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EVALUATION OF MOBILITY AIDS FOR THE BLIND

Proceedings of a Conference
June 22-23, 1970
Airlie House
Warrenton, Virginia

Patrick W. Nye, Editor

Subcommittee on Sensory Aids

Committee on the Interplay of Engineering
with Biology and Medicine

NATIONAL ACADEMY OF ENGINEERING
Washington, D. C.

1971

In Memoriam

J. ALFRED LEONARD

Dr. J. Alfred Leonard, whose many contributions to this conference can be found liberally scattered throughout these pages, died on December 9, 1971, at age 48 after a brief illness. In the short space of nearly ten years he succeeded in prompting and promoting several significant practical innovations in the field of blind mobility and influenced much of the prevailing thought on potential solutions to its problems.

Educated in Cambridge, England, Dr. Leonard worked for a few years at Ohio State University and returned to England to join the Applied Psychology Research Unit in Cambridge. During these years his work was concerned with the application of communications theory to the analysis of human operator behavior. His interest in blind mobility began in 1962 when he was asked to perform an evaluation study of early models of the Ultrasonic Torch developed by Dr. Kay.

Alfred quickly saw the need to know more about the characteristics and lifestyles of the blind with a view to bringing the needs and opportunities more sharply into focus. In 1963 he initiated the idea of conducting a national survey of the blind population of the U.K. and was actively involved in an advisory capacity throughout its planning and execution. (The results of this unique survey were published in 1968.)

A year later, in 1964, he visited the United States to study long-cane mobility training programs and visited Hines, Western Michigan, and St. Pauls. He was greatly influenced by the views of Richard Hoover and Father Carroll, and frequently recalled the visit as an important milestone.

On his return to England, Alfred vigorously set about work which resulted in the formation of the Midland Mobility Center (now the National Mobility Center) sponsored by the Royal National Institute for the Blind and St. Dunstan's.

In 1965 Alfred founded the Blind Mobility Research Unit in the University of Nottingham and directed its activities until his death. At Nottingham he strove to put into practice the philosophy of another friend and strong influence, John Dupress. Alfred described it as a scientific and humanistic approach.

Alfred, throughout his work, stressed the need to make the best use of every solidly practical opportunity for improving the mobility of the blind population while at the same time pursuing longer range research. He was an articulate, provocative and amusing advocate of this point of view. The conference drew much of its sparkle from his presence and it seems wholly appropriate that these proceedings should be dedicated to his memory. He will be sorely missed.

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2. To explore means of promoting cooperation in engineering in the United States and abroad, with a view to securing concentration on problems significant to society and encouraging research and development aimed at meeting them.

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New York, New York

THE SEEING EYE, Inc.
Morristown, New Jersey

PREFACE

> "And now that's done," said the blind man; and
> at the words he suddenly left hold of me, and
> with an incredible accuracy and nimbleness,
> skipped out of the parlour and into the road, where,
> as I still stood motionless, I could hear his stick
> go tap-tap-tapping into the distance.
>
> Treasure Island
> R. L. Stevenson

That a man can be blind and yet wish to remain independently mobile in spite of the hazards is often cause for admiration on the part of the sighted. The fact that some succeed is often cause for astonishment. But these responses to blindness embody a curious paradox, for it should be understood (certainly by the sighted) that for the blind man, as with any other, mobility is an expression, not only of the desire to demonstrate independence, but of a basic human need. Traditionally to meet this need, two principal tools have been adopted, the dog guide and the cane, both of which have come to symbolize the blindness rehabilitation movement, and both still represent today the best available aids to independent travel for blind people.

Since the end of the second world war there has been a growing effort directed toward the use of technology in the development of additional mobility aids. However, the blind have as yet derived essentially no benefit whatever from our enhanced technological capacity to explore the environment by means of techniques such as radar, sonar, lasers, etc. The reasons for this stem partly from a lack of adequate resources to exploit these technologies and partly from an inadequate basic understanding of the principles governing the effective presentation of visual information to a blind man's auditory or tactile senses. Without knowledge of the best ways to process and display information for given tasks, much experience must be gained by trial and error methods not all of which can be applied within the laboratory. This creates an important shift of emphasis in the strategy of mobility aid research and development which cannot be stressed too strongly. The major consequence of this shift is that evaluation and training techniques must be invoked more frequently to provide empirical data to guide further research and hence training and evaluation become a more intimate and important part of research and development than is customarily implied by the term R&D.

During the last ten years several devices have been produced in quantities large enough to permit small-scale field trials, and several groups of workers both in the U. S. and abroad have been independently engaged in training blind people to use these devices and in evaluating the behavior of both the device and the man.

The experience gained in these field trial studies has led to a growing awareness of the unique importance of systematic evaluation; a trend which can be traced in the Proceedings of the International Congress on Technology and Blindness held in 1962 (1)*, in the Proceedings of the Rotterdam Mobility Research Conference held in 1965 (2), and in the Proceedings of the International Conference on Sensory Devices for the Blind held in 1966 (3). Also apparent is the realization that the more important mobility criteria that must be defined involve the assessment of a highly complex array of behavioral variables that are difficult to isolate and to measure. However, these three earlier conferences, rich in valuable material documenting progress in sensory aid development, were able to devote only a small proportion of their time to the subject of evaluation and more particularly to the important matter of refining its methodology.

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* References in the Preface, Introduction and Discussion Report are found on page 140. References noted in a contributed paper are found at the end of the specific paper.

In view of the critical role that evaluation must necessarily play in defining the direction of the next decade of mobility aid development, the Subcommittee on Sensory Aids of the Committee on the Interplay of Engineering with Biology and Medicine (CIEBM) gauged this an opportune time to assemble an international group of experts on mobility training and the evaluation of mobility aids to review and combine their experience on this important topic.

This publication contains contributed papers and a report of the discussions which took place at the "Conference on the Evaluation of Mobility Aids for the Blind" held at Airlie House, Warrenton, Virginia, on June 22nd and 23rd, 1970, under the auspices of the National Academy of Engineering (NAE). The program of the conference is given in Appendix A. The list of invited participants is provided in Appendix B.

The Subcommittee on Sensory Aids gratefully acknowledges the support provided for its activities, including this conference, under the NAE contract with the Office of the Director, National Institutes of Health (NIH) for programs of the CIEBM. Additional financial assistance for the conference was provided by the American Foundation for the Blind, Inc., The National Eye Institute of NIH, and The Seeing Eye, Inc.

The success of this conference was the result of intensive and thorough participation on the part of each participant; to them the Subcommittee extends its appreciation. Also to be acknowledged were the efforts of the staff of the CIEBM; Charles W. Garrett (Executive Secretary), Dorothy B. Campbell (Administrative Assistant) and Mary Alice McDonough (Secretary) who ably handled all of the essential administrative details attendant to the conduct of a conference of some 35 participants, and to Sally Prewitt who typed the camera-ready copy of this report.

Patrick W. Nye, Editor

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INTRODUCTION

Patrick W. Nye

A Background Review and Summary of the Conference

In the absence of any nationwide register of the blind population, the estimated number of "legally" blind people* in the United States obtained by different methods ranges widely from about 400,000 (4) to about 1,100,000 (5). Some authorities believe that the true figure is more likely to lie closer to the larger estimate (6). It is known, however, that roughly half of the blind population are over the age of 65 years and that most have some residual vision, there being close to a quarter of the population who are totally blind. A significant but unknown proportion are thought to have multiple handicaps.

The two most widely used aids to independent mobility are the long cane and the dog guide. Again the figures are sketchy but estimates based upon small sample surveys indicate that at most only 15-20 percent of the blind population have received any form of cane-travel training and, much of this being inadequate, the proportion of proficient cane travelers is consequently a very small fraction of those presumed to have been "trained." Furthermore, only about 1 percent of the blind population use dog guides. In contrast, the proportion of the blind population often cited as being potential recipients of mobility aids (7) and candidates for all types of mobility training is approximately 10 percent of the total; a number exceeding 40,000

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* A definition of what is sometimes loosely referred to as the "legally blind population" (although it is not legally defined in all states) includes those whose visual acuity is less than 20/200 in the better eye using the best optical correction or a visual acuity of more than 20/200 if the widest diameter of the field subtends no greater than 20 degrees.

to 50,000 persons (see 3.01).* The fact that existing mobility aids fail to reach these people reflects a number of factors among which are shortcomings in the manpower and resources devoted to training; limitations in the methods used to screen potential candidates; the use of inefficient training techniques; psychological factors related to the acceptance of blindness; and above all the inability of the dog guide or long cane to fully meet the mobility requirements of many people. It is the stated intent of the proponents of most recently developed mobility aids that by harnessing a modern technology they will create a device which can supplement rather than supplant existing aids and therefore provide additional information to the traveler to make his task of obstacle avoidance and navigation easier. To be able to achieve this goal the designer requires the answer to two basic questions: What is the nature of the information that the device must select and a blind man needs to know, and how can this information be transmitted in a form that the man can utilize? However, a quest for the answers to these questions has in fact formed the starting point of very few, if any, mobility aid designs [8]. Rather, devices have tended to be strongly influenced by a gadgeteering philosophy and have evolved in an <u>ad hoc</u> manner. Too much attention has usually been given to technical feasibility, efficiency, cost and weight factors, and relatively little concern has been focussed on the needs and capabilities of the user. In some measure all of the devices in existence today represent the legacy of this approach. But the need to find answers to the basic questions is now more widely acknowledged (see 7.01) and it is generally thought that the existing devices may represent useful tools with which these questions can be explored and analyzed.

The task of conveying information about a blind person's surroundings in sufficient detail to enable him at the very least to avoid obstacles and ultimately to navigate is extraordinarily difficult. The problems to be faced have many parallels in the design of an automatic print reading machine for the blind, but unlike printed text, the input presented to a mobility aid is not well constrained (Bliss, p. 59),** and it is not always

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* References of this form refer to the indexed Discussion Report beginning on page 117 of these proceedings.

** References of this form refer to contributed papers by the invited speakers contained elsewhere in these proceedings.

possible to define unambiguously what constitutes <u>relevant</u> information about the environment. Also complicating the problem is the possibility that an individual's perceptual concepts of space may change with the onset of blindness or, in the case of the congenitally blind, their three-dimensional spatial concepts may be distorted (see 10.12) (Leonard, p. 66). Thus the conventional introspections of sighted people may be of limited usefulness in assessing important features of space as interpreted by a blind man. Moreover, the fact that the development of perceptual concepts is a process of exquisite complexity and carried out in an apparently unconscious manner (see 10.10) indicates that even introspective data obtained from blind people themselves is unlikely to reveal much that is useful (see 7.03). But without these data it is not possible to take the step that several conference participants recognized as desirable; namely, the development of a theory of mobility (see 10.06)(9). For despite the fact that it is possible to suggest the important elements of cognitive function that the theory should explain (see 10.12) and that one can provide general descriptions of some perceptual processes (see 10.10), there is very little known about the subject of human information processing that can be used to guide the development of mobility aids. It is clear that at the present time, while not overlooking what can be learned from psychology and neurophysiology, empirical experimentation remains the only alternative approach to the design of mobility aids. Moreover, the critical factor of the empirical approach, which distinguishes it from mere gadgeteering, is the close interaction between repeated modification and subsequent evaluation.

In the development of a device which is designed to conform to the physical characteristics and capabilities of a man, evaluation is one of the most difficult phases to complete. In a case where the visual information that the device imparts to the user must be processed and conveyed to substitute sensory channels in a form that he can readily understand, the difficulty is compounded many times. Such complex factors as the experience and personalities of the subjects whose performance is under test contribute to the difficulties of evaluation. Nevertheless, despite the many problems, the broad objectives that an evaluation must seek to reach are clear. They are:

> To establish that the device is robust, reliable, technically proficient, and that manufacturing variations lie within acceptable limits (Pugh, p. 30).

To derive significant measures of user performance which can be compared with those obtained with other devices or modifications of the same device.

To provide information that can ultimately lead to the production of better devices.

Both in the content of the papers and in the subsequent discussion periods, the participants at this conference focussed attention primarily on the development of measures of user performance. Nevertheless, at times the field of discussion ranged widely from consideration of methodological problems concerned in the conduct of an evaluation trial to broader issues concerning the resources required for mobility aid development, the need to characterize the population of potential users of mobility aids, and the need for more qualified mobility trainers (Curtis, p. 46).

At the present time, three mobility aids have reached a stage in their development where evaluation studies are either actually being planned or are indicated for the near future. The basic features of these devices, which utilize either ultrasonic or laser radiation, are described in section 1.0 of the discussion report and references (10), (11) and (12). Primitive prototypes of two of these devices, the "laser cane" and the "sonic spectacles", were the subjects of earlier evaluation trials(13, 14, 15). In general these studies were characterized by small numbers of subjects. For example, fewer than 30 people were employed in the largest evaluation of the sonic torch, and frequently reports were based upon a sample of only one blind subject(3). Even among the better-planned studies which sought objective measurements of mobility performance, the conclusions (admitting the inability to assess such factors as stress) often included subjective judgments of possible effects supported by anecdotal evidence. The need to strive toward the development of a "practice of evaluation" as a systematic discipline has been apparent for some time, and the evaluation techniques discussed at the conference represented extensions, improvements and reappraisals of some of the procedures which figured in these earlier studies. In addition, new techniques were proposed which are designed to provide the ability to monitor most of the many variables involved in mobility. The complex of interactions between these variables was recognized as a central factor in the evaluation of mobility aids, and as an essential area for further research.

Prominant among some of the evaluation techniques employed during the last ten years has been the use of obstacle courses (12, 14) (Russell, p. 40). More recently, however, there has been a trend toward the use of actual urban environments (15) (Russell, p. 40). In the former case the performance is typically measured in terms of travel speed and number of collisions, and although the conditions can be clearly specified, the usefulness of the procedure is limited, particularly as a training regime, by its inherent artificiality. The urban environment on the other hand, gains in realism at the expense of some degree of control and brings a greater variety of complex problems to the task of analyzing performance. A key approach to these problems has been the analysis of mobility into a system of sub-tasks, each of which can be assessed more or less independently in the manner adopted in operations research (17). The performance score at each of the sub-tasks is accumulated to provide a measure of the traveler's overall proficiency (see 2.09). However, this method is not entirely free of subjective factors and, more importantly, it fails to include a measure of the degree of stress, anxiety, or mental effort borne by the traveler.

One approach to this latter problem has involved the measurement of the heart rate of blind people when traveling with a sighted guide and when traveling independently (18). But the interpretation of these data suffers from certain ambiguities. In particular the question of whether the effects are due to stress or to mental effort will require further study (see 6.01). A supplementary approach, not yet employed in mobility research and yet deserving of attention, is the use of the secondary task. The mobile subject is given an additional task to perform which is compatible with walking, and the effect on the performance of the primary skill is observed as the duties of the secondary task are varied (see 6.03). This procedure is designed primarily to assess the amount of surplus mental capacity that the subject can afford to devote to the secondary task, but there are other interaction effects which can be studied as well (see 2.07).

An often-repeated conclusion of all recent evaluation studies has been the need to develop adequate screening procedures to identify those candidates who can make the best use of the device and the training that they receive [13, 15]. However, although it has been suggested that the attitudes, physical and mental capabilities and personality traits of potentially good trainees can be recognized, there have been no attempts to compare initial predictions with subsequent experience. It is to be expected that this approach will be followed in future evaluation trials.

Yet another evaluation criterion which received some discussion was that of user acceptability. Well aware that it hid a number of (as yet) unspecifiable factors, most participants recognized that it was crucially important, but they were unable to suggest how user preferences should be factored into a long term evaluation (see 2.05).

The essential role and the need for the cooperation of mobility trainers in the planning and execution of all phases of an evaluation trial was also stressed (Benjamin, p. 13). Peripatologists were seen as representing an important reservoir of experience (in the training of blind mobility with conventional aids) which can be usefully applied in the investigation of new devices. This was true not only because performance with an aid must ultimately be compared with known levels of performance using a dog guide or long cane (Pugh, p. 27) but also because mobility trainers possessed the best available knowledge of the rates at which certain types of skill can be acquired and therefore the amount of training time likely to be needed.

There also appeared to be general agreement on the need for the involvement of larger numbers of subjects than has often been the case in past evaluation studies. Groups of at least 50 subjects (see 2.08) were considered desirable to permit significant conclusions in the face of the wide range of age, personality, physical and background variables commonly found in a sample of blind people. The background or prior travel experience of the subject is often of dominant importance. One experimental method which has been adopted in several past evaluations has been the use of the subject as his own control (see 2.01). However, some doubt was expressed about this procedure owing to the possible presence of conflict between the skills required in the control and test tasks (see 10.14).

Looking ahead to the future, several authors drew attention to the need for more research on the development of a means of conveying information from a device to the traveler (Benjamin, p. 15). Signalling systems more complex than those now in use were indicated, for example, and displays involving large arrays of body stimulators and speech outputs were cited as deserving of attention (Leonard, p. 79). The evaluation of the technical and behavioral features of a mobility aid or its output by simulation techniques on a digital computer was another potential approach which aroused much interest (Mills, p. 88) (Mann, p. 101). As a technique commonly used in the aircraft industry in the study of man-machine behavior, it appears not unreasonable that simulation could be applied to the problems posed by a mobility aid. However, it was pointed out that the costs of a general purpose simulation facility for mobility aid evaluation and research are high in relation to current rates of expenditure in the sensory aids field. It was suggested that it would be both prudent and useful if, in the immediate future, simulation techniques could be applied (see 7.08) primarily to problems of information coding. Thus the potential of this technique in the field of sensory device development could therefore be initially demonstrated on a more modest scale than that which would ultimately be necessary (and, perhaps, desirable) to carry out the extensive program proposed by Dr. Mann.

Although attention was chiefly concentrated on the mechanics of evaluating the performance and training of groups of blind travelers, the conference did not overlook some of the wider issues. The need to obtain more data about the mobility needs and habits of the blind population was stressed for two important reasons. First, because there still is a great deal of ignorance about certain aspects of blindness, ignorance which is detrimental to the welfare of the blind and may lead to the initiation of unnecessary programs at the expense of more urgent work, the observation that good demographical data are essential to the rational ordering of priorities has been made many times [6, 8, 19]. Second, if efficient use is to be made of research funds, we need methods of assessing the impact of rehabilitation programs on the blind population at large so that the effects of improved devices, easier access to training, or better training techniques can be measured and the success or failure of a coordinated program fairly judged over a reasonable span of time [20].

In particular, a properly orientated survey of the blind population in the United States would be of enormous value at this point in time. It should be designed to provide an accurate snapshot of the activities and life style of the blind population for later comparison with other surveys made at regular intervals and thereby provide in the future the opportunity of assessing the impact of rehabilitation programs and devices now in the planning stage.

It is in many respects ironic that in summarizing the achievements of a conference it is necessary to perform an evaluation fraught with those very same subjective factors that should be avoided in assessing mobility. Nevertheless, such an admission does not absolve the need to seek objectivity. What then were the initial objectives? The conference program stated the intent to assess the requirements, delineate the problems and evaluate the progress in the development and use of mobility aids. It is unlikely that any conference could have fully met all of these objectives within two days. The limitation in time and the broad scope of many of these topics barred an exhaustive exploration. However, it would appear that the conference achieved much of its purpose and in particular that it served three important functions:

(1) On a personal level, the philosophies of those protagonists who will have a major influence on future developments have been made clearer to each other and to interested observers, and this should lead to a better understanding and closer cooperation.

(2) It has made possible the assembly, in these proceedings, of a guide to the methodology of mobility aid evaluation and related disciplines in their present stage of development. This is available through a compendium of ten papers and references to other key research sources to which careful attention should be paid in the planning of future evaluation studies.

(3) Perhaps more important still, by focussing attention on the critical need to establish coordination and comparability between evaluation studies and to develop a systematic approach to its problems, the progress of mobility aid research will be accelerated and the blind community will soon come to share some tangible benefit from the growth of our technological society.

THE BIONIC INSTRUMENTS C-4 LASER CANE

J. Malvern Benjamin, Jr.
Bionic Instruments, Inc.

Description of the Bionic Instruments C-4 Laser Cane

For the past several years a continuing effort has been made * to develop an electronic aid for the totally blind traveler. Its intended purpose is to warn of dangers in the traveler's path soon enough to allow the graceful application of evasive action, thus reducing the danger and nerve strain attendant on blind travel and increasing travel speed. The device is formed in the shape of a conventional long cane to allow the user the benefits of the conventional cane as well as the early warning features of the electronic aid.

The device emits pulses of infrared light which, if reflected from any object in front of it, are detected by a photodiode placed behind a receiving lens. The angle made by the diffuse reflected ray passing through the receiving lens is an indication of the distance to the object detected. See Figure 1.

The cane emits three beams which look simultaneously down, straight ahead, and upward. The downward channel will warn of any drop-off larger than 9" which appears approximately two paces in front of the traveler. The most serious of these would be a down-going flight of stairs, a train platform, or an open manhole or cellar-way, but large down-curbs can be frequently detected also. A low-pitched tone emitted by the cane notifies the user.

The straight-ahead beam, about 2 feet high, has a maximum range adjustable out to 10 feet in front of the cane tip

* Supported by the Veterans Administration of the U. S. Government.

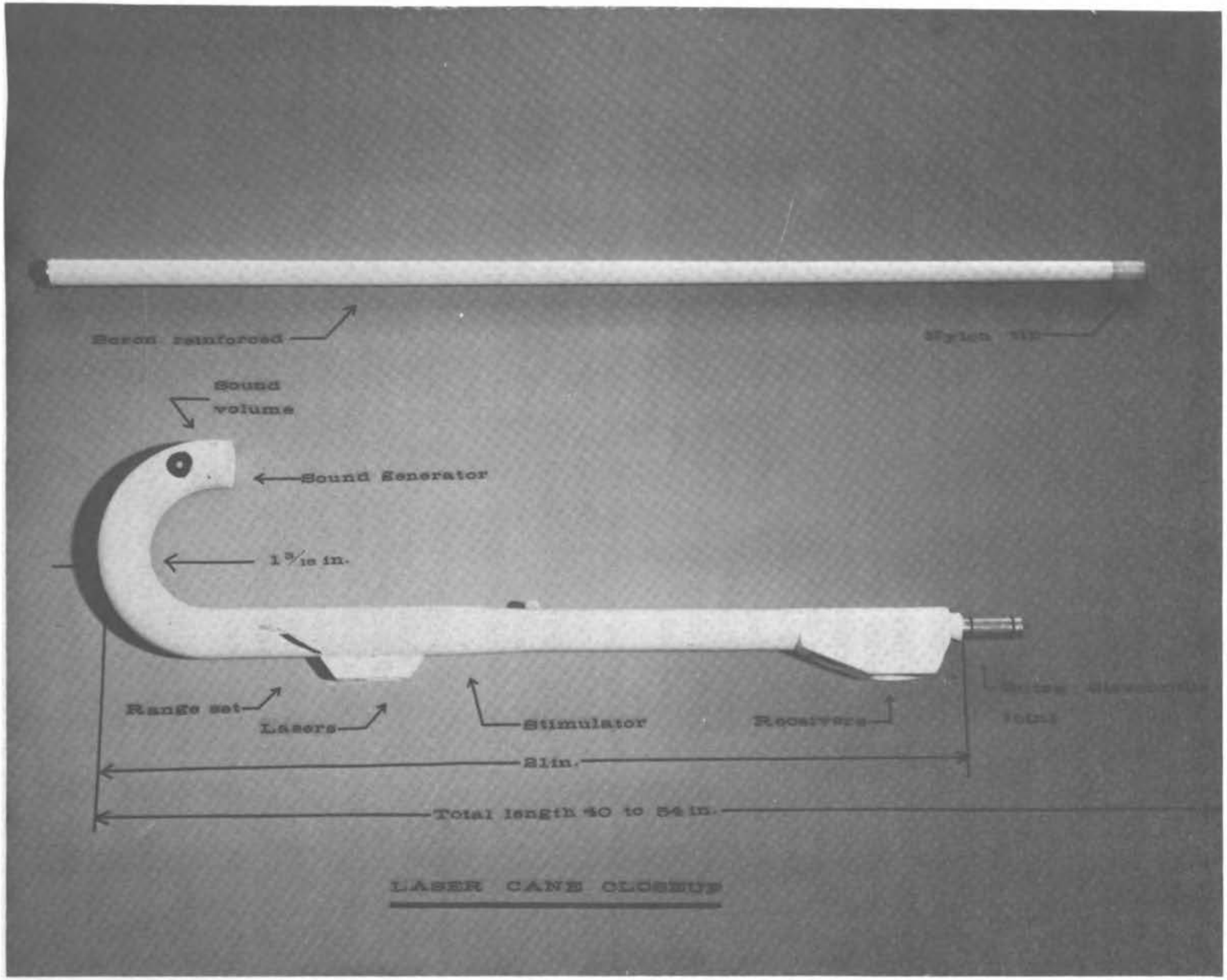

FIGURE 1

Bionics Instruments C-4 Laser Cane

by means of a button located near the user's thumb. Any obstacle detected within this range will actuate a stimulator that contacts the index finger when the cane is carried in the usual "long cane" manner.

The upward-looking beam will detect obstacles at head height appearing directly above the cane tip. Warning is given by a highpitched tone.

Each of the three beams is only 2" wide at 10 feet; so objects may be located with considerable precision by suitable scanning. The usual procedure is to twist the wrist slightly in a rhythmic fashion while walking.

Three GaAs room temperature injection lasers are connected in series to emit 0,1 microsecond pulses of 9000 Å 40 times per second. Outputs from three silicon photodiodes are each separately amplified, filtered, coherently gated to eliminate response to any rapid light transients, and then used to operate the appropriate tone generator or stimulator. Power consumed is 600 mW from a 12 V NiCd rechargeable battery.

Special attention has been paid to keeping the weight low and to distributing it so that the cane will approximate the "feel" of a conventional long cane,

Intercomparison of Several Aids

It is of interest to intercompare the Bionic Instruments C-4 Laser Cane, the Kay Ultra Aid, and the Russell Pathsounder. Such intercomparisons may be made on the following bases: (1) kind of information acquired, (2) means of sensory transduction, (3) means of carrying, (4) training time required for mastery, and (5) cost. I believe that in intercomparing and evaluating these and other devices it is important to make this sort of breakdown because while some features of a particular device may be inherent, others may be only trivial, and thus easily changed if desired.

(1) Kind of information acquired. As I see it, the Cane and the Pathsounders are useful primarily to speed travel and to reduce nerve strain attendant thereto. Each device does this by detecting obstacles far enough ahead of the traveler to allow

graceful avoidance of them. The design philosophy of both these devices is to provide only enough information to allow detection and avoidance, not usually enough to provide identification. The Ultra Aid, on the other hand, produces a signal with enough information content to allow not only the detection, but also the identification of the object, in many cases. For simple obstacle avoidance this extra information may not be needed. If not needed, however, the extra information may simply be ignored. In some cases this information may be used for landmark identification.

The C-4 Cane and the Ultra Aid when head-mounted can also detect overhead obstacles. In addition, the C-4 Cane can detect drop-offs in the terrain when they are sufficiently large (e.g., two steps, but not usually a curb).

(2) Means of sensory transduction. All three devices produce an auditory output. In addition, the C-4 Cane also uses a tactile output for the "straight ahead" channel. In our experience, an auditory output has proved to be much more attention-getting than a tactile output, but, if loud, it is also much more attention-getting from passers-by, while if soft, it may be masked by ambient noise. All three devices provide a manual volume control to help the user cope with this situation. Some users have felt that the acoustic signal from the Ultra Aid can mask other important aural cues, but the experience of sighted automobile drivers and the experience of P. Bach-y-Rita with his complex tactile output seem to show that the mind can learn to ignore unwanted inputs and concentrate only on needed ones.

(3) Means of carrying. Evaluation of our G-5 hand-held obstacle detector, the predecessor to the C-4 Cane, showed that the blind traveler objected to the extra encumbrance of a hand-held device in addition to his cane. He further felt that the amount of information produced did not allow abandonment of the cane; so when technology permitted, we incorporated the electronics into the cane itself. The Ultra Aid head-mounted and the Pathsounder chest-mounted also avoid encumbering another hand. I believe the head to be the best mounting place for any device with a fairly narrow beam because of the natural kinesthetic feel of head scanning, provided that the device is small enough to be inconspicuous and light in weight.

(4) Training time required for mastery. The three devices here considered predictably rank in training time in order of complexity of output. I consider it desirable to have available a series of devices of graded complexity for clients with varying motivations, learning abilities, and intellectual curiosities.

(5) Cost. With regard to this factor, the devices probably rank in this ascending order: Pathsounder, Ultra Aid, and C-4 Cane. While cost is an important factor for any device that will go into widespread use, I consider it less important than the foregoing factors, because advances in technology and increases in volume demand always reduce prices and because a good device can usually be subsidized somehow (e.g., the dog guide).

Mobility Aid Evaluation

The meaningful evaluation of a mobility aid seems to me to be an exceedingly difficult task. The first evaluation one should perform is the rather straightforward engineering evaluation of seeing that the device operates according to physical specifications. Additionally, however, an evaluation is usually trying to answer the question, "How much (in quantitative terms) does the device help the blind traveler?" Traditionally, the problem has been tackled either by timing travel speed and error rate through a special course or by the collection of anecdotal "testimonials." The first approach is too restricted and artificial to be definitive, while the second is inadequately scientific.

It appears to me that two things must be done to get around these problems:

(1) Recognize that the total man-machine system needs to be evaluated, not just the machine. This means that before attempting to evaluate a device, time must first be allowed for its use in a quite freewheeling way by combinations of trained perceptive peripatologists and blind users. During this phase, the questions to be asked are, "What will the new device allow the blind traveler to do better than he can otherwise do?" and "How shall we modify present travel techniques to make use of these new insights?" Thus, during this phase, which I would call a "brainstorming" phase, negative criticism should be held to a minimum. Little effort should be made to identify flaws in the

device except easily correctable technical problems. Rather, the concentration should be on discovering as much new information as it is possible to acquire. The next step is to build a new travel technique that will incorporate the findings. At this point a new man/machine system has been created that is capable of "evaluation."

(2) Decide what specific questions the evaluation is to attempt to answer. Is our baseline an unaided traveler, a cane traveler, a dog traveler, or a traveler with a sighted companion? What are the criteria -- speed, avoidance of obstacles, reduction of tension, independence, financial cost, aid in orientation, etc. -- that should govern the final evaluation? Should several such factors be chosen and weighted appropriately?

<u>C-4 Cane Evaluation</u>

The C-4 Cane is still at the stage when the man/-machine system is being constructed. To this end, 11 canes have been built and loaned to agencies, both Veterans Administration and private, for initial experimentation. We are making an effort to place the cane with people who are imaginative, and, while thoroughly knowledgeable regarding current travel techniques, are yet interested in exploring new approaches.

Eight organizations participated in the work herein summarized. The subjects, of whom there were approximately 21, were almost all mobility trainers operating under blindfold and working in pairs -- one operating the cane while the other was observing. In this fashion, they logged an estimated total of 250 hours of use, with an average session of approximately half an hour.

There was virtual unanimity that the forward-looking channel is a useful addition to a long cane. Opinion was divided regarding the usefulness of the upward-looking channel, and vitually everyone found the downward-looking channel difficult to use and hard to interpret.

Many found the cane uncomfortably heavy, especially ladies, and nearly everyone complained that holding the finger over the stimulator for as long as 20 minutes caused the finger to become numb. Several users had difficulty with the cane tip; it would catch in cracks and other irregularities in the sidewalk. Several found that the auditory signals could not be made strong enough to overcome loud street noises.

The upper channel was found to be a "definite aid to a skilled user." It was used by some for shorelining a wall, and it located awnings and other overhangs satisfactorily for several others. Several suggested that the range be moved farther from the tip of the cane in order to give somewhat earlier warning, because too quick a response was required by the time a warning appeared. Some felt that they spotted false alarms, but this may have had to do with the angle at which the cane was being held.

Everyone seemed to find the forward-looking channel useful. It was used variously for shorelining, obstacle detection, locating recesses in doors (even in heavy traffic where acoustic cues drop out), and avoiding irregular clutter in large indoor or outdoor areas. It was considered not to be useful with a range shorter than approximately six feet, and it was found by some to be useless when crossing a street because the traveler must concentrate too much on other cues. It was also found to be of no help in heavy pedestrian traffic.

The downward-looking channel seemed to perform satisfactorily in finding the tops of stairwells and large downslopes, and was found useful by some for detecting curbs, changes in ground texture, and mud puddles. It was also found useful in detecting many low-lying obstacles, such as footstools, coffee-tables, automobile overhangs, etc. On the other hand, it was a disappointment that it could not detect curbs as low as 6 inches in any reliable fashion, and that when the sensitivity is set so that it will pick up changes in texture, it also produces many false alarms.

Thoughts on the Next Steps in Mobility Aid Designs

Until the recent advent of integrated circuits, lasers, and other advances in the art, the field was really technology limited. That is, it made sense, in my opinion, to start by building what was practical and then finding out what it would do. At this point, however, there are many directions which one can take; so it now becomes more important to decide what most needs doing as well as what can be done.

The next logical extension of the work on any of the three devices discussed herein would seem to me to call for head or spectacle mounting and terrain sensing as well as obstacle sensing. This can now be done either optically or sonically. That is, the next generation device should probably have two channels. The obstacle channel should cover the full length of the body and extend out about three paces, while the downward-looking channel should warn of any drop-off of more than three feet. Probably this would best be done by sensing rate of change of a continuously ranging system.

AN AID TO MOBILITY FOR THE BLIND: WHAT PROGRESS IN TEN YEARS?

Professor L. Kay
University of Canterbury

It is just over ten years since I started working in the field of Blind Mobility, and it is only over the past three years or so that I have really begun to understand the problem Looking back however, I am not at all certain that had I taken the advice then offered me I would have arrived at this point in time with an aid for blind people which has the promise the new ultrasonic binaural glasses now offer.

A great deal was being learned during the last decade about developing devices for blind people and about their use to aid mobility. One of the most important lessons learned was the need for greater communication between the groups involved -- the engineer or scientist, the rehabilitation specialist, the blind user, and the administrators of organizations serving the blind. Conferences alone do not achieve this. My own experience suggests that it is only through personal contact with others that the engineer who develops the aid can begin to understand what is required of him. Herein lies the problem: if he finds it difficult to understand the needs of the workers for the blind, they find it even more difficult to understand his concepts. Our path is strewn with debris from misconceptions, and one should be sobered with the thought of the money -- and effort -- which could perhaps have been put to more effective use over the years. I'm sure the blind have not been well served.

Now, however, I believe we face a different situation; one which over the past three to four years I have tried to establish through regular and very lengthy travel (New Zealand is not the most conveniently placed of Islands). A team: Kay, Rowell, Clark, Pugh, Bell and Keith, has been gathered together at the University of Canterbury comprising engineers, mobility specialists and a psychologist, who are working very closely with the New Zealand Foundation for the Blind and the Royal Guide Dogs Associations of Australia. The aim is to provide blind people with greater mobility. We think we can do this. The communication which has been so sorely lacking in the past has now been established, and a mobility system which appears to offer promise at a significant level is being evaluated on a small scale.

<u>The Mobility System</u>

I conceived the idea of a binaural sensory system in 1959, but the technology was inadequate for it to be realized. Time has also shown that my understanding of the system was inadequate. It was only in 1968 through an engineered model that the engineering team, Kay, Rowell, Martin and Clark, at Canterbury finally showed that not only was the idea feasible but also that it worked.

By then, through my increasing contact with organizations for the blind and orientation and mobility specialists, I had thought out what I saw as the ideal mobility system -- the long cane and the Sonic Glasses.* I even suggested this in 1964 (1)**, but of course the Sonic Glasses (alternately called the Binaural Sensor) had not been made in a satisfactory form. No device can protect the feet of a traveling blind person as well as the long cane -- but the limitations of the long cane are well known. To be more effective the "Hoover" technique needs the addition of an environmental sensor. Naturally, if the sensor were good enough the cane would become superfluous, but this is not likely to happen for many years to come -- not if the system is to be safe.

There is of course a philosophy involved here, and it is perhaps highlighted in the recent article by Leonard <u>et. al.</u> (2) wherein he observes that many blind people are not as concerned about curbs as we thought they were. In fact "safe" is purely relative, and we should constantly bear this in mind.

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* I wish to leave the dog guide out of the discussion at this stage although it clearly has a place.

** References within a conference participant's paper are found at the end of the paper.

The sighted now take risks which 20 years ago would have been thought intolerable, and I sense these most acutely when landing on the West Coast of the U. S. A. The Blind must decide for themselves what is safe. So perhaps I should qualify my use of the term "safe." If a blind person does not have adequate knowledge of the terrain ahead, especially where the foot is to be placed, a risk is being taken -- a point most admirably made by the late John Dupress[3].

The Sonic Glasses aid has been designed to provide what I consider to be the minimum additional information about the environment required by a long cane traveler. It also appears to provide the maximum information which will be available for some time to come[4]. The essential features of the aid have been described in previous papers[5, 6]. The question which this conference asks of me is "What do current aids do to help mobility?" I must leave it to others to discuss their ideas and aids which they have developed.

Performance with the Sonic Glasses

In the period April-August 1969, four blindfolded sighted subjects were trained by Mr. Pugh to travel using the long cane and Sonic Glasses. One of these subjects is shown in a film traveling a distance of 3/4 mile from the University to a local business area. The route includes indoor travel, a quiet residential area, a busy residential area, crossing roads and a busy intersection controlled by lights, and a group of shops. (A further film shows a blind subject executing a complex orientation and constructional task.)

Three of the four subjects learned to travel significantly better with the cane/aid than with the cane alone. This is readily observed from noting the travel policy and the absence of collisions between the cane and objects along the travel path. Two subjects liked using the aid with the cane and the third felt that the aid removed the "challenge" offered by the cane alone! The fourth subject was a competent user of the aid as an environmental sensor and could do the training tasks described later, but as a traveler she required more than average long cane training. With the cane alone she would probably never achieve a satisfactory standard. With the cane/aid it was thought some travel could have been achieved. However, as this was a sighted person, the extra effort was not justified.

Clinical Fitting

It is first necessary to fit the individual with the aid in much the same way that optical glasses and hearing aids are fitted. A photograph of the glasses is shown in Figure 1. The hearing must be tested for normality. Abnormalities may give rise to sensory problems, and insufficient work has been done in this area. A long term hearing loss of up to 20 db has not so far presented problems; it is probable that greater loss can be tolerated provided it occurs outside the frequency band 100 Hz to 5000 Hz.

The aid can be adjusted to cater for a differential loss between the ears; should this be necessary, any adjustment would be uniform throughout the working frequency range. When a differential loss is encountered, the subject may experience a shift of the sound image to the side of the most sensitive ear. Adjustment then centralizes the image if the loss is not serious.

In addition to obtaining auditory balance, the auditory localizing function must be matched as closely as possible. Mismatch has the effect of distorting the perception of space. An object may be displaced from the subject's median plane by 20° say, but it may be sensed at 30°. This can be corrected by adjustment of the ultrasonic transducers in the aid.

Up to the time of writing, the method of adjustment which is being adopted is to train with a standard setting. As the subject becomes more perceptive and is seen to have errors in perception, an adjustment can be made to correct the error. There is the possibility that adaptation during learning may obviate the necessity for adjustment, and this is being investigated. A method of fitting before training is also being investigated through hybrid computer simulation [4].

Training of Blind People

Five blind people have so far been trained to use the glasses as a sensory aid, and three of these now use it to aid their mobility together with the long cane. One is a dog guide user, and another has for the present reverted to using the Sonic Aid because a permanent pair of glasses are not yet available, and cane training has not been given. This latter subject

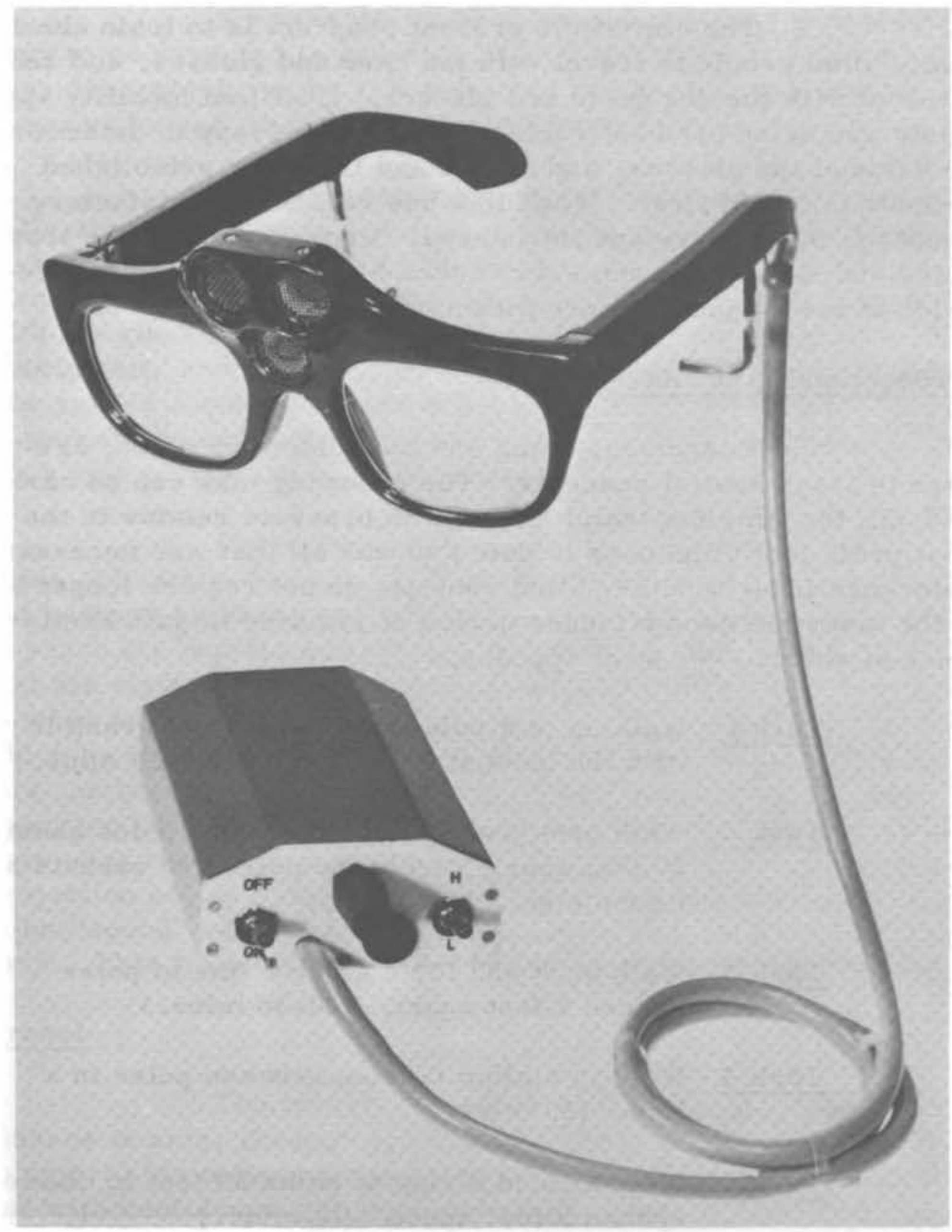

FIGURE 1

The Ultrasonic Binaural Sensor (Sonic Glasses) and Power Supply is a special case and was used in an experiment to determine the relative merits of the two ultrasonic devices: the Sonic Aid and the Sonic Glasses. Four more subjects are undergoing training with the long cane/aid and two are being trained with the dog guide/aid.

The aim of the present program is to train about twenty blind people to travel with the cane and glasses, and ten to travel with the dog guide and glasses. Qualified mobility specialists are being used as teachers. It is necessary to determine the value of the glasses, and to this end travel by established methods is taught first. When this has reached a satisfactory standard, the glasses are introduced. Improvement in the travel policy and skill of the subject can then be observed, and the reaction of the subject is more meaningful.

Introduction of the Glasses

Exercises, using one inch diameter poles, are given to teach spatial concepts. The following task can be carried out; the time for training shown in brackets relates to the most proficient blind user to date and was all that was necessary (reference film)*. Other blind subjects do not require longer to do the tasks but need a longer period of practice to gain confidence of ability -- or so it appears.

Task 1 Walk up to a pole from 15 feet and grasp it with the hand at about 2 feet. (15-20 mins.)

Task 2 Walk back and forth between two poles about 20 feet apart, circle the poles and execute a figure eight. (20 mins.)

Task 3 Walk back and forth along a line of poles spaced 5 feet apart. (20-30 mins.)

Task 4 Walk in slalom fashion between poles in a line. (20 mins.)

Task 5 Walk around a ring of poles 20 feet in diameter spaced 5 feet apart. (10 mins.)

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* A film of the trainees in practice situations was shown at the conference.

Task 6 Walk around the ring of poles weaving between them at will. (20 mins.)

Task 7 Walk between two rows of poles 3 feet apart. (10 mins.)

We have yet to determine the spread in learning time to be expected in general. There are numerous interesting exercises which can be given to keep up interest; any one task becomes boring when it can be done proficiently.

Probably the most difficult task executed involved collecting poles one by one from a bunch of 1 dozen standing upright 6-9 inches apart and placing them in a straight line commencing about 10 ft. from the bunch. The time taken to do this with the glasses can be almost the same as with vision at a leisurely gait, and the end result can be nearly as good (ref. film). The reader should think about the control policy and the degree of perception necessary to do this without fumbling when collecting a pole or making a crooked line.

From these tasks, the blind subject learns to perceive objects in the environment, and the sounds heard from the aid begin to be projected into space. Gradually the user seems to sense the objects as objects, not sounds. One subject who lost his sight at 12 remembers the perception as being similar to when he saw things visually. This in fact is the best way in which he was able to describe his experience. A second can feel this coming; two others are congenitally blind. The fifth has spent too little time using the glasses. The two engineers who have used the glasses over a long period experience a distinct projection of the sounds when travelling, but once the attention is on "sound" rather than "object", the sounds are heard at the ears. This forces one to be cautious in discussing perception.

Travel

The traveler using both the long cane and the glasses is able, through an enhanced sense of the environment, to control his movement and determine his path more skillfully and with confidence. It is only in open areas, where there are no orientation cues, that the glasses fail to provide constant assistance. This can occur with disturbing frequency in some suburban districts where there are no fences around gardens and open lawns are the vogue. Few areas however are devoid of anything such as lamp posts, mail boxes, trees, shrubs, etc. All these provide orientation cues even if well spaced. Since the sensing range is only 20-25 ft., it will be readily appreciated that there must be situations where the glasses are inadequate even for rote travel. The value of the aid is quickly appreciated however from the relief experienced when a pole or tree is located some 20 ft. ahead after walking apparently in an open space for 50-60 ft. (personal experience). The relief is even greater when that pole or tree is recognized as a landmark. This sense of relief indicates the kind of stress felt when traveling with the cane alone.

Evaluation

From the foregoing it may not be obvious why evaluation on a large scale is necessary. What has been discussed relates only to what can be done with the glasses by those who have learned to use them. We don't yet know what special personality profiles a person must have in order to be proficient. We don't know the age range over which this mobility system can be taught effectively, and we have yet to determine the best methods of training. In addition to usage of the aid we have to evaluate the reliability and life of the device, assess the ergonomics and rectify defects before general use. An organization must be established for servicing the devices if they are to be used widely and the evaluation will give agencies for the Blind an opportunity to express their views on this. They will also be able to plan the best method of screening blind people for training and set up suitable clinical facilities.

Finally -- and most important -- we have yet to determine user acceptance. If this is high we will have achieved our immediate goal, but we will have just started a long period of development.

Acknowledgements

I am indebted to my many colleagues who have over the past ten years assisted in the development at the University of Birmingham, Lanchester College of Technology, and the University of Canterbury. Many blind people have given their time as experimental subjects and contributed to the present philosophy, and not a few have influenced my thinking.

I am particularly indebted to those organizations which have provided funds for the research and development -- St. Dunstan's, National Research Development Corporation, Ultra Electronics, New Zealand Foundation for the Blind, and the Royal Guide Dogs Associations of Australia.

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EVALUATION OF A MOBILITY AID

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The establishment of specific universal standards for orientation and mobility, as well as a measurement scale to evaluate a man/aid system effectiveness, is not probable at this present time. A number of factors contribute to our inability to produce an effective measure:

(1) Not all devices are designed to help with the same problem(s) of blindness.

(2) The solutions to the problem(s) of blindness are not similarly constructed, presenting the many differential factors of search, energy and display to be considered in devisng our "universal mobility and mobility aid evaluation rating scale."

(3) Limited research in the area of mobility (both sighted and nonsighted) as a separate and distinct category.

Until more basic research is applied to the questions of orientation and mobility, we will continually find ourselves approaching the evaluation of each device on an individual basis, tailoring the measuring tools as we go.

Mobility for the blind today is assessed by the user's ability to function with either the dog guide or the long cane. These two systems are the "universally" accepted means to mobility and have been evaluated over a period of years simply through the process of general usage.

Without an aid, a totally blind person is, to all intents and purposes, immobile. However, this immobility cannot really be used as a base from which to build since there are aids (other than the cane and dog guide) available which can raise many above this "zero level." The aids may or may not be viable, but nevertheless they still need comparison to a standard before their relative value can be assessed.

It seems entirely reasonable then to use either the dog guide or cane as the basis of comparison. If, however, the concept of a new aid differs greatly from either of the two basic aids, the comparison can be difficult.

Where an aid is to be used in a complementary fashion to the dog or cane, the task is much simpler. If mobility with the cane (dog) is "good," it would seem reasonable to expect that with the complementary aid it would be improved. It must be noted, however, that the tasks differ between the long cane and the dog guide, and the influence of a new aid may also differ. The main aim of the new aid must therefore be clearly stated and understood.

At present there are four aids to be considered for evaluation, in order of dating: the "Sonic Torch," the "Pathsounder," the "Laser Cane," and the "Sonic Glasses."

The Sonic Torch

Whatever may have been said in the past, practical experience has shown that this can be used by some people as an independent aid. Some people may additionally carry a short cane for occasional use, while others may make occasional use of the torch while using either the long cane or a dog guide -- though these latter people are extremely few.

Evaluation of this device might best be twofold; as an independent aid and as a complementary aid.

The Pathsounder

This is quite clearly a complementary aid with little additional possibility. It can probably be said that the Pathsounder is complementary to the cane alone. In this case evaluation becomes relatively simple, and it should only be necessary to observe improvements in mobility performance when the Pathsounder and long cane are used together.

The Laser Cane

This is an independent aid, though originally it may have been thought of as combining the long cane and the "obstacle detector" (V. A. Program). The long cane technique requires that the cane touch the ground where the next step is to be placed. If the Laser Cane works adequately, then this is no longer necessary. But then, at the same time, contact with the ground is lost and so is the additional tactile information gained by this contact. In evaluating this aid, the obvious comparison is the long cane and special care should be taken to see whether or not this removal of ground contact decreases the overall performance of the user.

The Sonic Glasses (Binaural Sensor)

This device is designed to be complementary to both the long cane and the dog guide. Some people may hopefully look on it as an independent aid, but this is unlikely to be the case except in the most limited of circumstances (due mainly to its inability to discern sudden drops in the ground level), and it should not be considered as an independent mobility device. When using the glasses in conjunction with the cane, mobility should be improved when compared with the cane alone. The same might not be said for the dog guide/glasses combination as the function of the aid may become less of an orientation and mobility aid and more of an environmental sensor.

Functioning as an environmental sensor, the additional knowledge of the environment which a cane or dog user can obtain must also be taken into consideration, and its value assessed. This is seen to be the more difficult evaluation task.

Evaluation

It must be clear that it is not possible to evaluate all devices in the same way. Each must be considered separately. Also, in the absence of a universally accepted standard for mobility, each device must now be related by comparison to the long cane and/or dog guide in some way, otherwise the results are meaningless.

In this paper we are concerned only with the sonic glasses. Evaluation on a large scale is being contemplated, and preliminary assessment of this device is now taking place on a small scale with a program planned by a team at the University of Canterbury.

General Plan

Before the sonic glasses were considered for use by blind people, a great deal of thought was given to the problem of evaluation.

Initially only engineers were involved in the research program, and it was planned to involve psychologists in the team only when they could be given a device with which to work, and about which there was sufficient information to make meaningful behavioral studies.

One of the Canterbury engineers (D. Rowell) largely took over one of the tasks which would have been expected of a psychologist -- the study of psychoacoustics related to binaural perception. The other main task, which in the past has been the domain of the psychologist -- that of training a blind person to use a new aid -- was undertaken by an orientation and mobility specialist. This was a major departure from previous practice in the evaluation of mobility aids. It was, however, an obvious change in policy as there was clearly a need to train subjects to travel by use of a cane alone in order to assess any improvement resulting from the addition of the glasses.

A team was thus formed of electrical engineers, a psychoacoustic engineer and a mobility specialist. An audiologist/psychologist has since joined the team.

Training

Before training of blind people was contemplated, a method of training had to be devised. One basic question related to the order of training -- which should come first, cane or glasses? With only a very limited number of subjects available it was seen that our results could be attributed to chance alone. Nevertheless, two sighted blindfolded subjects were first taught the cane and at a later stage the glasses; and two others were taught to use the glasses, followed at a later stage by the long cane.

A very short period elapsed before it became clear that the cane should be taught first in an evaluation. It provided the base for measurement of performance, and with this we could quickly begin to see the benefit of the glasses in relation to the cane performance. The subjects appeared to learn more rapidly with this approach. If nothing else was significant, the reduction in collisions was clearly apparent.

Blind people are now being trained and similar results are being obtained. The numbers are still small, and the range of subject characteristics is not very wide, but the results have been gratifying. If the aid is to be shown to be of value and suitable for a significant portion of the blind population, an adequate sample is required. As too large a sample would be difficult to handle, approximately 200 has been chosen as a practical compromise.

Before undertaking a major evaluation, it must be established that the device is likely to be reliable. Experience in training is required before other teachers can be trained. For a number of reasons it was decided to train 20 people with the cane/aid and 10 people with the dog/aid as a pilot study in order to acquire this experience. Eleven people are undergoing training or have been trained at the time of writing and the results are positive in favor of the cane/aid. There is too little experience yet with a dog guide.

So that we may assess up to 200 man/cane/aid systems, 10 to 20 mobility instructors will need to be trained in the use of the device, be taught how it works, and be given instruction on how to teach blind people in its use. Through the experiences of a variety of instructors and agencies, as well as those of 200 blind people, the device will be given an evaluation which may well be more meaningful than any laboratory type exercise is likely to be.

Measures

It is felt that the following measures are the minimum needed properly to assess the sonic glasses:

(1) Reliability of the device.

(2) Variations in auditory characteristics of subjects.

(3) Effect of these variations on user performance in controlled situations.

(4) Time needed to train subjects to do controlled tasks, subdivided into age and personality groups.

(5) Performance with cane (dog guide) alone.

(6) Performance with cane/aid (dog/aid).

(7) Degree of perception at various stages in training.

(8) Degree of adaptation to specific settings of the device and adjustments required over a period of time.

(9) User performance at end of training.

(10) User performance three months after training.

(11) Acceptance after a period of time (say 3 months).

(12) Psychological profile:

(a) General.

(b) In relation to the aid.

(13) User impressions during and after training.

(14) Instructor's impressions during and after training.

Suggested changes to the device need to be noted and referred to the engineers for consideration.

Because of the inevitable variation in training which must occur between rehabilitation centers, this phase of the program must be monitored by observers who are fully familiar with the technical performance of the aid, training, and probable user performance. A representative of the development team is a likely choice through which uniformity of measurement can be obtained and by which the coordination and dispersal of information can be effectively handled.

Of all the information gathered, it is my opinion that the most useful information on the reliability and acceptability of the aid (both from the standpoint of user and agency) will be those comments made by the students themselves and the orientation and mobility specialists. It is to these people that the agencies will turn for guidance when determining whether they will supply the aid to blind people along with their other services.

PATHSOUNDER TRAVEL AID EVALUATION: 1

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Massachusetts Institute of Technology

The Pathsounder is a small, battery-operated sonar intended for use as a travel aid by the blind, and more specifically, those blind who travel independently with a cane. The Pathsounder complements (but does not replace) the cane; it is worn on the chest be means of a neckstrap, and warns the user of above-the-waist objects, other pedestrians in his path, and so on.

In simplest terms, the instrument gives the traveler an audible warning when there is something within six feet ahead of him at a level; roughly, from his waist to the top of his head. When there are no objects or obstructions so located, it makes no audible sound, though it continues to probe ahead silently, ready to respond to the entry of anything in the path.

The audible signal consists of a buzzing sound, which occurs when something approaches within 72 inches, and changes to a distinctly different sound, a high-pitched beeping, when it comes within 30 inches. The use of the two different sounds permits the traveler to distinguish between "close" and "very close."

Thus the user might walk for many minutes in an open area and hear no signal, but as he approached something dead ahead, a telephone pole, for example, and kept walking forward, he would hear, "Buzz buzz buzz buzz beep beep beep," etc.

This is an experimental technique; these instruments are not available to the blind at large, and Pathsounder travel is by no means an established scheme in the sense that the term might be applied to cane travel or dog guide travel.

The Pathsounder program was described at the 1964 Rotterdam Mobility Conference, the 1966 St. Dunstan's Sensory Aids Conference and the 1967 Conference for Mobility Trainers and Technologists at M. I. T. Reference is made to the proceedings therefrom for details of the earlier history of this work.

At the time of the last of the above-named meetings, December, 1967, the program was leaving the laboratory phase and entering a street-and-sidewalk stage wherein it was introduced, on modest scale, to some of the blind community and to the mobility instructors therein.

Important, at this point, is to note the two criteria by which the Pathsounder's usefulness to an individual is to be judged: (1) There must be some visible benefit to his travel performance; and (2) he must like using it enough to keep doing so if he can retain an instrument. This second criterion should not be undervalued. It is the sine qua non of the travel aid. However much better/faster/safer, etc., travel with the aid may be, if the cane-traveler leaves it home for not liking it, there is nothing accomplished. Reasons for not liking it may range from psycho-acoustic exotica to the most pedestrian ("strap makes my neck perspire," etc.).

Once the instrument design was reasonably refined, it was felt that a collaborative effort with the mobility training community would be the means of swiftest progress. Pathsounder travel is essentially cane travel with a small amount of extra environmental contact thrown in, and the teachers of cane travel should ultimately be the ones to teach the Pathsounder if the latter proves warranted. Meanwhile, they could be helpful in evaluating the new technique, refining schemes of instruction, and in general, injecting common sense bred from practical experience into the program.

In keeping with these points of view, eleven Pathsounders were made in 1968 and 1969, funded by the V. A., S. R. S., etc. Most of these units are in blind rehabilitation centers or, in the case of several, are retained by users who have undergone training and now use an instrument in their daily travels.

The Sensory Aids Center at M. I. T. has been the overseer of this program and has kept liaison with the rehabilitation agencies. It has urged a policy described: Find the Pathsounder a home. Get it out of the agency headquarters and into use in its intended way. This means, in effect, that if an agency has two instruments and finds in fairly short order two trainees, each of whom desires to keep and use one, the instruments should be handed them on long term loan, even though the agency's program for the Pathsounder will come to a halt for lack of more Pathsounders. The thought is that when we have a body -- even a small one -- of steady users, we will have at least some measure of the merit of this scheme of travel. Naturally, it is no small part of the program that an eye be kept on the long term users, so as to ascertain the amount and regularity of use, environments of greatest benefit, technique improvement after long practice and so on.

At the present moment perhaps ten or a dozen mobility instructors have had Pathsounder experience with at least one blind trainee. In each case, of course, a new task is thrust upon the instructor, teaching something which he himself was not taught in school or made familiar with by prior experience. Yet this process has worked out fairly well in spite of the program's still exploratory nature.

A sixty-page Pathsounder Instuctor's Handbook was prepared by the Sensory Aids Center; its purpose is mainly to serve the instructors remote from the Center, to give them something to go by which is at least better than the briefest description of the instrument. Although the handbook does not dwell at any length on technical or engineering details, it describes the principle of operation and some of the idiosyncrasies of the sonic reflection process so that the teacher will understand properties of different kinds of reflecting objects, including some, such as oblique planes, whose detectability may be marginal under certain circumstances.

A considerable part of this manual is devoted to navigation through pedestrian traffic, which, as a major facet of Pathsounder travel, has been developed into something of an art. The cane traveler has a number of factors already at work to smooth his passage along a sidewalk: the visibility of his cane to warn the sighted that he cannot see them, his own ability to use voice and footstep sounds, and so on. His primary use of this new instrument is to warn him when other collision-avoidance factors have failed, and what action he must take when he is so warned.

Some idea of the scope of this travel scheme is probably best illustrated by listing some of the manual's section headings.

Lesson Plan	Double Check
Putting it On	Cut-across
Post Drill - General	Head-on Collision
Find the Post	Backbouncing
Walk-by	Crossing the Street
Walk-between	Parked Automobile
Multiple Post Drills	Blind Inside Corners
Corridor Practice	Pace of Lessons
Wall Chatter	Trainee's Early Attitudes
Stationary Pedestrial	The Skilled Traveler

The foregoing is a brief description of the project and its history. Mr. Curtis' paper will discuss some of the technical aspects of training a person with the Pathsounder. The following remarks have to do with psychological questions, questions relating to user acceptance and motivation, and with a focal question of the entire project: Exactly what are we looking for at the end of the road, as it were, that will have made this development worthwhile?

It was mentioned earlier that in addition to getting some visible travel benefit (visible, in the main, to the eye of the trainer or sighted observer), not much will have been achieved by the training alone unless the trainee feels motivated to use the aid in his travel routine, and there are many psychological factors here.

What is meant is not the mechanical psychology -- reaction time, distinguishability of the sound against traffic sounds, etc. -- these are more properly cybernetic factors, the matching of the machine to the man in a useful way. There is a broader psychological question that must be addressed: If the blind person continues using the aid on his own, it will be because he wants to? Then why will he want to? To feel safer? From consideration for those in his path? There is usually some nuisance factor in using any travel aid; what reason will the user have to think this aid's benefits outweigh the nuisance aspects?

It is curious how little attention seems to be given to this question of motivation. Patent literature, descriptions of electronic mobility aids in publications -- these so often use the sentence: "With this device a blind person can . . ." (spot a tree at thirty feet, tell magnetic North, walk a straight line, etc.). Always, "A blind person can . . ." Seldom a word about why he may want to, whether what he does often or rarely needs doing, or fits in with real life travel needs or is really worth the trouble in the first place.

And the familiar sequel then follows (that sentence in some evaluation report): "The subject enjoyed participating in the test program but had no wish to retain an instrument for subsequent use, feeling that he got about quite well enough with his cane alone."

It is not intended to overemphasize this issue of motivation, only to point out that historically in this field, it has so often been nearly ignored. The engineer feels his job is done when the instrument functions. The trainer feels his is done when the traveler can use the technique with evident benefit. In truth, the entire job is really done when in addition, some of the blind have absorbed the existing aids and continue to use them effectively. Unless that criterion is met, it will ultimately matter little how clever the device is, how many are made, or even how impressively it seems to aid the traveler.

This line of thought has strongly influenced the informal program under which existing Pathsounders have been evaluated. In a way that is probably obvious, it forms the rationale behind the "find the Pathsounder a home" policy, the orientation toward observing users over the long term in a home setting. Also, this motivation-to-use question has spawned a number of suggestions to mobility trainers venturing out on their first try with Pathsounder and student:

(1) Among other criteria in selecting a trainee, don't forget NEED. The blind person who is not likely to travel out very much on his own may not be a good candidate. If he goes about mainly guided by his wife, or gets to work door-to-door by bus, then the instrument will probably end up sitting on the mantle most of the time, unneeded and unused. Far better to choose someone who must walk a few city blocks each day.

(2) Don't expect too much too soon. Negative though this advice may seem, think of the Pathsounder signal as an intrusion, initially, and confidence in its usefulness as a thing that will build up in a steady but gradual way. It is tempting to take the trainee into dense pedestrian traffic in the city (to get more "action"), but don't do this prematurely; wait until he is accustomed to the signals and responding to them reasonably well.

(3) In large part, the user's confidence will ultimately be built on second-hand information given him by the instructor. Suppose the trainee walks a long city block and gets signaled six times. If things run true-to-form, he might negotiate all six encounters without phvsical contact or any certain knowledge of what each was. A critical moment is then at hand -- a moment when he might think that the aid had stopped him six times and cost him an extra few seconds. The instructor's role is to explain what (or who) was blocking him each time, and assure him he would have been stopped in about two more steps anyway, with perhaps a need to murmur an apology for poking someone's ankle with the cane. The instructor must act as the learner's eyes for the first few hours of sidewalk travel and recount the details of each collision-that-almost-was.

It is tempting to examine records of Pathsounder trainees to date and speculate upon what fraction of the cane-traveling blind might want to benefit from this technique. One could classify as a "convert" or "dropout" each person who has developed some reasonable skill with the instrument, the distinction being, of course, in whether the person felt inclined to continue using the aid. Unfortunately, one quickly runs into a thicket of complications that make the distinction hard to come by. There are those who wanted to keep an aid but none were available. There are apparent converts who kept using the aid but, one suspects, out of loyalty to the inventor or trainer, or from fear that it would be taken away if not professed to be used regularly. Then there are true converts who use the device regularly and beneficially and would be, in the trainer's view, hurt and disappointed to lose it. And there are true dropouts, often those long blinded and with well entrenched travel habits. In some cases their auditory and cane skills are so effective in relation to daily travel needs that using the aid is simply not worth the extra trouble. In other cases, their performance may be benefited by the aid, but they are accustomed to occasional clumsy encounters and have only a negative view toward possible improvement. ("I often knock over a bike at this corner. It's the owner's fault for parking it like that. It doesn't bother me.")

There is one psychological factor that seems to emerge as strongly bearing on user acceptance. The dropout continues to view the occasional stop signals as slowing of his travel by the aid. The convert, more wisely, ascribes the need to stop to what is "out there" and knows the Pathsounder signal to be only an advance cue to trouble ahead. It is that simple, and this is why the trainer's main psychological task is to spend enough travel time with the trainee to explain the early contacts.

If motivation to keep using a mobility aid is a necessary criterion for its usefulness, it is certainly not a sufficient criterion. A teen-ager, for example, might keep an aid for the novelty of being a walking radar set, or because he has something his blind companions do not have. So the other necessary condition is that there be some visible benefit to the travel performance. What is meant by "visible benefit" is simply (1) that the protection of the user from injury or embarrassment should function in practice as it is supposed to in theory, and (2) there should be no severe negative trade-off; unwarranted loss of speed, increase in stress, masking of natural sounds and so on.

This is a subjective criterion, leaving much to the observer's (or trainer's) opinion and, perhaps, personal biases. One could well ask: Isn't there some more tangible thing than "visible benefit," something that could be better measured or put somehow in more scientific terms? Unfortunately there is no easy answer. One can visualize blind subjects traversing some sort of obstacle course or jungle of vertical posts, with a psychologist noting collisions, transit time, etc. Indeed, navigating around posts is suggested as a trainee's initial familiarization drill with the aid. Making one's way through a post array quickly becomes easy; though for that matter, one can easily avoid vertical posts with the cane alone. More importantly, however, stationary objects are a terribly simple special case of the more general sidewalk situation where, in pedestrian traffic, the thing blocking one's path is generally itself in motion. Recall the croquet game in Wonderland where the wickets were ostriches, which got up and moved about as they pleased. ("Makes it an altogether different game," observed Alice.)

If the sidewalk environment cannot be easily simulated in the laboratory, one can perform some measurements "on location" and gather at least certain kinds of statistical data. This was done once in Boston; a blind college-age lad circled a downtown city block twenty times, ten with cane and Pathsounder, and ten with cane alone, alternating at each circuit. This was in December, 1968, in Christmas shopping crowds; the particular city block was chosen as a challenging course, where the Pathsounder would get plenty of work -- dense pedestrian traffic, some sidewalk segments rather narrow, high background level of street noise. The student's mobility instructor, a teacher at Boston College, measured transit time and counted collisions or other physical contacts with sighted pedestrians.

The results:

Cane & Aid: 3 collisions, none "major"; 10 min. 33 sec. average

Cane alone: 126 collisions, 14 "major"; 10 min. 18 sec. average

These data suggest a pronounced improvement in collision avoidance and a small penalty in speed. There are several qualifying observations, however:

(1) Every pedestrian contact -- cane or body -- was counted as a "collision"; bear in mind that most of these were minor, many so minor in fact that the other pedestrian may not have consciously noticed them; also that sighted people graze and sometimes bump one another in heavy traffic, rounding corners, etc.

(2) The lad may have traveled a bit carelessly switched off; perhaps if he had used his hearing more intently and been more cautious he might have done better switched off (i. e. using only the cane).

A "major" collision is, for want of a better definition, one that warrants apology. Most of these were high-speed bumps or body checks; however two were cane trip-ups. In each of the latter cases, the pedestrian was not "dropped" (i. e. did not fall to the sidewalk) but fell against another person or the side of a building.

Also of interest is the fact that there were, on the average, 15 Pathsounder contacts during each ten minute circuit of the block, switched on (an average of about one every 40 seconds).

Statistics notwithstanding, there is an opinion held by some, and to which the writer subscribes to a considerable degree, that if an electronic travel aid is of any real benefit, the benefit ought to be more or less obvious. If it cannot be seen except by sifting a large amount of data, then quite possibly it may be hardly worth having in the first place. It is this feeling that has steered the Pathsounder evaluation in its present direction. Develop a body or cadre of professional mobility teachers who will have had Pathsounder training experience -- first hand -- on the sidewalk. Then these people, if anyone can, should be able to evaluate the usefulness of this travel aid, and one could do worse than to let things rest on their collective opinion.

PATHSOUNDER TRAVEL AID EVALUATION: 2

William R. Curtis
Massachusetts Association for the Blind

The Pathsounder, also commonly referred to as the "Russell Pathsounder" and the "M. I. T. Pathsounder" was first tested and evaluated as a mobility aid for the blind in the summer of 1963 when the late John K. Dupress, then of the American Foundation for the Blind, collaborated with the inventor, Lindsay Russell, taking the device into the environment and examining its performance.

Both the operating techniques and the instruments themselves have been improved over the intervening years, and several units have been distributed to various individuals and organizations for evaluation. In addition, a Pathsounder Instructor's Handbook has been published by the M. I. T. Sensory Aids Center to assist those practitioners who will be teaching the use of this aid to blind travelers.

Of the three travel aids being discussed at this conference, the Pathsounder is, perhaps, the least sophisticated in its intent. Its sole purpose is to alert the blind traveler to obstacles that lie in his direct path. The beam emitted by the device is designed to give an audible signal to the traveler when an obstacle is encountered at a range of six feet and at a level that is roughly from the waist to the top of the head vertically, and to the limits of the widest part of the body horizontally.

As early as May, 1965, in Proceedings of the Rotterdam Mobility Research Conference, it was indicated that the Pathsounder is meant to be used in conjunction with, (not as a replacement for) cane travel. It is hopeful that the Pathsounder will enable the good cane traveler to travel smoother and in a more expedient fashion by changing his course to avoid obstacles before actual contact is made with the cane. In addition, the device is designed to detect overhanging obstacles that ordinarily would not be picked up by the cane.

When first approached by personnel at the M. I. T. Sensory Aids Evaluation and Development Center to become involved with Pathsounder experimentation, I was somewhat hestant. My hesitancy did not stem from any negative feelings toward electronic travel devices, rather it was based on the fact that none of my students in mobility training were seasoned, experienced travelers. Should I become involved with one of my students in Pathsounder experimentation at the time that I was approached, a new dimension of Pathsounder experimentation would take place. All prior subjects in the Pathsounder program had been fully competent, seasoned travelers when the device was introduced to them. In contrast, I would be introducing the device to a subject who still had a significantly long period of time left in his drive toward independent travel.

Of the five students for whom I was providing mobility training, there was only one possible candidate for Pathsounder experimentation. He was a 17 year old student at Perkins School for the Blind, above average in just about all of his abilities. In addition to being a top student, he was very athletic and in top physical condition. He participated in a wide range of extra-curricular activities, and he adapted rapidly to techniques of cane travel. At the time of considering this person as a candidate for Pathsounder experimentation, he was neither a fully competent, independent traveler, nor were he and his parents convinced that the cane and the travel techniques employed with it would be a panacea for his travel ills. He was, however, a competent student and a fast learner.

The subject and his parents, when approached, readily agreed to the experimentation. The program that was proposed was rather simple. As each new lesson was given in cane travel techniques, the subject would then repeat that same lesson, using the Pathsounder. If the subject's performance in any new lesson was negative, the lesson would be sufficiently repeated before introducing the Pathsounder.

At the time of Pathsounder introduction the subject had completed units of work on residential travel, street-crossings, utilization of business establishments and had considerable exposure to moderately heavy pedestrian traffic.

He had been exposed to the use of public transportation facilities but was not yet ready for their independent use.

At this time I would like to make it very clear that any lauditory merit that I give the Pathsounder is based solely on my experience with this one subject in this unique training/experimental approach. The results of this experimentation are based on what appear to be the right combination of several variables with no assurance that future experimentation with different subjects will achieve desired results.

After initial orientation to the mechanics of the Pathsounder and a series of indoor drills as are outlined in Chapter 2 of the Pathsounder Instructor's Handbook, the subject was exposed to approximately 35 hours of active, supervised experimentation and approximately 20 hours of independent experimentation.

A typical experimentation report would read as follows.

10/11/68 Lesson Time - 8:00 - 9:00 p.m.

Throughout this lesson the device was constantly turned on. During this one-hour session in a medium-sized business area the subject avoided the following obstacles as a result of reacting to Pathsounder signals:

Four posts -- (street signs, bus stop signs, etc.).

One tall fire hydrant.

Three store front projections.

One set of low hanging tree branches.

Miscellaneous trees along the curb edge of a residential sidewalk.

The following bodily contacts were made:

One each of a police alarm box and a pedestrian (both on the subject's right side). Both had slipped into the beam's blind spot.

In addition, numerous pedestrians were avoided, too numerous to list. In several instances it was impossible to establish whether avoidance was a result of Pathsounder signals, pedestrian traffic cues or if oncoming pedestrians deliberately avoided the subject's path.

The subject generally felt comfortable with the device, moved faster than usual through moderately congested areas and reacted well both to Pathsounder signals and ambient sounds.

What I have found from this one test experience is that the Pathsounder does the job that it was designed for. It is an obstacle detector. It enables the blind traveler, using proper long cane techniques, to detect distant obstacles in the environment and alter his path of travel when necessary.

On the positive side, the following features of the Pathsounder were extracted from the subject's experience with the device:

(1) If the device is properly set on the subject's body, appropriate reaction to its signals can result in almost certain avoidance of pedestrians, vertical stationary obstacles such as trees and posts; horizontal projections such as fire alarm boxes, mail boxes, tree limbs and overhanging shrubs; store front projections and vehicles parked in crosswalks. In addition, the device will detect such things as bicycles, baby carriages and rubbish barrels if their height is sufficient to reach the low limits of the Pathsounder's beam.

(2) The device, though commonly documented as a navigational aid primarily designed for obstacle avoidance, is also extremely useful in the familiar environment for locating landmarks necessary for orientation. For example, if the user knows that a pole signifying a bus stop in familiar territory is the fourth pole from the corner, he can locate that pole with the Pathsounder more smoothly than by employing shorelining techniques with the cane. Again, at a bus stop, if the traveler is standing at the curb and the bus pulls up to a stop, he

can tell if the bus has pulled up sufficiently for ease of entry or if the bus has stopped short of where he is standing. If the bus has stopped directly in front of him he will receive a signal from the device. To be sure, most good travelers should be able to gather this information without the Pathsounder. The device, however, might help eliminate guesswork in this type of situation. The subject encountered a situation in a metropolitan subway station that made it difficult for him to find the correct berth at which to board a particular bus that he would be using often. The only information available to him to indicate the whereabouts of this particular berth was that it was in the same spot as the tenth supportive pole on the platform. By taking a line of direction from a landmark at the subway entrance, he merely had to count the poles by casting the Pathsounder's beam toward the poles. Again, this could have been accomplished by employing shorelining techniques with the cane. Using the Pathsounder, however, proved smoother and more expedient. After becoming familiar with the platform and the position of the berth in question, the subject relied primarily on distance estimation and used the Pathsounder for reinforcement.

(3) A third area of benefit is in the situation where the traveler executes a diagonal, inside crossing of an intersection. In most cases, a blind traveler using cane techniques would recover his original or intended line of travel by following the intersecting shoreline back to the open sidewalk of the street that he wishes to be on. If the shoreline is vertical in structure, the traveler can direct the device's beam against the shoreline and follow it without contacting it with the cane. Here, again, the device allows for smoother and faster travel than the cane alone.

Many blind people have indicated that they might feel conspicuous using a device such as the Pathsounder, mainly because of their assumption that the auditory signals would be also heard by passing pedestrians. It has been observed, however, that the signals are generally inaudible to pedestrians when there is light pedestrian and vehicular traffic present.

Negatively, any comments that I have to offer are more related to design rather than function and reliability:

(1) The subject found the neckstrap to be extremely uncomfortable in hot weather, especially when wearing a collarless shirt.

(2) The neckstrap is not designed to make allowances for varied bulk of outer clothing from season to season. As clothing gets heavier, the device changes position on the body.

(3) For ease of manipulation, the on-off switch could be located on the vertical surface of the left side of the device.

(4) When ascending long staircases or when riding on escalators, the device must be turned off to eliminate meaningless signals.

(5) The optional ramp effect was of no apparent value to the subject. It would appear that the unimpeded cane traveler moves too fast to interpret the subtle ramp effect.

(6) The device can obviously use some cosmetic refinement.

At the time of this writing the subject is a safe and independent traveler. More than a year has passed since he has completed the prescribed course of mobility instruction. In the interim he has kept the Pathsounder in his possession and uses it at will. As a practitioner in the field of orientation and mobility I can say that I would not have recommended his continued use of the device had it not met my preconceived standards of safety and performance reliability.

It would appear that the Pathsounder does that for which it was designed with a high degree of reliability. It seems logical, then, that the next step in Pathsounder evaluation would be to place many of the devices into the hands of competent cane travelers, train them to use the device, and evaluate their experiences after a period of unsupervised use.

Beyond questions concerning the present state of the devices and their respective levels of reliable functioning, ease of interpretation by the traveler and application to independent mobility skills, I believe that serious consideration be given to the following:

(1) Where is the potential market for mobility aids? I feel that it is only an undefinable segment of the blind population that would ultimately be the market for these devices. Although it is not known just how many members of the blind population are fully competent independent travelers, it would appear that this segment of the blind population is a minority within a minority group.

(2) The question of consumer acceptance must be considered. Since the devices must be used in conjunction with long cane travel, would the blind population that travels independently via the long cane consider the information given by the devices superfluous and nonessential to safe and independent travel?

(3) From where are the instructors to come to train people to use these devices? Although more instructors are being trained for the profession each year, the basic mobility needs of the blind population at large are not being met. It would seem foolish to have instructors spend more time making better travelers out of good travelers than meeting the basic mobility needs of that segment of the blind population that has not yet received orientation and mobility services.

(4) Finally, should the devices be proven useful and a definite market becomes defined, what resources will make these devices available to a market that is not generally considered to be a good financial market?

AN ENVIRONMENTAL SENSOR *

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Unlike the previous papers, which describe operational mobility aids, I will discuss results from the development of a reading aid and possible implications of this development in the mobility area. There are two reasons for discussing this reading aid research at this conference. The first is that the reading aid is approaching the point in which an evaluation will be needed, analogous to the mobility aids we have heard about. There may be some mutual lessons to be learned about evaluations of sensory aids so that evaluation plans should be compared. The second reason for discussing this particular development at this conference is that it represents some technology that is relevant to the possible development of a mobility aid along the lines of direct optical-to-tactile image conversion. It is important to consider this possibility, and whether or not such a development is needed, and if so, along what specific approach.

Since this discussion is related to the reading aid, I will begin with a brief explanation of how the reading aid functions. This device, which we call the Optacon [1] (for Optical-to-Tactile Converter), weighs about eight pounds and is shown in Figure 1. It has an array of 144 tactile stimulators as shown in Figure 2 in a 6-by-24 matrix, and they are mounted so that they stimulate the palmside of one finger. The reader places his finger in a trough curved to fit the finger.

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* The work described on the Optical-to-Tactile Environmental Sensor has been primarily supported by the Social and Rehabilitation Service under Grant VRA-RD-2475-S-67 and contract and partly by the Seeing Eye, Inc. The Optacon research described was primarily supported under Office of Education Grant No. 0-8-071112-2995 (032).

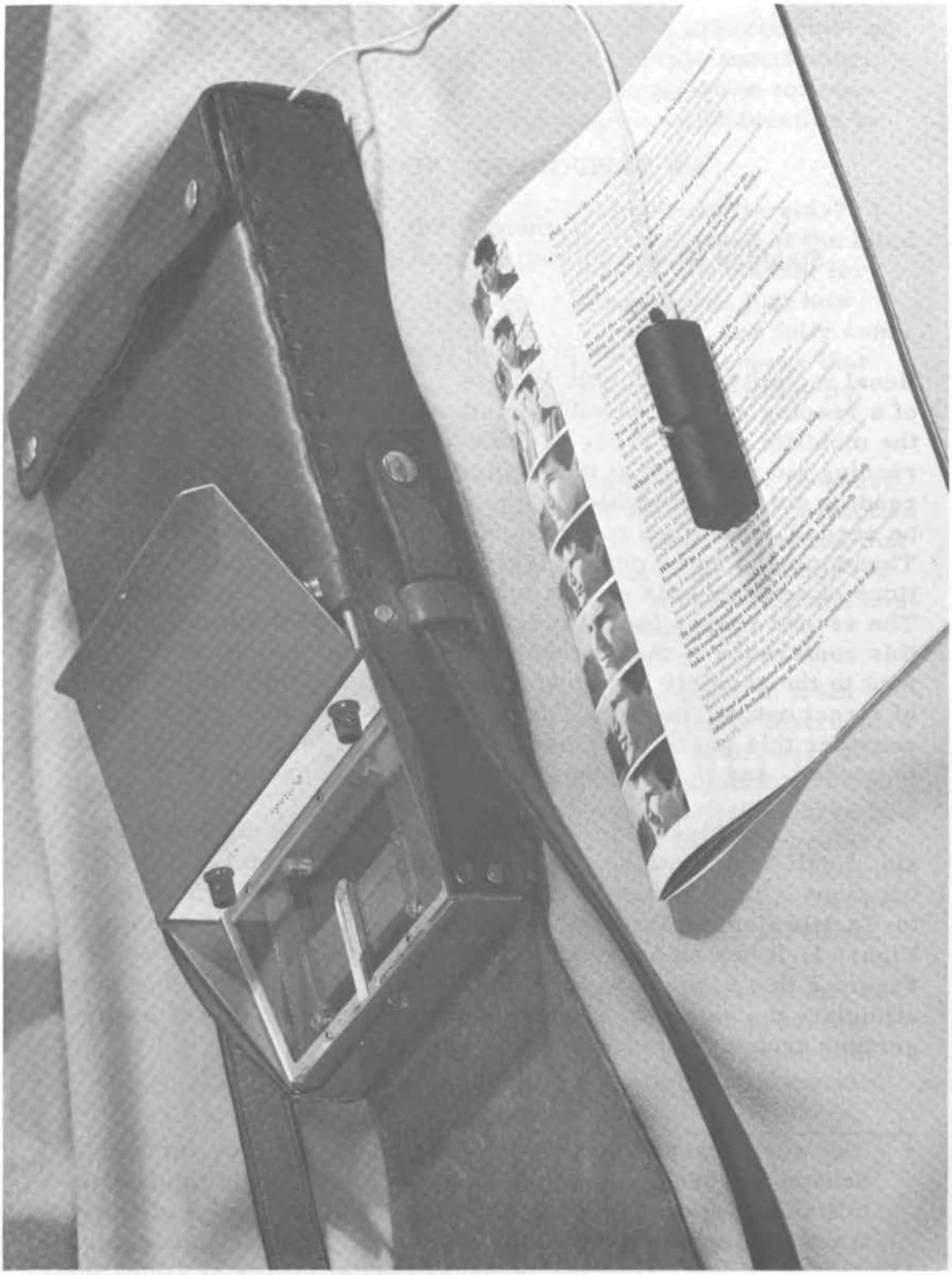

FIGURE 1

The Optacon -- A Reading Aid for the Blind

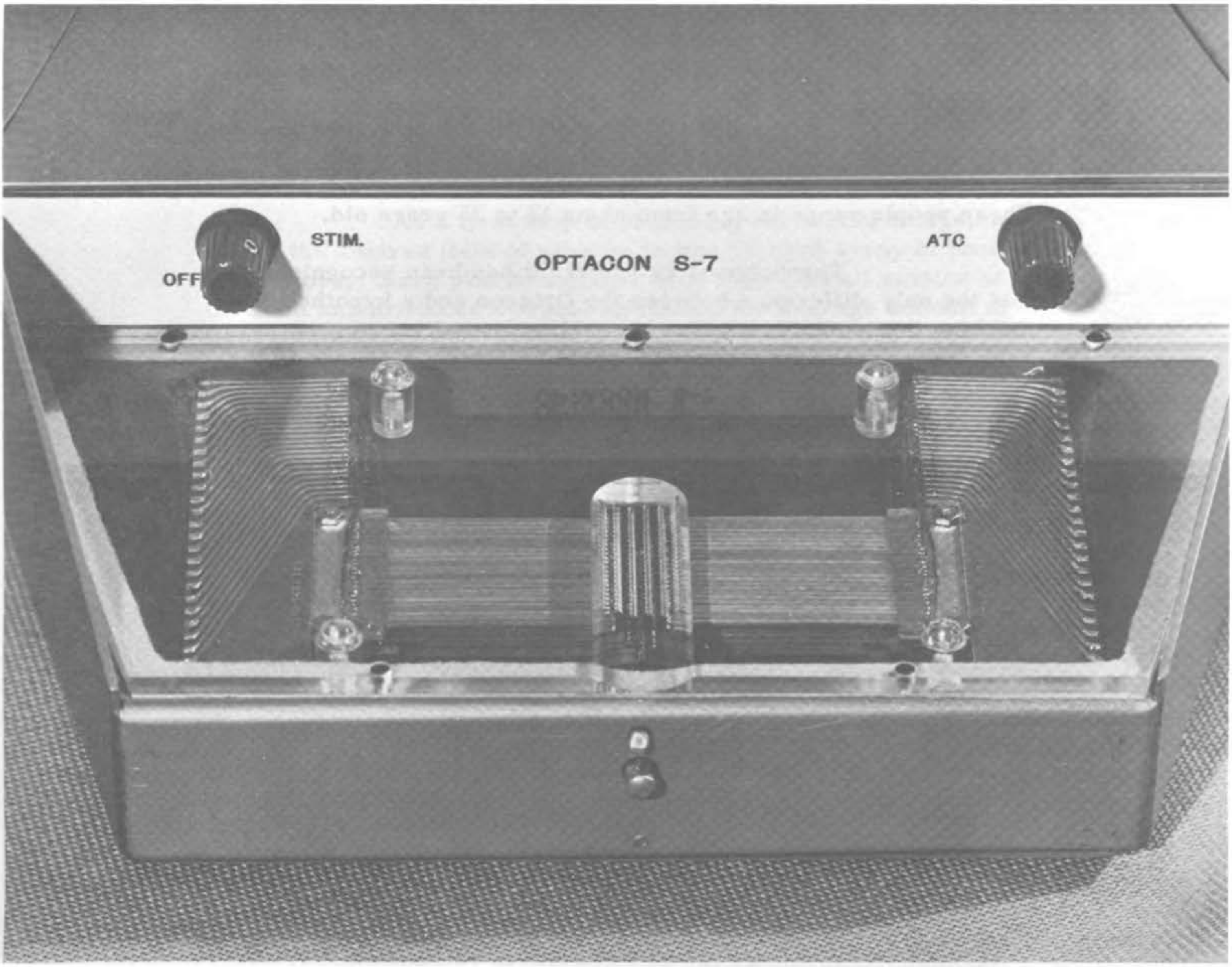

FIGURE 2

The Fingerboard and Bimorph Stimulators of the Optacon

The device is essentially a very small scale closed circuit TV system, except that the output is tactile instead of visual, and that it has many fewer image points than a commercial TV system. Following this analogy, the small component (shown in Figure 1 resting on the printed page) is analogous to a TV camera. It contains a zoom lens system, an array of 144 silicon phototransistors, and 6 pre-amplifiers. This camera converts an image of an area on a printed page about the size of a letterspace into electrical signals, and those 144 points are displayed tactually. Thus, the entire system simply copies in a one-to-one fashion.

We have built about ten Optacons now, and we have five people who are using them as if they were their own. They are reading with them in everyday life at home and work or school. These people range in age from about 13 to 35 years old.

Throughout this project it has been recognized that the only difference between the Optacon and a hypothetical machine that could be used as an environmental sensor, or perhaps some sort of mobility aid, would be simply a change in the optics. If the optical system was not focused on the printed page, but was instead focused at several feet, then two-dimensional spatial information from the environment would be obtained.

In fact, to bring this point home, I would like to show a movie that was shown at St. Dunstan's in 1966 [2].

The following subjects are covered in the film:

(1) The device and its components.

(2) Pattern-processing modes.

(3) Searching for a small object.

(4) Finding the corners of a large square.

(5) Determining the orientation of striped patterns, and the number of stripes.

(6) Determining the aspect ratio of rectangles.

(7) Distinguishing a square from a circle.

(8) Describing the movement of a target.

(9) Determining the distance to the target by parallax.

(10) Determining which of two objects is nearer.

(TEXT OF FILM COMMENTARY)

This film reports on a research program investigating the possibility of developing a small device to produce a tactile image of the optical field of view. A major question is whether such a device could convey sufficient information to a blind person to significantly aid him in everyday tasks.

As a first step in producing our tactile image, we image the desired field of view on to this 12-by-8 array of phototransistors. Each phototransistor sees only a small portion of the field and produces a signal indicating the average amount of light illuminating it.

The signal from each phototransistor can be used to drive a tactile stimulator in a corresponding 12-by-8 array of tactile stimulators.

This array of tactile stimulators was built at Stanford University and consists of 96 piezo-electric reeds. Each reed can be made to vibrate by applying an electrical signal. If the signal applied to each reed is from the phototransistor in the corresponding array position, then a vibrating tactile picture will be produced which is a very grainy facsimile of the image seen by the lens.

However, to allow us to experiment with several possible designs, without actually constructing these designs, we have interposed a small digital computer between the phototransistors and the tactile stimulators.

The light box permits us to show you visually the image displayed tactually to the subject. Each light indicates whether the corresponding tactile stimulator is turned on in the array of stimulators. The computer permits us to experiment with several different ways of presenting the tactile image. For example, we can make the tactile image only report change or relative movement. Or we can make the stimulators only report the outlines of solid objects. This is called the edger mode.

Now, let us observe a typical experimental session in which a subject is attempting to learn to obtain information from this device.

In this demonstration, the subject will try to locate a small object which may be placed anywhere in front of him. His task is to point the sensing head so that it is centered on the object.

Since the field of view of the sensing head is fairly small, first the subject has to search broadly. Now he has the object in the field of view, and, by small adjustments in his aim, he is centering it so that the stimulators that he feels vibrating are in the center of the array. The light box is just an indicator of what the subject is feeling.

This is a relatively easy task.

Now the task will be changed somewhat. The subject is instructed to find the corners of the large square. First he finds the square.

Now he finds an edge of the square and moves along it until he feels the corner, where he pauses, indicating that he has found it. Then he goes on finding the other corners. In general, it is easy to follow the outline of any large object in this way.

If the subject were able to keep track of the movements he made with the phototransistor array while following the outline of a figure, he would be able to identify its shape.

To illustrate this for a simple case, the subject is shown a large figure. By both feeling the tactile stimulators and keeping track of his movements he determines whether it is a square, a triangle, or a rectangle.

Next the subject traces a rectangle and indicates whether the long side is vertical or horizontal.

The shape identification just illustrated depends upon the subject's ability to trace an outline and interpret the movements that the tracing required. It is also possible for him to identify the shapes of some objects that are small enough to fit entirely within the field of view of the sensing head. For instance, here the subject is instructed to indicate which of the two is the triangle.

He gets his information about shape from feeling the pattern on the tactile display.

This task is somewhat easier if the pattern is processed to display only the outline or contrast boundary of the figure now displayed on the light box and tactile stimulators.

The research described in this film is merely exploratory -- aimed at getting some indication of what is possible and what is likely to be useful.

Here is a similar task. The subject is asked to say whether the stripes are horizontal or vertical. This is a measure of acuity.

For the particular photocell spacing in this sensing head, and for the particular magnification between the object and the tactile array, the subject is consistently correct even for these relatively fine stripes.

With smaller stripes, he is often wrong. Notice, with these still finer stripes, it is almost impossible to tell the direction of the stripes on the light box. Conversely, when the direction of stripes is detectable on the light box, the subject is usually correct in his judgments. In other words, the fineness of the stripes that can be distinguished -- the subject's acuity -- is limited not by his tactile sensing ability, but rather by the resolution of the device in its present state.

When the stripes are still wider, he can feel and count the individual white stripes, as he is doing here.

The motion of objects is very easy to detect with this device. Here the subject senses the direction of movement of the experimenter. It is easy to feel the direction and velocity of movement of the experimenter's arm in the tactile display.

A subject can quickly learn to use the device to locate objects in depth. Here he is asked to determine how far away the target is from him. He makes the determination by moving the sensing head from side to side and getting the feeling of the angle he must twist the sensing head in order to stay on the target. This is essentially a triangulation procedure. If the target is very close, as it is now, sideways motion must be accompanied by a relatively large twist.

Now, when the target is far away, a much smaller twisting is required. This task is relatively easy even without an apparent size change.

The subject can also tell which of two objects is closer to him without using size cues, by sensing the relative motions of their tactile images as he moves from side to side. His decision is based on the same cues which, for the visual sense, are called the cues of motion parallax. If, as he moves in one direction, the objects move closer together on the display, he knows he is moving toward the nearer object. If the objects appear to move farther apart, he knows he is moving toward the farther object.

Of course, this research is in a very early stage. However, with the development of micro-electronics capable of producing hundreds of photocells in an integrated array and the development of piezo-electric tactile stimulators requiring only 30 microwatts of power, it is clear that the device suggested here could be developed into a very small and compact unit with adequate sensitivity in normal room illumination.

(END OF FILM COMMENTARY)

After taking this movie in 1965, we began work on a portable device. Within a year we had a self-contained portable system that was battery operated (see Figure 3). The system of Figure 3 again contains an array of 144 phototransistors which were mounted in a box behind a 35 millimeter camera lens. Each phototransistor is functionally connected by electronics carried under the other arm to a 12-by-12 array of tactile stimulators which is also in the handheld phototransistor box. In this way the tactile patterns are sensed by the hand that points the camera.

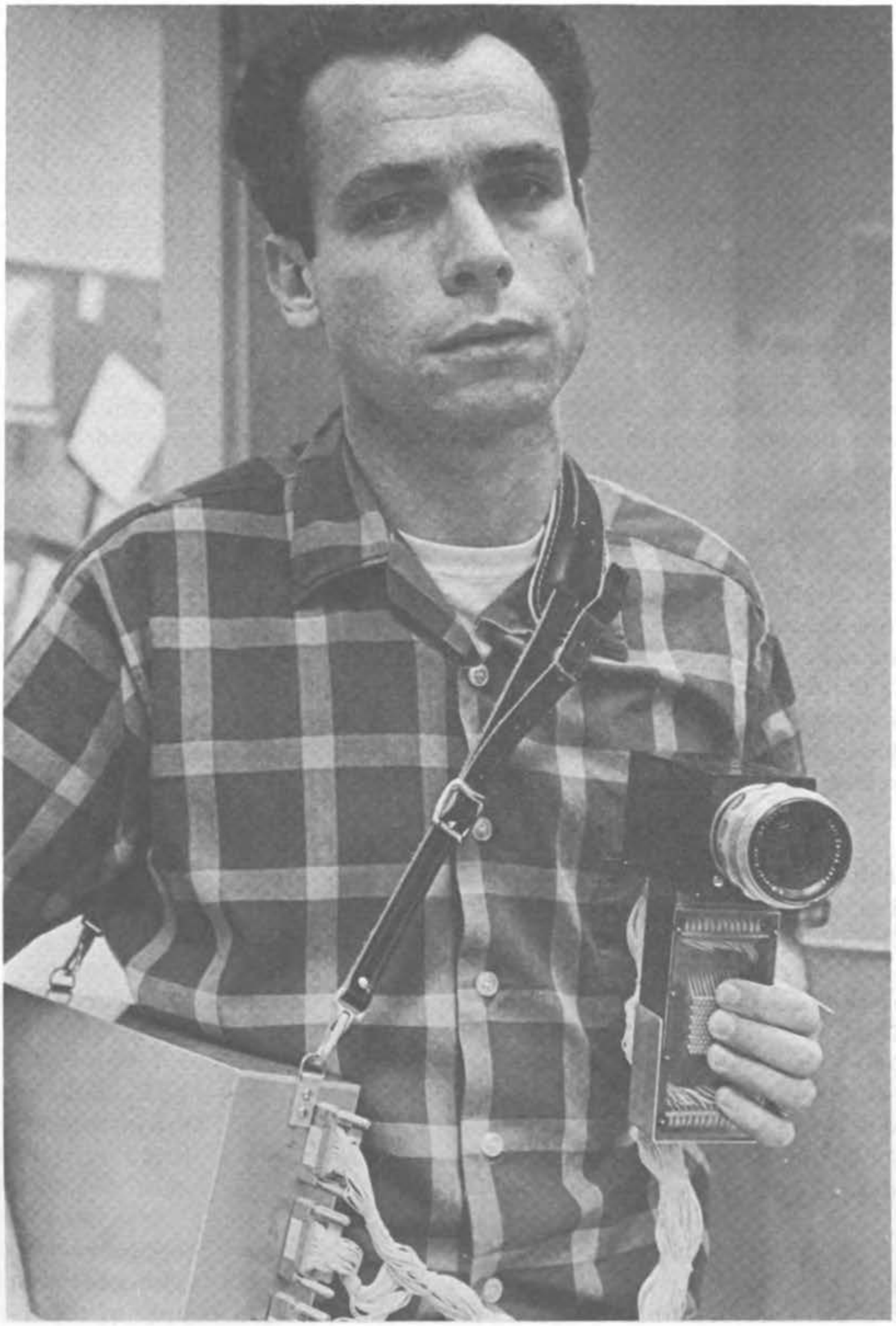

FIGURE 3

An Environmental Sensor with a Bimorph Tactile Output

After initial experimentation with this system, we felt that there was considerably more to this than first appears. Considerable basic research needs to be done, both psychological and technological, before a practical device can be developed. Some considerations that appear to be important in this development are techniques for sensing and for stimulation. In the area of sensing, the first considerations are resolution and field of view. These two parameters interact, and there are tradeoffs involved. On the one hand, the most resolution and the widest field of view possible are desirable, but you have to pay for this, of course, in terms of size, weight, and power. We are often led astray when we see how electronics has been able to microminiaturize systems in recent years. This leads us to think that even though a system weighs three hundred pounds now and consumes 750 watts, further research and development will make it microminiature. But there is very little that can be done to microminiaturize the power requirements of the sense of touch. If a part of the body is used in which the inherent threshold of touch and the mechanical impedance of the skin implies a certain power consumption, then there is very little that can be done to reduce the size and weight. Power is a very real consideration not because of the power that the electronics consume, but because of the power necessary to stimulate the tactile sense. This is why it is very important to use a very efficient tactile stimultor, and to use an area of the body that is very sensitive.

In terms of resolution and field of view, and the tradeoffs with size, weight and power, there is also an interaction with other mobility aids that might be used at the same time. The most interesting possiblities regarding optical-to-tactile image transformation are in combination with an obstacle detector, or in combination with another device that gives range information. Thus, I believe an attractive system would be a combination of Dr. Kay's sonic glasses, for wide angle object detection and localization. For example, with such a system one could conceive of the possibility of a blind person finding a street sign with the sonic glasses and reading the name of the street with the optical-to-tactile image converter.

In the area of stimulation, we have techniques put very closely packed stimulators together, and techniques that can produce good stimulation on the finger with a couple of milliwatts per stimulation point. But even with this, the idea of making a truly portable system that will have many more than a thousand stimulation points becomes difficult to conceive. The primary constraint is the number of points in the stimulator array, and the question becomes what can be done, in terms of obtaining environmental information, with very few image points. In other words, how good an image for environmental information can be obtained with only a thousand points?

This brings up the question of performing pre-processing on the image to reduce the number of image points needed. I think there are some very good possibilities along these lines. We have done some computer simulation experiments with pre-processing for the Optacon, and it appears to be quite attractive to have one tactile stimulator per two optical image points (instead of one-to-one). This is because a better image can be obtained at less cost than we are producing now. The idea behind this algorithm is that in recognizing characters it is essential not to miss any strokes or gaps, but the precise location of a stroke or a gap is not essential. If a stroke or gap is moved a half a stroke width one way or the other, it really does not make much difference as far as recognizing the letter goes.

This pre-processing is not equivalent to a blurring operation. It involves doing some nearby neighbor logic using "and" and "or" gates. It is sort of an ad hoc algorithm that, of the many we tried, seems to work. The logic looks at whether the nearby neighbors are white or black, and then knowing something about the connectivity of letter shapes decides whether the stimulation point in question should be "black" or "white." This rule works most of the time but it is not perfect.

The difficulty in trying to extrapolate this kind of pre-processing to the mobility situation is the unconstrained nature of the input. People involved in the development of character recognition systems may think that their input is fairly unconstrained, given all of the different type fonts, ink, and formats, but character recognition images are at least an order of magnitude more constrained than real world scenes. In this latter case not only is the input unconstrained, but there is no control over the illumination. At least in the reading aid, we can control the illumination with a couple of light bulbs in the device.

Nevertheless, I think pre-processing does have something to offer about the problem of too few image points, but what may have to be developed is a repertoire of pre-processing algorithms that one can switch between for each situation. I feel it is going to be extremely difficult to find a general purpose pre-processing algorithm, and it is more likely that if any pre-processing technique turns out to be beneficial, it will only be beneficial in certain situations and harmful in other situations. Thus a repertoire of algorithms may be necessary.

The existing optical-to-tactile image conversion systems, such as the Optacon, have been binary systems with each image point being either on or off. Thus every stimulator is on or off depending on whether the input light intensity is above or below a threshold. We have been looking at the possibility of introducing a "gray" scale into the system. To transmit as much information as possible with only a few image points, an analog intensity scale will be important.

An inexpensive way to obtain a "gray" scale in these systems is to have a variable threshold, either automatically variable or under the control of the subject. For example, consider a threshold that varies in a sawtooth fashion between two values every half second. Such a continuously variable threshold at some point will display both shades of every contrast boundary in the scene. If the subject could integrate all of this in his mind, he would have a continuous gray scale. Of course, much simpler things for the user to understand can also be built. For example, the threshold could automatically zero in to some particular value. In fact, even in the Optacon we found an automatic threshold adjustment to be useful which compensates for any changes in illumination or reflectivity of the page.

Another important consideration is the body location of the sensors and the stimulation. With a camera of this size or smaller, it is quite possible that the unit could be mounted on eye glasses frames, fitted in a case mounted on the chest, or mounted in a cane. All of these locations are quite different psychologically in terms of proprioceptive information received, and the ease and simplicity with which scanning can be done. If such a system is combined with a rangefinder or an obstacle detector, then the question becomes how to coordinate the two systems. Should they both be head mounted, or one be head mounted and one be mounted on the hand, and so forth.

In terms of stimulator size, we can build 144 tactile stimulators in a box about 3.5 by 1.0 by 3.75 in. with the tactile stimulator array of 144 points at one end of the 3.5 by 1.75 in. face. Something like this may be quite simple to mount on the body, but it is not going to be cosmetically very attractive if it is mounted on the head. Still, this is what we can do today, and there are some possibilities for making this considerably smaller.

This stimulator box would only include the vibrating reeds and the scan circuitry for the reeds, but it would not include any of the input circuitry. The sensor input would be somewhere else. Enough scan circuitry would be included so that only about six leads are needed to go to the box. If the scan circuitry were not in the box, there would have to be 144 leads, which would be a cabling problem. Huskier bimorphs may be required in order for the bimorph power outputs to be compatible with the dermal thresholds on the parts of the body, other than the fingertips and very sensitive places. There is quite a variability in threshold over the body. Very recently we have found some ways to double the motion we can obtain with our "standard-sized" bimorph stimulators. This will permit things to be made smaller with greater drive. For example, up until very recently the limiting factor on how great the bimorph units could be driven was that too much drive would cause the bimorph to bend enough to break itself if it was unloaded. Once this excessive motion is restricted, they can be driven much harder than when they are unloaded. This allows the same units to be used in a much more powerful system. Our sensing plate protects the stimulators, or limits the amount of pressure that the man can exert on the stimulators, because the skin is pressed against the plate.

It is obviously different if the tactile display is static for finger exploration or moved on the surface of the body. But, since the number of stimulation points that can be tactually sensed at one time is limited, it is much more efficient in terms of equipment, even if active finger exploration is desired, to attach the stimulators to the subject's fingers and have him move his fingers over a virtual image space. In this way the hardware of a big tactile area is unnecessary. Therefore, it is preferable to either mount the stimulator on his body and let him move the camera around to move the picture under the stimulator array, or to couple the sensory and stimulator arrays together and mount both on a movable body member.

Besides the fingers, we have considered tactile information displays for the forehead, the temple, and the chest. There are a number of problems with head mounting that perhaps can be overcome, but we have not as yet overcome them enough to do the proper experimentation. For example, one of our problems with head mounting is that bimorph stimulators make significant auditory noise, which has to be minimized, especially if they are mounted on the head. For head mounting I would like to be able to reduce the size so that, for example, the stimulators could fit into the not too heavy side arms of eye glasses. I think this is possible, but it is going to take more work on the bimorph elements and techniques for mounting them.

Besides using very efficient units and being concerned about power in the tactile stimulators, it is very important to do the analogous thing in the photo input end. I feel in this area that silicon phototransistor arrays may have many advantages over, for example, Vidicon tubes. Phototransistor arrays are becoming more and more available and are fairly inexpensive. There are companies that offer these arrays for sale, and they can be ordered in various configurations.

Figure 4 is one made in the Stanford Electronics Laboratory [3]. It is a 24-by-6 array, 144 photo-transistors on roughly a 2 millimeter by 4 millimeter chip of silicon. It is about the same size as the letter space, so that our nominal magnification in this camera is one-to-one. In one dimension the elements are every six mils and in the other dimension they are every twelve mils. The elements are twice as wide as they are high, and the columns are staggered. It is this phototransistor chip that made it possible to make the small Optacon camera.

The final problem is that out of all of the technical possiblities that have a chance of being useful, how will we ever know what is useful? This brings us to the theme of the conference, evaluation. Evaluation of a new system is a very difficult problem. The dilemma is that if a quantitative experiment is performed in which the stimulus and response is precisely specified, then the experiment is too trivial to be of any interest. If an experiment is performed which makes full use of the capabilities of the man-machine system, then such a complicated situation is obtained that about all that can be reported is an anecdotal description of it. In this case, it is very difficult to tell how much the experimenter is reading into it, and how much is actually taking place.

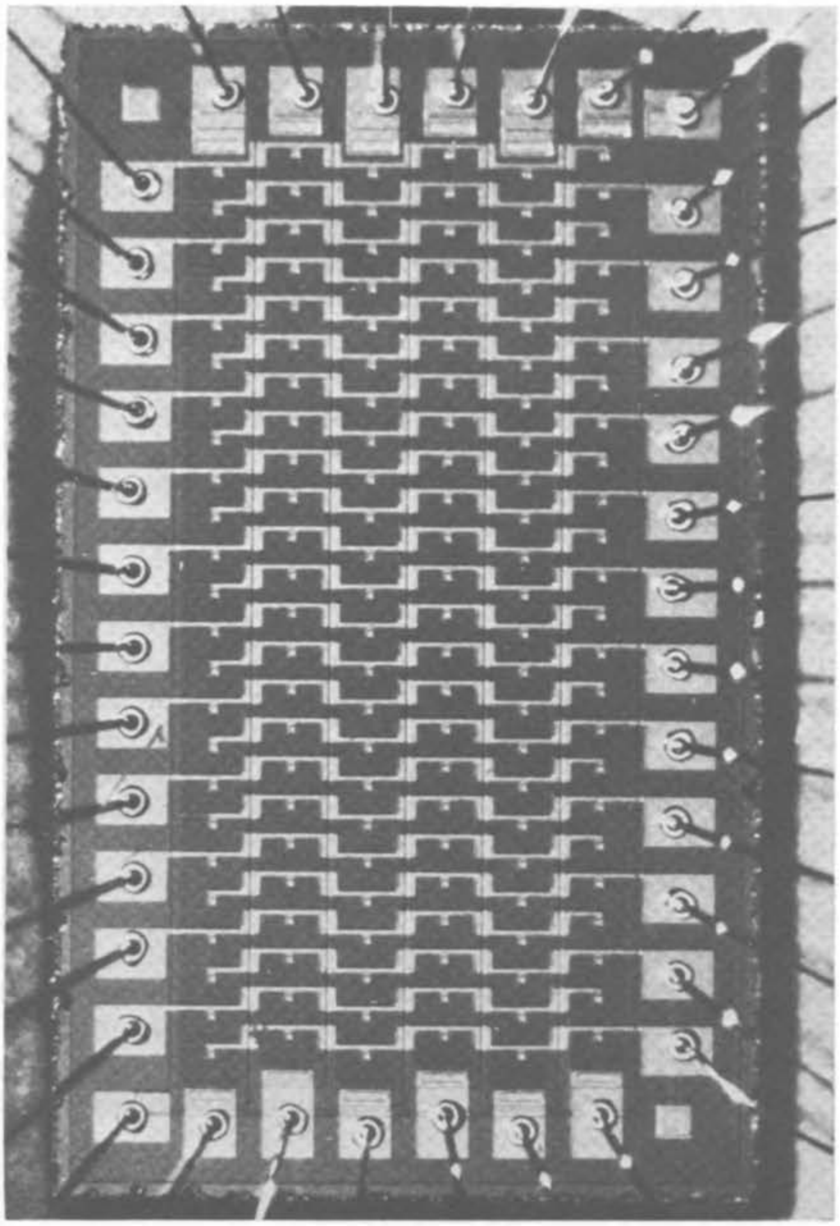

FIGURE 4

24 x 6 Array of Silicon Phototransistors in a 2 x 4 Area

In our previous work and in the system of Figure 3, we reported [1] two quantitative experiments. One was an experiment on form perception, and the other was a tracking task. Another technique that is very revealing is tachistoscopic presentation applied to tactile images. Results from this experimental technique provide important comparisons with the great amount of work that has been done in vision. The differences between vision and the sense of touch are much more interesting than the similarities. The skin is not a retina, and the characteristics of taction that are different from vision are worth investigating. For example, a "Times Square," or moving belt, kind of presentation where the letters are stationary and are jerked from position to position is better visually. I think most experiments with tachistoscopically presented tactile images indicate that the latencies in recognition are much longer with tactile images than with visual, and the ability to perceive detail in the center of a fairly complicated image is much poorer tactually than visually, at least initially. But all of these things are complicated by the fact that we find that our subjects change with time. We have had some subjects around for several years doing tactile experiments, and the difference between their tactile image perception now and their abilities, say, three or four years ago is quite fantastic.

Another kind of experiment that is very important to this kind of system is aimed at determining how many image points are tactually useful. This is a very obvious and easy kind of experiment to do simply by turning off stimulators in an information display and observing any change in performance. With the Optacon, we have already done a considerable amount of this experimentation [1]. But again there has been a vast change over the past three or four years in our subjects. Three or four years ago when we did this in reading [4], we found that performance leveled off at three columns and more columns didn't improve performance. With the same subject, after another year of letting her work with a machine that had six columns, the new performance peak was at six columns [1]. Now the peak is at eight columns, and who knows, with greater exposure it might be greater.

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THE CONCEPT OF THE MINIMAL INFORMATION REQUIRED FOR EFFECTIVE MOBILITY AND SUGGESTIONS FOR FUTURE NON-VISUAL DISPLAYS

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I have usually taken opportunities such as this conference to emphasize to my listeners the importance of coming to terms with the realities of the problems of blind mobility and of providing solutions which had a chance of being accepted and implemented soon on a fairly wide scale. For once I have decided to forgo the self-imposed rigours of this particular approach, partly because I am sure most of the present audience are only too aware of the realities of the situation and partly because the approach which I favour has just been widely circulated and is available to anyone interested (1). Most of what I want to talk about will therefore be in the nature of speculation rather than based on hard evidence, and indeed, for the core of my argument I shall have very little experimental results at all.

Let me begin, however, with a brief visit to the real world. Figure 1 shows a list of attributes of the blind population which in that real world we have to take account of: Onset and degree of blindness; age and sex; additional impairments and socio-economic status; motivation, intelligence, and personality. Thus, "the blind man" is an almost untenable concept unless we do specify more clearly. One consequence of this position is that there is a very considerable need for a variety of solutions to meet individual requirements and needs.

Another consequence, and one which is equally important, is that we must be very careful not to become over-determined by the opinions expressed by a single blind user, however good and competent he may be. For as often as not he is most likely to speak from his own experience only. It is clearly up to us to establish the extent to which one would be justified to generalize from his experience to that of other blind users.

PERSONAL VARIABLES

Age

Sex

Onset of Blindness

Degree of Blindness

Motivation - Mobility Needs

Additional Impairment

"Intelligence"

"Personality"

Socio-economic status

FIGURE 1

Figure 2 shows at least one dimension of the definition of needs: the range of attainment in terms of the spheres of mobility activity. At one end is the chairbound individual and at the other the sighted pedestrian. In one sense the answer to our question is quite simple: our blind man needs to see. But as far as the realities of the situation are concerned, the case for social spending (where the blind are in competition with other disabled populations) cannot be sustained beyond the limit of self-dependent, safe, and reliable travel in familiar areas up to and including the route to work. If our solutions could just do that for most of the population at risk, we could be very pleased. It is reassuring to note that the range of solutions presently available; short cane, long cane, dog guide, sonic aid, are well on the way towards achieving this aim. In the foreseeable future it is my guess that the only practicable steps will be in the direction of improved and more widely available training schemes for these existing devices. If, beyond the point at which travel along familiar routes up to and including travel to the place of work is achieved, it is possible to provide the capability of travel in unfamiliar areas, this is a bonus as far as the real world is concerned. Desirable undoubtedly; a need, more questionably.

I am therefore very glad to have this opportunity to associate myself very closely with a good many of the points made by Bill Curtis in his paper on this topic yesterday.

Figure 3 shows in more detail what we expect qualitatively from the best of our existing travelers, regardless of aid employed. I have elsewhere described it as representing the core of sighted mobility. Those who at present meet all those criteria to the full are doing so by virtue of either lengthy training or a good deal of initially painful experience; their vocabulary of routes is fairly restricted, and as far as our evidence goes, they pay the price of heartrates higher than when walking about guided (2). There will soon be a further index, that which relates to the smoothness of progress, but so far we do not have enough data. Here let it suffice to say that any new device or training method will have to equal or surpass these criteria. This, together with the cost of training and of devices, forms a good part of any cost-effectiveness equation.

Figure 4 lists the categories of information supplied by vision for the purpose of sighted mobility. Object detection, orientation, posture, and terrain changes are the four

MOBILITY NEEDS IN TERMS OF AREAS OF ACTIVITY

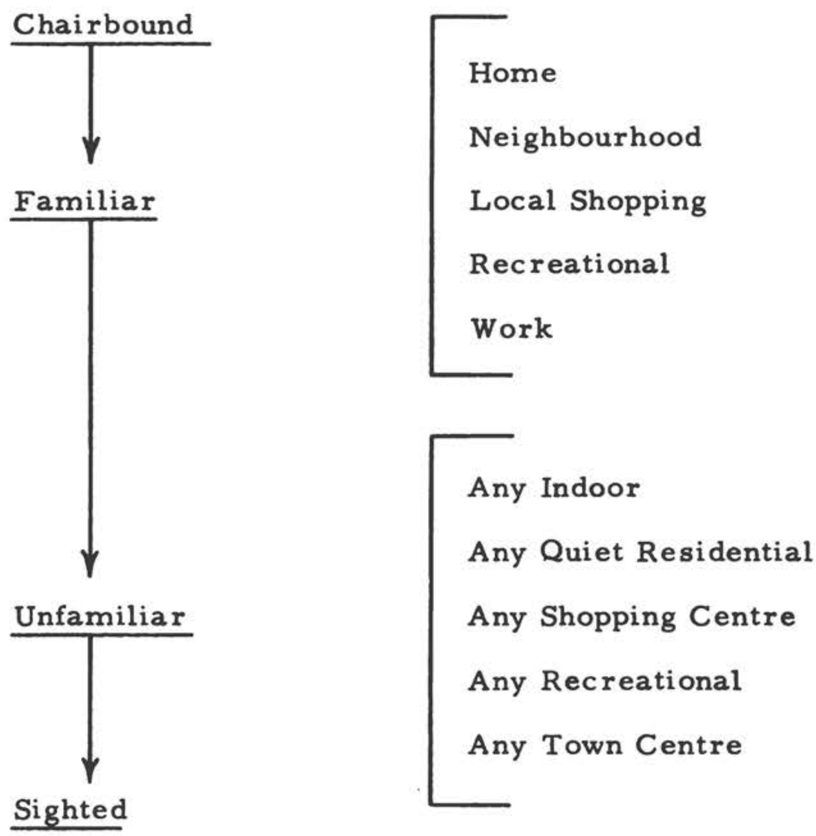


FIGURE 2

TRAVELLER CAN:

Move through familiar environment

Move through unfamiliar environment

Move at speeds equal to sighted

Travel straight line midpavement or sidewalk

Detect end of blocks

Detect and anticipate downkerbs

Cross roadway straight or correct veer

Detect and anticipate upkerbs

Make indentations

Pick up true paths

Detect obstacles/landmarks auditorily-tactually

Sense environment auditorily-tactually

Handle effectively sighted help

Handle effectively public transport

FIGURE 3

Range of Attainment for a Blind Traveler

VISION ORDINARILY PROVIDES INFORMATION FOR:

- Object Detection
  - Obstacles
  - Landmarks
- Orientation
  - Near
  - Far
- Terrain Changes
- Posture

This information is generally capable of being:-

a) monitored at low levels of awareness

b) acquired well ahead of time action is required i. e. it is anticipatory.

The information provided by an aid to blind mobility should have the same capabilities.

FIGURE 4

large categories, and again it is good to realize the extent to which existing mobility aids and training methods are providing nonvisual equivalents of these categories. But of course, vision does so "naturally" for man is a visual animal; and vision does so with vastly greater richness and over a much wider range.

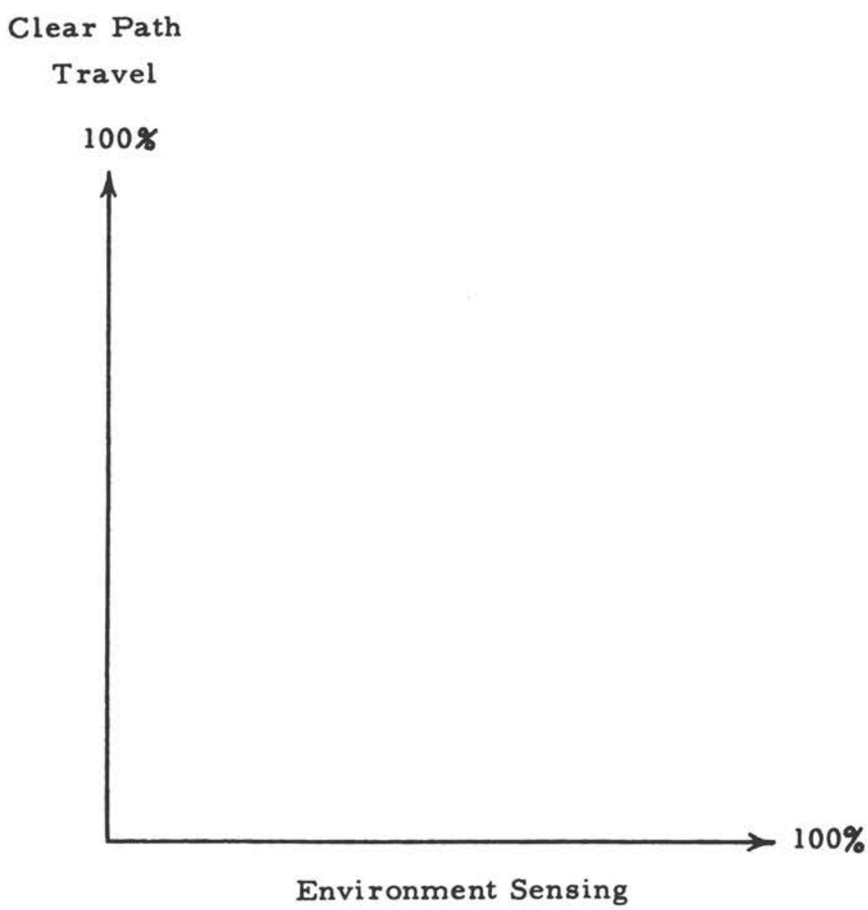
To illustrate this let me just insert an anecdote from the early days of my work when I spent a good bit of time watching blind travelers. I would do this for about ten consecutive working days on their own familiar route to and from work. After one such stint, I discussed the experience with this particular blind man and pointed out some ten or so instances where on most mornings he got himself into more or less dangerous situations -- dangerous to himself or others. He could have avoided these by making use of quite simple landmarks. He accepted two of my suggestions, but for the rest: "Dear Dr. Leonard, I have got better things to think about on my way to work than think about finding your bloody landmarks." That, in a manner of speaking, puts it in a nutshell, I have that engraved somewhere on my desk.

Let me digress here very briefly. There is an immediate need for more work on the postural side, particularly for the congenitally blind. Here the problem is one of providing adequate feedback, detailed, augmented, non-visual feedback for actions which are predominantly under kinesthetic control. The pioneer work of Kooyman (3), Doris Tooze (4), and Cratty (5), is of great value here, but it must be extended.

Figure 5 looks at the <u>need</u> problem another way around. Given that the traveler describes or follows a path between any two points, what kind of information about this path is required? On the figure I have put down simply two headings: clear path and environment sensing. I leave it to you whether you prefer to think about this as two distinct categories or two dimensions. But the point is really quite simple: Does the traveler need mainly clear-path information or does he also need information about the nature of the boundaries of that path or any object within that path? It is my impression that most of the blind people I have observed so far are interested primarily in clear-path information and only very incidentally in environment sensing. To become concrete: My impression is that most travelers want to know at most that there is a tall round object in their path, but they are not concerned about distinguishing between

MOBILITY NEEDS IN

TERMS OF REQUIRED INFORMATION



Most users needs are satisfied by maximising on C. P. T. with a minimum of E. S. for intermittent orientation. Some users might have no C. P. T. requirement but have great intellectual/emotional need for E. S.

FIGURE 5

tree, lamp-post, traffic-sign, etc. Most blind travelers are primarily interested to know that they are maintaining their desired path, but are not particularly interested in knowing (most of the time) whether they have passed trees, lamp-posts, parked cars, or bus-shelters. They may want to do so at certain points of a route and undoubtedly there are some travelers who do like to know a lot about the environment through which they are traveling. Equally obvious, what blind people say at any moment in time is conditioned very much by the ease with which they can obtain more detailed information. Thus, an improved method of gathering and displaying information might well change the stated needs of blind people. One of the disincentives to independent blind travel at the moment is that it is confoundly lonely and boring. If easily handled environment sensing could overcome that, then the position I have stated above might well change.

Figure 6 takes us a little bit further into the theoretical realm. This is a highly schematic block/flow diagram of the systems involved in natural as well as aided mobility. Everything solid is natural, while everything dotted is aided. On the left we have the environment, which feeds into the Sensory Surfaces, which feed into the Projection Areas. The next box we'll just leave with a question mark because that's as good a symbol for it as any other. From here we go into a box labeled Mobility Control where all action required for mobility is initiated. This feeds back mainly into the environment of course, but there is a parallel line back to the Sensory Surfaces as well. The dotted (aided) system starts with an Information Gathering box which is fed by the environment. It feeds into an Information Processor which in turn feeds into the Information Display. This feeds into the available Sensory Surfaces, or in the case of implants into the Projection Area directly. In fact the scheme drawn out here applies to any kind of sensory-aiding situation. One of the perpetual arguments is just how much processing needs to be done in the dotted system and how much can be left to the solid system.

If then we restrict our thinking for a moment to an adult blind person, otherwise fit, adventitiously blinded, about average intelligence and wanting to be self-dependent in his mobility (where the latter is operationally defined in terms of the effort and the cost he and/or society are prepared to make available towards that aim), our problem is to present non-visually the information which is normally available through vision.

AN INFORMATION FLOW MODEL

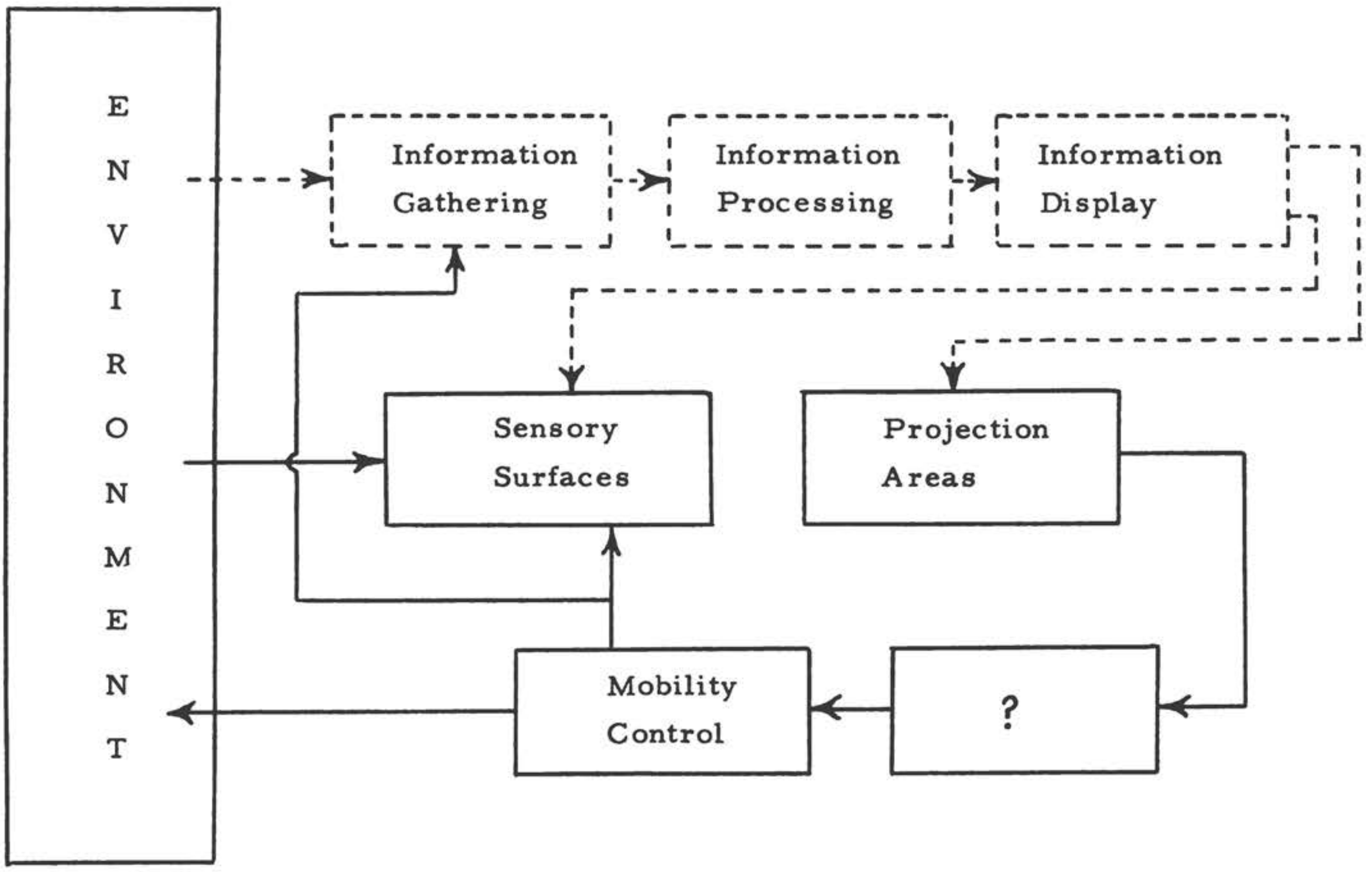


FIGURE 6

Systems in Natural and Aided Mobility

From here on out I propose to extend an argument which I have only sketched in briefly in another paper [1]. On the one hand we know that if a sighted person is suddenly bereft of sight (e.g. by blindfolding him) he is to all intents and purposes totally incapacitated as far as effective mobility is concerned. This is the measure of the extent to which intact man depends upon vision for his mobility. On the other hand we also know that there are at least some congenitally blind people who manage to move about pretty well without any aids at all. The difference between their achievement and that of sighted mobility is a measure of the extent to which it is possible to achieve effective mobility by non-visual means. While so far I have not met any totally blind person who has been able to move about as well as a sighted person, those who come closest to those levels manage to do so almost certainly on very much less information than do the sighted. I therefore want to examine in more detail the concept of the minimal information required for effective mobility.

To start with, it seems reasonable to assume that we do not have to present all the information non-visually which is normally available through vision. We know, for instance, from observing people with very small amounts of residual vision (so little that it can often not be specified) that they have almost all the mobility characteristics of a sighted person. One of the most obvious limitations is in the realm of range, or better still in terms of overall coverage. Clearly, for the vast majority of the criteria of sighted mobility to be met we need neither the 100 meter range nor the visual angle of some fifty degrees or so.

It is also fairly certain that we do not need anything like the normal degree of visual accuity for most purposes under consideration. For you have to have pretty high degrees of myopia before you become markedly helpless in the mobility field.

Finally, as an example of arriving at some idea of an irreducible minimum of information required, it seems reasonable to assume that we do not need all of that information all of the time -- there could presumably be some economy by time sampling and possible by time sharing. We can certainly shut our eyes for seconds at a time without much apparent decrement as long as we have full vision. Just how much bandwidth is required is a moot question at this time, but no doubt one could carry out experiments along the lines of Senders' subjects who drove along certain stretches of highways with only intermittent vision permitted. There are some quite serious methodological problems about the equivalent experiments for our purposes -- for instance, it is known that there is a tremendous learning effect with residual vision cases --but no doubt these problems could be overcome.

Let us assume that in one way or another we have arrived at specifiable minima of information and let us assume further that we have encountered only non-academic problems, such as cost, in devising methods of gathering that information. We now have to display it. So here we are entering the area of coding, but more importantly of the relationship between displays and controls. The time has come to talk about compatibility. Now in ordinary human engineering parlance what we mean by that is the extent to which changes in the display state can be translated into appropriate action more or less easily. When it is easy we talk about high compatibility, and when it is difficult we talk about low compatibility. We are not particularly concerned in the first instance whether high compatibility is the result of natural inclination or of learning; compatibility is a purely operationally defined concept and usually it is measured by comparing sets of display-control relationships and observing speed, accuracy, and rate of acquisition for each one.

The point about compatibility is of course that it refers to a relationship between display and control, and that it is meaningless to talk in terms of either displays or controls being compatible by themselves. Within a given display, display states will have to be discriminable from each other, and within a given control there will have to be sensitivity. The overall problem is how to achieve the best transfer of information from the environment to the operator so that appropriate action, whatever that may be, can be carried out.

When we come to consider the problem of mobility we are dealing with a fixed display-control relationship in the intact organism; the display is provided primarily by vision and the controls are the various movements that have to be carried out in order to move from A to B and in order to maintain our orientation and our posture. In this sense, vision provides the natural display for mobility, and anything non-visual has to be considered as unnatural and as requiring a measure of learning before it can begin to approach the efficiency of vision. We can go further and say that the mediating process between display and control is natural and highly developed in intact man, just as it would appear to be natural for some species of bats to process auditory information for the purposes of mobility.

Let me quickly go over the crucial properties of vision in man; it is a parallel processing system covering a very wide segment of the environment relative to man's size and relative to a pedestrian's speed. It is conventional to speak of the richness of visual information and of its acuity; I would want to stress the fact that it provides us with a constantly present and effectively stable frame of reference which includes a surprising amount of our own body as an anchor. In general we tend to think of vision as presenting considerable amounts of information simultaneously, while the non-visual senses operate primarily sequentially. Thus the problems in vision tend to be those of analysis, while those of the nonvisual senses tend to be those of synthesis.

Given, then, that the control element of the mobility task remains constant, let us consider first of all existing non-visual displays which are at least "good" in their own right (if you will let me get away with that for the moment) and which are known to produce at least a measure of compatibility in the mobility situation.

Tactually, there is in the first instance the whole of the body surface and more particularly the extremities. Contact with the environment is a fairly direct signal in that system, but it is of course very limited in range and therefore some extension is required. The displays provided through canes and the handles of dog guides are evidently "good" and can achieve fairly high levels of compatibility with the control system. Their use clearly increases the limits and speeds of progress, once their manipulation has been learned. In this context it is of some interest to note that one of the initial problems in learning how to benefit from the long cane is not so much to recognize that the tip has made contact with an object, but to know where the tip is in relation to one's body.

On the auditory side we have known for some time about the role of the display properties entailed to so-called facial vision, and we have learned a lot more about the "goodness" of active environmental noise patterns in recent years. With regard to the display properties involved in "facial vision," a careful study of the work of Ivor Kohler might clearly be in order when we come to consider the position of artificial auditory displays.

The display of the Sonic Aid provides a rather splendid example of the relationship between the properties of displays and any resulting compatibility. Consider in the first case texture information presented by the Sonic Aid. This is almost a natural; most individuals I have tested could tell a hard from a soft surface on first exposure. With the aid fixed and a good reflector moving at right angles to the transducers, it is not very hard for most subjects to tell a near from a far signal; and with not very much learning they can make fairly accurate verbal judgments which relate perceived pitch to distance. With the reflector less good, or set obliquely to the transducers we begin to run into some difficulties even in a judgment situation. Matters begin to get distinctly more difficult in terms of learning times when the display state has to be related to action, rather than described verbally. But much can be learned, and thanks to the work of Sharpe [6] we do now have a much better idea of how much learning may be required for what kind of achievements.

What the Sonic Aid story illustrates extremely well is that a display may be jolly "good" when it is measured in terms of one set of criteria, and not quite so good when measured by another set; there may well be all sorts of other artificial displays which may be "good" in the sense that one can obtain efficient verbal responding to them when they are tested in the laboratory, but which may not have very high compatibility with the control system involved in mobility.

This is, of course, simply restating what I said earlier about the definition or specification of compatibility, i.e. that it refers to the examination of the relationships between sets of displays and sets of controls and that some of these relationships might be better than others. There is thus a sense in which it is right to say that certain aspects of the Sonic Aid's display are highly compatible when studied in relation to a verbal output but that they produce much less compatibility when studied in relation to a mobility output.

But there is of course one non-visual display which everybody handles every day and knows how to deal with; speech. How useful could speech be as the output of a mobility device?

Now before everybody combines to pick up objects detected in the environment and to hurl these at me, let me duck and assert that I think we should consider this quite seriously for a moment. At the very least as a tool in an intellectual exercise, but also possibly as a tool in experimentation. Let me just remind you that we are here and now in an era in which substantial claims are being made for both vision substitutes and visual prostheses. In both these cases the information gathering side of the shop is a TV camera and in both at least a measure of processing has to be carried out before the gathered information is displayed. And, as far as one can tell at present, the problem is going to be a fairly hefty one when one moves from degraded to real-life situations. Let us assume that a speech output from a TV camera might be technically feasible. (Why not?) Let us then consider for a moment the kind of situations in which speech is already used in mobility-like situations. The most dramatic one is of course the "talking down" of aircraft. In these situations both the controller and the pilot make use of a language system specially acquired for the purpose, i.e. the major problem was one of software. Less dramatic, but perhaps more to the point is the use we make of speech in giving overall directions for all kinds of users, and more detailed directions about some aspects of blind mobility when as a sighted person we guide a blind client or subject -- as the case may be.

The least that the idea of using speech may enable us to do is to sort out the different levels of commands which are required for mobility purposes. If we go back to Figure 4 for a moment, we will see that we should have no trouble at all in using speech for object detection -- whether we restrict ourselves to saying that there is an object in the desired path or go into details about describing this object. We could use speech to ensure that our subject avoided an object or that he was aware of the nature of that object. Similarly we would have little difficulty about orientation, both far and near. And it would not be hard to instruct a subject to stay in midpavement, though it might be a bit harder to ensure straight travel. And while there would be no problem about informing our subject about relatively large changes in terrain, there might be very severe problems about the smaller unevenesses of the terrain. Posture would be the most difficult and would require some additional fairly simple feedback devices, at least intermittently.

Thus, on the face of it, speech could be used quite easily for all those actions for which there is already an agreed language system such as "left-hand down a bit", "slow down", and so on. And it might well be that for quite a number of other situations one could develop additional vocabularies.

Experimentally then, the problem is to devise a simple mock-up and to study the extent to which speech can be used to guide a blind or blindfolded subject through various situations so that he performs at least as well as under any of the existing systems. This might very well provide us with a tool in our study of estimating the type and amount of information required and the rate at which it would have to be supplied for different situations. In practice I suspect that we would not be able to do this with any subjects until they would have acquired at least a modicum of pre-cane skills so that they would no longer be afraid of walking about without the use of their eyes. This could very well prove to be a more useful approach than that which I have suggested in the past, i. e. the study of the role of residual vision or of restricted vision referred to earlier on.

I hope to be able to present some evidence about the use of speech and to discuss some of the difficulties encountered during this or the next session. I suspect that once a subject had acquired full trust in his "controller" he would be able to rely on speech for all but the fine terrain structure information, for which he might still want a long cane. For it is here that the long cane comes up trumps since it speaks "body-language" as far as these small unevenesses are concerned.

I suspect that the same constraint will apply to almost all other artificial systems. For if speech is not on for one reason or another, my guess is that the next most meaningful display will be some sort of body-tactual such as that on which the group at Smith-Kettlewell are working(7). Now as I understand the philosophy of both that group and the people working on implants, it is that the information gathering system should look at the raw environment and that the information obtained should be displayed with as little processing as possible in "raw" terms". If we would just look at Figure 6 again and stick with vision substitutes rather than with implants I think I know what I would go for by way of a body-tactual display if we were to be asked to build upon the work at Smith-Kettlewell and were given the resources to do so. I would aim at having a very simple display representing the clear-path configuration no more than 10-15 feet ahead and covering not much more than two or three shoulderwidths in the up-down dimensions. On most occasions such a configuration would, in the U.K. at any rate, include a representation of the shoreline, because with us there are usually walls or fences, and this would help the user to maintain moment-to-moment orientation without the need to have relative motion between himself and the environment.

To achieve such a body-tactual display one might have to have quite a lot of processing between the information gathering device and the display, and no doubt it will be argued that this processing had best be left to the user's central nervous system. I have my doubts about that one, at least as far as the majority of potential users is concerned. But in any case I would put forward the plea that in the first instances in which the new devices are to be employed in a mobility setting, the range involved should be relatively short and the amount of detail displayed relatively little when compared with the range and detail available via vision. As far as one can tell at the moment, for most practical purposes the range provided by the long cane seems to be sufficient while the somewhat longer range of the existing sonic aid may well be too much. (It is, of course, quite possible that with a better display, and particularly with one which could mimick vision in its simultaneity, the user could benefit from more range and volume of explored space.) What I am suggesting here is that one should begin relatively simply.

Short of being able to go directly into the visual cortex, speech and body tactual displays seem to me the only really viable artificial displays for other than experimental purposes as far as the <u>bulk</u> of the blind population is concerned. I may change my mind in the light of the work now being undertaken by Dr. Armstrong of my Unit on the use of various auditory displays grafted onto the output from Sonic Aids. But everything we have seen and done so far suggests that most existing or contemplated forms of artificial display are not sufficiently compatible for mobility control; the gain for the user is not sufficient to make him want to put forward the effort required to improve the compatibility. It is worth bearing in mind that so far the only aid to mobility which does not show a sizable post-training wastage is the dog guide. Long cane/orientation training, particularly when provided without selection or on a shoestring budget, appears to have sizable wastage. It is too early to say what the situation will be like for the hand-held Sonic Aid since so far we still have to persuade the powers that be to provide appropriate training facilities. If we simply take the number of people supplied with an aid in the U. K. and with some form of training then the wastage is considerably higher than that for long cane/orientation.

I am very nearly done. Way back I said that I would restrict myself to an adult blinded person, adventitiously blinded with about average intelligence, and wanting to be self dependent in his mobility. By now you will see the reason for most of these specifications, and only the exclusion of the congenitally blinded person must be accounted for. I excluded the congenitally blinded from this argument solely on the grounds that by definition they first require to be provided with a great deal of background information about their own body and about the nature of the world around them before you can start providing them with any mobility device. This, at any rate, has been our experience so far. Certainly most of those I have met needed to know a lot, for instance, about hand-positioning before they could benefit from a cane or sonic aid; much the same applied to the use of the headmounted sonic aid. Up to this time in the U. K. the majority of the congenitally blind have relatively little generalized knowledge which would enable them to recognize common configurations described either by speech or by a spatial tactual display.

Since I have already gone out on a limb in this paper way beyond the point to which I am accustomed to doing, let me give you my view of the present position in work on blind mobility. By now, well above the horizon are solutions which are certainly expensive, equally certainly very attractive, and just a shade less certainly feasible. I refer here to more than just the concepts of vision substitute and implants. At the same time there are with us a number of existing and viable solutions, the cost-effectiveness of which it is not impossible to assess. By now, most blind users and those providing services for them will want to know about the cost-effectiveness of any interim solutions which might be proposed. They will want to know the cost in terms of money, time, and effort in relation to demonstrable or likely gains.

Perhaps one might have a try at conceptualizing this a little bit better. In Figure 7 I have a shot at this by showing a three-dimensional coordinate system with effort, gain, and risk as the three axes. (Note that this is as close as I propose to get to the problems of acceptability which were discussed in other sessions.) Effort might be measured in terms of actual cost, training time, ease of handling, etc. Gain might be expressed in terms of the extent, quality, and ease of traveling as discussed earlier on; risk in terms of likelihood of incurring accidents above a stated severity or part of body left unprotected. Obviously one wants to try to minimize on effort and risk, and maximize on gain. What I have been saying in the last two paragraphs can now be restated. Existing methods enable quite reasonable gains to be attained at evidently acceptable levels of risk, but at quite considerable effort. I doubt whether users on the whole would be prepared to accept an increase along the effort dimension unless there could be very significant increases along the gain dimension.

Note also that this kind of scheme may help one to categorize individual users; for each one can in theory be located somewhere within that effort-gain-risk cube, and quite obviously they will not all be in the same location. For instance, some users appear to be much less worried about falling off a curb than about injuring their heads, while others are prepared to put in considerable effort in order to achieve the gain provided by a dog guide. As a result of a systematic comparison of different mobility aids, we in this Unit are beginning to build up an interesting collection of materials on this topic.

As far as the work of my own Unit is concerned, we shall continue to put most of our effort towards improving the cost-effectiveness of existing methods -- and that obviously includes measuring costs and gains. We will also try to do some denting of the frontiers, but we shall try to do so in a small-step, realistic kind of way. To those who have the material and financial resources to go for the most exciting solutions, we wish luck and success in their work, and hope that they will progress at such a rate that our own type of work will become unnecessary.

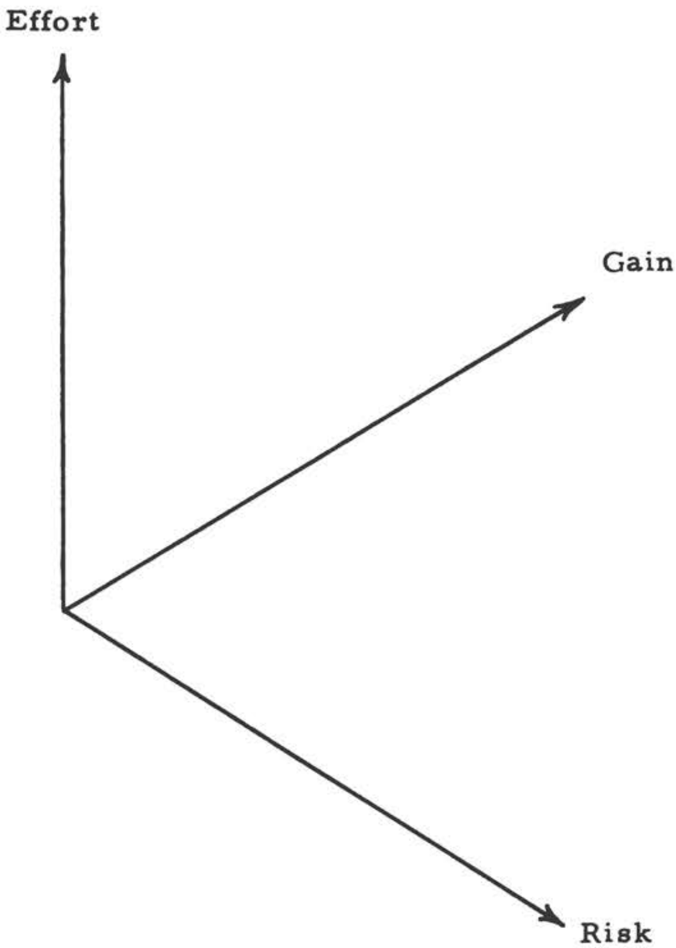


FIGURE 7

A Coordinate System for Mobility Aid Evaluation

Let me sum up. I started by dealing with the properties of our potential user population and its needs. From there I went on to show the extent to which existing methods of aiding mobility are able to meet these needs. This led to an examination of the role of vision in sighted mobility and the presentation of the information flow for sighted and aided mobility. I then sought to develop the concept of minimal information required for mobility and the means available to display that information to the user. This led to a discussion of the concept of compatibility between displays and controls. I went on to suggest the use of speech and body-tactual displays as being the only viable artificial displays and spoke briefly about the cost-effectiveness of existing and suggested methods of aiding mobility.

Let me end by restating the concept of "minimal information" with a caution; it is just possible that the difference between visual achievements in mobility and non-visual ones may come down to having just a little more than minimal information. It could be that sighted mobility is as good as it is because there would appear to be an awful lot of redundancy.

Postscript

Since writing this I have had a quick chance to try out the sonic glasses and Dr. Armstrong and I have visited both Smith-Kettlewell and Stanford Research Institute. The only substantial change I would want to make to what I said earlier on in this paper is to include Jim Bliss' types of displays in my comments on the need to display the "clear-path" configuration to the traveler.

Also as an addition to the discussion on simulation, I have one other comment which arose from our visits made after the conference. This is that whatever reservations one may have about full-blown simulation of the whole mobility situation, I am quite certain that one can make out a very good case for simulation in a more limited sense in connection with this work. I was greatly impressed with the potential of the body-tactual display which I was allowed to try out at Smith-Kettlewell. I am much less convinced that the presently used information-gathering system (i. e. a camera) is the appropriate one for mobility purposes. It would be most useful to be able to simulate a range of information gathering and processing stages with a range of body-tactual displays. This is clearly an area in which simulation could be by far the most cost-effective procedure to employ.

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A SIMULATION APPROACH TO THE DEVELOPMENT OF MOBILITY AIDS FOR THE BLIND

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A Statement of the Problem

The development of mobility sensory aids for the blind has been dominated by gadgets. The usual point of departure has been a specific device for probing the environment and presenting signals to the user. The choice of what information to obtain and how to present it to the user has been circumscribed by the peculiarities of each device to the exclusion of systematic experimental investigation of the optimum kind and amount of information required by the blind traveler and the optimum use of his remaining senses to perceive it.

It now appears feasible to conduct more general and systematic investigations of the usefulness of various types of real or potential guidance devices by means of computer simulation without actually constructing all of the components of each device to be studied. Those parameters of each device that concern the acquisition of information about the environment may be either simulated or embodied in real hardware. The processing of this information into a form suitable for perceptual display to the blind traveler may be performed entirely by computer simulation. Only those parameters of the output transducers that limit the kind and range of stimuli available would then require the iterative redesign of physically real hardware of practical weight and size that has made the specific-device approach so expensive in both time and money.

Mobility is the capacity to move quickly and conveniently through the environment without: (1) colliding with obstacles, (2) falling down, or (3) getting lost. The first requires the detection and localization of obstacles, and the second the detection and localization of discontinuities in the terrain about to come underfoot. A device that serves these first two functions distinguishes open paths of travel from blocked paths, but it does not distinguish the desired path of travel from other open paths. The ability to navigate requires the recognition of landmarks and implies at least a rudimentary perception of the environment.

The detection, localization and, if possible, the recognition of objects at a distance is the basic requirement for full mobility. The detection of an object at a distance requires that we sense its effect upon a field of radiation, either electromagnetic or acoustic. Vision relies upon the transform that the presence of an object imposes upon a narrow band in the ambient electromagnetic field. So-called "facial vision," which has been shown to depend primarily on unconscious echo location, makes similar use of the audible part of the ambient acoustic field. The addition of an active source of acoustic or electromagnetic illumination has the advantages of a searchlight. It can be directed and modulated under the control of the user to actively explore the environment and test for distinctions among the objects in it.

A taxonomy of the operation of a sensory aid to mobility is shown in Figure 1. As the blind traveler moves through the environment he carries out search strategies under his own control, such as scanning the space ahead of him, which may be supplemented by modulation of the illuminating signal under the automatic control of the input processor, such as automatic gain control. The display he receives contains information about the path ahead in a form determined by his control actions, especially reafference [1] from his own body motions, and by the strategy of information encodement in the program of the input processor. The blind traveler also receives reafference through unaided sensory pathways. The process of learning to use such a device depends upon experiencing sufficient opportunities to observe correlations between the output of the device and the unaided sensory inputs.

An Approach By Computer Simulation

A system for simulating various types of real or hypothetical devices for detecting, localizing and perhaps

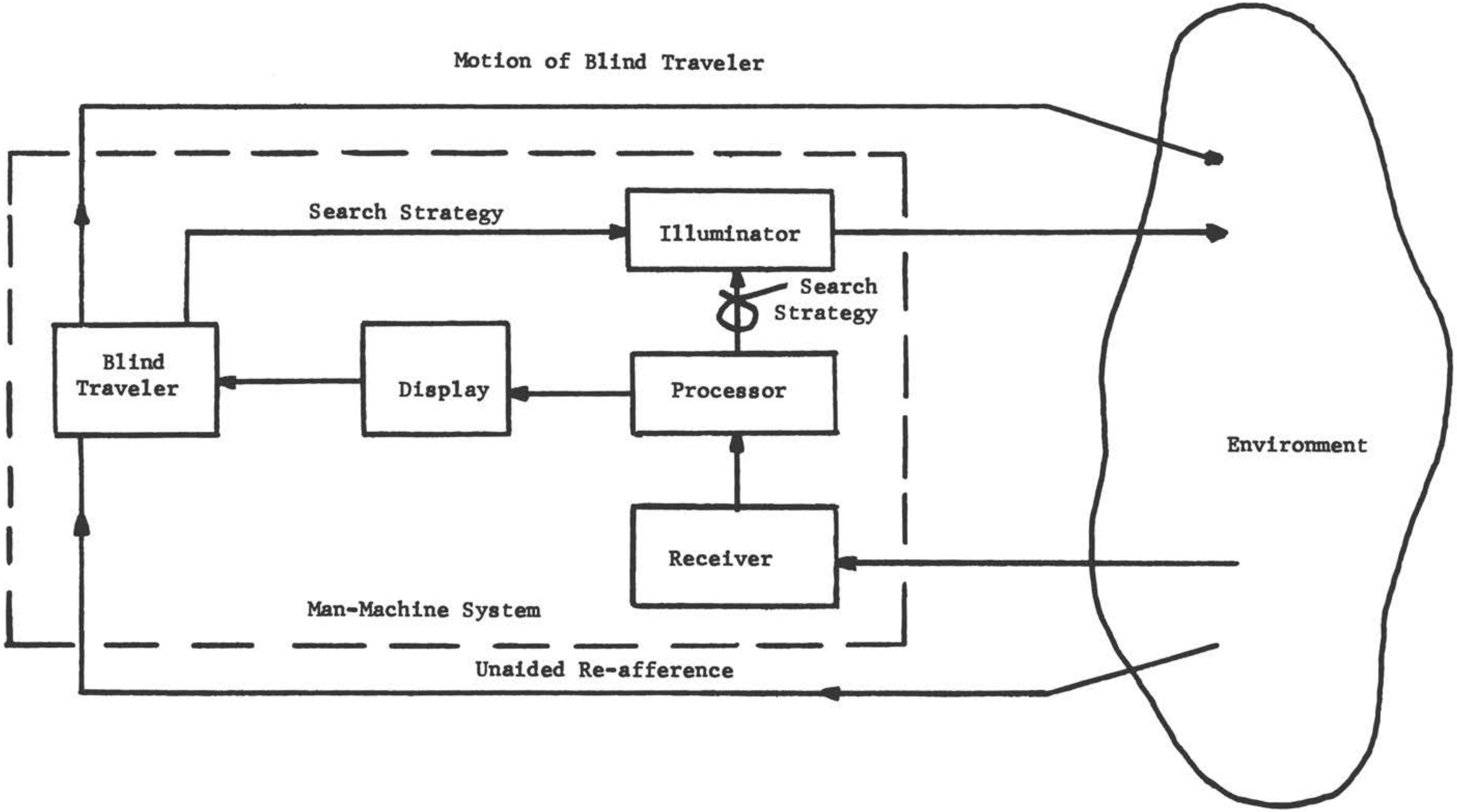

FIGURE 1

Taxonomy of Blind Mobility Aids

recognizing objects at a distance with a minimum of hardware that is peculiar to each device can be considered in three parts:

(1) the emission, reflection and detection of electromagnetic or acoustic radiation by means of real or simulated signals and environments;

(2) tracking the position and orientation of the blind traveler through a real or mockup environment;

(3) re-coding the detected field of radiation into a form suitable for perceptual display as a real-time function of the position and orientation of the blind traveler, and also of his control actions upon the (simulated) guidance device, i. e. his search strategy.

Representing the environment. The first part of the problem is clarified by recognizing that the distant environment (i. e. out of reach of hand, foot or cane) is operationally indistinguishable from the transformation it performs upon the incident radiation. Techniques for making, processing and storing such representations of environments have been studied extensively in holography, radar and sonar, but very little in relation to mobility aids. The representation of the environment may be approached in two ways.

(1) By means of records (such as ultrasonic or microwave holograms) of real environments made and stored in advance to be accessed as required by the motions of a blind traveler through the same environment (or a mockup of it) in order to generate the perceptual displays he would receive if he were using the simulated guidance device in the stored environment. A taxonomy of such a simulation is shown in Figure 2.

(2) By means of signals emitted by real illuminator(s) and detected by real sensors actually carried by the blind traveler through a real environment and processed in real time in order to generate the perceptual displays that he would receive from the simulated guidance device. Since only the processor is simulated, the taxonomy of this simulation is the same as shown in Figure 1.

The advantage of the stored representation of the environment is its independence of real hardware carried by the

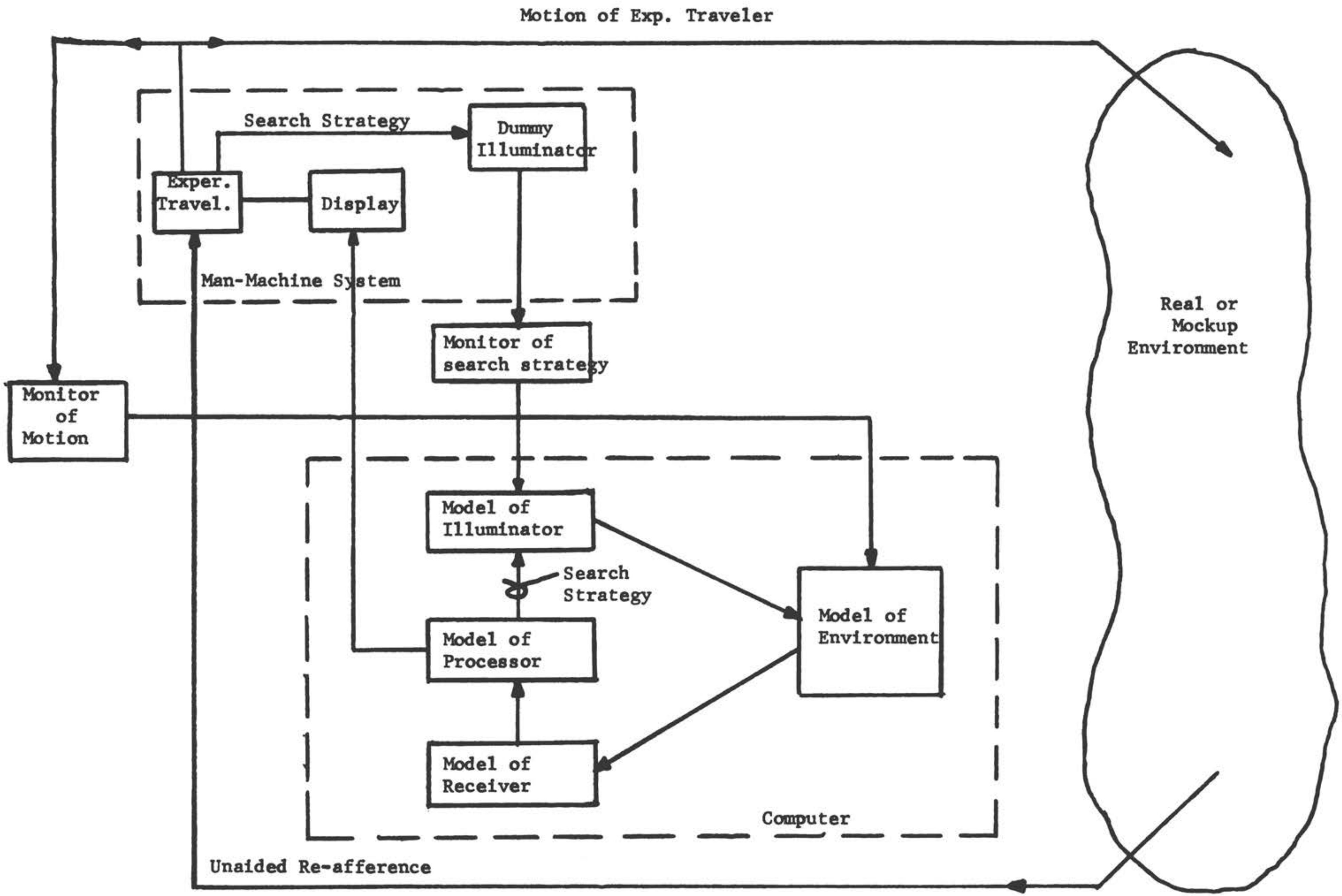

FIGURE 2

Taxonomy of Blind Mobility Simulation

blind traveler during the simulation. The disadvantage of the stored representation is the large amount of information that must be held in rapidly accessible form. The difficulty of representing environments that include moving objects would be particularly formidable.

The advantage of the real environment approach is that mobility experiments could be carried out in any convenient environment with much less elaborate prior analysis of its structure. The principal disadvantage of using real environments is that all of the hardware (except the processor) associated with each mobility device to be investigated must be fabricated in a sufficiently realistic form to be carried by the blind traveler. The real environment approach also requires that all of the information processing be performed in real time, including the acquisition and any initial transformations upon the input. The rate at which signals coming into the simulator need be processed depends upon the velocity of the radiation; however, the rate at which the corresponding output signals need be generated depends upon the velocity of the blind traveler.

Tracking the blind traveler. Techniques for tracking the position and orientation of a blind traveler and representing these in forms suitable for computer input in real time have been partially developed by Mills (ultrasonic)[2], Stoutmeyer (electromagnetic)[3] and Rinsky (inertial)[4].

The ultrasonic system is based on acoustic ranging by means of three loudspeakers fixed to the ceiling of the experimental space and three microphones mounted on the head of a freely moving subject (Figure 3). It tracks the position and orientation of the head in all six degrees of freedom with high resolution ($\pm$ 1/2 mm) at a sampling rate that depends upon the speed of the general purpose computer used to perform the trigonometric calculations upon the raw input (e.g. 50 or more fixes per second). This system was designed to study the effects of sensory feedback from self-motion upon auditory localization and echo location. Its suitability for studies of blind mobility is limited by its requirement for an ultrasonically dead space and by potential interference with the use of real ultrasonic guidance devices.

The electromagnetic system developed by Stoutmeyer employs an optical tracking system that measures the

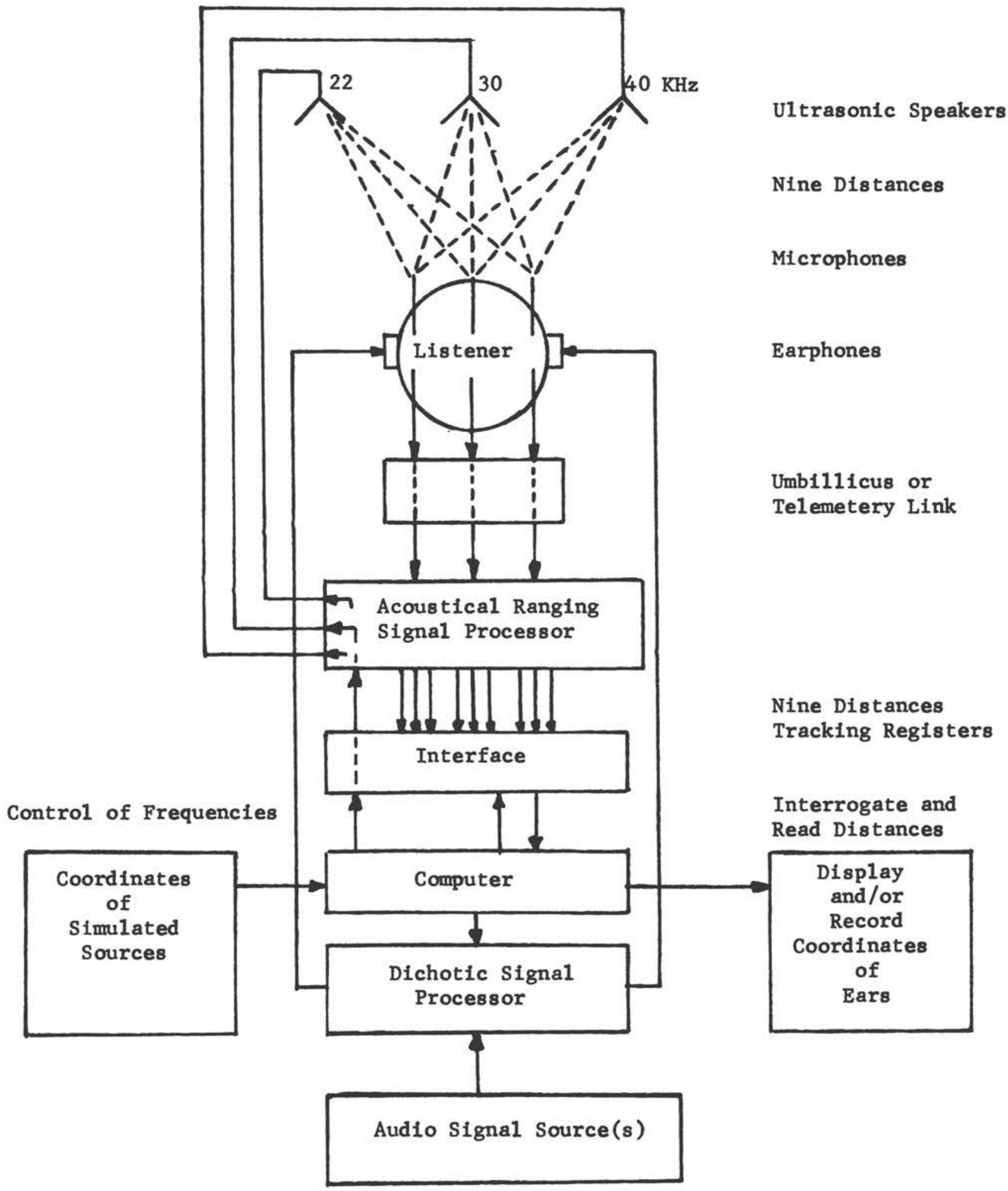

FIGURE 3

General Pseudophone

position of a light attached to the subject at the point of interest. A pair of star trackers mounted on military surplus stabilized platforms provide signals to the platform which in turn keep the tracker aligned on the light. Resolvers on the platform axes feed angular information into the computer where simple trigonometric calculations generate the x, y, and z coordinates of the path of the target point of interest. Discrimination among several targets on the man or device could be accomplished by using different spectral emissions and appropriate filtering, or by means of polarization techniques. With two such trackers on poles of reasonable height, the path of a subject could be observed over a football field area. A third tracker would provide a redundancy check and insure against tracking loss due to temporary obscuration of the target.

The third alternative, a subject-born inertial guidance system, is attractive for its general applicability without requiring a specially instrumented experimental space, but considerations of its probable weight and cost have deterred actual development. Limited studies have been conducted on a one-degree-of-freedom system by Rinsky at M.I.T.

If the experimental blind traveler used a real source of acoustic or electromagnetic radiation for probing the environment, these signals could also be used to track his position in an environment which was previously provided with sensors located along the anticipated paths of travel.

Perceptual Displays

Relevant Information. How much and what kind of information about the environment is necessary for independent mobility? A knowledge of the relative importance to mobility of such parameters as aperture, range and resolution and how these parameters vary from one kind of environment to another (e.g. indoor-outdoor) is a prerequisite to a systematic consideration of how best to employ the blind traveler's remaining senses. Our present understanding of the question above is confounded by our ignorance of the non-visual perception of space. We are now little able to distinguish which limitations of a guidance device may be due to inappropriate selection of information and which may be due to inappropriate perceptual display. (Mr. Leon Harmon later suggested that an investigation of the mobility of sighted persons while using visual inputs artificially degraded in such respects as aperture, range and resolution might be a fruitful way to escape this double bind (see 7.05).)

Appropriate sensory modality. Touch and hearing are the obvious modalities for presenting spatial information. Although the possibility of making some use of the other senses ought not to be rejected out of hand, neither smell nor taste seem well suited to generate spatial percepts. The traveler's proprioceptors are presumably preempted by their essential functions in motor coordination.

The ears provide a conveniently accessible and relatively wide-band pair of channels between simple transducers and the brain. The bandwidth of any one point on the skin is very much less than that of an ear, but if we consider the whole surface as a potential receptor the bandwidth is not so small. The practical difficulty is that there are no one or two places to plug into the whole skin. The recent development of improved mechanical and electrical stimulators has encouraged a surge of investigations of pattern perception by the skin by means of arrays of stimulators[5, 6].

An object at a distance is "out there" in the world and the blind traveler should ideally experience it as an object "out there" and not as an event in the hardware that he is using, in his head or upon his skin. Sounds are perceived as originating from locations in three dimensions, provided that the sources are not coupled to the motions of the head as in wearing earphones. When earphones are worn the sound is usually heard inside the head unless a system has been arranged to modify the earphone signals appropriately according to the listener's own head movements[7, 8]. The perception of the azimuth of a stationary source is fairly accurate, at best to within a degree. The perception of elevation and range is usually considered to be very poor, but they have not been examined under the conditions of listener movement that would provide the best information on elevation and range.

Under some conditions unaided echo location produces the perception of objects in the environment. Twenty years ago Dallenbach and his associates showed that the "facial vision" of the blind is based primarily upon the echo location of ambient sounds. On blindly approaching a large obstacle, the subjective experience is one of imminent collision with something in front of the face. The blind traveler may be subjectively unaware of the increase in the pitch of the ambient noise caused by interference patterns between the incident and reflected sounds, which is the physical basis of the effect (9). Facial vision works well only for large surfaces at ranges of less than a few meters. With reflectors at longer ranges, ten meters or more, short impulsive sounds produce echoes that can be heard as separate sounds. With practice a listener comes to perceive the reflector directly without having to attend consciously to the echo (2). At an intermediate range a listener can detect and locate reflectors with linear dimensions as large as the shortest wavelengths of the sounds he emits (10) but the subjective experience of a real object in the environment is not as clear. The precedence effect obscures echoes from nearby reflectors by the preemption (for several milliseconds) of the apparent direction of a source of sound by the direction from which it reaches the ears first (11). A blind traveler using an audible "clicker" attributes the echoes from nearby reflectors to the clicker instead of to the environment. An artificial echo locating system using ultrasound could circumvent this result of the precedence effect by gating the receivers off while the source is on.

Skin percepts may also be three dimensional, if active exploration is allowed, but the naturally occurring skin percepts are of the shape of proximal objects and not of the location of distant ones. The extent to which a blind traveler might be trained to attribute distal perceptual properties to stimulation of the skin need to be explored. The transformations that self-motion perform upon a two-dimensional display of a three-dimensional array are rich in information about the missing dimension (12). The importance of motion parallax to the visual perception of distance is well known, but much less attention has been given to similar effects in other senses.

A serious objection to the use of an auditory display is interference with the blind traveler's normal use of the ambient acoustical field to locate active sources of sound and large reflectors or apertures (facial vision). It is not necessary to occlude the ears as with ordinary earphones. Insert earphones can be ported to admit ambient sound, as Kay has done, with only minor loss at the higher frequencies. The masking of ambient sounds by artificial display signals remains a potential problem. If the guidance device were better than facial vision, the blind traveler could give that up, but he cannot well give up his ability to hear speech, and certainly not his ability to hear an oncoming truck. This objection does not eliminate the use of acoustical displays, but it does limit the dynamic range and available bandwidth. Masking is asymmetrical. Low frequencies mask high much more than high mask low. Limiting the artificial display signals to the higher frequencies would alleviate the masking problem, but it also would eliminate many aged blind who often have high-frequency hearing losses.

A tactile display would interfere with other essential sensory functions less, and also be useful to the deaf-blind. Some areas, such as the tongue, lips and fingers, which have the greatest sensitivity, may be already busy or inaccessible, but large areas of skin are left which perform no essential function during travel.

Strategies of encodement. This question concerns not only the resolving power of the sense organ selected, but also the organization of the central processing of neural signals from it. For instance, speech presented visually in the amplitude-time domain (as on an oscilloscope) is visible, but totally unintelligible. If speech is presented in the frequency-time domain ("visible speech"), an observer can learn to read it. In the other sensory modalities there are surely good matches to be exploited and mismatches to be avoided which have not yet been identified. For instance, should "where" information always be presented in a code which produces a "where" percept and "what" information in a code that produces a "what" percept? Some existing guidance devices use qualitative differences in an acoustical signal to represent differences in the range of an object (e.g., pitch to represent distance). Is this a good strategy, or would it be more effective to transform the signal so that objects at different distances are perceived as spatially different?

Perceptual-motor learning. If a guidance device is to be really successful, its use should become with practice as easy and unconscious as, say, riding a bicycle. Numerous experiments with prisms, lenses or pseudophones that rearrange the geometry of visual or auditory reception have shown that humans can adapt rapidly and accurately to novel transformations upon sensory location[1, 13]. The critical factor in establishing new perceptual-motor coordinations is the manifestation of a new set of invariant relations between self-produced motions of the subject and the sensory feedback created by those motions. One important implication of these experiments on sensory rearrangement for the design of perceptual displays and for training in their use is the importance of active motor exploration of the environment in order for perceptual learning to occur. The ability to adapt to more fundamental changes in the kind of stimulation (e.g. substituting audition or taction for vision) has not been much explored, but must also depend upon the opportunity for motor actions and sensory feedback in which the invariant relations between motion and the environment are manifest in the display.

Conclusion

The representation of the environment and the tracking of the subject require only the ingenious application of existing technology based on theoretical formulations already well defined in physics and information processing. The identification of the information necessary to independent blind mobility and the encodement of that information in forms well suited to non-visual perceptual displays require an understanding of the nature of man's non-visual perception, decision making and motor response that is beyond the current state of the art in sensory physiology and psychology. Largely untried yet are the experimental investigations prerequisite to formulating, testing and reformulating theoretical models of these processes in sufficient detail to provide adequate prescriptions for the parameters of blind mobility aids. The justification for the substantial investment that would be required to implement the kind of simulation described above lies not primarily in the possibility of inventing a specific new and better kind of blind mobility gadget, but in more clearly defining the realm of possible ways of adequately perceiving and responding to the environment without vision.

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MOBILITY AIDS FOR THE BLIND-AN ARGUMENT FOR A COMPUTER-BASED, MAN-DEVICE- ENVIRONMENT, INTERACTIVE, SIMULATION SYSTEM

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Introduction

I find it challenging to enter an arena in which the ox already has been gored. The opinions, if not prejudices, of some of the participants vis-a-vis simulation and computers are evident. Nevertheless I would like to try to make a case for the role that simulation -- I want to make it very clear that I mean man-interactive simulation -- can play in the whole arena of the mobility of the blind. I am not concerned only with the evaluation of existing mobility devices but I include them. I am not speaking expressly to the role of simulation in determining the specifications of proposed mobility devices but I include that. I am not speaking uniquely about the general study of human mobility but I include that with all of its interrelated questions of sensory input, behavioral and motor response, kinesthesis, etc. In other words I shall consider mobility overall and make an argument (responsive I hope to some of the criticisms already made) for the utility and feasibility of computer-based mobility simulation.

At the outset let me make it clear that I describe research. I do not say that I know precisely what can be done or that I know it can be done with a certain guarantee of output, or that this approach offers a certain cost-benefit advantage. But I have reason to believe, on the basis of both my own experience which I will describe, and the experience of others employing man-interaction simulation as in the aircraft industry that man-interactive simulation enhances understanding and leads to better solutions to problems.

Since this is a conference stressing the evaluation of mobility devices, I would like to cite Lord Kelvin: [1]

> "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thought, advanced to the stage of science."

In two days of conference I have heard precious little reference to evaluation being measured in Lord Kelvin's terms, that is to say objectively, quantitatively and statistically.

The evaluation schemes reported thus far range from simple customer acceptance -- go, no-go -- whatever the users' reasons, to approaches where human observers make subjective assessments of the performance of blind travelers. While the first approach must be the ultimate measure of any product, as an evaluation measure it offers no means of sorting out technical assets and liabilities from personal likes and prejudices. The preclusion of any scale of performance eliminates data on the change, over time, of the mobility of any one traveler and prevents comparisons between travelers of differing inherent abilities pursuing routes of varying difficulty. The observer assessment approach generates qualitative, subjective judgments which are frequently "quantified" by the assignment of numbers, thereby providing an aura of precision which Lord Kelvin would find unjustified.

By comparison if the computer can be made the observer and bookkeeper of the mobility scene, data must necessarily be quantified (since the computer deals only with numbers) and the objectivity of the processor and reporter can raise no question.

Equally important, all of the schemes proposed at this conference so far assume the existence, in reasonable quantity, of functional, reliable, mobility aids of a particular type. Thus evaluation of the man-device-environment system is not undertaken until the completion of the research and development phases of the particular device. Because of the cost and time span involved, precious few alternative mobility devices are brought under scrutiny.

Let me illustrate this by drawing a comparison between the classification of all known mobility device studies placed on the board yesterday by Leon Harmon (see p. 136) and the particular devices under scrutiny during this conference. A 3 x 3 matrix will suffice. Define one coordinate as the human body reference for the mobility device and the other the "complexity" of its display. Call the simplest display "go -- no-go." Call the most elaborate display "environmental sensing." In between, define a display of "intermediate" complexity. On the reference coordinate, insert head, hand, and body.

If we now enter into this matrix the devices discussed at this meeting, Lindsay Russell's Pathsounder will occupy the body-mounted, go, no-go cell. Leslie Kay's Sonic Glasses are head mounted and present a rich environmental display. Mal Benjamin's Laser Cane is hand-held; its tactual and audio on or off outputs constitute a display intermediate between the simplest and the most complex. Now note that the six empty cells in the array suggest potential mobility devices which might have some merit, yet we have no opportunity to assess their utility.

Leon Harmon's diagram (see p. 136) introduced the categories of passive and active devices each with many subsets, totalling perhaps 15 or 20 combinations. If you wish to explore the feasibility of any of these devices (or perhaps some concepts still yet unexplored), the matrix must be expanded to include several more dimensions.

Because they depend upon working hardware, traditional evaluation schemes discussed thus far automatically rule out consideration of potentially beneficial alternate choices. How much more attractive would be an evaluation scheme which permitted one to ascertain the utility of potential systems without assuming the burden and time for their physical realization.

The generalized mobility device consists of: (1) a detector -- which explores the physical space before the traveler using appropriate forms of electromagnetic or sonic irradiation in any one of a large number of possible combinations of search strategies, (2) the processor -- which transforms the information gleaned from the physical world into the forms appropriate for driving the final element, and (3) the psychophysical display -- the physical interface with the human by which information is imparted through the surrogate sensory modality or modalities.

Of these three elements, detector, processor and display, the most difficult and ambiguous problems are posed by questions of how to process and how to display the information to the human. Alfred Leonard earlier in this conference used the term "compatible display." I personally prefer "congenial" display.

Even with his sensory loss, we deal with most of the human being. We therefore deal with a "computer" which has benefitted from millions of years of evolution and which is uniquely qualified congenitally to deal with the environmental circumstances which confront human beings. A "congenial" display interfaces with the human so as to maximize the transfer and utilization of detected information from the environment through the device to the human being.

But with the cornucopia of opportunities represented by alternative detection, processing and display possibilities suggested above, the greatest limitation and liability of traditional evaluation approaches is their lack of flexibility.

On a particular project the original notion must be pursued with narrow commitment. In fact practical engineering considerations frequently result in further restriction of the seminal idea. The project's investment in the particular concept grows; what begins as restricted flexibility can become defensive rigidity.

With respect to competitive approaches, the long time span and substantial investment involved in engineering research, prototype development and small scale manufacture are so expensive that very few significantly different original concepts are explored by different investigators who then become enamored (if not obsessed) with their own particular approaches.

This inability to concurrently consider alternative approaches and variations thereupon imposes an incalculable creative loss. The innovative process [(2)] is basically dynamic conceptualization and evaluation, and then concatenation of progressive ideas with minimum inhibition, exploring a wide range of alternative approaches to a problem. In the traditional mode of mobility aid development even serendipity suffers; the commitment to one approach and the long development and manufacture period before the moment of truth militates against and obscures those fortuitous interplays which yield insights.

Man-Interactive Simulation

The notion of a man-interactive simulation system to study the mobility of the blind in my experience (3) had its origins at M. I. T. in the early 1960's in the discussions between the late John K. Dupress and Samuel J. Mason of the Research Laboratory of Electronics and Professor Thomas B. Sheridan and myself of the Mechanical Engineering group.

At the same time I was also involved in research and development on artificial limbs for amputees. In our search for a "congenial" interface between the amputee and his prosthesis we developed the hypothesis that the very best approach would employ the residual human neuromuscular system (4) as the source of control signals for the prosthetic joint. By using bioelectricity associated with contraction of muscles which prior to amputation serviced the now ablated joint, the amputee would very quickly and naturally achieve control over the artificial appendage. We chose the particular problem of the above-elbow amputee, both on its own merits as a practical need and because of the relatively simple anatomy of the upper arm, one bone and the two muscles, the bicep flexor and the tricep relaxor. The design concept employed electromyographic potentials detected by skin electrodes over the remnant but disfunctional upper arm muscles to control a servo flexing the elbow joint.

If we had followed what appears to be routine procedure in mobility devices for the blind, we would have built such an arm and then evaluated it. However, we felt then as now that to commit ourselves to hardware at the outset would foreclose some alternatives and narrow others. Many questions loomed ahead. What quality of bioelectric information would we get from such remnant muscles? How should these signals be processed? How would we use the EMG signal to control the servo? What would be the consequence of different static and dynamic feedforward and feedback characteristics of the artificial limb?

To help resolve these questions and to permit us to explore many alternatives in the search for an optimal approach, a man-interaction simulation system was devised, (5) illustrated in Figure 1. Surface electrodes on the investigator (or amputee)

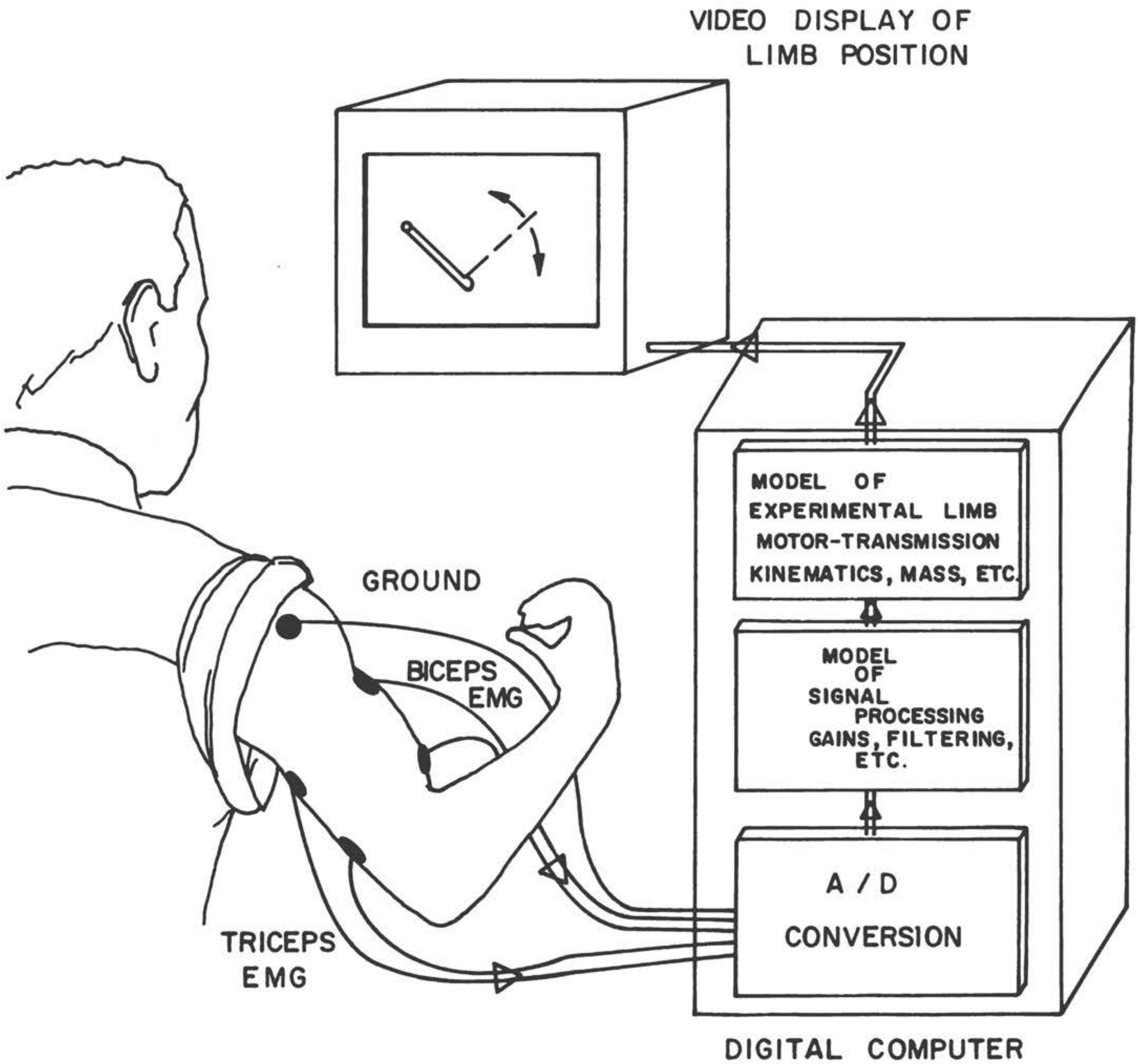

FIGURE 1

Simulation of a Forearm Prosthesis

delivered EMG signals from the bicep and tricep muscles through analog to digital conversion to a small digital computer. Programs of a very flexible nature in the computer modeled the signal processing of the EMG -- rectification, filtering, summing, etc. The output of this signal processing program in turn drove a model of the electromagnetic and mechanical characteristics of a potential limb-motor torque speed characteristics, mechanical transmission, mass, center of gravity, etc. The output of the limb simulation model in turn drove a television-like display visible to the investigator of a stick figure representing the forearm and upper arm.

This man to computer to video display system operated on the same time scale as a normal limb. Thus the investigator could flex his muscles and virtually simultaneously observe the resulting flexure of the simulated limb on the TV screen. To achieve changes in response, or to explore the consequences of alterations in the signal processing of limb characteristics, the investigator only had to change the values of parameters in the computer program or the programs themselves. Most of the important parameters were accessible to the investigator through a teletypewriter keyboard attached to the computer. Experience with the simulator established the specifications for the electronic signal processing of the electromyographic signal and for the elbow joint.

This particular investigation has almost gone full circle. The very first limb (6) actually built could be controlled quite satisfactorily by amputees. A number of a refined version have now been manufactured and are in use by amputees, in some cases for periods of several years (7).

Another example of a man-interactive simulation study is directed towards the feasibility of bioelectric control of the lower extremity (8) as illustrated in Figure 2. The amputee wears a simulated prosthesis and a hydraulic cylinder which imposes a torque about the knee, controlled by a servo valve through umbilical lines and an overhead trolley. The servo valve is in turn operated by an analog computer which receives EMG and other control information from the human. We plan to use the system to study the feasibility of adaptive knee prostheses controlled by electromyographic signals, including such dynamic and reflexive responses as stumble control. As in the case of the elbow

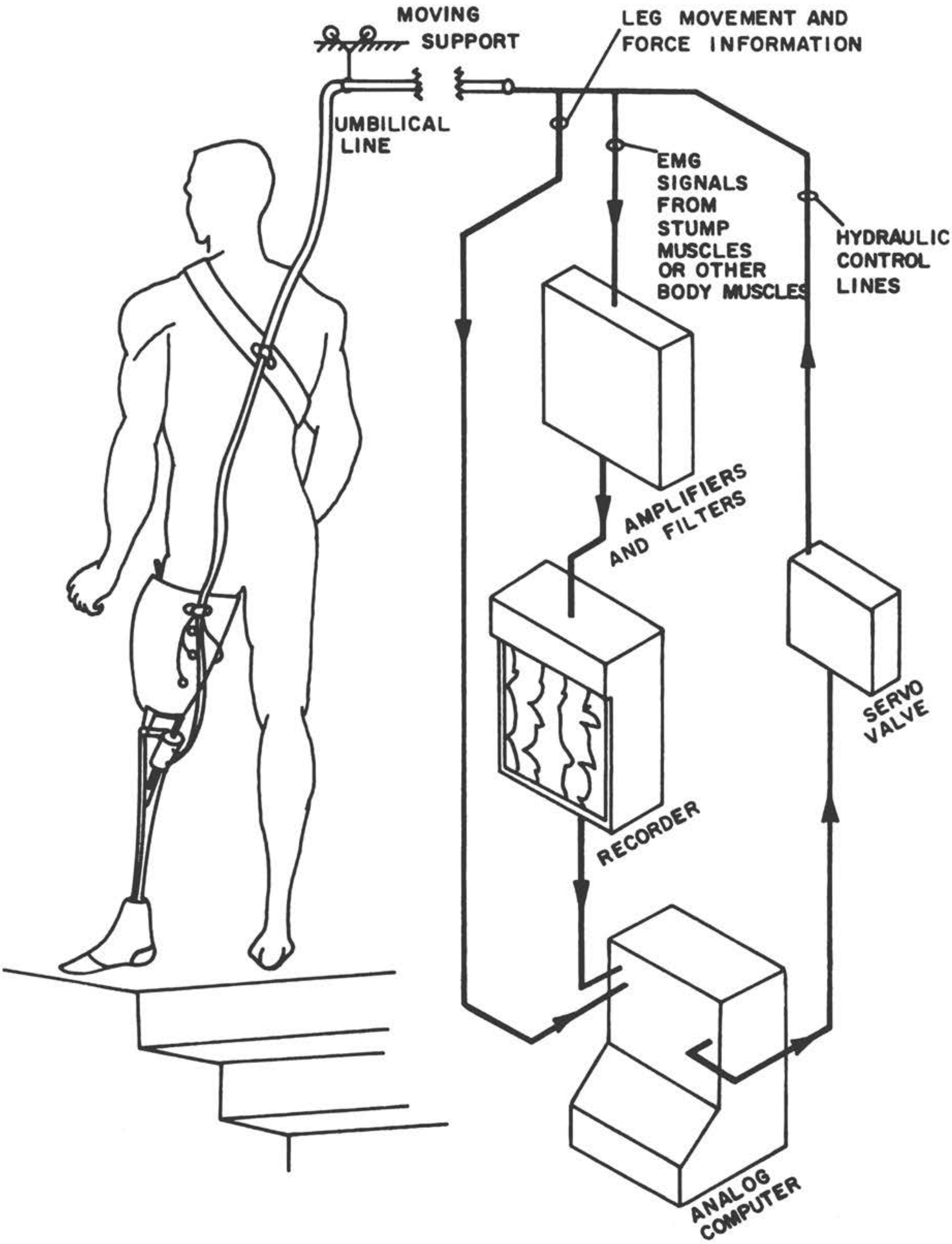

FIGURE 2

Adaptive Knee Prosth :sis Study Using an Analog Computer prosthesis, the modelling of knee prostheses' characteristics on the analog computer will provide guides for the specification and subsequent fabrication of physical hardware. We also believe that the simulation system may prove a useful diagnostic tool for the orthopedic surgeon. The ease and flexibility with which prostheses' characteristics can be altered should permit him to more rapidly and comprehensively diagnose alternative prosthetic designs and prescribe the optimum for each particular patient.

Mobility Environmental Simulation

Let me now try to transfer these experiences with man-interactive simulation of the upper and lower extremities to the feasibility of a man-interactive environment in which to study the mobility of the blind. I recognize that the blind human mobility problem is tougher than either of the precursors. Explicitly we know little about how sighted humans are mobile and how they use vision and other cues; thus our even greater ignorance of how blinded men are, or can be, mobile through the utilization of their substitute sensory modalities. Even so we see a blind mobility simulator as a logical (though substantial) step beyond the elbow simulator, which involved no mobility on the part of the patient, and the knee simulator, which involves perambulation.

Figure 3 depicts a mobile blinded human with a real mobility device in a real travel situation in comparison with the physical arrangements and computer surveillance, processing and telemetry system of a mobility environmental simulator, Figure 4.

Note that for the simulator the travel arena must be a real, physical space. Our ignorance of the complex and subtle cues produced in, and modulated by, the ambient environment makes this mandatory. However we do not need a physical mobility device; the detector and processor functions can be represented as appropriate computer programs in a moderate-sized digital computer. As the human moves through the physical space replete with obstacles and landmarks which provide the unaided reafferance he normally perceives, he is under surveillance by a monitoring system feeding the computer which generates continuous or sampled information on the trajectories and orientations of pertinent parts of his body. The illuminator simulating program in the computer projects before the man's location a hypothetical active volume of potential radiation from the presumed

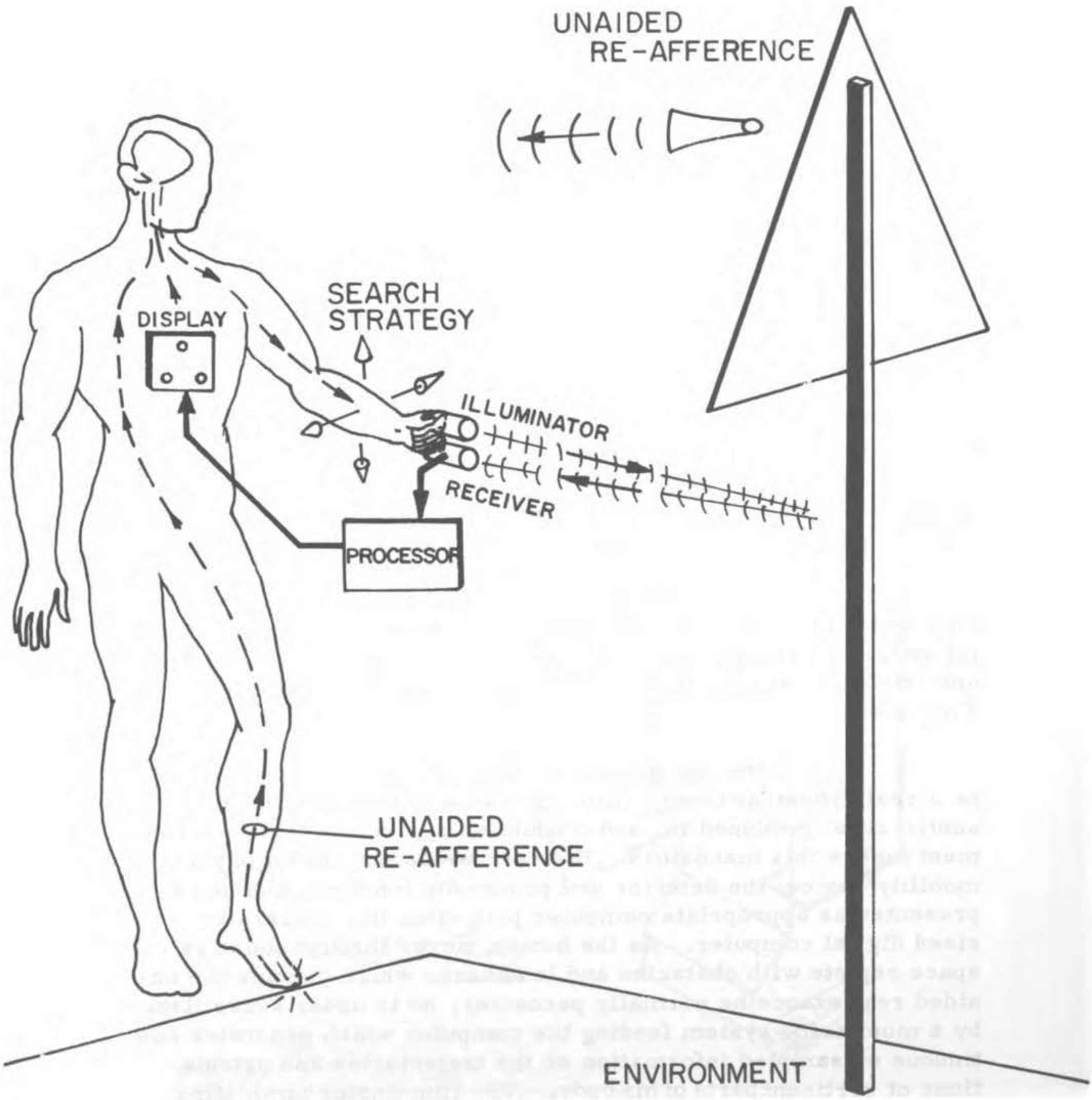

FIGURE 3

A Blind Man in a Travel Situation

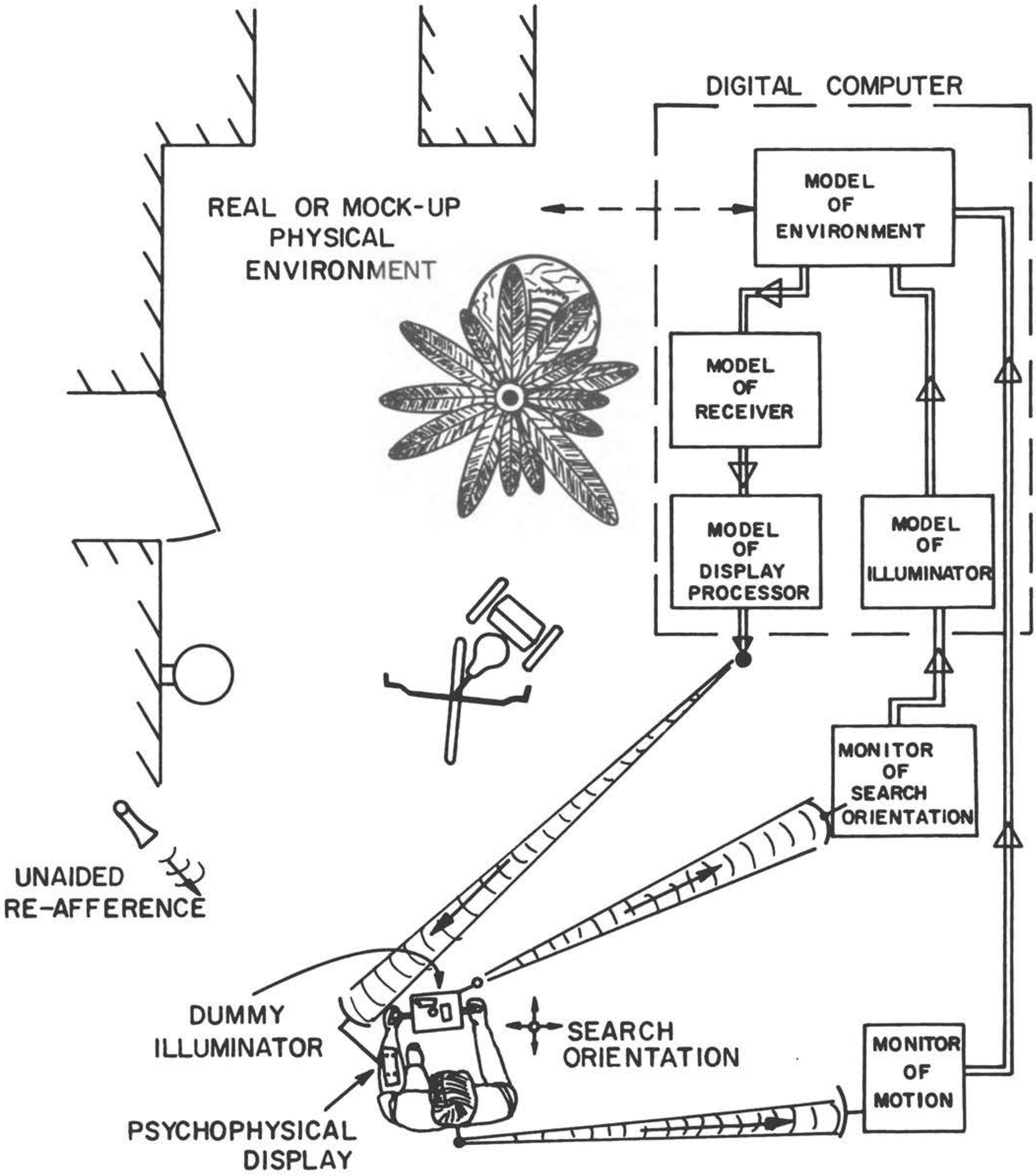

FIGURE 4

A Mobility Environmental Simulator

mobility device. The computer contains a representation (appropriately coded to minimize computer storage and access time) of the features of the real space which are salient to the mobility device's detection capability.

When the physical location of the man (as represented by his trajectory position and orientation in the computer), coupled with the modeled search characteristics of the device, intersects computer memory of obstacles or landmarks, the computer registers this occurrence. The detection is then processed in the computer by a program which models alternative ways of modulating the psychophysical display. The display, the only physical artifact carried by the man is appropriately energized by telemetry from the computer and man responds to his presumed detection of the obstacle. The psychophysical display, the only hardware fabricated for any particular mobility device study, could range from very simple go, no-go to complex multi-modality, time-modulated arrangements.

As in the limb prosthesis simulations, since the illuminator, receiver and display processor are computer programs, their overall configuration and/or parameters could be changed with great flexibility and convenience, incurring none of the cost and/or time lag associated with the physical realization of similar capabilities in practical working hardware. All of the earlier arguments on the virtues of such flexibility and of their contribution to innovation and even serendipity become pertinent. When the manipulation of all of the variables produces a hypothetical device of satisfactory performance, the specifications for the device are encapsulated in the topology and parametric values of the computer programs.

Since the entire process is marshalled by the computer, all of the data is available in quantitative and then, if desirable, in statistical form. Questions such as when did the man first show evidence of obstacle perception through change of forward velocity of path deflection, or how close to an obstacle did he approach before taking evasive action, could be answered in precise, quantitative terms. Serial trials of the same man with the same model of mobility device would generate learning curves on his improvement and performance. Quantitative comparisons between the performance of humans of different native ability using the same presumed device could be documented as could the comparative performance of the same human employing models of different devices.

Thus a mobility environmental simulator could provide both enormous flexibility in the pursuit of alternative strategies and the elucidation of optimal mobility devices, as well as producing objective, quantitative records of man-device performance.

A substantially abbreviated version of the complete system could quantify the evaluation of existing mobility aids for the blind. If we retain the physical space and monitoring system augmented by telemetry to the computer of the device's cues, then the computer will record both the device's and the man's response to a mobility situation. Even such a reduced system could provide quantitative data on the performance of the same man in different stages of his training using a particular device, comparative data on performance with variations of the same device, or different devices, and longitudinal data on the performance of representative subject populations.

In addition to its potential role as an evaluator of existing devices and as a means of establishing the optimum specifications for potential devices, the mobility environmental simulator would provide for the first time an experimental environment in which to study mobility per se on a scientific basis. That is to say the simulator could be an enormously valuable and insightful source of experimental data on the mobile performance of human beings. Ultimately our creation of really sophisticated mobility devices must hinge on a more profound, detailed and scientific understanding of human mobility.

Feasibility and Status

Our direct simulation experience with limbs, as well as with relevant efforts in military/aerospace simulation, assures us that the overall concept is sound. Most of verbalized apprehension at this meeting and elsewhere revolves around the implementation of the scheme, the scale on which it is proposed and "cost-benefit" considerations.

With respect to implementation, surveillance or monitoring systems have been studied. Optically and ultrasonically based approaches appear feasible. Some consideration has been given to inertial sensing [9]. Computer simulation of the detection and processing aspects of a generalized mobility device [10] follow directly our experience with related aspects of the limb simulations. The telemetry considerations are routine. The psychophysical displays to be employed would be based on concepts and techniques already used in research studies of tactile and audio communication (11). Some consideration has been given to the representation of salient aspects of the physical space in computer memory (12), but more needs to be done to establish the relationship between computer-memory size and cycle time, and travel-space size and detail.

Computers have and of course are being used widely in conjunction with the organization, control and reporting of experiments, large and small. The system proposed here becomes viable only when mounted at a certain level of scale. Unless the relatively unencumbered human can be accorded mobility in a sizeable, realistic travel space, the experiments conducted do not adequately and truly represent the mobility of the blind. But this means dedicating a moderate-sized computer to the simulation task, along with substantial peripheral equipment to handle monitoring and telemetry.

The configuration of a particular computer system depends on a detailed study to satisfy specific dimensions such as size and character of travel space, detector parameters, telemetry transmission rates, etc. It simply is not possible to project the overall cost of a particular system until a detailed design study is carried out. Thus the "cost-benefit equation" cannot be assessed until such a design study can be implemented. We can, however, estimate that the development of a mobility simulation system will exceed the total research and development costs of a particular mobility device. However note that the simulator cost does not escalate linearly with each different mobility device suggested and explored as does traditional R&D. Rather, the inherent flexibility and adaptability of the simulator makes possible the study of many ramifications of mobility devices and the evaluation of this universe of concepts in a quantitative and objective fashion.

Finally, the traditional development process contributes very little to the elucidation of a comprehensive theory of human mobility. Perhaps this is the basic thesis on which one should now promote the simulator concept. High-flown arguments of this sort have proven enormously successful in automata theory and artificial intelligence. Certainly the development of a theory of human mobility is an equally respectable pursuit.

Perhaps ultimately, a computer-based, man-interactive, mobility environment simulation system study expressly committed to the theory of human mobility will have, as a "spin-off," the development of specifications for optimum mobility devices for the blind and their objective, quantitative evaluation!

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DISCUSSION REPORT

P. W. Nye

In order to provide the opportunity for contributions and commentary from all those in attendance, more than half of the conference program was devoted to discussion, much of which centered on methods of evaluation and the views expressed in particular papers. However, the conversation often strayed to cover somewhat broader -- and narrower -- issues, with some inevitable misunderstandings and overlapping argument. In the following pages, in the interest of brevity, an attempt has been made to select the main discussion topics, to paraphrase the most cogent arguments and to provide some threads of cross reference between ideas. It is intended that this reorganization will make the contributions of the conference stand out more clearly, but it is unfortunate that this cannot be done without penalty.

Many of those who attended the conference will no doubt detect the loss of much of the wit and atmosphere of lively discussion. Moreover, the answers to several key questions inevitably found their way into the amended texts and ultimately avoided the need for inclusion in the Discussion Report. Thus the contributions of many a perspicacious questioner have regretfully gone unrecorded.

Finally, attention should be drawn to the fact that contributors cited in the Discussion Report (written from a verbatim transcript) were not given the opportunity to check its accuracy. Any omissions, errors, or misquotations are entirely the fault of the editor who tenders his apologies to those concerned.

Each paragraph of the Discussion Report is decimally indexed and has been cross-referenced with the other portions of these proceedings.

1.0 TECHNICAL FEATURES OF EXISTING DEVICES
A Brief Summary

1.01 The Laser Cane contains three optical triangulation systems built into a long cane (see Benjamin, Figure 1). Three gallium-arsenide lasers are positioned in the upper region of the cane so that when it is inclined at the angle employed in normal cane travel the beams project upward (to strike objects at head height), forward (to explore the body space 12-15 feet distant at waist level), and downward (to detect low-lying objects and steps down). Three photocells are located at a lower point along the cane and have their acceptance cones directed into the three regions just specified. When an object appears in the region ahead where a laser beam and photocell field of view intersect, a signal is generated and delivered to the user. Hazards at head height, forward and at foot level are all signalled by a single tactile stimulator in contact with the index finger. In addition a small loudspeaker emits a high pitched tone for obstacles at head height and a low pitched tone for surface hazards. No sound is generated by the forward channel. For further details see reference (10).

1.02 The Sonic Glasses utilize a pulsed ultrasonic transmitter and two receivers whose outputs are introduced to the user binaurally. The transmitted pulse sweeps from 90 kHz to 45 kHz and is propagated over a solid angle of about 55 degrees. The reflected echo is intercepted by the two receivers, mixed with the transmitted pulse, and the two difference frequency signals which lie in the audible range are conveyed to the user binaurally through earphones. For reflection from a stationary object the difference frequency is constant and proportional to the range of the reflecting object. The amplitude of the signal pulse depends upon the properties of the reflecting surface as well as its distance. The transmitter and receivers are built into a pair of spectacle frames, and the power supply is located in a pocket (see Kay, Figure 1). See reference (12) for more details.

1.03 The Pathsounder, worn around the neck in the manner of a 35 mm reflex camera, directs an ultrasonic beam into a body-sized volume directly ahead of the subject. It therefore embodies the assumption that only the existence of objects in the immediate path is of importance. When no object is detected within 6 feet, the device emits no audible sound, but as an obstacle enters the 6 foot range, a ticking sound is broadcast from loudspeakers attached to the neckstrap. The ticks become louder at closer ranges until at 30 inches the signal changes abruptly to a beeping sound. Further details may be found in reference (11).

2.0 WHAT TECHNIQUES SHOULD BE ADOPTED IN THE EVALUATION OF A MOBILITY AID?

This question, which represented the main theme of the conference, occupied a substantial portion of the discussion period. It brought into focus the basic tools in use and in process of development and also indicated at least one technique, the secondary task, which deserves further attention.

2.01 Mr. Rowell opened the discussion by pointing out that most mobility devices were intended to be used in conjunction with existing aids such as the dog guide or long cane. He asked Mr. Benjamin how one might determine the relative contributions of two aids when combined into one as in the case of the laser cane. Mr. Benjamin was probably not unaware of the ramifications of the question, for his reply was obviously circumspect. He stated that the problem might be solved by observing the performance decrement when one or the other aid is removed or switched off; then each subject would in effect be his own control. However, before he could be pressed for more detail, he stressed that his concern has been to answer the question of how the device, as a whole, influences the subject's performance compared with what that subject had previously been using. Mr. Benjamin, on several occasions, recommended the whole-system approach, i.e. evaluating the combination of sensor, processor, display and man as a whole. His argument appeared to be that the study of a man and device as a single entity neatly avoided the problems met with in performing a systematic analysis of the amount of information available at specific points in the system. The systematic approach was attractive, but so little was known at the present time about the information required for mobility that it was unprofitable to pursue this line of reasoning in detail. All measures of "system" performance must of course be interpreted against the background of the subject's physical and psychological characteristics. The subject may travel no faster than with conventional aids, but he may be more relaxed (see 6.01) when using both sources of guidance, and this fact should be taken into account.

2.02 Mr. Whitehead reviewed the evaluation procedure adopted in a familiarization study on the laser cane carried out at a Veterans Administration Hospital (Hines) over a period of between two and three months (see 13.01). Three sighted mobility trainers had been exposed to a 17- to-20 element obstacle course, and observations had been made both of their performance and of the audio and tactile signals provided by the cane. The latter were conveyed to the observer via a telemetry system. Several discussants averred to the usefulness of telemetered signals from a device both during training and evaluation.

2.03 After suggesting that at least one objective which should be sought from an evaluation is data that could lead to the design of a better device, Dr. Nye asked how the 1971-72 evaluation study of the Sonic Glasses, being organized by Dr. Kay, would seek the necessary data, and secondly, what methods he was adopting to measure the behavioral performance of subjects with and without sonic aids. Leading off with the comment that this kind of information is difficult to obtain, Dr. Kay went on to review the structure of his planned evaluation. He explained that the program will begin with a training course for a few mobility instructors who will subsequently disperse to centers at Boston and Western Michigan. The program at Western Michigan will be primarily concerned with the development of training techniques, while the Boston program, under Dr. Kay's direction, will involve a more experimental approach. For example, it is proposed to carry out tests on the technical efficiency of the device, on the subject's ability to identify the direction and distance of objects, and on the adjustment and fitting of the device to maximize a subject's performance. Following this preliminary study, a more thorough course for instructors will be developed, and the cycle repeated with the eventual introduction of field-measurements. Special emphasis will be given to:

(1) Ensuring that the instructors have an intimate knowledge of the design of the device.

(2) Establishing that the devices are reliable.

(3) Ensuring that the instructors know which questions must be answered.

(4) Discovering the range of manufacturing variations which are tolerable.

(5) Determining mobility performance before and after training.

(6) Assessing the acceptability of devices 3-6 months after training.

(7) Personality profiles of the subjects.

(8) A comparison of mobility performance using dog guide or long cane alone and in conjunction with the device.

Dr. Kay expressed the belief that only when field measurements had been completed would it be possible to assess the usefulness of the device. The need for any additional features can be expected to appear during field trials, at which point new ideas must be developed to meet the need.

2.04 Questioned on the subject of what information he would like to see emerge from an evaluation of the laser cane, Mr. Benjamin raised, once again, the issue of measuring anxiety; a subject which had been on the minds of several discussants (see 6.01 and 6.02).

2.05 Mr. Russell's response to the same question led to the introduction of the concept of user acceptability as a potentially useful evaluation criterion. His policy and program for the next three years could be characterized as one of making more units available and allowing the degree to which the devices meet particular needs stimulate demand which in turn would alone control the supply. Dr. Kay took up the task of defining user acceptability by relating past experience with the ultrasonic torch. Four-hundred torches had been distributed, and four years later he believed that upwards of two hundred were still in use, although he admitted that records were scanty. He implied that the ratio of these figures could be used to form a measure of user acceptability and suggested that such a figure calculated for the torch might indicate its basic acceptability despite the technical limitations and "lack of adequate evaluation." However, to establish a criterion of merit for this ratio was extremely difficult. Dr. Leonard warned against an uncritical acceptance of such figures indicating that user acceptability of the ultrasonic torch must be interpreted against the background of a captive market and the novelty of the device (Russell, p. 44). He reported that out of 29 people who were known to have been actively using the ultrasonic torch in the U.K., only 5 or 6 were recently found to be making effective use of the device. Dr. Leonard concluded by making a strong appeal for evaluations carried out by persons who are independent of designers and inventors.

2.06 Seeking to define the essential elements of evaluation, Dr. Miller delineated three stages. The first stage is developmental evaluation and is concerned with refining the technical efficiency of the device. The second stage he described as an economic evaluation involving an assessment of costs, potential user acceptability and competitive products. Finally, the third stage is a functional evaluation. This should preferably be carried out by an independent agency and involve a comparison with another system "because comparative evaluation is so much easier than absolute evaluation." Such an evaluation should begin with a clear statement of objectives that the system is intended to achieve. He claimed that no satisfactory statement of objectives had yet been made, and he challenged those present to remedy this. Having established these objectives, he said measurements must be developed to determine the extent to which the objectives have been met. Finally, "and this is often overlooked," the results of the evaluation must be disseminated in sufficient detail that others can fully appreciate their range of application ensuring that the evaluation need never be repeated. A point added later by Mr. Harmon stressed the importance that the measurements be of a sufficiently general, standardized nature that they can be applied to different devices in different establishments and yet can still be compared. Several speakers agreed that functional evaluations should be carried out independently of the inventor, but Dr. Murphy made an additional plea for consultations with the designer on questions he would like to see answered and his being kept informed as to the results. As a result of Dr. Miller's remarks, Dr. Kay found himself once again under attack on the question of what initial objectives he set for his device. He parried by saying that if he were able to state what the sonic glasses should be capable of achieving in advance of evaluation, then the evaluation would be largely unnecessary. Although a vulnerable reply, the expected redoublement failed to appear.

2.07 Extending his remarks on the use of a secondary task (see 6.03), Dr. Kraft pointed to the case where one may wish to select the best of two devices which lead to equal performance of a primary objective. In this case, the choice may hinge on the fact that one device may interfere with some other part of behavior; a part which does not appear in the primary task. Under these circumstances the introduction of a secondary task (preferably some task which might ordinarily be undertaken while walking) coupled with a multivariate analysis of the interactions as the workload is altered, can reveal the first and second order interactions on the basis of which it is usually possible to identify the best device.

2.08 Responding to a question from Dr. Kraft on the minimal number of subjects required in an evaluation and the methods used in assessing their training, Dr. Leonard indicated that based on recent experience gained in collaboration with Mr. Cross at Birmingham, England, a figure of at least 50 persons appeared desirable. On the question of methods of assessing performance, he recommended a technique described in a paper by Leonard and Wycherley [17].

2.09 A variant of this technique involves the filming of each traveler as he negotiates a representative course, and the subsequent showing of these films to a panel of experienced mobility judges who are required to analyze each performance into a series of sub-tasks whose execution is rated on a specified scale. The total score gives a measure of the overall performance. Although the judges are required to assess complex multidimensional variables such as style and anticipation, the method nevertheless proves to lead to consistent and reproducible figures. He also volunteered the view that comparative tests of a crucial nature could not be carried out with sighted people because their motivation was seldom sufficiently high (see 10.14).

3.0 RESPONSE TO THE QUESTIONS POSED IN THE PAPER PRESENTED BY MR. CURTIS.

3.01 Mr. Curtis concluded his paper by posing four questions (see p. 53) which owing to lack of time did not receive all of the attention they deserved. His first question on the potential market for mobility aids drew a response from Dr. Leonard who estimated that in the U.K. from a total of 116,000 registered blind persons, "the population at risk for mobility training" (i.e. potentially capable of utilizing training) was at most 10,000 persons. (Assuming that the incidence of blindness is approximately the same in the U.S. as it is in the U.K. would lead to a figure of about 35,000 persons at risk in the U.S.) A rider he added later in the conference indicated that if one must set a criterion of user acceptability for various aids, then in his view it was unlikely that the figure can be expected to exceed more than between 10 and 15 percent of the population at risk (i.e. a total of about 1,200 persons in the U.K. and 4,200 in the U.S.). (see 2.05)

3.02 Responding to the second and third questions, Dr. Leonard stressed the need for the development of good screening techniques to establish the suitability of the various training regimes (e.g. either dog guide or long cane) to meet a particular individual's needs and capabilities. Such measures were particularly necessary to conserve today's highly restricted resources. He quoted the results of an inquiry carried out by his unit into long cane training in the U.K. which showed that owing to inadequate screening, as many as seven out of every thirty persons trained failed to achieve adequate levels of proficiency. Dr. Leonard also agreed that there was an urgent need for more mobility instructors.

3.03 A later remark by Mr. Thornton sounded an implied warning against the too-ready assumption that all those who Dr. Leonard had defined as "the population at risk" were eager to be mobile. He pointed out that some means must be found to motivate those that appear to have no desire to be independently mobile and indicated that only a very good aid would be capable of doing this.

3.04 Dr. Kay felt that it was not possible to determine the market for a device until adequate evaluation had shown what the device can do for the user. He also indicated that the New Zealand government intended to pay the costs of training mobility instructors and he predicted that other governments would eventually take on similar responsibilities.

3.05 In his summary comments on these answers, Mr. Curtis reiterated the need to select candidates for mobility training by suggesting that the Pathsounder was more likely to make a good traveler better than to improve the performance of a poor traveler.

4.0 WHAT MAY THE EXISTING MOBILITY DEVICES BE EXPECTED TO DO TO AID BLIND PEOPLE?

This question was put to Mr. Benjamin, Dr. Kay and Mr. Russell. In their replies, all three speakers carefully parried in much the same way as Dr. Kay had done earlier (see 2.06). It was evident that from the designers' viewpoint that the question, although appearing ingenuous, seemed to hide many elements of the chicken-and-egg paradox.

4.01 Mr. Benjamin had explained in his paper that the laser cane utilized three channels. One is set to detect objects at head height or below. A second channel covers the body width, while a third is intended to detect steps down. He claimed that the unit is technically capable of performing all of these functions and therefore of providing information that the traveler needs to know. He thought that the major question is now centered on whether, via tactile and auditory signalling, the mobile subject could be trained to make use of the combined information without confusion. Training programs had not reached a sufficiently advanced stage to provide more than anecdotal evidence on this important question, although such evidence as was available did suggest that the straight-ahead channel was the most useful.

4.02 In response to close questioning by Dr. Cooper and Dr. Leonard, Dr. Kay indicated that the beam angle of the binaural sonic glasses is such that at a distance of ten feet in front of the subject the beam width is ten feet. Furthermore, he stressed that the device should be described as an environmental sensor as distinct from an aid to obstacle avoidance and in addition should be used in conjunction with a long cane or dog guide. Dr. Mann recalled that Mr. John Dupress, the late director of the MIT Sensory Aids Evaluation and Development Center, had advocated that a mobility aid should merely provide the assurance of a clear pathway or body-sized tunnel between two points. Mr. Dupress had held the view that information about objects lying outside the immediate path was largely superfluous. Dr. Foulke and Mr. Thornton, however, countered this by expressing the view that information about objects lying outside the immediate pathway was useful for navigational purposes. The sonic glasses appeared to provide some help to navigation in that they indicated the texture of objects. Moreover, on the strength of a short examination of the spectacles, Dr. Foulke thought that Dr. Kay's contention that the device constituted an environmental sensor could be supported.

4.03 When the question of what did he expect of the ultrasonic spectacles was put to Dr. Kay, he replied that the device provided an auditory transformation of three-dimensional space from which one could discriminate direction and range for the case of simple structures (poles erected in an empty field). In the complex surroundings of an urban environment it would be too difficult to attempt to physically analyze the dimensions of the signal from the device and directly relate the information they provide to various aspects of a subject's performance. For it is well known that the perceived dimensions of a stimulus frequently bear little relation to its physical dimensions. Hence as an alternative means of measuring the utility of a device, it is necessary to provide the means by which a sufficiently large number of people can be given an adequate amount of training and experience under controlled conditions and then to determine from behavioral and introspective observations whether the device provides significant assistance in maintaining mobility. Thus it became clear that Dr. Kay's views were closely aligned with the whole system approach of Mr. Benjamin (see 2.01). Moreover, Dr. Kay made it clear once again that he could not hazard a statement on what the device was expected to achieve without possessing some knowledge of what aspects of the display his subjects were utilizing and furthermore having more experience with large numbers of trainees from whom it might be possible to obtain more reliable behavioral measures.

4.04 Dr. Mann pointed out that telemetry could be of assistance in the former case, and Dr. Kay indicated that this was in the process of being developed (see 2.02).

4.05 Mr. Russell summarized his answer to this principal question with respect to the Pathsounder as, "confidence, security and protection against the unexpected." Lack of time prevented further elaboration of this statement.

5.0 A COMPARISON OF SELF-TAUGHT AND INSTRUCTOR-TRAINED MOBILITY SKILLS

5.01 Dr. Cooper asked whether Mr. Benjamin had had occasion to allow a blind man to use the laser cane on his own with the understanding that he may keep it. In reply, Mr. Benjamin explained that this had not been possible because only eleven canes were now available, and it had been thought more prudent to place them in the hands of mobility trainers who are conversant with mobility problems and therefore are in a better position to analyze and identify the roles in which the cane can be most useful.

5.02 Dr. Leonard commented that he knew of cases in which highly motivated blind subjects had taught themselves long cane technique, use of the Kay monaural aid, and use of a dog guide, but in nearly all cases they seemed to get markedly less out of the aid than people who had received instruction. This view was reiterated by a number of discussants.

5.03 Mr. Whitehead expressed the opinion that the biggest fault of all sensory aids produced up to the present time has been the lack of an organized training program to provide the necessary support. The lack of this support "has led to many aids being exposed to the blind public in a bad light."

5.04 However, Dr. Leonard countered, qualifying both Mr. Whitehead's and his own statement, by warning against a too rigid attitude on the need for training. He pointed out that this implied that we know exactly what skills are required and can be trained, whereas in fact, there is still a need for expanding our knowledge and allowing freedom for individuals to discover new techniques by themselves, for this can sometimes assist in developing better training programs.

6.0 THE MEASUREMENT OF STRESS, ANXIETY, OR TENSION DURING AN EVALUATION TRIAL.

6.01 During a review of the kind of test methods he would like to see adopted in the evaluation of the laser cane, Mr. Benjamin suggested that there may be a trade-off between the speed with which a subject negotiates a course and the amount of stress he is prepared to accept. Hence, to obtain a more comprehensive evaluation of the contribution made by a device, some measure of stress should be attempted. Responding to Mr. Benjamin, Dr. Leonard reviewed the results of some experiments that he and his staff had performed on blind travelers.

After assessing the suitability of several physiological measures which included galvanic skin response and heart rate, the latter was chosen, and it was discovered that the rate was indeed consistently higher when the traveler moved by himself than when he was guided. However, the simple interpretation of this finding is clouded by the fact that the increased heart rate may be due not to greater anxiety but simply to the fact that the traveler is responding to the greater mental effort required to process information, or to both factors. Nevertheless, he said this study was continuing. A report of this work has been published by Wycherley and Nicklin (16).

6.02 Dr. Kraft agreed that the interpretation of physiological measures presented some difficult problems. He recalled one study carried out for the Strategic Air Command on 11-man crews which utilized $2.5 million in equipment and was intended to assess the relationship between anxiety and behavior. After two and a half years of work the physiological responses were abandoned and only the behavioral data was used. Similar difficulties had arisen in a study of air traffic controllers.

6.03 Dr. Kraft suggested that if one were seeking an indication of modification of performance, a secondary task was much more effective. This task should preferably be chosen so that it is compatible with the main task (see 2.07). Dr. Leonard indicated that he had attempted to find a secondary task which did not interfere with the on-going task but had not been successful.

7.0 RESEARCH AND DEVELOPMENT STRATEGY: THE STUDY OF DISPLAY REQUIREMENTS BY SIMULATION TECHNIQUES.

The topic of research strategy emerged at several points during the discussion which surrounded particular devices. It was finally climaxed by a vigorous exchange over the role of simulation techniques.

7.01 Mr. Foulke opened the discussion by noting that Mr. Benjamin had followed the procedure of first developing a device and then assessing its utility. He asked whether Mr. Benjamin would now wish to adopt a different approach. In his reply Mr. Benjamin stated the opinion that there were two major prerequisites to future development: First, a better definition of the problems of blind mobility and the needs that must be met and second, a clearer understanding of the mechanisms of sensory perception that can be used to guide the construction of efficient auditory and tactile displays (displays that can readily facilitate the formation of internal concepts of external space).

7.02 To the question of defining needs, Mr. Long responded with information about an informal poll he had carried out among his colleagues which indicated that the most useful mobility device would pick out a building line on the opposite side of the street thus enabling the traveler to cross at the corner or to cross the street safely in the shortest distance.

7.03 After considering Mr. Long's remark, Dr. Foulke suggested that the polling technique could be extended to a large number of blind travelers who could perhaps be canvassed on the subject of what kind of device they would like, but he immediately qualified his proposal by cautioning that the replies may not be very useful because he doubted that many blind people were able to analyze the processes involved in mobility (see 10.06 and 10.12).

7.04 Characterizing much of the ongoing discussion as being directed to the question "We have a device now what can the traveler do with it?", Dr. Cooper suggested somewhat later in the conference that "a shorter, more tangible list might emerge" if one began by acknowledging the dog guide and long cane and then asked "What more is needed?"

7.05 Some discussion of one way of identifying the needs of mobility, in a manner closely paralleling the approach suggested by Dr. Cooper, was prompted by a remark from Dr. Leonard to the effect that some people with quite severe visual deficits can nevertheless remain surprisingly mobile. Dr. Bliss took this point further by observing that one could occasionally find puzzling instances in which people with low visual acuity were highly mobile while others with better vision were poor travelers. He implied that a study might be made of this phenomenon perhaps by simulating various forms of visual defect. Mr. Harmon later made the point more explicit by suggesting that a traveller armed with a portable video camera and transducer system could, at the turn of a knob, alter image resolution from a 1000 x 1000 point array down to a 10 x 10 array. With such a system Mr. Harmon suggested that one could determine how many bits of information are required for any given level of mobility. He noted that Dr. Ivan Sutherland at the University of Utah had constructed a pair of goggles incorporating cathode ray tubes which might be employed for such experiments.

7.06 Questioned on whether adaptation phenomena occurred when using tactile stimuli, Dr. Bliss replied that it was evident in the early stages of learning to read with the Optacon, but his experienced blind subjects thought it presented no worse a problem than when reading Braille. Dr. Mann then added that his group at MIT had employed tactile stimulation to provide position feedback for an artificial limb and had met no problems. However, Dr. Leonard made the point that the adaptation problem was aggravated by excessive pressure of the skin surface against the stimulator, and he suggested that this might be more likely to occur under the stress of a mobility situation than when reading. Mr. Benjamin agreed and added that one also had to take into account the fact that more stimulus power was often required to gain the traveler's attention in a mobility situation.

7.07 Predicated on the belief that the purely technical aspects of sensing the environment are largely realizable, papers by Dr. Mills and Dr. Mann discussed the potential benefits resulting from the simulation of different kinds of processing algorithms and stimulus systems. Dr. Mann confessed that the cost of the system proposed was high but defended this expense by pointing to the fact that the blindness system in the U.S. expends over $500 million per year of which only 0.2% is spent on research[21]. Indicating that simulation techniques were applied successfully (and presumably economically) in either branches of human engineering (in particular the aircraft industry which Dr. Kraft represented), Dr. Mann went on to imply that the benefits of the technique were not only that it provided a quicker route to the specification and construction of better devices, but possibly that it was the only way to effectively apply intensive research to the problem.

7.08 Dr. Bliss, however, continued to pursue the question of the cost-benefit trade-off by asking if the task of estimating costs would be easier if, instead of the total simulation of a man-machine environment, one were to contemplate a more modest project utilizing a real environment, a real sensor (a Vidicon tube) and a stimulus system with the signal-processing part of the device being simulated by the computer. In reply Dr. Mann acknowledged the existence of a variety of subsets of the main system all of which were useful in one way or another, but he had not studied all their costs and potentialities. Dr. Bliss responded by recommending that a better strategy might be to start with a simpler simulation project. This sentiment was also endorsed by Dr. Cooper who felt that the highest cost-effectiveness trade-off was likely to appear in studies of information transformations between sensor and display.

7.09 In responding to these criticisms, Dr. Mann coined the word "micro-simulation" to describe the proposals of Drs. Bliss and Cooper. He exposed a weakness of micro-simulation by pointing out that the procedure deemphasizes the importance of maintaining mobility performance while processing the information from a display. It is not sufficient to know merely that a particular display can achieve a given rate of information transfer to a subject sitting in a laboratory chair. The important question is ultimately whether the information can be assimulated at the same rate in a mobile situation. (A comment on simulation added after the conference appears in a postscript to the paper by Leonard, p. 86).

8.0 MOBILITY TRAINING FOR THE YOUNG

8.01 During a film sequence presented by Dr. Kay, it emerged that the subject of the film, an 18 year old woman, had received only 50 hours of cane travel experience. Dr. Mann suggested that this very limited experience was possibly due to the prevalent "very strong bias against early training with any kind of device" for young people. Several discussants confirmed this opinion although Dr. Leonard, laying the blame largely on overprotective parents, thought that the practice was changing.

8.02 Dr. Kraft expressed his surprise if, in the face of so much data on the relation between mobility, proprioception and the formation of spatial concepts, such a practice should continue for very much longer. One could draw the conclusion from Riesen's work [22] that if a blind child's mobility is discouraged early in life he is likely to be a less proficient adult traveler. Mr. Harmon fully endorsed this view and added that in the case of using the skin as an alternative input channel, it is conceivable that if training in tactile perception were initiated with the very young, the level of skill they could achieve with this form of communication would be much better than that of adult trainees.

8.03 As an example partially supporting this argument, Dr. Leonard cited the performances achieved by adult and child students of Braille, but he qualified his statement by saying that the picture was complicated by the fact that language skills in a child tend to mature around eleven or twelve years of age (somewhat later than basic tactile discrimination) thus imposing a delay in the achievement of a child's potential performance.

8.04 However, in the case of essentially untried experimental aids to mobility, Dr. Kay indicated that there was a natural reluctance to place these devices in the hands of a child because one is often not entirely sure what it is going to be able to do, and therefore one cannot provide the guidance that a child may require. He implied that without this guidance the child may achieve only a poor performance and become disillusioned, permanently discouraged and even psychologically damaged.

9.0 THE NEED FOR VITAL STATISTICS OF THE BLIND POPULATION

9.01 Expressing regret that statistical data on the blind population in the U.S. was so sparse, Dr. Mann made an appeal to those present for the next best thing, namely estimates or educated guesses of the proportion of the population likely to benefit from particular regimes of training or specific devices. Dr. Leonard interjected that he had earlier provided an estimate applicable to the U.K. (see 3.01).

9.02 Acknowledging this, Dr. Mann continued by pointing to the need for providing adequate projections of costs and adequate assessments of the size of the potential market. For whether the development of mobility aids is seen against the background of a profit-oriented free-enterprise market or under the support of subsidy, there is still a need to justify cost and measure benefit. Dr. Leonard stated that some attempt had been made in the U.K. to obtain the information from which such figures could be calculated, and he cited a survey published by Her Majesty's Stationary Office in 1968 [20].

9.03 On the subject of whether, given a mobility aid, the potential increase in a blind man's productivity could be assessed -- a question posed by Dr. Mills -- Dr. Leonard said that the government survey which had been carried out in the U.K. had discovered that few blind people are prevented from working because of a lack of mobility. Relatively easy access to public transport and help from sighted friends appeared to ensure that the majority who desire to travel can travel to a place of employment. Thus it was not possible to find enough employable but immobile blind people on which to base the assessment Dr. Mills had suggested.

10.0 THE FORMATION OF THE CONCEPT OF SPACE AND THE ROLE OF PROPRIOCEPTIVE FEEDBACK

10.01 Remarking that in normal long-cane technique the cane executes a sweeping motion, Dr. Mann asked whether the varying amount of space that the ranging system would scan at different positions of the Laser Cane was likely to influence the ease of signal processing on the part of the user. Mr. Benjamin ventured the opinion that it was too early yet to answer this question because no one had used the cane long enough for it to become a "part of him". But Mr. Apple countered this by reporting that at least one man, an experienced cane traveler at the Veterans Administration hospital in Palo Alto, had reached the stage of "automatic conceptualization" (i.e. not consciously analyzing the signal and the position of the cane by proprioception but forming a mental schema or picture of the existence of some object in space) following three months of training. His comment was that he could "visualize his environment much better," but this visualization tended to be confined to the pathway and its immediate border. Furthermore, conceptualization came more easily by assuming a slower pace.

10.02 When probed on the question of whether the slower pace was caused by the subject's exploration of the environment beyond the physical limit of the cane, Mr. Apple replied that he thought not and that it was likely that the man was speeding up as he continued to use the device.

10.03 The same theme was taken up by Dr. Kraft who argued that the ability to conceptualize the meaning of a signal was a very important goal which could be reached more rapidly by training than by letting the subject discover it for himself. Moreover, the skill is developed with duration and variety of exposure as well as experience.

10.04 Mr. Pugh, reporting on his studies of subjects using the sonic glasses, also indicated that his students acquire the ability to perceive the sound as originating where the object lies in space.

10.05 Mr. Apple then asked how much movement of the subject's head was required to fix his position relative to an object. Mr. Pugh replied that two subjects employed side-to-side motion of the head when walking but volunteered the suggestion that this was probably a vestigial and now unnecessary habit which originated during their earlier training with the monaural hand-held aid.

10.06 Dr. Foulke pointed out that psychological stu ies indicate that the perceptual process of maintaining an accurate internal awareness of the environment appeared to be achieved by continually examining the congruity between the internal representation and the actual state of nature and making corrections to the internal store of knowledge when this proves necessary. He concluded that aids which permit environmental sensing (or, in other words, provide some information about shape and texture as distinct from merely indicating the presence of an obstacle) are therefore inherently more likely to provide the information conducive to the function of the normal perceptual processes; a point elaborated in more detail in a recent paper (9).

10.07 Prompted by a question from Dr. Cooper, Mr. Thornton indicated that despite the narrow acceptance angle of the hand-held sonic torch, the space ahead could be scanned, and it was easy to integrate the proprioceptive information into a total construct of the surroundings (see 10.05).

10.08 Late on the first day it became evident that not everyone was entirely in agreement with the approach to evaluation adopted primarily by the mobility aid designers (see 2.06 and 4.01). As the issues became more sharply drawn, increasing concern developed over the need to define the function that a device was intended to perform (even if only in the broadest sense) before evaluation could begin. On the one hand it appeared that the training and evaluation procedures may well be quite different if the device was intended to be an environmental sensor rather than an obstacle detector, while on the other, the question of whether the device presents its information to the user in serial or parallel form could indicate obvious aspects of training and evaluation which should receive particular attention. If the information was delivered in serial form, scanning would be necessary, but if delivered in parallel, it would not. There were many dimensions to the problem, and Mr. Harmon attempted to order and classify the various alternatives (Figure 1).

10.09 Amid mounting murmurs of disagreement the diagram was completed, but before Mr. Harmon had the opportunity of expanding on how different evaluation procedures might be applicable to the different classes of devices, discussion erupted over the question whether the sonic glasses did, as Dr. Kay contended, provide parallel information. However under questioning by Mr. Harmon, Dr. Kay admitted that if the subject remained stationary in front of two poles placed side by side, he would not be able to discriminate them. If the subject were free to move, as indeed he would under normal conditions, then Dr. Kay claimed that the subject would identify the number of poles correctly. Thus he appeared to yield the point that scanning and proprioception are important ingredients in forming the internal representation with the sonic glasses. Realizing the implication of this statement, Dr. Bliss pointed out that it indicated the conclusion (at least at the level of the man-machine interface or the perceptual processes) that information from the sonic glasses was being processed serially. He contrasted the ultra-sonic aid observations with similar observations made on tactile and visual sensory systems which carry out parallel processing. In both of these systems recognition can occur under tachistoscopic conditions, although in the tactual modality it is less precise. He added that some sequential information, though not essential, is apparently helpful because visual and tactile recognition accuracy can be improved if the stimulus is allowed to make controlled movements across the sensory surface. A confused argument then

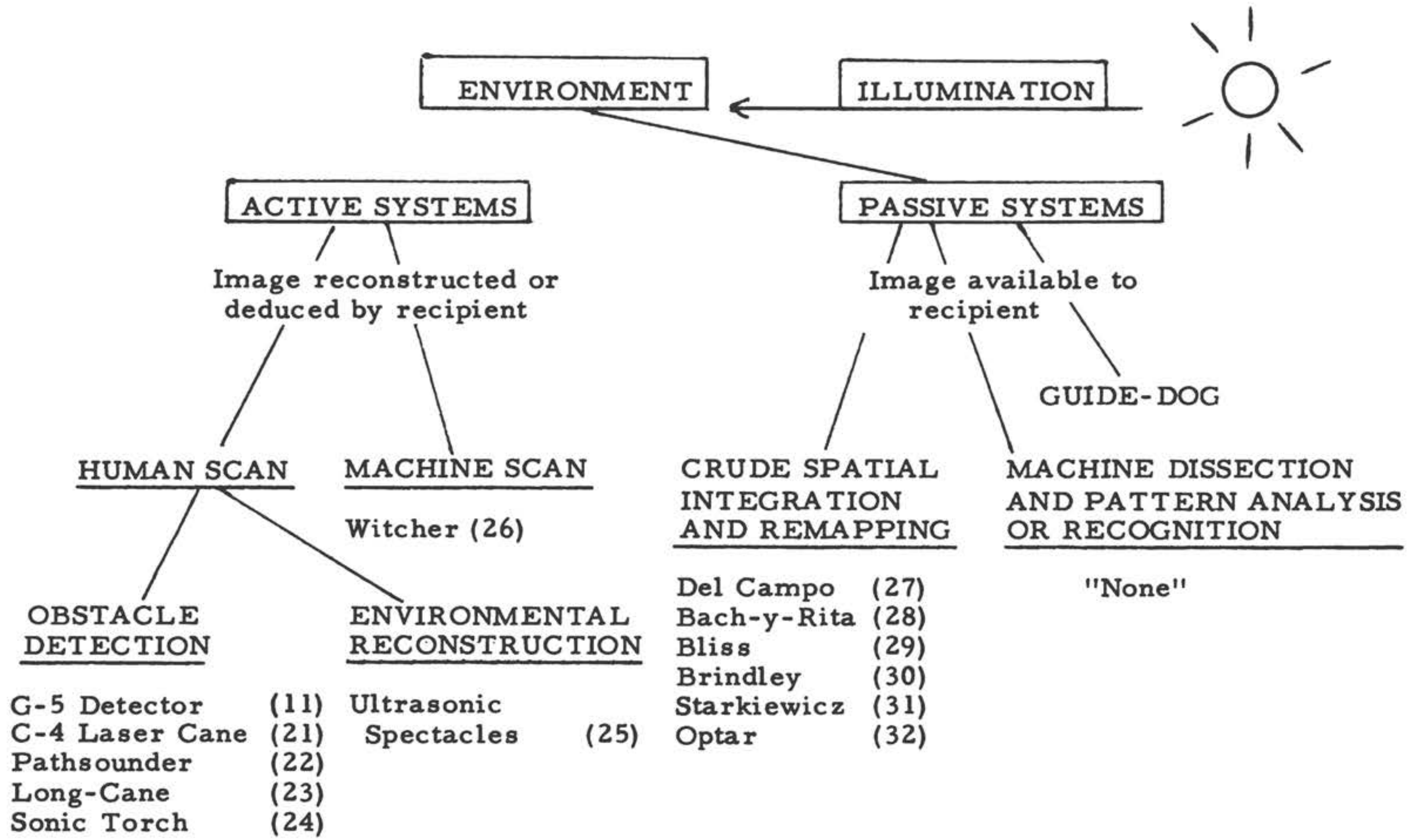

FIGURE 1

Classification of Mobility Aid Systems

followed during which Dr. Leonard, supporting Dr. Kay's position, argued in favor of displays providing parallel information. Eventually an armistice was established which appeared to leave Dr. Kay still not entirely reconciled to Dr. Bliss' point of view.

10.10 Dr. Miller noted that in much of the discussion the use of the term "processing" was largely confined to internal descriptions of various devices, and he mildly chided those present for not paying very much attention to the processing being carried out by the nervous system. However, although "really critically important," he admitted that "we don't know enough about it to really be very helpful." He illustrated the ability of the visual system to form schemata by describing a hypothetical experiment in which five pictures of a complex object seen from different viewpoints are exposed sequentially to an observer who builds a concept of what the object is. The observer is then asked to identify this object from among a collection of other similar but different objects, and he can do so easily. Then, however, if he is required to identify the five original viewpoints of the object from among a set of ten different views, the observer's performance is likely to be very close to chance. Dr. Miller concluded that the visual system discards the detailed evidence it receives and substitutes an internal cognitive representation. Some of the complexity of this kind of transformation is evident in the processing of speech by the ear which results in the retention of only the concept that the message conveys.

10.11 Stressing again the importance of internal schemata, Dr. Miller indicated that this ability can only be achieved by the patient learning of an association between the signal and its meaning until an unconscious relationship develops. If this condition can be reached, then the stimulus or signaling system is said to be <u>compatible</u> (a term defined in this manner and attributed to Fitts) (see Leonard p. 79). However, the criteria which determine whether or not any particular system will be compatible with a given objective are not defined.

10.12 Pursuing his argument a step further, Dr. Miller went on to explore the question of what the mobile blind person might need by way of an internal representation of his environment. He commented that a basic concept in a <u>theory of mobility</u> might be expected to define the difference between path-free and path-dependent mobility. The sighted person operates in a path-free condition; the blind person does not, and the cognitive maps that he forms must be quite different. Consequently, he concluded, "there should be a tremendous difference between the cognitive representation of the adventitiously blinded and congenitally blinded subjects." Thus the evaluation of a mobility aid display is a very difficult thing for a sighted person to carry out effectively, and more effort must be spent in evaluations in trying to understand more about the internal transformations within the subject rather than relying on correlation between the display and behavior.

10.13 Responding to Dr. Miller, Dr. Leonard challenged the notion of there being differences between the adventitiously blinded and the congenitally blinded pointing out that his studies on the use of tactile maps (32) had shown the congenitally blinded to be equally proficient in solving detour problems. He warned against the "equating of spatial perception with visual spatial perception" for "it is quite clear that you can have the concept of space without having visual imagery." Dr. Miller readily agreed.

10.14 Then Dr. Miller, returning to his remarks on internal transformations and comparative evaluations (see 2.06), added a caveat to the effect that having trained a subject to perform a particular transformation, it is difficult to get him to convert to a different system without curious interference effects. Facility with new cognitive transformations is not acquired or disposed of easily, and therefore different devices <u>must</u> be tested on different populations. Prompted by Dr. Cooper, Dr. Miller thought that it was at least questionable whether the use of sighted subjects did not therefore have its pitfalls. Mr. Benjamin's suggestion of using the subject as his own control (see 2.01) had been made several hours earlier and had remained unchallenged up to this time.

11.0 MISCELLANEOUS COMMENTS ON THE PATHSOUNDER

11.01 At the invitation of the session chairman, Dr. Cooper, Mr. Whitehead (V. A. Hospital Hines) and Dr. Kimborough (Greater Pittsburgh Guild for the Blind) reviewed their experiences with the Pathsounder. Mr. Whitehead explained that the Pathsounder had been made available to five clients who received no formal training. Its reception was enthusiastic, at least by three people who said that they were prepared to purchase the device. If more personnel were forthcoming, Mr. Whitehead said that the staff at Hines would like to make a more detailed study of the value of the device, particularly for multiply handicapped patients who use a limb prosthesis or wheel chair and where early warning is vital.

11.02 Mr. Kimborough described a similar informal exposure program carried out in Pittsburgh. Thirty-two patients were given the opportunity to try the device without supervision, but only two people indicated a wish to proceed to formal training. Mr. Kimborough expressed a desire to give the device a closer evaluation but indicated that financial constraints made this difficult. He felt that the device would be a useful adjunct to the cane in the role of providing security from above-the-waist-level hazards.

11.03 In response to questioning on the future of the Pathsounder, Mr. Russell indicated that a redesign was being contemplated in the near future and that the production of more devices was planned (12 are currently in existence). However, he was not encouraged by the current tight money situation.

12.0 MISCELLANEOUS COMMENTS ON THE SONIC GLASSES

12.01 Questioned by Mr. Harmon on the likely unit cost of the sonic glasses, Dr. Kay pointed out that this must include the cost of training; an unknown quantity. He implied that an accurate estimate of the total amount of training required must await the results of the evaluation study planned for 1971. Later in the course of obtaining some general information about the sonic aid, Dr. Miller put a question which drew the reply from Mr. Pugh that two of the three subjects with whom he had worked had good facial vision and that because the insertion of the auditory signal from the spectacles did not interfere with the reception of ambient sounds, these subjects could make use of both sources of information with no evidence of confusion.

13.0 MISCELLANEOUS COMMENTS ON THE LASER CANE

13.01 Following Mr. Benjamin's paper, Mr. Whitehead reported on a preliminary study of the Laser Cane by three sighted mobility trainers at Hines. Using a telemetry system supplied by Mr. Benjamin, records were kept of the position of the subject relative to an obstacle at the time of receiving the signal and of the closest point subsequently reached before taking avoidance action. Several instances were found in which, despite a clear warning, a collision occurred. In general the forward channel was found to be the most useful although, when attempting to detect objects of low reflectivity, increasing the sensitivity led to numerous false alarms. Mr. Whitehead also added the remark (echoed later by Mr. Curtis in respect to the Pathsounder) (see 3. 05) that the Laser Cane would not make a bad traveler good and without training it could make a good traveler bad. Furthermore, the audio stimulator was more successful at attracting attention than the single tactile stimulator, and it also consumed less power.

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APPENDIXES

Appendix A

COMMITTEE ON THE INTERPLAY OF ENGINEERING WITH BIOLOGY AND MEDICINE

SUBCOMMITTEE ON SENSORY AIDS

CONFERENCE ON THE EVALUATION OF MOBILITY AIDS FOR THE BLIND

June 22-23, 1970
Airlie House
Warrenton, Virginia

Purpose:	To bring together a small select group of experts to assess the requirements, delineate the problems and to evaluate progress in the development and use of mobility aids for the blind.
Invited Speakers:	The conference consists of three topical sessions, each with a session chairman and a number of invited speakers. A total of thirteen contributors are involved. Of these, three are foreign and ten are from the United States.
Discussants:	Approximately twenty other leaders in the field have been invited as discussants. This group, which includes representatives of government agencies, private foundations, universities, and industry will participate in the discussion sessions.

CONFERENCE ON THE EVALUATION OF MOBILITY AIDS FOR THE BLIND

MONDAY, JUNE 22, 1970

8:00 a.m.	BREAKFAST	
9:00 a.m.	WELCOME	Mr. Charles W. Garrett, Executive Secretary Committee on the Interplay of Engineering with Biology and Medicine
	INTRODUCTION	Professor Robert W. Mann, Chairman Subcommittee on Sensory Aids

SESSION I CURRENT STATUS OF MOBILITY AIDS

Dr. Franklin S. Cooper, Chairman

This session will explore the current state of development of mobility aids for the blind.

Invited Papers:

Mr. J. Malvern Benjamin, Jr.	"The Bionic Instruments C-4 Laser Cane"
Professor Leslie Kay	"An Aid to Mobility for the Blind What Progress in Ten Years"
Mr. Lindsay Russell	"Pathsounder Travel Aid Evaluation"

DISCUSSION

12:30 p.m. LUNCH

CONFERENCE ON THE EVALUATION OF MOBILITY AIDS FOR THE BLIND

MONDAY, JUNE 22, 1970 (continued)

2:00 p.m. SESSION II REQUIREMENTS OF MOBILITY AIDS

Professor George A. Miller, Chairman

This session will be directed toward the problems of sensing, coding, and displaying spatial relationships with an emphasis on the latter two. Crucial problems and constraints on human performance together with mobility aid capabilities will be considered. Both present and future states-of-the-art will be explored.

Invited Papers:

Dr. James C. Bliss	"An Environmental Sensor"
Dr. J. Alfred Leonard	"The Concept of the Minimal Information Required for Effective Mobility and Suggestions for Future Non-Visual Displays"
Professor Allen W. Mills	"A Simulation Approach to the Development of Mobility Aids for the Blind"

DISCUSSION

SOCIAL HOUR

DINNER

CONFERENCE ON THE EVALUATION OF MOBILITY AIDS FOR THE BLIND

TUESDAY JUNE 23, 1970

8:00 a. m.	BREAKFAST
9:00 a. m.	SESSION III EVALUATION OF HUMAN MOBILITY-AIDED PERFORMANCE

Mr. Leon D. Harmon, Chairman

This session will consider three aspects of performance of mobility aids: obstacle detection, navigation and perception. The problems of obtaining objective measures of demands by a mobility aid upon the physical and mental capacities of the user will be considered, as will the question of estimating the cost effectiveness of a proposed or actual device.

Invited Papers:

Dr. Conrad L. Kraft	"Mobility for the Blind, Can the Aircraft Industry Contribute to the Solution of this Problem"
Professor Robert W. Mann	"Mobility Aids for the Blind--An Argument for a Computer-Oriented, Man-Device-Environment Simulation System"
Mr. Robert Pugh	"Evaluation of a Mobility Aid"
Mr. William R. Curtis	"Pathsounder Experience"

DISCUSSION

12:30 p. m. LUNCH

CONFERENCE ON THE EVALUATION OF MOBILITY

AIDS FOR THE BLIND

TUESDAY, JUNE 23, 1970 (continued)

2:00 p.m.	SESSION IV	OPEN DISCUSSION	
3:45 p.m.	INTERMISSION		
4:00 p.m.	SESSION V	SUMMARY STATEMENTS	
		Session I:	Dr. Franklin S. Cooper
		Session II:	Professor George A. Miller
		Session III:	Mr. Leon D. Harmon
4:45 p.m.	CONCLUDING REMARKS		Professor Robert W. Mann

Appendix B

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