality.

The first problem, that of optical character recognition, has received considerable commercial development in recent years. Simple systems exist that read only the ten digits and a few other symbols in a fixed-type style and format. Others are elaborate computer-coupled multimillion-dollar systems that read multifont typewritten characters at high speed and with great accuracy without human intervention (5). Because of their limited scope the simpler machines are not useful for blind sensory aid, and the more versatile systems are far too expensive.

Typical approaches to solutions of the second problem, that of transformed output, are to read out, on command, individual letters (previously spoken and recorded) or to synthesize speech from stored speech elements in response to the recognition system (8). Devices developed to date provide partial effectiveness but leave much to be desired.

One approach to achieve an individually owned recognition machine is to make maximum use of the blind operator (whose presence inherently limits usable speeds) to locate and track the lines of type and to decipher characters not in the repertoire of slower but simplified machines. The blind operator is also assumed to be more tolerant of reading error than would be a machine.

Most of the effort so far on recognition reading machine development for the blind has been on systems intermediate between the primitive direct-translation systems and the elaborate, costly commercial machines. However, they are still in relatively early stages of development and exist only as laboratory devices of limited performance (8).

Printed texts are frequently supplemented by line drawings and illustrations that must be converted into palpable objects or other forms intelligible to the blind. While facsimile-like devices with a raised-line output have been devised, they have not been practical or economic. Direct tracing of the ink-print lines by the blind person using a light-probe and relying on kinesthetic mental reconstruction is intolerably slow and restricted to very simple diagrams.

Mobility Aids

Efforts to increase the mobility of blind persons likewise have a long history. Auditory cues, long or short canes, guide dogs, or sighted companions are used by many, but the need for effective and readily available technological aids is great.

The simple light pattern to tone (or tactile) pattern output concept has been repeatedly reinvented to provide a <u>direct-translation</u> view of the environment. In addition to the problem of slow speed that plagues the application of this approach to reading, there are a great many other problems specifically related to mobility, such as infinitely variable scenic cues (compared to a few letters), shifting perspective of given cues, and changing illumination. Probe-type detectors have, therefore, seemed more practical, in spite of their obvious limitations. Most designers have used relatively narrow beams requiring manual scanning of the environment and relying on proprioceptive feedback of hand, wrist, and arm position to convey spatial concepts. Some, however, envision automatic scanning and a map-like tactile output.

Under the program of the Committee on Sensory Devices, at the end of World War II, three laboratories built ultrasonic mobility aids, and two built optical-triangulation devices. One of these led to a laser cane that is about to be evaluated. The current concept in this work is to preserve the many advantages of the long cane yet add tactile and audible signals giving early warning of objects (landmarks), stairs, or other major discontinuities of the terrain, and overhanging objects endangering the head and shoulders of the user (8, 20).

An ultrasonic device developed in England in the early 1960's has been evaluated in many countries, including the United States. Used like a flashlight, it provides a complex auditory signal potentially allowing discrimination of target texture (hard walls and bushes, for example) as well as distance. Psychological factors in selection of subjects and prolonged training appear to be important in the effectiveness attained with this device.

Another device using ultrasonic energy is carried on the chest like a small camera and explores the intended travel path of a blind user above and ahead of where he is probing with a cane. Early warning of sighted pedestrians and objects that could cause injury to his head or shoulders are examples of useful data acquisition by this system. The display is simple, and decisions can be made in real time (8, 20).

Numerous mobility aids have been built, but few designs have reached extended systematic trials. Thus far, such aids are most effective in combination with the long cane. Some aim at simple "go," "no-go" output, sacrificing information to simplify training; others provide richer outputs requiring extensive training for full utilization. Thus far no device for the blind attempts automatic recognition of features of the visual field (9, 20).

COMMENTS ON PRESENT STATUS

More recent efforts have acknowledged the need to bear the user in mind, but there still exists a bias toward technological development of devices in effecting improvements that do not always significantly benefit the user. Ambitious developmental projects have been undertaken without the aid of some preliminary user-oriented research as distinct from technologically oriented development. What is lacking is sustained study in which the several stages of technological improvement are closely tied to evaluations of the benefits to the user of the developmental and unit costs of improvement.

Some consideration has been given to the physical characteristics of a sense organ in designing devices, but a very small amount of attention has been paid to the crucial characteristics of the man-machine interface in designing aids for the blind. It is assumed that the subject will learn sufficient skills or that he will somehow adapt to an output that has been chosen chiefly for its technical simplicity. Common sense, intuition, and hindsight can be of some assistance, but as the sole guides in designing displays, they inevitably provide poor understanding of the principles underlying sensory perception. Without this fundamental knowledge, the choice of good display characteristics will be difficult and somewhat arbitrary, and progress will be slow.

Past experience indicates clearly that to approach sensory aids as a gadgeteering problem is to invite further disappointment. There is a critical need for more fundamental research on the psychology of sensory communication. This mislocation of research emphasis can be illustrated by the fact that useful available psychological knowledge is frequently ignored. For example, it is clear that the simple buzz, click, or tonal displays common to some devices recently developed to the evaluation stage are deficient by virtue of the sparseness of their perceived dimensionality; they fail to exploit many well-known aspects of sensory perception. We should do more to study such principles by simulation techniques before the design concept for a device reaches the hardware stage.

REQUIRED RESEARCH

The three steps in the process leading to eventual sensory-aid development should be: demographic and sociological assessment of user requirements and capabilities; realistic and specific definition of the technical problems based on facts as well as on intuition and speculation; and development of technology, devices, and systems to meet demonstrably important problems.

ASSESSMENT OF NEEDS

There is a critical requirement for clear, detailed assessments of the deficits and needs of, and potential benefits to, future users of sensory aids. It is necessary to have tangible answers to questions such as the following: How many blind persons want to read newspapers, typewritten documents, signs, or labels? How is this population distributed by age, sex, and education? What is the distribution of concomitant sensory or motor deficits? What proportion is willing to carry or to use elaborate mobility aids? Which classes of obstruction detection are most valuable, and which are second-order? In view of these and many other assessed needs, what kinds of research and development efforts should be mounted, and in what priority? What do projections indicate about the problems of integrating the blind into the society and work force of that time? What are the economic and social implications of raising these blind people to higher levels of effectiveness and self-worth? Obviously these questions precipitate many more relevant and necessary inquiries.

A detailed delineation of such data is urgently needed. Their collection and interpretation will involve biometricians and social and behavioral scientists from government agencies and private organizations.

PERCEPTION

To aspire to the optimum design of devices and systems for sensory supplement, a greatly enhanced understanding of those aspects of human perception germane to sensory aids is required. In contrast to earlier, isolated, unsystematic studies, an orderly comparative study of all areas that are likely to lead to that understanding is essential.

Despite the extensive existing total body of knowledge on perception, that part especially relevant to or supported by sensory-aid programs has been relatively meager. The many physiological and psychophysical studies of vision that may bear on sensory aids must be surveyed in order to define and initiate new research to fill obvious gaps. Besides the obvious relevance of understanding the visual processes, it is crucially important to have extensive information regarding the remaining sensory systems--those which the blind must use as replacement input channels (10, 11, 12).

Vision

The traditional studies of visual perception are concerned primarily with certain areas such as visual illusions, size constancy, depth, span of attention, pattern recognition, the effects of context, and the neurological and photochemical processes that give rise to these effects. Adequate prosthesis requires expansion in all of these areas, but two are worth singling out for special attention.

The first is the study of the neurological systems that underlie the basic perceptual processes. Microelectrode studies of the visual systems of vertebrates are revealing the organization of the networks in the retina and brain that detect and abstract complex visual information. This kind of knowledge is useful both in the design of prostheses to simulate nervous system processes and as background for the long-range possibility of direct access to the brain. It is important to note that the latter avenue--direct electrical intervention in the nervous system--is at present technologically impossible when the desired result is a semblance of useful vision. The very few studies of visual or auditory electrode implants in humans have clearly demonstrated the enormous gulf between present techniques and adequate direct neural stimulation.

At a more behavioral level, improved understanding of the perceptual and motor processes involved in visual reading is needed to guide the effort toward high reading rates with machine aids. In particular, the effects of field size and resolution; the span of immediate memory, context, and redundancy effects; and the scanning strategy of the eye in relation to sentence content are areas requiring study. The conditions that permit the sighted reader to achieve high speeds involve a complex interaction in which factors at syntactic and semantic levels control the activity of the scanning system, in this case the eyes. It will be important that methods be incorporated into reading aids for blind people that will permit similar efferent control over the input.

Audition

The sensory channels into which substitute visual signals can be introduced must also, of course, be well understood for effective prosthesis. But in such special applications, problems arise that have not necessarily been considered in conventional studies.

Consider, for example, the transformation of a visual image into the auditory modality. This requires the conversion of spatial dimensions into a perceived auditory space, necessarily having time as one of its dimensions. The fact that a reader can carry out these transformations and generate speech that can be understood at speeds of 200 wpm indicates that the auditory channel has sufficient capacity if the sounds are correctly structured. A considerable body of data concerning the physical properties of the auditory system is already at hand, but the study of auditory perception is still a long way from fitting these data into a theory of auditory communication. One reason for this slow progress lies in the inherent "nonlinearity" of the sensory and perceptual process, which makes the response to a complex stimulus difficult to predict on the basis of the responses to its constituent parts.

Numerous experiments demonstrate that the information-carrying capacity of simple auditory stimuli is generally insufficient for normal communication purposes. Complex sounds having a more varied perceived dimensionality transmit information more rapidly and efficiently. In addition, it has been shown that the duplication of information along different dimensions can improve performance and probably reduce the risk of error in the presence of a disturbing noise. Research shows that the perceptual processes operate on discrete bundles of information that are segmented within a short-term memory. The precise conditions governing this segmentation are not fully understood, but it is evident that these processes are reflected in the structure of natural languages and the production of speech.

To make multidimensional nonspeech sounds as discriminable and efficient as possible for communication, the individual dimensions must be perceived without confusing interaction effects. Therefore, in the absence of a theory of communication or a knowledge of the nonlinearities of audition (as a guide to the design of auditory displays), it is necessary to adopt an empirical approach to the choice of auditory presentation. Some limited progress has been made in this direction in research on outputs for direct-translation reading machines, although guidance devices for the blind may ultimately prove to be the more promising application of such displays.

Speech, being the familiar and socially important method of auditory communication, has received much attention from psychologists and psychophysicists, some of it directly relevant to the reading-machine problem. There is a substantial body of evidence that speech communication can and does bring to bear coding and decoding operations that are unique to the speech process and, indeed, make use of parts of the brain not used by other sensory inputs. There is, then, reason to suspect that there are inherent factors that cause communication by speech to be substantially faster than by any presently known set of nonspeech auditory signals. This poses a dilemma for the designer of reading machines which, in its simplest terms, is whether to elect speech with its built-in perceptual advantages and proven speed but at the price of instrumental complexity, or whether to press for simpler engineering solutions with uncertain prospects as to performance.

Thus, the problems involved even in the restricted and "applied" nature of designing sensory aids have deep roots in basic questions about speech perception and communication theory. It should be possible to interest a wider section of the academic community in these basic problems with much mutual benefit.

Taction

The use of the sense of touch to replace visual function has in the past been restricted principally to Braille reading. However, recent technological developments have made tactile stimulation practical with over 100 stimulators. Experiments with multiple tactile-point stimuli have indicated that more than eight bits of information can be reported by a subject after a stimulus presentation as brief as 10 milliseconds. In addition, humans have been shown to have a short-term memory for tactile stimuli, lasting about a second, and this memory can be trained to make considerably more information available than is normally the case. Tactile patterns, such as alphabetic shapes, can be recognized with well over 90 percent accuracy if presented briefly in a stationary position, and the accuracy is even greater if the pattern is moved while it is being sensed.

Braille readers and blind-deaf persons using the vibration method for perceiving speech have proved that the tactile channel is capable of communication at rates approaching 200 wpm. The present state of technology indicates that active tactile displays operating at a distance from the information source could be developed with a capability of producing stimuli that are informationally rich enough to realize these communication rates.

A relatively neglected area of tactile research, important to making tactile displays more practical, is the further development of tactile stimulators. The repertoire of types of stimulators that can be conveniently controlled and used has to be increased. Tactile-stimulator development has to be recognized as an area that is important not only for prosthetic [illegible]ds but also for implementing further research in tactile percept[illegible] processes.

While empirical data are accumulating to the point where development of rudimentary models of the spatial and temporal aspects of tactile perception appears imminent, much more work of this nature is urgently required.

Further understanding from basic research on tactile perception should eventually lead to perceptual models that will put the design of complex tactile displays on a scientific basis. This kind of research may someday lead to a degree of utilization of the tactile channel not yet imagined (13, 21).

Multimodal Communication

In general, sensory-aid use implies multimodal communication, even though a particular device may stimulate only one sense modality. Little is understood about how people handle information presented simultaneously in two or more modalities. Extensive fundamental research aimed at understanding these processes to form a basis for the development of efficient multisensory displays should be encouraged.

The increasing body of research literature on early sensory experience suggests that the state of development of an organism may be a crucial factor in determining the effects of experience with some kinds of stimulation. Findings of this sort have a bearing upon our objectives because of the possibility that the developmental state of the central nervous system of young children may be at a peak of "readiness" for the kind of learning imposed by a sensory aid, with the result that they can learn to interpret the signals from a sensory aid more easily and completely than adults. The conduct of this kind of research requires a long, sustained effort and access to a special subject population.

Perception researchers, as well as those concerned with demographic assessments and intrinsic design features of sensory aids, must recognize and study the differences in perception, mental constraints, and capabilities of the congenitally blind as compared with those of adventitiously blinded people (14).

READING AIDS

Individual Devices

A highly desirable type of reading aid is one that accepts ordinary printed material, recognizes the alphanumeric characters, and produces natural speech as its output. It has obvious advantages in terms of speed and familiarity, but it implies complex equipment and sophisticated processes. These may be appropriate to a library or a service center, but hardly to incorporation in a personally owned reading device. There are, in fact, situations for which the personal (and hopefully portable) device would have virtues that might offset its limited performance. This has motivated substantial amounts of work on several types of simpler devices.

The first of these is a direct-translation unit that converts the output from an array of photocells into a simple one-dimensional auditory display or into a two-dimensional facsimile display for tactile reading. These devices have been technically within reach for the last decade or so, and recent developments make feasible the volume production of small, highly portable units at relatively low cost. The performance of the present direct-translation units is hampered by inherent limitations in the crude transformation the device offers to the user's sensory and perceptual processes. Research directed toward reducing these limitations by improved device design and by optimal training procedures has had very little success. Presumably the main difficulty is the great information loss through the system. Nevertheless, a direct-translation aid may be of value to some blind people in certain limited but important situations. Too little effort has been put into discovering who these people are and defining the situations. If this work were done, it is entirely possible that some segment of the blind population might be significantly assisted by these simple devices, and at modest cost.

A type of reading aid between a direct-translation device and one that can generate synthetic speech is also receiving some attention. This intermediate type contains electronic logic for recognizing printed letters, allowing a spelled-speech output. Despite the low speed and accuracy requirements, the design of a low-cost character recognizer presents many technical difficulties; however, progress is being made in this direction in at least two laboratories. Furthermore, some of the studies on spelled speech suggest that it can be comprehended at speeds up to 100 wpm, though control studies with blind listeners and long passages of spelled speech at these rates have yet to be made. The effect of errors on recognition (and other factors that would emerge from such tests) could have a fundamental influence on the design of an intermediate-type recognition reader; hence, there is here, as in so much sensory-aids and prosthetics research, a need for more work to examine the underlying assumptions before they become too deeply enmeshed in the final design of a specific device.

Service Centers

Research on direct-translation and intermediate-type reading machines has been oriented toward self-contained, personally owned devices, accepting the performance degradation forced by the constraint of individual possession. Other possibilities appear, however, when the emphasis is put on performance. The rapidly expanding computer industry offers blind people the prospect of being able to share in the use of complex data-handling equipment that could outperform in both flexibility and reliability any personally owned equipment so far considered. Broadly speaking, there are three distinct possibilities, though they have so much in common that any eventual realization must certainly capitalize on the features of all of them.

The first system would make Braille material virtually universally and instantaneously available to blind students and professionals who depend upon it, and to those blind who prefer to use it for recreational reading despite present limited selections and long waiting periods (15). There are computer programs that translate English into perfect Grade II (contracted) Braille. Input can come from on-line, remote keyboards for real-time translation and embossing, from character-recognition machines where warranted, or, in the case of ink-print (the bulk of the blind's needs), from machine reading of the same type-compositor's tapes used for automatically setting type for upwards of 95 percent of all periodicals, books, and newspapers. There are computer programs that will take any of these input formats and automatically interface them with the Braille-translation program. Output in tactile Braille can be provided by remote, electric typewriter-size-and-speed Braille embossers, commercially available or modified computer high-speed printers, and several other experimental devices. All aspects of this Braille system have been successfully demonstrated to critical audiences of blind Braille readers (15).

Whether for ultimate Braille output, or as audio output, as described in the next paragraph, the resource of type-compositor's tapes as the efficient, less costly input means must be exploited. Economic and competitive pressures in the publishing industry are dramatically enhancing the automation of the editorial, format, composition, and printing functions. These improvements, undertaken with no regard for the blind, are producing ever more perfect type-compositor's tapes in greater quantity and variety. A coordinated, systematic program to collect these otherwise discarded tapes from publishers and type-composition firms should be established as soon as possible.

More interest in the use of Braille by students, employed blind persons, and the aged blind might be generated by efficient shorthand Braille codes equivalent perhaps to stenotype, and new Braille codes for music, mathematics, and the physical sciences. The current and almost exclusive emphasis on teaching literary Braille may be a prime factor in the relatively small minority of blind persons who are active Braille users.

A second system possibility would provide, in effect, an "audible-reprint" service for the blind. A central library installation would prepare tape recordings in spoken English from the books in its collection and send the recording to the person who had requested this specific selection. The central library would presumably keep a copy of materials likely to be requested by other users so that a second request would involve only dubbing the library's tape recording. The equipment needed to prepare the original recording would be, at minimum, an optical character recognizer for books already printed or type compositor's tapes for new books, a speech synthesizer, and a control computer. All of this equipment could operate at 10 to 20 times real time and, on such a basis, become economically reasonable in spite of high rental costs. Again, most of the component devices have reached a state of development that would justify the pilot trial of such a library center for the blind in the near future. The major problems will be those of organization, effective contact with the blind user and his needs, and work schedules that will make effective use of machine capabilities.

Any system with a speech output, including current talking-book programs should incorporate provision for time-compression of audiomagnetic tape. "Speeded-up" speech has been shown to be intelligible at rates in excess of 300 wpm (for real-time 180-wpm recording), and recent technological developments indicate that even greater comprehension rates can be obtained than were previously possible. But more thorough evaluations are needed for both the comprehension and user acceptance of such material. Speeded-up speech is a good example of an application that is of obvious value to the blind who must do most of their "reading" via the ear, but which can be important to a potentially much wider segment of the population (students and professionals, for example, who listen, in part, to their language input). The wider application can provide some of the incentive and economic basis for research, evaluation, and hardware development.

More extended utilization of speeded-up speech by taping and broadcast sources would probably be useful. A comprehensive study of production and distribution methods and an assessment of the potential audience population and requirements should be initiated.

As a third approach, it now appears feasible to link individual members of the blind population of a city with a central computing facility that could recognize print transmitted from personally owned scanning units (perhaps outputs of personally owned direct-translation devices) and send back a Braille or spoken output. Many advantages could result from such a service center. The individual would possess only the simplest part of the equipment, and the major maintenance problems would be transferred to the central facility. Moreover, it would be possible to continually upgrade the central hardware and software for all users as the technology and acceptance of the service advanced.

Special services extending far beyond access to the printed page could be offered. For example, it would be relatively easy to make it possible for the blind person to abstract, edit, or take notes on the material he is reading. Furthermore, the source of the information does not always have to be the printed page. It should be possible to make the user's terminal look like a teaching machine, a desk calculator, or a mailbox. The reading rate and other characteristics could be easily and accurately monitored and adjusted to the needs of the individual user. A record of the use and preferred adjustments during routine operation would provide valuable data to guide further research.

The probable cost per individual of such a library center or service center for the blind, or both, would almost certainly be high, and it is hoped that society as a whole, and not the individual, will desire to bear the necessary expense, at least for the central facilities. However, to cope with the practical and organizational problems and to make optimal use of computers in the prosthetics field, it would be most useful to begin at this time to examine some of the problems and assumptions and to carry out some preliminary cost and feasibility studies aimed at determining the best match between the blind users' needs and the capabilities of a computer facility.

Such studies should also assess parallel studies of computer-based systems proposing services to other segments of the population, to industry, and to government, in order to be able to exploit bases of utilization broader than the blind and thereby effect economies of scale or increased services, or both.

Several special technical developments will be required to meet the needs of blind users, and it is already possible to see where some of these requirements diverge from current computer practices. For example, the demands upon a print recognizer for commercial purposes are for high speed and high accuracy. These capabilities can be used to the full in a library center and so reduce the cost per reader hour of output. In a service center for the blind, the speed and accuracy requirements might be considerably lower, in part because the bandwidth of the input scan would be restricted by the characteristics of the telephone link and the human rate of scanning.

Further, the relationship between the needs of a group of blind readers and the characteristics of time-shared computer systems requires examination. In particular, questions such as the potential market demand, the clients' desires and needs, the number of subscribers required for efficient use of the facility, the amount of peripheral equipment required at the remote site in relation to the size of the central processing unit, and the possibility of other services should be under study now. Some of these questions are less crucial for a library center than for a service center, but time-shared use of a central computer is relevant even in the former case. There is also a need for an evaluation of the likely implementation costs, both present and future.

If the results of these studies prove encouraging, it will be logical to initiate very soon an experimental program to try pilot tests, probably in some large city, with the cooperation of a representative group of blind persons.

MOBILITY AIDS

The problem of conveying sufficient information about a blind person's surroundings to enable him to avoid obstacles and to navigate is probably the most difficult in the whole sensory-aid area. Unlike printed text, the input is not well constrained, and it is not always possible to define unambiguously what constitutes relevant information about the environment. Also complicating the problem is the possibility that the individual's perceptual concepts of space undergo a radical change with the onset of blindness, or in the case of the congenitally blind, three-dimensional spatial constraints may be ill-formed or distorted. Thus, the conventional introspections of sighted persons may be of limited usefulness in assessing important features of space as interpreted by the blind.

It is commonly agreed that all mobility-aid devices so far developed fall far short of providing the blind with complete mobility, although it is interesting to contrast the enthusiasm of an active minority of blind subjects with the pessimism of psychologists whose task has been to evaluate performance with a particular device. We may, in part, be contrasting the well-known and understandable proclivity of subjects to drive performance indices upward when they are receiving unusual attention with the realistic appraisal of the investigators who must compare the ease, speed, and effectiveness of these proposed mobility substitutes with the cane and dog.

While many aspects of current mobility devices are still controversial, it appears that with greater refinement they could be made useful enough to be valuable in certain limited situations as supplements to the use of a long cane or guide dog (20). In addition, some of the devices may provide highly useful mental constructs of the three-dimensional world to congenitally blind children.

The device-oriented character of past work in sensory aids again asserts itself in mobility studies. Given the immense complexity of the environment-device-man system, experimental hardware is essential for exploration leading to understanding. But device-orientation must not obscure our abysmal ignorance of normal (as well as the blind) human mobility and navigation. We desperately need research directed toward the formulation of a theoretical understanding of human mobility analogous to what reading and speech research is discovering about how humans communicate. Only the barest beginnings have been made along this line of attack.

And then, for evolutionary mobility devices, we likewise badly need accurate, systematic, objective, accepted <u>evaluation procedures</u> to correlate research hypotheses, to determine device effectiveness, to identify promising directions of design change, and to study significantly sized and varied subject populations in different mobility situations.

Functionally the blind mobility problem can be broken down into the blind man's "next step," his directional orientation, and his ability to navigate over reasonably long travel paths. Current devices address themselves to providing partial information about the next step or the next several steps. Is there an aperture adequate for the passage of his body? Are there significant terrain elevation changes that he must anticipate to maintain his balance or ensure his safety?

The "aperture" problem has been the prime focus of past and current efforts. While demonstration devices exist, there are serious unresolved questions of their effectiveness in real time and in realistic public environments. Further, there are severe questions that include the identification of and reaction to moving or multiple obstructions, or a combination of the two, in the face of clutter and at the price of tension and anxiety caused by false alarms.

The terrain change, in particular the "step-down" or unexpected-hole problems--sources of understandable anxiety to the blind that have been resolved so nicely by the cane or dog--although they are the subject of several investigations, are still elusive. No mobility aid can begin to cope with problems of the blind person when there is a question of whether the surface afoot is about to impinge upon his adequate area and strength.

But travel is more than the progression of next steps. Getting from here to there demands periodic orientation with respect to the environment and navigational decisions based on maps and geography. The rich visual orientation cues that the sighted exploit must be supplemented by information accessible to the blind. Tasks subconsciously simple to the sighted, like straight-line travel across unobstructed, acoustically cueless spaces (such as large parking lots or wide avenues) remain a trial to the blind. Whereas rapid movement in crowded spaces may require simply coded sensory displays to permit real-time reaction, orientation needs may demand probes that provide that rich sensory input necessary to distinguish between objects of potential interest--trees versus buildings, or picket fences versus brick walls. Ultimately perhaps, the chore of object identification can be progressively transferred to the device's pattern-recognition capability thus achieving a more satisfactory trade-off between rapid-but-simple and rich-but-slow information.

Navigation decisions are based on recourse to graphic descriptions of the environment and mental constructs of the desired route. Again the blind's assimilation of and ready reference to a store of what is basically visual data must somehow be enhanced beyond the necessarily simplified, raised-line maps used in sheltered residences for the blind. And again, lest the easy unawareness with which the sighted orient and navigate lull us, note well the distinction, for the blind, between travel in familiar and unfamiliar surroundings. All too often the confidence and ease of a blind traveler along a particular route is a reflection of his familiarity with and careful memorization of many subtle aural and textural cues characterizing navigational decisions and potential hazards.

Where the system is concerned, the man-machine symbiosis represented by a blind man and a device can be segregated into search and detection, coding, and display. Search and detection questions are predominantly technological. The kind of search energy, optical or sonic, whether passive or active, send versus receive times, sampling rates, scanning strategies, location relative to the human body, and other factors are strongly influenced by such questions as bulk, weight, complexity, and reliability of power supply, signal transmitting, receiving, discriminating, and amplifying. Sensory aids stand to gain significantly from progress in solid-state devices, microelectronics, battery research, and other studies undertaken for reasons quite remote from the problems of the blind.

Ultimately the information collected by the device must be presented to the man in such a way that it can be comprehended rapidly and with minimum training and stress. The basic perception research--modality, coding, stimulation--discussed on page 16 is relevant, but now must be structured so as to be relevant to the mobility situation.

Within the wide range between alternative environmental information that the device can be designed (or conceived) to generate, and the rich variety of aural, tactile, and multimodal physical sensory displays that can be conjured up, is an equally vast repertoire of alternative coding and decision logic that can be built into device hardware.

The fascinating and challenging problem is to discern optimal combinations of device detection and coding interfaced with man-machine sensory display. The permutations of alternatives are enormous, and even were we to attempt to quantify the detection, coding, and display alternatives, we are at a loss to characterize the man part of the symbiosis.

Simulation would appear to be called for (16). The computer could maintain in real time, by means of a subject-tracking scheme, the path of a blind traveler as he traversed a physical space. Computer programming could characterize, with great flexibility, alternative search and detection specifications of proposed mobility devices. The real-time knowledge of subject location, coupled with simulated device characteristics, could permit continuous calculation of the (simulated) detection of obstacles stored in computer memory, which obstacles might or might not exist physically on the obstacle course. The computer could likewise be programmed to simulate a wide variety of alternative logical coding decisions based on the detection information. The outcome of the computer-simulated device could then be transmitted to a physical sensory display worn or held by the man.

Since only the display itself need be physical a great many more alternatives could be considered, especially since no hardware design, fabrication, or test would be involved in different combinations of device search, detection, or coding characteristics.

The very substantial investment in computer hardware and software and subject tracking and telemetering need not be justified only on the basis of the search for mobility device specifications. The "mobility simulator" would also represent a valuable experimental resource in the establishment of a theory of mobility. Furthermore, and perhaps justification enough, the mobility simulator would provide an indefatigable, errorless, unprejudiced observer and recorder of man-device effectiveness, thus organizing and regularizing device evaluation and permitting longitudinal testing of significantly large and varied subject populations.

Another potential computer application relates not to research, design or evaluation, but rather to the day-by-day orientation and navigation problem discussed above. All mobility aids considered in the past have been devices carried and used by the individual. But another approach, now becoming increasingly feasible, is the use of a central, time-shared computer system similar to that envisioned for reading. One can speculate on the not-too-distant possibility of a computer storing a map of the city and, by means of closed-loop telemetry, conveying to remote users specific information regarding direction, landmarks, and potential hazards at particular locations.

EVALUATION

Frequent reference to evaluation in this report attests to its unique importance and the need to incorporate a discussion of evaluation in a separate section even at the risk of duplication. To many workers in the field it looms as the greatest problem (17, 18).

It is perhaps trite to note that the only measure of utility or effectiveness of sensory aids is the amelioration of the effects of blindness. However intriguing as research, or brilliant in conception, or clever as engineering design, only wide acceptance and regular use of sensory devices signifies progress. Unfortunately, virtually all incentives of the free-enterprise system do not apply to this field. As yet, and for the foreseeable future, there is no profit-oriented inducement--no sensory-aids industry. In fact, against the million or so visually impaired and blind in the United States and the multimillions in the world and the organizations that in part represent them, the impact of scientific research and technological development in sensory aids has been so vanishingly small as to have virtually no effect. There may even be a built-in, psychological antipathy to the introduction of new and unfamiliar proposed aids by a deprived population which has adapted itself to its loss using time-tried remedies.

The absolute criteria for utility, the very innocence and defenselessness of the ultimate users, and our ignorance of their numbers and needs illuminate the very special role evaluation plays in sensory-aids development. Furthermore, there is an almost total absence of the usual infrastructure of product design, manufacturing, and marketing associated with product innovation and introduction in the consumer goods fields. Unlike commercial products, sensory aids cannot use the customer as an evaluation means. Even incomplete success is too hazardous physically and psychologically, beyond which the customer has no receptivity to, even awareness of, devices with which he has had no experience. Unlike the drug industry, no profit seems likely. Unlike the introduction of a new surgical tool, no expert body of customers exists that can and will provide informed, critical, and useful feedback on improvements, performance, and utility.

Faced with these overwhelming problems, workers in sensory aids have subsumed evaluation as part of their over-all responsibility. The burden is not unilateral or unrewarding; the same key criteria of utility <u>to</u> the blind, and therefore evaluation <u>with</u> the blind provide invaluable insights and data on what the blind need and how to satisfy these needs.

But we have only begun to realize the scale on which evaluation must be done and resources absorbed, if the process is to be meaningful. Even were one to concede that some, if meager, research and development funding of sensory aids is available, it is eminently clear that the resources essential to adequate evaluation have yet to be planned for.

Existing facilities for evaluation of sensory aids reflect the piecemeal and uncoordinated means available for bringing advanced technology to bear on the problems of the blind and deaf-blind. Evaluation must be seen in the context of the entire process of research and development on the one hand, and of deployment and training on the other. As things stand, evaluation is carried out, for the most part, by separate organizations that are the passive receivers of prototypes that have come into being as the result of the ideas of scattered individual researchers.

The process of evaluation can be more sharply focused when the use of a particular device is considered within the context of a comprehensive inventory of the needs of the blind for access to information or for mobility. Implicit in an adequate needs assessment are criteria that can be used in the evaluation process.

Comprehensive evaluation of sensory aids should result in (a) recommendations for redesign of the device, (b) statements about the gamut of needs the device can fulfill, (c) statements about the segments of the blind population that will find the device most useful, and the segments that will find it of limited utility, and (d) statements about the nature and amount of training that will be required to introduce various segments of the blind to efficient use of the device.

Evaluation in this broad context will require diverse skills: engineering, psychological, educational, computational, and sociological. No single organization is apt to have all these skills on tap full-time for such use. The ideal solution would be an institute that could call upon the intellectual resources of nearby universities in a consultative capacity. It would also be desirable to have it conveniently located with respect to institutions directly engaged in the training and rehabilitation of the blind. Such an organization will need to provide sustained support for core personnel so that the energies of its staff are not dissipated in annual fund-raising.

We are convinced of the absolute necessity of one or more evaluation centers, with a funding commitment of not less than five years and a team of behavioral scientists, technologists, and mobility rehabilitation specialists whose mission would include research or evaluation, as well as the evaluation of specific devices.

READING-MACHINE EVALUATION

Relatively little effort compared to that required for mobility devices is required in the evaluation of reading machines. Behavioral scientists rely on comprehension measures that include word- or syllable-presentation rates and reader accuracy in tests of information content. The evaluations, of necessity, are limited in total reading time, variety of material covered, numbers and kinds of readers, and comparisons with alternative displays. Studies of reader acceptance, demonstrated motivation apart from motivation inspired by the experiment, reading material of the individual blind person's choice, sufficiently long reading time for plateaus of comprehension to be established and maintained, and numerous other factors that extend beyond a preliminary analysis are often neglected.

If reading-machine evaluations are to be truly meaningful, the following important factors must be included:

1. The selection of reading materials must be matched to the interests and education of the subjects.

2. Short-term comprehension must be measured relative to presentation rates. However, information retention over much longer time spans than those covered in typical evaluations is also very important.

3. A particular reading machine that enables the blind person to do certain kinds of reading must be compared with alternative solutions. For example, although the use of a sighted reader implies dependence upon another human and a loss of privacy, how do the human and the machine compare in efficiency of reading and cost?

4. User acceptance under voluntary reading conditions and for tasks related to vocational, educational or recreational pursuits are the true measure of the worth of a reading machine.

In conclusion, there is sufficient experience in the measurement of reading by sighted persons to enable transfer of testing methods and materials to the evaluation of reading by the blind.

MOBILITY-DEVICE EVALUATION

It is well to recognize at the outset that we have much to learn about the process of evaluation, especially when we are concerned with mobility devices. A primary problem is the necessity to develop methods and data peculiarly appropriate for this task. This will involve highly detailed descriptions of the environments in which the blind move and the kinds of problems they encounter in each. Just as the problem of reading the labels of cans and denominations of bills is vastly different from the problem of gaining access to current technical periodical literature, so the mobility problems presented by the interior of an office or residential building are likely to be different from those that arise on the street or sidewalk in an urban setting. A step-down in an unfamiliar split-level house is rather unlike a fireplug on a sidewalk, yet both can be hazardous to a blind person.

Also needed will be extensive data on the capabilities and limitations of the remaining sensory channels available to the blind. Unless such data are available, evaluation cannot be directed to useful statements about a given device, its limitations, and its capabilities.

Particularly in the area of mobility aids, a long period of research is necessary before adequate results will be forthcoming. In such a situation, evaluation will be initially directed not to a decision about final production and deployment of a device, but back to the research laboratory with recommendations for redesign. For such feedback to be fast and effective, evaluation cannot be performed in isolation by a completely autonomous organization, but must be closely related to the entire research and development effort.

Engineering analyses and tests of device specifications must be applied to the laboratory prototype and continued through the production and evaluation phases. Sensory aids often change characteristics after being used for a considerable length of time. Unless there is up-to-date information on the performance characteristics of each device, variables will be introduced that are difficult or impossible to measure or control.

Experiments should be conducted both under laboratory conditions and in the field. As a practical matter, most experiments are now conducted under carefully controlled laboratory conditions in order to employ rigorous scientific methods. However, these relatively simple testing situations bear little resemblance to blind mobility in the real world. Although measurements of performance in real situations are much more difficult, extensive testing should be undertaken in the field to enhance the limited controlled experiments.

Blind subjects should be used. A number of evaluations have been attempted with blindfolded sighted subjects; if partially sighted subjects were used, their remaining vision was deliberately masked. Selection of blind subjects from the blind population should not be at random; the subject should be matched to the capability of the device. For example, aids intended as environmental sensors are probably more useful to the congenitally blind child or adult than to the newly blind and partially sighted. Similarly, early-warning object and terrain change detectors are of little value to a guide-dog user. It is rarely possible to locate, and virtually impossible to match, experimental and control groups of blind subjects. Each subject can be established as his own control in order to determine change in performance.

In such a complicated task as blind mobility a carefully planned and documented training procedure and adequate time for training are absolutely essential.

Instrumentation for measuring all the factors and events--spatial and temporal, stimuli and responses--in evaluation experiments should take full advantage of data gathering, recording, and analysis equipment used in astro-space, military, automation, and other specialized fields. Systematic recording of data will not only enhance the specific evaluation but will contribute to an information resource useful to others for evaluation, systemization, behavioral research, and other fields.

DEPLOYMENT

Deployment encompasses the problems of transition from research, development, and evaluation to routine use of new devices and techniques. The introduction of new items implies a process that includes not only procurement but also training, servicing, and operation. The cost of this process must be anticipated and planned for by public and private agencies.

Even well-known, proven items like talking books or guide dogs are used by only a small percentage of the blind population. The identification of those blind persons likely to benefit from a specific service or device is difficult, yet important. Past experience indicates that no single device or technique serves the entire blind population--nor need it do so to be of real benefit.

We stress the significant contributions to society and the substantial economic returns that can result from the better rehabilitation of the minority of younger blind persons with many productive years ahead, the people most likely to use new devices and techniques. We also recognize, though, that in the United States the majority of the blind are elderly and retired, people who are concerned primarily with the creative use of leisure time. Deployment of services and devices that reduce the dependency of these elderly persons upon sighted relatives and volunteers might also have substantial benefits for society at large. Demographic and economic studies should be undertaken to generate estimates of projected costs and benefits associated with enhanced capability of the blind resulting from the introduction of sensory aids and systems.

In addition to economic aspects, there are other important if less tangible merits of better sensory aids. Social contacts of the blind with sighted persons, often by-products of the use of a sighted guide for mobility or a sighted reader for study or entertainment, should be enriched by removal of dependency and by increased possibilities for activity. A recent survey showed that veterans given rehabilitation training at Hines Veterans Administration Hospital and furnished not only with a long cane but also with a variety of other technical aids, and assured of a minimum income, were exceptionally active and had an above-average level of participation in community and leisure-time activities (19).

Some devices and services are now substantially ready for field trials by blind users. Using these as examples, deployment studies should be undertaken that would include the establishment of criteria for matching a device to a blind individual; the estimation of the population likely to be affected; the definition of training methods; the orientation of appropriate field personnel; and the estimation of costs for hardware and for training, service, and maintenance costs.

Several devices will be the subject of modest trial introduction by various agencies within the next fiscal year. If adequate funds were available, though, these studies could be expanded to include larger samples and more varied populations--blind children, working adults, elderly blind, and women as well as men--from different geographic locations and sponsored by other types of agencies for the blind. Currently available facilities and funds permit only very brief and partial demonstrations.

Substantial additional funds would be needed to support large-scale trials of systems requiring a central computer facility to produce contracted Braille or to synthesize speech from type-compositor's tapes or from multifont reading machines; yet such systems are at hand or will be available in the next few years.

Government and private agencies may well consider several levels of impact from the products of new research and advanced technology to aid the blind. There is already some limited support for research, development, and evaluation, with tangible yet relatively limited results. A substantial expansion of research and development can be justified in terms of the economic return from the systematic deployment of results to increasing numbers of clients.

With respect to range planning, each agency for the blind must consider the profound impact upon its functions, its caseload, its budget, its personnel, and its public relations that will result from the vigorous deployment of new services and devices. There are dramatic possibilities at hand to make blind persons more mobile and better able to perform, even slowly, limited but important tasks like recognizing paper money or proofreading typewritten material. In a very few years the blind should be more capable of independent reading at worthwhile rates.

An analogy to the successful orthopedic and prosthetic appliance clinic teams now widely used by government and private agencies is pertinent. While individual specialists can best perform specific actions, a team of these specialists (including the patient himself) can reach wiser decisions on the prescription of the best available device, initial inspection or checkout of the device, the application of proper training, and the final approval of the combination of the trained patient and device. Prosthetics education courses for members of orthopedic clinic teams have been developed. As new devices and services for the blind involve more complex information from more specialties, somewhat similar teams will be needed in work for the blind; specialized educational programs and modification of existing courses will become necessary.

Important right now are the results of evaluations and initial deployment of presently available, if very limited, aids. The extension of results from tests of these handmade models will guide further research and development, leading to new cycles of improvements. These interlocking, mutually interacting steps all participate in realistic efforts to assist the blind of this generation.

RECOMMENDATIONS

The considerations explored in the preceding sections lead the Subcommittee to make four over-all recommendations.

1. The scientific, technological, rehabilitation, and economic resources of the nation should be mobilized to provide an effective program to meet the needs of the blind. Such a program should embrace research, development, and evaluation of blind aids, their eventual deployment, and training in their use.

2. Three major thrusts of basic research are required:

   a. Assessment of information requirements of the blind

   b. Assessment of human perceptual and sensory capabilities

   c. Technological studies on the acquisition, processing, and display of information.

3. The systematic evaluation of sensory aids to determine utility, to guide research, to feed back information for redesign, and to establish valid certification procedures is mandatory and must be carried out in close liaison with research efforts.

4. The developmental facilities and costs associated with the production of small, experimental lots of promising devices must be recognized and provided for, as must the ultimate production engineering, operational, and maintenance aspects of deployed devices and systems. Concurrent demographic and economic studies must explore cost-benefit prospects for prospective devices and systems to plan adequately for deployment costs and organization.

With respect to program priorities:

1. Emphasis should be placed on the reading problem, because of the present promise of early significant results that will require substantial developmental efforts.

2. A concerted attack on the mobility problem should proceed concurrently with that on the reading problem, but owing to our ignorance of human mobility (compared to reading) and the need for experience with man-device interaction, research and small-scale evaluation should be emphasized.

3. A strong effort should be made to provide various technological aids that can widen the vocational horizons of the blind.

Research, both basic and applied, is central to these recommendations, but effective research requires good men, a suitable environment, and an appropriate organizational framework. Because teamwork across disciplines is required by the nature of the problems, the research can best be done in research centers that must then take responsibility for the selection of personnel as well as for the environment in which they work.

Important ingredients in an effective research environment are built-in mechanisms to ensure that the investigators have access to important scientific developments, an atmosphere of fair and lively competition, and adequate technical support services and facilities. The high cost of modern research facilities and the need to exchange information with colleagues puts a high premium on being in or near a major scientific research community.

The organizational framework appropriate to a national program on sensory aids for the blind should itself be nationwide in scope and character, cooperative with the government, but not a part of government. To discharge the several functions of guiding the over-all fiscal and scientific aspects of the program, collecting and disseminating information, and conducting the research, the Subcommittee recommends a tripartite structure:

1. A committee on sensory aids, providing connective structure between federal agencies and scientific and technical communities should be established. A suggested vehicle is the National Academy of Sciences-National Academy of Engineering-National Research Council, because that organization is well placed to recruit advisory panels to formulate long-range plans, review proposals, and advise on funding.

The present Subcommittee on Sensory Aids was established as a matter of administrative convenience under the Committee on Prosthetics Research and Development of the NRC. The promotion of the Subcommittee to full committee status would recognize both the maturing of the potential for aiding the blind as well as the substantial differences between the problems of sensory versus muscle-skeletal deprivation. The new sensory aids committee would require the services of a full-time professional person and a secretary, who would help document the work of widely scattered volunteers, follow and correlate laboratory and field studies, and help the committee to develop realistic proposals for expanded efforts in the sensory-aids field.

2. An information center on blindness, providing a primary channel for dissemination of information to workers, users, and other interested individuals, should be created. Suggested responsible agencies are the National Institute for Neurological Diseases and Blindness and the American Foundation for the Blind.

3. Several research centers should be located so as to combine the mutually beneficial resources of university and industrial organizations capable of making contributions to fundamental and applied research and development.

Action to implement these recommendations could appropriately begin with a decision by the National Academy of Sciences-National Academy of Engineering-National Research Council, to form a committee on sensory aids, the selection of a suitable chairman, and the recruitment of a full-time executive secretary on the NAS-NAE-NRC staff.

These seem necessary steps in planning the research program and in enlisting the aid and support of interested government agencies and of organizations outside government.

Finally, the participants recognized that, although this conference has concentrated on the blind, a comprehensive program should include other forms of sensory deprivation, and that the proposed committee on sensory aids should expand its concern to include other sensory losses.

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21. P. W. Nye, "Reading Aids for Blind People--A Survey of Progress with the Technological and Human Problems," in Med. Electron. Biol. Eng., 2, 247-264, Pergamon Press, London, 1964.

APPENDIX A

PROGRAM

Chairman: Robert W. Mann

March 30, 1967

ORIENTATION	Robert E. Stewart Robert W. Mann
POSITION PAPERS	
Research and Development	James C. Bliss
Evaluation	John K. Dupress
Deployment	Robert W. Mann

Luncheon

GENERAL DISCUSSION	Plenary Session

March 31, 1967

PANEL MEETINGS

Research and Development

Evaluation

Deployment

Luncheon

CLOSING SESSION	Plenary Session

APPENDIX B

PARTICIPANTS

PANEL ON RESEARCH AND DEVELOPMENT, EVALUATION, AND DEPLOYMENT

Dr. James C. Bliss, Research Engineer, Control Systems Laboratory, Stanford Research Institute, Menlo Park, Calif. 94025	R
Dr. C. Warren Bledsoe, Division of Services for the Blind, Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, North HEW Building, Washington, D.C. 20201	D
Dr. Robert A. Bottenberg, Chief, Mathematical and Statistical Analysis Branch, Air Force Personnel Research Laboratory, Lackland Air Force Base, Tex. 78236	E
Mr. Leslie L. Clark, Director, International Research, American Foundation for the Blind, Inc., 15 West 16th St., New York, N.Y. 10011	D
Dr. Franklin S. Cooper, President, Haskins Laboratories, 305 East 43rd St., New York, N.Y. 10017	R
Mr. Gilbert B. Devey, Program Director, Engineering Systems, Engineering Division, National Science Foundation, Washington, D.C. 20550	R
*Mr. John K. Dupress, Managing Director, Sensory Aids Evaluation and Development Center, Massachusetts Institute of Technology, 292 Main St., Cambridge, Mass. 02142	E
Dr. Emerson Foulke, Department of Psychology and Social Anthropology, University of Louisville, Louisville, Ky. 40208	R
Mr. Howard Freiberger, Electronics Engineer, Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, 252 Seventh Ave., New York, N.Y. 10001	D
Mr. Charles Gallozzi, Division for the Blind and Physically Handicapped, Library of Congress, Washington, D.C. 20542	D
Dr. Robert H. Gibson, Associate Professor of Psychology, University of Pittsburgh, Pittsburgh, Pa. 15213	R
Dr. Hyman Goldstein, Associate Director, Division of Research, Children's Bureau, Department of Health, Education, and Welfare, Room 4640, North HEW Building, Washington, D.C. 20201	--
Mr. Leon D. Harmon, Bell Telephone Laboratories, Inc., Murray Hill, N.J. 04971	R
Mr. James R. Kingham, Staff Editor, Committee on Prosthetics Research and Development, NAS-NRC	--

* Deceased.

Professor John G. Linvill, Department of Electrical Engineering, Stanford University, Stanford, Calif. 94305 R

Dr. Douglas C. MacFarland, Chief, Division of Services to the Blind, Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, Room 3280, North HEW Building, Washington, D.C. 20201 --

Professor Robert W. Mann (Chairman, Subcommittee on Sensory Aids), Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass. 02139 D

Mr. Glendon L. Smith for Mr. Hans A. Mauch, Mauch Laboratories, Inc., 3035 Dryden Rd., Dayton, Ohio 45439 R

Dr. A. William Mills, Assistant Professor of Psychology, Tufts University, Medford, Mass. 02155 E

Mr. Harold E. Morse, Office of Education, Room 3069, Regional Office Building, 7th and D Sts., S.W., Washington, D.C. 20202 D

Dr. Eugene F. Murphy, Chief, Research and Development Division, Prosthetic and Sensory Aids Service, Veterans Administration, 252 Seventh Ave., New York, N.Y. 10001 D

Dr. Patrick W. Nye, Willis H. Booth Computing Center, California Institute of Technology, Pasadena, Calif. 91109 R

Dr. Leo H. Riley, The Catholic Guild for All the Blind, Newton, Mass. 02160 E

Dr. Mark R. Rosenzweig, Professor of Psychology, University of California, Berkeley, Calif. 94720 E

*Dr. Robert A. Scott, Russell Sage Foundation, 230 Park Ave., New York, N.Y. 10017 --

Professor Thomas B. Sheridan, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Mass. 02139 E

Dr. Matilde Soloway, Chief, Program Project and Clinical Center Grants, Extramural Programs, National Institute of Neurological Diseases and Blindness, Room 7A03A, National Institutes of Health, Bethesda, Md. 20014 D

*Dr. Robert E. Stewart, Director, Prosthetic and Sensory Aids Service, Veterans Administration, Vermont and I Sts., N.W., Washington, D.C. 20420 --

*Miss Mary E. Switzer, Commissioner, Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, Room 3300, North HEW Building, Washington, D.C. 20201 --

Dr. Wilson P. Tanner, Jr., Sensory Intelligence Laboratory, University of Michigan, Ann Arbor, Mich. 48104 R

* Did not attend.

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Dr. Harry J. Friedman for Dr. Edward J. Waterhouse, Director, Perkins School for the Blind, Watertown, Mass. 02172 D

Mr. Benjamin W. White, LIN-D270, Lincoln Laboratories, Massachusetts Institute of Technology, Lexington, Mass. 02173 E

Mr. Russell Williams (11F), Chief, Blind Rehabilitation, Veterans Administration, Vermont and H Sts., N.W., Washington, D.C. 20420 E

Mr. A. Bennett Wilson, Jr., Executive Director, Committee on Prosthetics Research and Development, National Academy of Sciences, 2101 Constitution Ave., N.W., Washington, D.C. 20418 D