TECHNOLOGY

RESEARCH   CLINICIAN

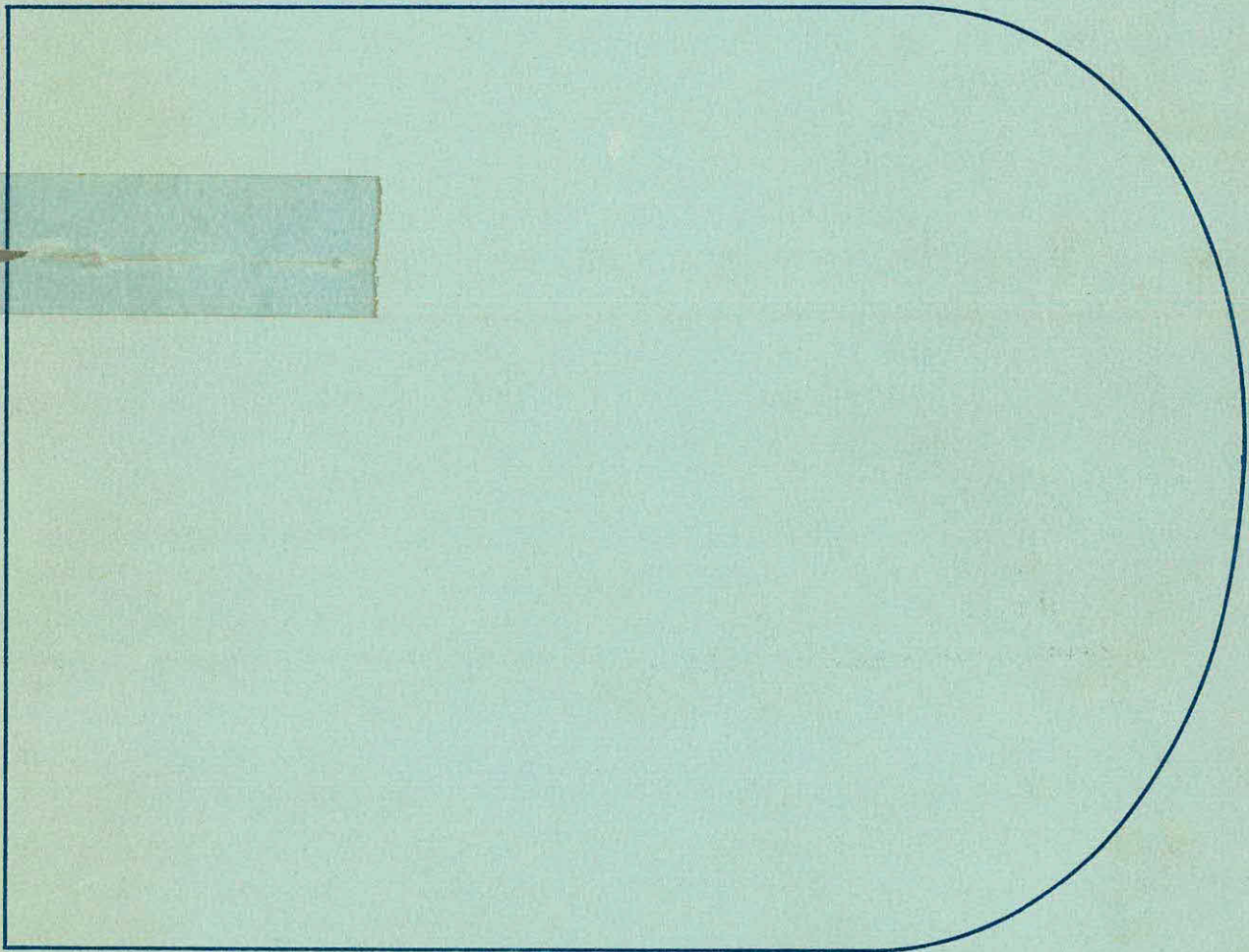# DEVICES and SYSTEMS for the DISABLED

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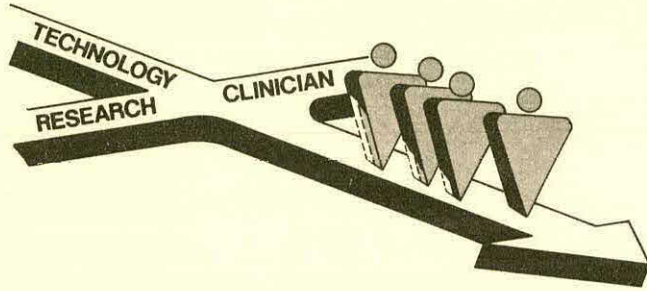F. Ray Finley
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DEVICES and SYSTEMS for the DISABLED

Sponsored by:
   Krusen Center for Research and
   Engineering at Moss Rehabilitation Hospital,
   Temple University Health Sciences Center
Editors: Eugene Kwatny
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april 29th & 30th, 1975
holiday inn, city line avenue
philadelphia, pennsylvania

OPENING ADDRESS

Margaret C. Pfrommer
Northwestern University

Title of Paper: Synergism In Rehabilitation Engineering

Category: (check one)   Device Development /X/   Research Study /X/

Brief Description: An account of a quadriplegic's experiences with assistive systems (mobile, environmental, and vocational) modified or developed by the Northwestern University Rehabilitation Engineering Staff. These systems are individually accomplishing the purpose for which each was developed. Used together they are producing synergistic effects both good and bad. This paper also stresses the importance of immediate feedback from the disabled to the engineering staff for purposes of improving engineering design.

Intended User Group: Severely disabled persons

Stage of Development: (Check all that are applicable)

A. Device There are several devices involved, each in different stages of development. The environmental system is available for sale.

   Prototype Development   / /

   Feasibility Testing   / /

   Clinical Testing   /X/

   Available for Sale (check one)   Yes /X/   No / /

   Price per unit $ 890.00 (environmental system)

   Availability of constructional details: Fidelity Electronics, Chicago

B. Research Study

   Intended Utilization: Severely Disabled Persons

   Intended Device Application: These systems provide, for the severely disabled, mobility, some control over their environment, and vocational aid.

   Availability of Intended Device: Devices are in different stages of development. The environmental system is available for sale.

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SYNERGISM IN REHABILITATION ENGINEERING

by

Margaret C. Pfrommer
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Chicago, Illinois

Summary - This is an account of a quadriplegic's experiences with assistive systems (mobile, environmental, and vocational) modified or developed by the Northwestern University Rehabilitation Engineering Staff. These systems are individually accomplishing the purpose for which each was developed. Used together, they are producing the synergistic effects envisioned by their developers: reduction in the amount of attendant assistance and improvement of morale. Other effects, not anticipated, have been both good and bad. The paper stresses the importance of immediate feedback from the disabled to the engineering staff. Seeing their devices in practical use, the developers become more sensitive to varying human needs and thus improve engineering design.

Members of the Rehabilitation Engineering Staff of Northwestern University, in their efforts to develop systems and devices to make life less difficult for the disabled, have found the success they expected, plus bonuses they could only have hoped for. My specially adapted motorized wheelchair, equipped with recliner unit and puff-and-sip control, was expected to provide increased comfort and mobility. The Northwestern University Comfort and Communication System was expected to provide additional comfort in specific ways (e.g. operating electric light, bed, and fan) and improve communications through use of signal light, telephone, typewriter, television, etc. In their simultaneous action, the two devices have had a greater total result than the sum of their individual effects. One and one has produced three, a phenomenon referred to as synergism.

The combination of the modified chair and the comfort-and-communication system, when used together, have enabled me to spend longer periods of time by myself in relative safety and yet be productive.

The recliner unit mounted on the chair enables me, by means of head-control switches, to raise and lower the chair's back, thus changing my position and redistributing pressures in the hip area. In the past it was necessary to have an attendant for this sole purpose. Even with the attendant on duty, I was hesistant to ask for a position change as often as I would have liked, so as not to seem overly demanding. If I wanted some time alone, I would tolerate extreme discomfort in exchange for the feeling of freedom and privacy.

Acknowledgement

Another use of the recliner unit has come as a surprise to me. I find that I am using the up-and-down movement to relieve the tension of anxious moments.

The mobility of my chair provided me with totally new experiences such as not having to face in the same direction for long periods of time and being able to move out of another's way.

Although the chair has enabled me to spend more hours in comfort without an attendant, these would have been unproductive hours had not the comfort-and-communication system been installed in my apartment. It is smooth and easy to operate and requires little maintenance or additional expense. A variety of electrical appliances can be controlled by this system. Because of it, for the first time since my illness I have choices. By puffing and sipping on a straw, I can adjust the light in my living room to suit my own convenience. I can tune in a concert on the radio or dial a TV special. I am able to summon assistance, when I feel that it is needed, by means of an emergency signal light. I can involve myself in typing projects. I can answer incoming phone calls, and make outgoing calls with the help of the operator. Most important of all, I can engage in my chosen activity whenever I wish and without having someone present to help me.

Each of these two assistive devices--the adapted chair and the comfort-and-communication system--provides its own peculiar benefits. But the chair makes the comfort-and-communication system more accessible. I can pull up to, or back away from, the work-table on which the straw control is mounted.

Outside of my home environment, a further example of this synergistic effect has oc-

curred. The comfort and mobility of self-initiated chair movements has allowed me to make use of the Northwestern University Telephone System designed to permit a severely disabled person to perform in an on-the-job situation. Using a puff-and-sip control, I am able to operate all the functions of a regular push-button call-directory phone: answer incoming calls, put them on hold, dial intercom, release lines, dial out-going calls, and tape messages.

Remarkable as this system is, its usefulness for me was greatly enhanced because of the motorized chair with its recliner unit. It has been said that the value of a disabled employee most often depends upon how little he involves others in assisting him with his personal needs while on the job. The comfort of the chair and the independence it provides minimize the involvement of others. The comfort of the chair also reduces fatigue and allows me to operate effectively throughout a five-day week.

The chair and the telephone system together have made possible my introduction into the worlds of business, medicine, academic life, and research. I have gained increased knowledge, responsibilities, and duties. I have met people from all parts of the world and established new, valued personal relationships.

The three assistive devices referred to above provide mobility, environmental control, and vocational aid. In tandem they have enabled me to have success of a kind which boosts my ego, encourages me to become more involved in life situations, and to strive for greater self-fulfillment.

The developers of the three assistive systems were hopeful that they would result in a reduction of attendant assistance and improve morale. Through the feedback I have provided, they know that their hopes have been realized, at least in some degree.

However, all the synergistic effects have not been easily or quickly achieved, nor have the good and bad effects always been clearcut. I can best illustrate this with an account of the modifications made on my wheelchair.

It should be pointed out that the Northwestern Rehabilitation Engineering Staff did not develop the puff-and-sip controlled wheelchair. Fortunately, I began work at the laboratory shortly after obtaining it.

Although I was well aware of the chair's fast acceleration and abrupt stops producing extreme jerkiness, I was willing to tolerate this in exchange for the first independent mobility I had experienced in seventeen years. I hoped that as I gained experience, my reaction time would decrease and my driving become more skillful.

The engineers at the laboratory, however, looked at the chair with different eyes. They observed that when driving the chair in either forward or reverse direction, I reached maximum speed quickly. This was because the chair was equipped with an on-off control and in many situations did not allow me sufficient time to react. Therefore, rounding corners, clearing dorrways, and executing 90-degree turns were necessarily difficult or impossible. The engineers saw the answer to my problem not in terms of increased effort or experience on my part, but in terms of a technological solution --the acceleration limiter.

Another problem noticed was that there was excessive play in the chair's back. This was especially apparent when I was seated in the chair and riding in a vehicle. The exaggerated motion put undue stress on the supporting bar. The solution was to replace the recliner unit with a new one constructed of heavier, more durable metal.

As it was being installed, the engineers were concerned that I might be unhappy with the slower movements which it necessarily produced. None of us were then aware that the slower movement would prove to be an asset. It gives me more reaction time to choose precisely the angle at which I want to stop, or to reverse the downward direction if I discover the area too limited or obstructed.

The vapor switches controlling the recliner unit provide another example of the impossibility of clearly delineating between good and bad effects. The switches did permit me to change my position, but did not allow me full control because of their sensitivity to the amount of moisture in my breath or in the air.

For example: whenever the chair was brought indoors out of the cold, condensation formed on the switches and caused the chair's back to raise and lower itself until the moisture dissipated. In periods of excessive humidity, my slightest breath would carry the chair beyond the angle at which I wished to stop.

The replacement of these vapor switches with mechanical switches was already in the planning stage when one of the vapor switches failed completely. Out of their consideration for my immediate need, the engineers installed makeshift head switches and speeded up their work on the design for the head switches I have now. They consist of two four-inch cylindrical Delrin tubes, encasing McGill miniature switches, mounted one on each side of my head. No matter where my head makes contact along the four-inch tube, the chair will move.

Another modification of the chair was in the conventional wheelchair head extension. The leatherette soon lost its shape, so that when I reclined, my head rested in a depres-

sion great enough to make reaching for the head switches difficult.

Sometimes I sat in an upright position without the headrest in place and found that the air circulation and light were much greater. Also, my enlarged peripheral vision made for better driving. Many people in the laboratory commented that the removal of the wide, sagging headrest improved my appearance. Thus a new, firmer headrest was designed. It is cut away at the sides and can be removed and replaced as easily as the old one.

The modifications of the chair which I have described were made in answer to needs which I expressed and which the engineering team appreciated. They came to know me as a person and saw that their modifications and systems changed my life style, making me less dependent on them and others, but increasingly dependent on the systems themselves. Thus they recognized the need to make these systems as reliable in performance as possible.

Assistive devices are always developed in anticipation of positive results, with perhaps little thought of possible negative effects. It now seems apparent to me that if the original designers of the puff-and-sip-controlled chair had worked more closely with a disabled person or persons, they might have been able to create a product which met human-factors more adequately. I respect our engineering team for seeing the importance of the chair in my life and for assuming the responsibility of making desirable modifications.

As everyone knows by now, I think highly of my modified chair, but it has brought some problems. Because of the two motors, the two regular-sized car batteries, the heavier re-cliner unit, the acceleration limiter, the head switches, and other attachments, the chair weighs considerably more than a conventional wheelchair. Furthermore, it cannot be folded up for easy storage or transport.

Although I have a ground-level apartment, the threshold step is nine inches high. When I had the lighter-weight wheelchair, this posed a difficulty for my assistant; the heavier chair makes surmounting this step a real hardship. The same thing can be said for the ordinary street curbing. Although my church is only half a block from my apartment, my new wheelchair cannot be carried up the four stairs leading to the sancturary.

I tried to solve my apartment entrance problem with a ramp. A safe ramp must be one running-foot in length for each inch of height. Although it was, therefore, no small object, it was so placed that it did not interfere with anyone's access to the building. It was accepted by all the tenants in my building and in the adjacent building, but it met with strong objections from the landlord. To insure renewal of my lease, I removed the ramp.

In order to go for an outing around the neighborhood and to save my companion the hardship of lifting and lowering the chair over curbs, I use the residential driveways. This means riding for brief periods in the street which poses some hazards.

The problem of church entrance has been solved by the congregation's purchase of a portable ramp. This experience was most gratifying because it showed a recognition of the needs of a disabled person and subsequent action to find an appropriate solution.

The heavier chair also meant that in order to get to my job, twelve miles distant from my apartment, someone had to lift me from my chair and transfer me to the front seat of a station wagon, then, working with another, lift the heavy chair into the back of the vehicle. So long as I worked only two days a week, I was able to get the loan of a vehicle and volunteer drivers. When the opportunity for full-time employment came, other arrangements had to be made.

Upon investigation, I discovered that there was little transportation available to the disabled. That which did exist--private minibus--was fully utilized. I also learned that such transportation averaged approximately $20.00 per day. With the help of others, I was able to put a down payment on a vehicle and assume the expenses of both the van and driver at half the cost. The van is equipped with a hydraulic lift which permits me to remain in my chair during the drive to work. Loading and unloading is performed without great effort.

I realize that private subsidy would not be available to every disabled person. Perhaps in this area of transportation, the government could provide some service for the disabled.

Another way in which the government could be more helpful is in providing motivation for the disabled by supplementing their wages to meet their expenditures. For example, the wages I could earn would not be enough to pay my expenses, which are higher than those of the average employee. Although technology has greatly improved the quality of my life and reduced the amount of assistance I need, it can never completely replace personal care. As a quadriplegic I will always need such help as feeding, bathing, dressing, and grooming. If I accept the available salary at the laboratory, my public aid funds are cut off entirely. Therefore I work as a volunteer. I do it gladly, of course, appreciating the fact that modern technology has enabled me to escape from my former sheltered world to one of greater concern for the needs of others.

Through the Rehabilitation Engineering Program I have been provided with a way to

lead a worthwhile, productive life. Through
the feedback which I provide to the engineers
and through our cooperative efforts, others in
the future may have opportunities similar to
mine.

I am gratified by the growing interest in
a technology involved with the varying human
needs of the disabled. It is a gentle tech-
nology aimed at bettering the lives of a small
segment of society - a segment possessing
hitherto untapped resources which may return
to society, benefits yet unimagined.

SENSORY SUBSTITUTION / BIOFEEDBACK

Chairman, Richard Herman, M.D.
Department of Rehabilitation Medicine,
Temple University School of Medicine &
Krusen Center for Research and
Engineering

Title of Paper: SENSORY SUBSTITUTION FOR PREVENTION OF DECUBITAL ULCERS

Category: (check one)   Device Development /x/   Research Study / /

Brief Description: Decubital ulcers developed from prolonged stationary sitting present serious and costly problems to the spinal cord injured patient. A system was developed which will warn the patient that he has exceeded prescribed ischial or sacral area tissue pressures for an allotted time by providing him with visual and tactile sensory substitution information.

Intended User Group: SCI patients with loss of sensation in the sacral and ischial areas.

Stage of Development: (Check all that are applicable)

A. Device

        Prototype Development   /x/

        Feasibility Testing   / /

        Clinical Testing   /x/

        Available for Sale (check one)   Yes / /   No /x/

            Price per unit $ _____

        Availability of constructional details: Only block diagrams are presented in this paper; but when the system is finally developed, all
B. Research Study   construction details will be made available.

        Intended Utilization: This system is an institutional training/learning system for O.T., P.T., and nursing staff; but, will later be designed into a wheelchair transportable take-home system for patient use.

        Intended Device Application: To be carried by the patient on his wheelchair to remind him to periodically shift his weight.

        Availability of Intended Device: To be made into a commercial production for national distribution.

For further information, contact: Name   Joe Canzoneri
                                     Address Biomedical Engineering Dept.
                                              1333 Moursund Avenue
                                              Houston, Texas   77025

by

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Summary – Decubital ulcers developed from prolonged stationary sitting present serious and costly problems to the spinal cord injured patient. A training/learning system called the REP for reminder of excessive pressure was developed to warn the patient that he has exceeded prescribed ischial or sacral area tissue pressures for an allotted time. The REP system provides visual and tactile sensory substitution information and has two independent monitoring and stimulus producing channels.

A REP system is now being evaluated in the Occupational Therapy Department. Results from this evaluation will be utilized in the redesign of a lower cost and smaller size take-home unit.

A major problem identified in the rehabilitation of spinal cord injured (SCI) patients is that of the formation of decubital ulcers or cellular necrosis produced as a result of prolonged stationary sitting.[2,3] Prolonged obstruction of the local capillary circulation due to excessive pressures leads to cellular necrosis. These ulcers not only increase tremendously the cost of the medical rehabilitation program, but also increase the patient's discomfort and decrease his productivity.

At present, there seems to be no documented evidence of a seat cushion or device that is ideal for prolonged sitting by patients with decreased or no sensation.[5] The general conclusion of many investigators is that only alternate shifting of pressure from one area to another provides adequate protection against the development of ischemic ulcers.[2]

In view of the above, a project is in progress for the purpose of developing a system which will provide sensory substitution information to those SCI patients with loss of sensation in the sacral and ischial areas. The system is to alert the patient when he has exceeded prescribed pressures for longer than an allotted time.[6] Since this problem is a

serious one, it is necessary that the SCI patient pay attention to the given warning. Therefore it was decided to remind the patient by providing him with an electrical stimulus in addition to a visual one.

The system described herein was designed primarily as a training/learning instrument (1) to train the SCI patient to periodically shift his weight, etc., and (2) to study and evaluate the respective problems and solutions associated with decubitus ulcers resulting from excessive stationary sitting.[1,4] Dubbed the "REP," for "reminder of excessive pressure," the system provides two independent channels of biofeedback in the form of visual and percutaneously applied electrical stimuli.

In general, the operation of the REP system can be expressed in terms of the following conditional statements:

If the pre-adjusted pressure threshold, P_t, is exceeded, a warning light will glow. After a 5 minute* interval of sustained pressure above the P_t value, the patient will begin to receive a continuous electrical stimulation. Once the 5 minute time interval has elapsed, the electrical stimulation will cease immediately if the patient relieves the pressure from the tissue area being monitored, but will be re-initiated each time a pressure value above P_t is exceeded. The patient must relieve the pressure below the P_t value for a non-accumulative period of 15 seconds* in order to be awarded a 5 minute interval free of electrical stimulation. Since each channel of the REP system is independent of the other, the patient can be trained to shift his weight from one side to the other thus satisfying the requirements to avoid stimulation.

The system is presently being modified to include an additional warning light which will glow 30 seconds prior to time out of the 5 minute interval timer. This light will warn the patient that he is about to be stimulated and thus he can shift his weight to avoid the stimulation. This feature should be useful in the early training phase.

Shown in Figure 1 is the block diagram of the basic system which is comprised of three major sub-systems: 1) the pressure sensors, 2) the electronic unit, 3) the electrodes. The pressure sensing elements

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(Figure 2), which are presently blood pressure cuff bladders, and the pressure transducers (Bell & Howell bonded strain gage type #4-312-0007) will eventually be replaced by wafer-thin transducers.
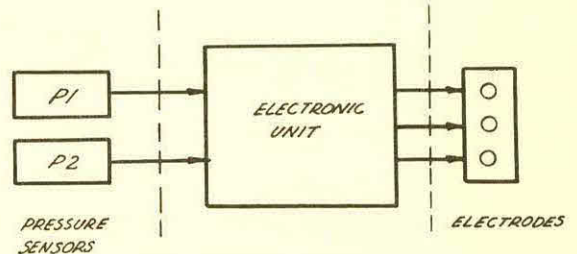

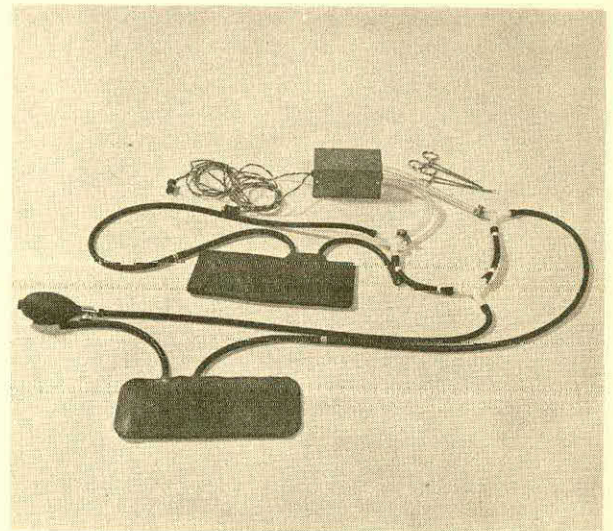Figure 1. "REP" Basic System Block Diagram

Figure 2. Pressure Sensing Elements

The electronics unit (Figure 3) contains the controls, displays, pressure signal conditioners, decision-making elements, and electrical stimulators. The range of pressure measurement is 0 - 200 mm Hg.

The electrodes (Figure 4) are of the gauze covered button type mounted on a velcro-elastic belt. The center electrode is common to both the left and right channels. For quadriplegics, a small belt is used with electrode placement on the arms, and for paraplegics a larger torso belt is used for electrode placement on the patient's back.
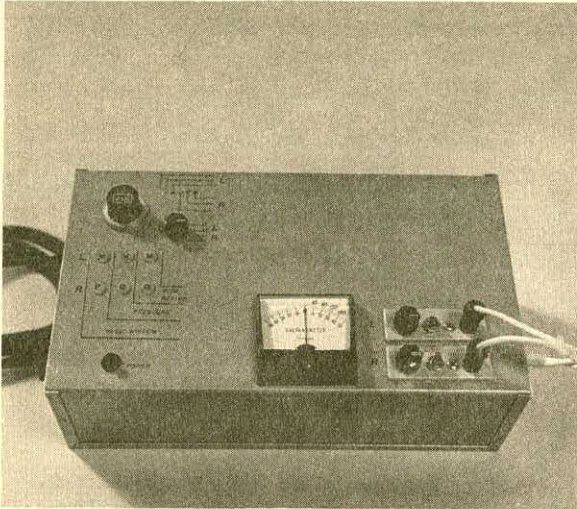
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* times are adjustable
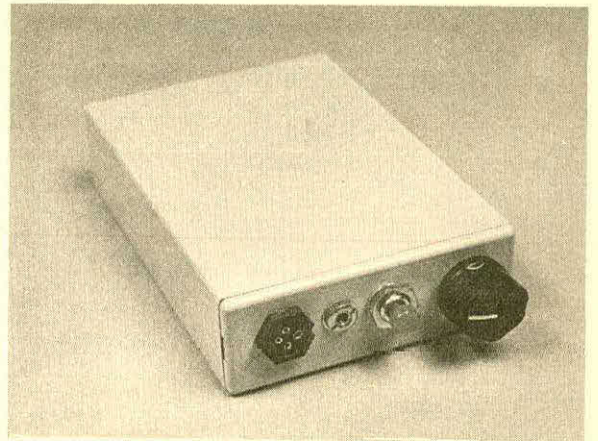
Figure 3. Electronics Unit

Figure 5. Electrical Stimulator (ENA-2)

A complete REP system is shown in Figure 6 and a detailed block diagram is shown in Figure 7 to illustrate the major elements of one channel. Figure 8 shows an occupational therapist during the initial evaluation phase of the system.
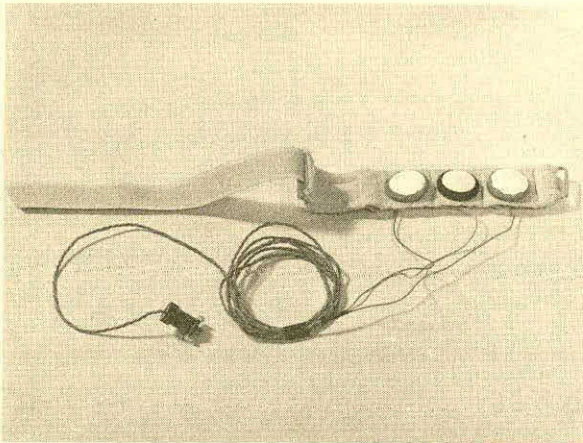
Figure 4. Stimulator Electrodes

Harmless stimulation is produced by the electrical stimulators (Figure 5) because their output strength is limited. In fact, they are ENA-2 units which are used in the TIRR stroke program or peroneal nerve stimulation to produce dorsal flexion of the so-called drop foot. The stimulus parameters are constant current fixed amplitude pulses, 1 ms wide and 20 Hz pulse repetition rate.
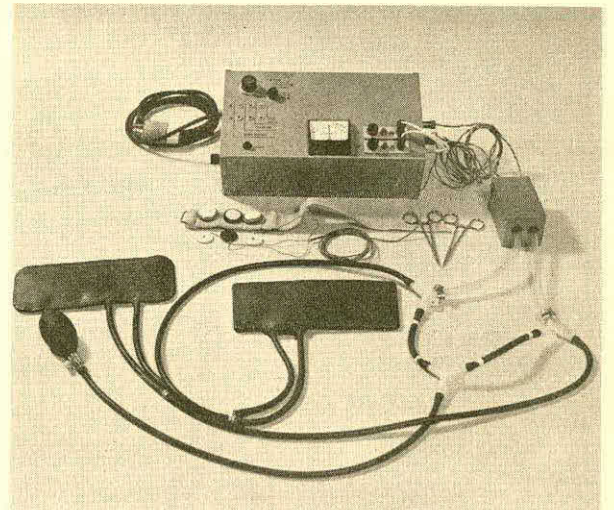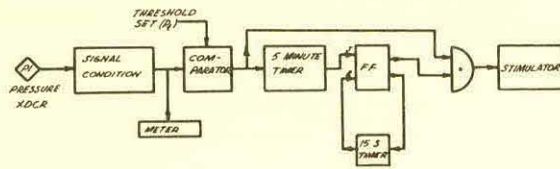

Figure 6. REP System

Figure 7.   Detailed Block Diagram
            of "REP" System

Figure 8.   O.T. Evaluating "REP" System

Early reports from the Occupational Therapy Department inform us that the REP system appears to be an effective method of biofeedback training. It is easily adjusted to various seat dimensions, threshold pressures, and intensity of stimulation. The pressure sensors are quickly and easily applied in the appropriate location on the wheelchair seat. Recommended modifications are that it be made wheelchair transportable and that the time interval be made adjustable to allow for more specific individual application.

The REP system as it is now has two identical channels and is only intended to be a training/learning device. In the future, after considerable evaluation data is obtained, the system will be simplified and redesigned into a lower cost take-home system.

References

1. Hertzberg, H.T.E. Some Contributions of Applied Physical Anthropology to Human Engineering. New York Academy of Science Annals, 63, 1955.

2. Houle, Rollin J. Evaluation of Seat Devices Designed to Prevent Ischemic Ulcers in Paraplegic Patients. Archives of Physical Medicine, 50, October 1969.

3. Kosiak, Michael, et al. Evaluation of Pressure as a Factor in the Production of Ischial Ulcers. Archives of Physical Medicine and Rehabilitation, 39, October 1958.

4. Krouskop, Thomas, et al. Effects of Posture on Pressure Distribution Under Wheelchair-Bound Patients. To be presented at the Symposium for "Devices and Systems for the Disabled," April 29 thru 30, 1975, Philadelphia, Pennsylvania.

5. Mooney, V., et al. Comparison of Pressure Distribution Qualities in Seat Cushions. Bulletin of Prosthetics Research, Spring 1971, 129-143.

6. Patterson, R.P. and Stradal, L.C. Warning Device for the Presention of Ischaemic Ulcers in Patients Who Have Injured the Spinal Cord. Medical and Biological Engineering, July 1973, 540-505.

Title of Paper: BRAIN PLASTICITY AS A BASIS FOR SENSORY SUBSTITUTION

Category: (check one)   Device Development /‾/   Research Study /X/

Brief Description: of the Vision and Auditory Tactile Sensory
 Substitution System developed by the Smith-Kettlewell Institute
 of Visual Sciences. The principal part of the paper will be
 a discussion of the theoretical (primarily brain plasticity)
 basis of sensory substitution.

Intended User Group: All

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   /X/

    Feasibility Testing   /X/

    Clinical Testing   /‾/

    Available for Sale (check one)   Yes /‾/   No /X/

        Price per unit $ _____

    Availability of constructional details:

B. Research Study

    Intended Utilization: All groups interested in
    sensory substitution.

    Intended Device Application: Sensory aids.

    Availability of Intended Device: Not at present.

For further information, contact: Name   Paul Bach-y-Rita, M.D.
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BRAIN PLASTICITY AS A BASIS FOR SENSORY SUBSTITUTION

by

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San Francisco, California

Summary - Sensory substitution systems such as those developed at the Smith-Kettlewell Institute of Visual Sciences for deaf and blind persons take advantage of the capacity of the brain to reorganize in response to functional needs. This paper will evaluate neural mechanisms that may underlie these adaptive capacities. The practical implications will be discussed.

The achievements of the human brain are dependent upon its plasticity, i.e., its adaptibility to change. Without alterable structures and connections, the central nervous system (CNS) would be unable to adapt to new demands or to meet the dangers of life. Learning would be impossible, as would be restoration of adequate function following cerebral damage. Indeed, CNS plasticity may be the major factor in functional recovery following brain lesions in man; in turn, such recovery provides convincing evidence for plasticity.

In recent years brain plasticity has been demonstrated by an entirely different type of functional adaptation, with studies of sensory substitution. Sensory plasticity has been defined as the ability of one sensory system to assume the functions of another sensory system. That is, the receptors, sensory pathways and CNS representation of a sense such as vision are functionally replaced by those of another sensory system, such as touch. The actual specialized receptors of the eye, the rods and cones of the retina, cannot, of course, be replaced by skin receptors which are too insensitive to light; rather, artificial receptors sensitive to optical signals must be used.

Sensory substitution may be defined as the replacement of the normal input of a lost or damaged sensory system by information received through intact channels of another sensory system. Its practical realization, even on a limited scale, had to await technological developments and advances in electronics of the last few decades. Today it is possible for a blind person to receive a certain amount of pictorial information through his skin rather than through his eyes. A miniature television camera can be substituted for the eye to receive optical signals; it can be directed to different parts of the "visual" field by the blind subject. The optical signals captured by the camera are transduced electronically into signals or patterned stimuli to the skin for relay to the brain.

A number of systems have been designed, in different laboratories, to relay optical information to the brain through the skin of blind persons. Each of these systems utilizes a matrix or mosaic of artificial photoreceptors

connected point-to-point with a corresponding matrix of stimulators on the skin.

The skin of the fingertips is extremely sensitive; Linvill and Bliss[1] and Bliss[2] have made use of this sensitivity in developing a reading aid for the blind. The Optacon has six rows of 24 tactors, or skin stimulators, which provide excellent resolution of one letter at a time as the fingertip is moved along a line of printed matter; with this apparatus, blind persons can read at rates up to 80 words or more per minute.

We have developed several systems of presenting optical information to the skin of the trunk. With this approach, the hands are freed for other tasks. Further, it has allowed us to present three-dimensional information. Our first system, designed to test the feasibility of projecting visual information through the somatosensory system, was a cumbersome mechanical device utilizing a 20 x 20 array of vibrating rods to impress the image on the skin of the back. With this system we could determine that tactile-visual substitution was indeed a practical method of presenting visual information to the blind. Our next system was electrical, designed for greater economy of space and weight; pulses of electrical stimulation were delivered to a 16 x 16 array on the skin of the abdomen. In an effort to achieve greater detail and resolution of pictorial information, we are developing a more refined portable system with an array of 32 x 32 electrical stimulators to the abdomen. With each of the systems studied, even congenitally blind persons have developed the ability to process the information received through artificial channels by visual means of analysis so that it can be used as a visual input.

Our original involvement with techniques of sensory substitution was founded on the premise that the brain had sufficient plasticity to provide a substrate for processing information received through one sensory channel in terms of another sense. Some of the evidence for such plasticity will now be discussed briefly, followed by a description of some of the neuronal mech-

anisms which may underlie such plasticity. Our results, and the theoretical basis for our work, has been discussed elsewhere[3-13]. The remainder of this paper will largely summarize this work, and so additional references will only relate to studies not cited in these publications.

An evaluation of clinical data, particularly with reference to the recovery of function following extensive damage, has supplied some of the strongest evidence for cerebral plasticity. The extent of recovery following lesions in highly differentiated structures in the brain and spinal cord has been shown to be greater than previously thought. Thus many paraplegics, who used to be considered hopeless cripples, can now be returned to gainful activity provided extensive treatment and training is begun early enough after the onset of their disability. Several important studies of war injuries have demonstrated the ability of the CNS to reorganize and to recover, to a greater or lesser extent, many functions damaged by the lesions. With sufficient training and motivation, arm and even hand movements can be restored in adult human patients in spite of anatomically verified degeneration of the pyramidal tract. A variable degree of recovery is possible even following extensive brain damage due to stroke or other types of cerebral vascular accidents; the extent of recovery seems correlated with motivation and intensive training as well as being dependent on the type and amount of brain tissue which escaped damage.

Experimentally produced brain lesions have long been studied in an effort to determine conditions under which functional recovery can occur. When removal of an area produces an initial functional deficit, and if those parts of the brain remaining intact assume the lost functions, this indicates a reorganization of cerebral tissue. The studies of early investigators of experimental lesions led to the conclusion that the high degree of plasticity in man and higher vertebrates is due to dynamic reorganization and adaptation to new circumstances rather than to actual regeneration of the damaged structures.

Recovery following experimental removal of specific brain areas requires time. It is improved by forced use, for example, of a limb paralyzed by removal of the corresponding motor cortical area. Training is of great importance in functional recovery from many types of experimental (and clinical) lesions. Recovery has been shown also to be dependent on the abruptness of onset of a total lesion, compared with a gradual or sequential removal of tissue(14).

A number of factors and neural mechanisms are considered to contribute to the plasticity and variability of the CNS. Some of these must underlie the ability to compensate for functional disabilities caused by injury or disease. Presumably they also permit the CNS to adapt to new functional demands such as those imposed on a given sensory system by sensory substitution.

With the Tactile Vision Substitution System (TVSS), a mosaic of stimulators will activate receptors in the skin. From these receptors, impulses travel to the spinal cord and up to the brain by one or more of several available paths. The impulses will be relayed through various synaptic junctions on their way to the higher centers of the cortex, where they will be processed and analyzed for ultimate interpretation of the "visual" information. At several parts of these sensory paths and centers, mechanisms for plasticity are known. Some of these will now be discussed briefly.

Certain mechanisms are available for altering or modifying the sensory input from the skin itself. One of these, a type of sensory inhibition, provides an increase in contrast and sharpens controus of an impressed image. This is lateral inhibition, a mechanism found in the retina and in the skin; when a single receptor is activated, the adjacent and immediately surrounding receptors will be inhibited. A second type of modification of sensory input is known as centrifugal or descending control; such control is imposed on lower parts of the sensory system from higher centers. The descending control components are predominantly inhibitory and have the effect of filtering out excess or extraneous information by selectively allowing only parts of the sensory input to proceed to higher CNS levels. An ultimate outcome of normal centrifugal control is that the brain is not overloaded or bombarded with excessive signals.

Plastic changes in the CNS can be demonstrated by alterations in structure and biochemistry of parts of the nervous system at the cellular level. While it is known that nerve cell bodies do not regenerate after destruction, their processes, the axons and dendrites, can and do respond to functional demands. A number of morphological and chemical changes in neurons have been shown to be associated with use and disuse. For example, in studies comparing animals reared in sensory-rich and in sensory-deprived environments, use and disuse of neurons have been correlated with biochemical alterations such as changes in acetylcholine levels and with morphological alterations such as in the number of dendrites, dendritic spines, and cortical cell junctions. Recent evidence indicates that the responses of individual cortical neurons can be and are modified during the learning process; experiments reveal that persistent plastic changes occur as a function of learning. A number of studies indicate that individual cells may participate in many tasks, and may be recruited for particular learned tasks. Among the consequences of this, one most important consideration is that the cortical area representing a particular part of the body is not static, but rather changes in response to current demands.

The functional reorganization of the CNS which underlies the recovery from brain damage is accomplished in part by the establishment of new synapses and the facilitation of existing synapses. Potential connections are transformed into actual connections; other synapses are inhibited or suppressed. The probability that some synapses and pathways exist as a "subliminal fringe" is supported by data from the study of human patients with lesions of the precentral gyrus or internal capsule. For example, the degree of paralysis of an affected

limb varies from day to day in such patients. Indeed, the paralysis may partially or wholly disappear during an emotional disturbance, only to recur when the disturbance is over. These clinical observations are part of a large body of evidence which suggests that the central structures and pathways subserving any function are potentially larger in number than in baseline conditions. The "subliminal fringe" also suggests the presence of structures and pathways available to a CNS in the process of learning to adapt to a substitute sensory system.

Cortical areas are not exclusively conerned with a single unique function; each area is involved in multiple functions. This multiplicity of functions offers a further substrate for functional reorganization which may be applicable to sensory substitution as well as to recovery from CNS lesions.

Our extensive early work with vision substitution has led us to certain conclusions regarding the potentialities and limitations of the TVSS. Even with further refinements of equipment in terms of greater resolution of details of pictorial information, we foresee utility in practical terms of educational and vocational applications rather than as an aid to mobility in everyday use. The blind person has to recognize his disability and must adjust his daily living to compensate for his handicap. The TVSS can be used as a tool to improve certain specific parts of his life; it should not be posed as a threat to the adjustments already made by the blind.

There are several applications of the TVSS which have already proven beneficial in education. Pictorial information including forms, objects, letters, and graphical material such as bar graphs can be presented to, and recognized by, blind persons trained in the use of the TVSS. Instruction on spatial perception, as in the appearance of a coin from different angles, or the localization in depth of several objects in the field of vision, has provided our blind subjects with concepts not available by any other means. Concepts of visual space, and visual techniques of analysis, are important

to a number of disciplines including experimental psychology, physics and philosophy. Intensive training of congenitally blind persons with a professional interest in visual concepts has demonstrated visual phenomena and taught certain concepts to these persons for the first time. An example of adaptation of the TVSS to special educational purposes can be found in the use of a TV camera mounted in the eyepiece of a microscope. This has enabled blind students to appreciate microscopic displays such as the details of a fly's wing or the structure of salt crystals.

Many blind persons have indicated that a major need is for some type of visual aid which would increase their employment opportunities. Several specific job categories which require an amount of visual information within the presentation capacities of the present TVSS have already been identified. These include the fields of electronics and biomedical instrumentation. A major tool used by electronic engineers and technicians is the oscilloscope; a TVSS with a miniature camera attached to an oscilloscope screen has already proven useful in increasing the occupational capacity of a blind electronics technician on our own staff. Microcircuitry assembly by the blind with the use of a modified TVSS is currently being tested with promising results. In fact, a three-month, on-the-job study revealed that a totally blind assembly line worker was able to perform the microassembly and inspection tasks in the same time and with the same accuracy as the sighted workers.

The techniques of communication through the skin which have permitted replacement of some types of visual input for the blind are also applicable to other types of disability including deafness, loss of touch sensation and amputation.

Some of the problems of the profoundly deaf are currently being studied with the development of a portable speech-analyzing tactile aid which translates sound into touch patterns on the skin. Sounds in the relevant part of the hearing spectrum are picked up by a microphone and

analyzed according to frequency. The frequencies are displayed on a belt of tactile stimulators across the chest or forehead, arranged in order from low to high as on a piano keyboard. We foresee that our tactile auditory system could provide a measureable improvement in the daily life and the vocational capability of deaf persons. For the adult, our system can supplement the visual cues of lip-reading as well as permit identification of such common auditory signals as doorbells, telephone ringing and sirens. For the deaf student receiving speech training, the system provides the information necessary for him to regulate the intensity and rhythm of his own voice, and allows a direct comparison of his vocal sounds with those of a teacher or a recorded model. For the profoundly deaf infant, our system promises to provide feedback during babbling and other self-produced sounds, without which he soon becomes mute. While our system has already produced encouraging results, it should be recognized that its development is still only in a preliminary stage.

A replacement for the lost sense of touch is also under investigation. Some individuals lose the sense of feeling in their fingers due to nerve injury or disease. For such persons, a special glove has been fabricated with pressure and temperature transducers on the fingertips. These relay the pattern "felt" on the fingertips to an area of healthy skin on another part of the body, providing information on the shape and texture of objects and surfaces, and helping avoid trauma such as burns.

For an amputee with limb prosthesis, we have proposed a tactile kinesthetic substitution system designed to provide information on the position of joints. From our experience with other types of sensory substitution, we suggest an amputee should be able to learn to respond to the stimulus as if it originated in the appropriate part of the prosthesis. Thus the ultimate result could be that the prosthesis would become functionally a part of his body.

Communication through the skin may be of value not only in substituting for functions of a lost or diseased sensory system, but also in the augmentation of existing, functioning senses. For example, we have proposed utilization of tactile input of flight instrument information to a pilot for aircraft flight control. Preliminary testing has already demonstrated the feasibility of supplementing information to an otherwise overloaded pilot. Instrument-rated pilots have successfully controlled a sophisticated aircraft flight simulator, making satisfactory landings under gusty weather conditions. Additional possibilities for sensory augmentation by cutaneous stimulation include supplying patterned directional information to divers for underwater orientation, and permitting communication in a noisy environment.

Recently, a group at New York University has applied sensory substitution concepts to the treatment of patients with several neurological diseases including spasmodic torticollis, dystonia and hemiparetic disorders of varied etiology[15,16]. Their excellent results have demonstrated that brain plasticity concepts have practical applications in these disease states.

There are doubtless many other possible extensions of sensory substitution to aid the disabled and the healthy. Techniques are constantly improving and systems are being refined. It has already been well documented that the brain does exhibit sufficient plasticity to process information from one sensory system in terms of another sense. Among potential applications of sensory substitution systems may be mentioned their contribution as tools for basic scientific investigations into the mechanisms underlying not only brain plasticity but also other CNS functions. Sensory substitution today is in an early stage of development; its future would appear to hold great promise.

1. Bliss, J. D. Proc. tactile displays conference. IEEE Trans. Man-Machine Syst. 11:1-122, 1970.

2. Linville, J. G. and Bliss, J. C. A direct translation reading aid for the blind. Proc. IEEE 54:40-51, 1966.

3. Bach-Rita, P. Sensory plasticity: Applications to a vision substitution system. Acta neurol. scand. 43:417-426, 1967.

4. Bach-y-Rita, P. Brain Mechanisms in Sensory Substitution. New York: Academic Press, 1972.

5. Bach-y-Rita, P. Comments on central nervous plasticity. In, Cerebral Localization, K. J. Zulch (Ed.) Berlin: Springer-Verlag (in press).

6. Bach-y-Rita, P. Visual information through the skin—A tactile vision substitution system. Trans. Amer. Acad. Ophthal. Otolaryng. 78:729-740, 1974.

7. Bach-y-Rita, P. Sensory substitution. In, Handbook of Sensory Physiology, Vol. VIII, "Perception." New York: Springer-Verlag (in press).

8. Bach-y-Rita, P., Collins, C. C., Saunders, F., White, B., and Scadden, L. Vision substitution by tactile image projection. Nature 221:963-964, 1969.

9. Collins, C. C. and Madey, J. M. Tactile sensory replacement. Proc. San Diego Biomedical Symposium. Vol. 13, 1974, pp 15-26.

10. Guarniero, G. Experience of tactile vision. Perception 3:101-104, 1974.

11. Scadden, L. A. The tactile vision substitution system: Applications in education and employment. New Outlook for the Blind 68:394-397, 1974.

12. White, B. W., Saunders, F. A., Scadden, L., Bach-y-Rita, P., and Collins, C. C. Seeing with the skin. Perception and Psychophysics 7:23-27, 1970.

13. Stein, D. C., Rosen, J. J. and Butters, N. Plasticity and Recovery of Function in the Central Nervous System. New York: Academic Press, 1974.

14. Brudny, J., Grynbaum, B. B. and Korein, J. Spasmodic torticollis: Treatment by feedback display. Arch phys. Med. 55:403-408, 1974.

15. Brudny, J., Korein, J., Levidow, L., Grynbaum, B. B., Lieberman, A., and Friedmann, L. W. Neurol. 24:925-932, 1974.

Title of Paper: THE LIMB LOAD MONITOR: AN AUGMENTED SENSORY FEEDBACK DEVICE

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: The limb load monitor is a biofeedback device which is designed to provide continual auditory information for lower limb loading The device is comprised of a force sensor which is fabricated as an insert to the patient's shoe, and a control box which houses the auditory display. The device is set to the desired limb loading and the patient receives immediate auditory information about correct or incorrect loading.

Intended User Group: Physicians, physical therapists, occupational therapists, nurses, patients who require increased or restricted loading on an involved limb.

Stage of Development: (Check all that are applicable)

   A.   Device

            Prototype Development   / /

            Feasibility Testing   / /

            Clinical Testing   /X/

            Available for Sale (check one)   Yes /X/   No / /

               Price per unit $ 300.00

            Availability of constructional details:

   B.   Research Study

            Intended Utilization: _____

            _____
            _____
            _____

            Intended Device Application: _____

            _____
            _____
            _____

            Availability of Intended Device: _____

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THE LIMB LOAD MONITOR: AN AUGMENTED
SENSORY FEEDBACK DEVICE

by

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Summary - The limb load monitor, a biofeedback tool, was designed to provide the patient with precise, continual information about the amount of weight placed on the lower limb. Using the limb load monitor, the patient can monitor proper loading and is provided with information with which to correct improper loading. Two studies were conducted to determine the clinical usefulness of the limb load monitor. The purpose of the first study was to describe the patient population who can benefit from use of the device, its effect on goal achievement when incorporated in the treatment program, and the therapists' reactions to its ease of operation and clinical applicability. The second study was designed to assess the ability of the patient with brain injury to retain a skill acquired using the device. This paper will discuss the results of these two studies.

Introduction

Ambulation training is an important phase of the rehabilitation process in patients with a variety of disabilities. Specifically, this training should be concerned with such control factors as standing balance, initiation of the stepping cycle, and symmetrical limb placement and loading. Patients who have sustained a peripheral or central sensorimotor and/or motor sensory lesion may lack adequate sensory information and/or integrative processing of sensory information by which proper spatio-temporal patterns can be developed to guide limb movement. Most likely, this inability is due to impaired spatial data reduction of sensory information, leading to defective calibration of input signals. As a result, there may be dissociation or a mismatch between the intended act and information of the actual performance. [1]

What methods can be utilized during ambulation to enhance compensation for such deficits? The Krusen Research Center staff have developed a series of sensory aids to provide patients with an informational source to enhance the ability to recalibrate. Recalibration, therefore, is the most important issue in compensating for sensorimotor disturbances. The limb load monitor (LLM) is one of the sensory aid systems designed and developed at the Krusen Research Center.

This device provides continual, precise information of limb loading during standing and walking. This information is delivered, without significant temporal delay, through intact auditory channels. In this manner, the patient is made aware of the direction and magnitude of the error between intended and actual limb loading.

Investigations

The applicability of an instrument and claims of its clinical usefulness must be demonstrated objectively if it is to be widely accepted by clinicians. The successful transfer of a device from the design and development scientific study stage to the clinical setting requires: 1) a precise definition of the relevant patient population and selection criteria, 2) a set of clear and concise operating instructions and treatment techniques, and 3) evidence of the device's clinical usefulness with patients as demonstrated by a structured and well organized clinical investigation. Therefore, following the initial testing of the LLM which affirmed its linearity and reliability, two separate studies were executed to establish the efficacy of the LLM as a therapeutic tool to enhance control of balance and locomotion. The first study was designed to evaluate the suitability and usefulness of the LLM in the clinic. The second study was conducted

because it was not clear whether certain categories of patients (e.g., brain injured) could retain the achieved level of performance over a period of time without the sensory information provided by the device.

Device Description

The LLM is comprised of a force sensor (transducer) which is fabricated as an insert in the patient's shoe, and a control box which houses the auditory display; the latter is connected to the transducer by a coaxial cable and is generally worn on the belt (See Figure 1).

The transducer consists of three layers of copper Mylar laminate separated by two layers of closed cell foam tape. The middle layer of metal is connected to an inner conductor and the outer two layers are connected to the shield of the coaxial cable. The configuration acts as a force variable capacitor which "senses" total vertical force applied at any point.

The circuitry within the control box is utilized to transform the capacitance input to a voltage output, leading to a display of an auditory signal with the frequency changing as a function of the load. The "null point" is defined as that point at which the pitch of the tone passes through zero Hertz and it occurs when the desired amount of weight is borne on the extremity.

Two modes of feedback signal are available. In Mode 1, as load increases toward the desired level, auditory frequency decreases until the "null" point is achieved. In Mode 2 the signal is initiated at the desired "null" level and increases as a function of load. Hence, by utilizing this device, the therapist can provide both a precalibrated loading level ("the intended performance") and an on-line feedback source of actual load development ("the actual performance"). When the null point is reached, the patient has properly matched the intended with the actual performance.

Clinical Study

Questions to be answered by this study included: Does the limb load monitor facilitate loading? What categories of patients benefit from the use of the LLM? Can this treatment approach be standardized with different patients? Is the LLM easy to operate? Do therapists consider the device to be useful?

Methodology

Setting: Two general hospitals, two rehabilitation centers, and a large private orthopedic practice were selected as sites in order to examine the efficacy of the LLM in a patient population comprised of various disability categories. This six-month trial enabled the limb load monitor to be assessed with inpatients who were considered to be either acute and short-term, e.g., patients with fractures, or chronic and long-term, e.g., patients with amputation or hemiplegia; another category, namely outpatients with orthopedic disabilities was investigated.

Sample: The LLM was used in ambulation therapy among 49 men and women with a mean age of 52 years (Table 1). Both inpatients and outpatients were included in this number. The patient population could be classified into two categories: patients with orthopedic disabilities and patients with neurologic disabilities. Thirty-four patients demonstrated orthopedic disabilities, which included post-fractures, total hip replacements, and lower limb amputations. The neurological category of fifteen patients included the subgroups of hemiplegia, cerebellar ataxia and paresis. An additional twenty-four patients with repaired intracapsular or extracapsular hip fracture received treatment with the LLM. Results for these patients are subjective and will be included in the discussion.

Procedure

All therapists were instructed in the application technique (e.g., calibration functions). Patient selection criteria were based upon: 1) readiness for ambulation therapy or training, 2) adequate discrimination of varying auditory frequency levels, and 3) ability to correlate the auditory frequency to the preselected or calibrated level of loading. Selection criteria based upon the patient's diagnosis or category of disability, and standardization of the feedback technique or method were determined independently by the therapist. With suitable functional progress, and the ability to calibrate the LLM independently, the patients were permitted to utilize the device on the inpatient service or at home following discharge.

When a patient was selected to use the LLM, the ambulation subgoal of symmetrical weightbearing, weight shifting, or limited or incremental loading during walking was recorded in a log. Therapists also recorded

Table 1. Record of Patients who Participated in the Limb Load Monitor Clinical Study

Patient Diagnostic Category	No. of Patients	Age (Yrs)		Sex		Achieved Loading Status (%)	Progressed to Less Supportive Device(%)	No. of Rx's	
		Median	Range	M	F			Median	Range
ORTHOPEDIC	34	56	12-86	20	14	30 (.88)	18 (.60)	8	2-44
Limb Fracture	16	49	12-79	7	9	12 (.75)	6 (.50)	5	2-17
Total Hip	9	65	28-80	9	0	8 (.89)	5 (.63)	8	6-11
Amputation	9	62	12-86	4	5	9 (1.0)	7 (.78)	24	6-44
NEUROLOGICAL	15	56	16-73	10	5	14 (.93)	6 (.40)	7	1-36
Right Hemiplegia	7	62	21-73	5	2	6 (.86)	2 (.29)	7	3-19
Left Hemiplegia	5	64	46-64	3	2	5 (1.0)	3 (.60)	9	2-36
Ataxia	2	20	16-24	2	0	2 (1.0)	1 (.50)	9	2-17
Paraparesis	1	–	–	0	1	1 (1.0)	0 (0)	–	–

the following information for each patient: functional diagnosis, age, sex, treatment goal, initial and final loading status, initial and final assistive device, and number and length of treatment sessions utilizing the limb load monitor.

At the conclusion of the six-month trial, clinicians who used the limb load monitor were asked to evaluate its functional usefulness and its ease of operation.

Results

Eighty-nine percent of the patients demonstrated improved loading status accompanied by precise control of loading; forty-nine percent progressed to a less supportive assistive device within an average period of eleven treatment sessions of thirty minutes duration. Forty-eight percent of the patients were able to utilize the device outside the clinic, e.g., on the inpatient service or at home.

Both orthopedic and neurologic patients were selected to use the LLM and demonstrated an improved loading status with use of the device. The post-fracture patients were selected most often and achieved the ambulation treatment goal within the shortest number of treatment sessions. In general, patients with lower limb amputation required more

treatment sessions than were required of all of the sub-groups in order to achieve an improved loading status as well as precision loading. There was a tendency for patients in the neurologic sub-group to require considerably more treatment sessions as compared to the post-fracture and hip replacement groups. This result is most evident when comparing the ranges of the number of treatment sessions among these three groups. Seven of the fifteen neurological patients (compared to four of the twenty-five postfracture and total hip replacement patients) required more than eight treatment sessions to achieve the program goal.

Although no standard treatment was outlined for the therapist, specific ambulation training techniques were developed by the therapists during the clinical trial. Patients with fractures were selected as candidates when restriction to a prescribed load was desired or gait observation revealed that the patient was unable to increase loading on the limb during "routine" treatment sessions. If a patient who sustained a total hip arthroplasty expressed or demonstrated fear of loading, and/or could not load the limb with the equivalent of 30% of body weight four days post-surgically, the patient was selected as a candidate.

Following patient selection, the LLM was

used similarly with both groups of patients, i.e., patients with fractures and with total hip replacement. For these patients, the objective was to use the LLM as an aid to achieve control of independent ambulation with the necessary assistive device.

Patients with lower limb amputation or with a neurological disability were selected as candidates if they demonstrated difficulty in standing with symmetrical loading, shifting weight in the anterior-posterior or medial-lateral planes during standing, and/or fully loading the "involved" limb during walking. The ambulation program for these patients was defined as a more complex procedure than for the patients with fractures or total hip replacement, as proper limb loading is only one of several sub-goals in the ambulation training process.

The therapists reported that the LLM was easy to operate and required a maximum of five minutes for patient application and calibration. During the six-month trial, the only reported interruption in equipment service was the need to replace batteries.

Concerning the usefulness of the device, on the basis of their past clinical experience, the majority of the clinicans (90%) felt that the device was useful in enhancing the ambulation training program of the patient with orthopedic and neurologic disability for the following reasons: 1) it aided in allaying the patient's fear of loading; 2) it enabled precise monitoring; 3) it provided a tool for independent ambulation according to the prescribed loading; and 4) it provided an objective measure of progress.

Discussion

The results of this study indicate that continual information (i.e., of the magnitude and direction) of limb loading enabled patients to load their limb consistently within the prescribed restricted weight, or to increase limb loading gradually.

The complexity of the ambulation program for both the amputee group and the neurologic category, as compared to the post-fracture and hip arthroplasty sub-group, was considered to be cause for the larger number of treatment sessions. For example, 88% of the amputees experienced secondary complications which delayed post-operative recovery. The ambulation training process would include such tasks as standing balance, weight shifting, control of limb placement and proper loading,

a sequence of events unnecessary with the post-fracture and hip arthroplasty patients.

The success of the program among patients who used the device indicates its suitability for these categories of patients, and the clinician's comments about the use of the device support its clinical efficacy. However, this study made it obvious that one general standardized approach is not adequate for all patient categories. Materials which describe the use of the limb load monitor must detail its application with each category of patients if the device is to be applicable to a variety of disability categories. In addition, training programs which emphasize these approaches may augment the use of the LLM.

A final question posed by therapists and unanswered by this study was whether the patient with brain injury could retain the skill acquired through use of the LLM. The following laboratory study was therefore conducted.

Laboratory Study

The goal of this study was to train hemiplegic patients to achieve equal weight-bearing during standing, without the use of any external support, e.g., a cane.

Methodology

Sample: Twelve hemiplegic patients (two and one-half years post-stroke) who had completed a conventional therapy program and, therefore, were considered to have attained optimal recovery were selected to participate in this study. The selection criteria required that the patient possess good hearing (frequency discrimination), and no overt mental disturbance or other diagnosis which would interfere with ambulation training. Hemiplegics with right and left side involvement were equally represented. Their ages ranged from 30-60 years and their disabilities revealed varying degrees of involvement, e.g., the extent of spasticity, and of sensorimotor control, and the need for an assistive device for ambulation.

Procedure

Each patient was given an LLM to use during the training period. The patients were seen one or two times per week for half hour sessions. A training session at the Center consisted of an initial assessment of standing performance and practice period of about twenty minutes. At the beginning of the session, the patient was equipped with an LLM and the device was calibrated for 50% bodyweight. For

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the assessment, the patient stood "straight" (on the force plates) for two minutes without feedback; this provided an immediate readout of loading performance.

A training session consisted of an initial assessment of standing performance and a practice period of approximately twenty minutes. The practice consisted of one-minute standing, and one-minute resting periods, with feedback elicited periodically, i.e., each one-minute period, alternate periods, every third period, etc., according to the patient's level of performance. To test the sensivity of the feedback techniques, the audio signal was turned on and off; this was utilized to indicate to the patient the magnitude of the error in loading. After the second visit, the patients were usually familiar with the device and could take it home for regular training. If necessary, a family member was taught how to handle the device and how to conduct the practice procedures.

At home, training was conducted for half-hour sessions which consisted of one-minute standing periods, utilizing feedback, and short rests in between. The patients and accompanying family members were interviewed at each visit to determine the regularity of the practice sessions.

When the patient could maintain symmetrical standing on the force plates without feedback, he was subjected to perturbations by means of four slight pushes, one from each side of the body, to assess consistency in control of loading. If the patient could resume his position, the feedback training was concluded. Patients were evaluated at weekly, then monthly and finally semi-annual intervals to determine if they maintained the ability to stand symmetrically in the absence of feedback.

Four patients had some degree of sensory deficit in the lower extremity, and the clinical evaluation revealed that three of these patients had poor motor control (impaired synergic construction). In the group of eight patients with intact sensory modalities, all patients demonstrated at least partial, independent control over movements of the lower limb. Four patients were considered hypotonic while the others had various degrees of spasticity. Four patients used a quad cane for ambulation, five patients used a quad cane regularly, and three patients needed their canes only when walking out of doors. All but one patient used an ankle-foot orthosis.

Results and Discussion

At the termination of the first training session, all patients could attain an improved symmetrical loading during upright posture. This ability was not maintained between the first and second session. After a second training session, daily training at home ensued. All patients were allowed to continue their standing and postural training until the set goal was achieved, namely, control of symmetrical weightbearing. The duration of time required to achieve this goal ranged between six to twenty-eight days.

Five patients required more than two weeks to reach this stage; four of these patients exhibited sensory disturbance, while the fifth patient demonstrated left-right imperception. The seven patients (without sensory impairment) required less than two weeks to achieve equal weightbearing.

When the patients were evaluated one month following the conclusion of the training period, three showed a decline in the weight-bearing level on the paretic limb - ranging from thirty-three to forty-three percent of body weight (i.e., a decrease of seven to seventeen percent). These three patients had originally required more than two weeks to gain control of symmetrical weightbearing and were found to have some degree of sensory disturbance. At the six-month follow-up evaluation, the results in all ten patients were unchanged.

The results suggest that patients with neurosensory handicaps are able to use biofeedback to learn a skill, provided that regular and frequent training can be effected. However, if the patients exhibit poor motor control and/ or some sensory deficit, some reinforcement may be needed when the acquired skill is not an integral part of the patient's daily activities.

The functional evaluation during the follow-up time indicated an increased use of independent standing activities and a shift toward less reliance on assistive devices during ambulation, in most cases. This was true regardless of the ability to maintain standing control.

The subjects who are involved in this continued program used the LLM to gain control of ambulation, after having achieved postural control. The importance of postural control as a precursor to ambulation training

would, therefore, have to be further investigated.

Conclusion

The limb load monitor was demonstrated to be a sueful adjunct to ambulation training and enhanced this program for the orthopedic and neurological patient. Therapists were provided with an objective tool with which to evaluate a patient's loading performance. If selected according to suggested patient criteria, both orthopedic and neurologic patients were able to attend to the auditory display and attempted to condition their performance accordingly. Patients continued to work toward their ambulation goal independently in the hospital and at home because of the immediate feedback of "correct" and "incorrect" performance. Neurological patients also demonstrated the ability to stand with symmetrical loading in the absence of the biofeedback device. The results of these studies identify the necessary information that therapists must receive if the LLM is to be utilized beneficially in the clinic. Additional clinical trials are underway to assess the standardization of the treatment approach for specific categories of patients.

Figure 1. The Limb Load Monitor

References

1. Herman, R. Augmented Sensory Feedback in the Control of Limb Movement. In: Neural Organization and its Relevance to Prosthetics. Miami: Symposia Specialists, 1973.
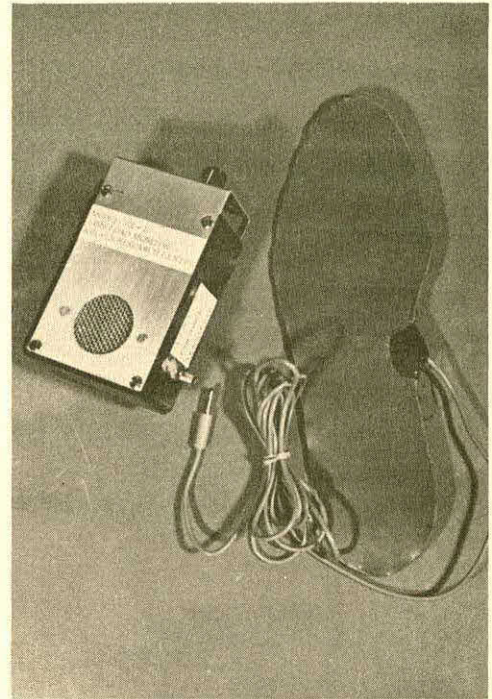
Title of Paper: Two systems for EMG biofeedback treatment of spasticity and paresis.

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: A miniaturized EMG biofeedback trainer which (a) is the size of a 100 mm cigarette package and battery-operated, (b) can be palmed or pocketed or clipped to the clothing and (c) has been used to train activity or relaxation of individual muscles in patients with neuromotor disturbances.

Intended User Group: Medical, dental and psychologic patients with upper motor neuron disturbances, hyperactive muscle groups resulting in symptoms and muscle transfers.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   / /

Feasibility Testing   / /

Clinical Testing   /X/

Available for Sale (check one)   Yes /X/   No / /

Price per unit $ 275.00 (approx.)

Availability of constructional details: From manufacturer:
Biofeedback Technology, Inc.
10592 Trask Avenue
Garden Grove, California 92643

B. Research Study

Intended Utilization: _____

Intended Device Application: _____

Availability of Intended Device: _____

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TWO SYSTEMS FOR EMG BIOFEEDBACK TREATMENT

OF SPASTICITY AND PARESIS

by

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Summary - One system is based on an inexpensive hand-held device designed for clinical use and soon to be available commercially, the Mini-trainer. Studies are reviewed which show this device to be an effective muscle trainer. A procedure is outlined by which a therapist can use the Mini-trainer systematically while keeping a concurrent graph of the patient's progress. The second system, designed primarily for research, relies conceptually on a multi-level hierarchy of training tasks and technologically on on-line computer control of shaping, feedback displays and data recording.

EMG biofeedback has obvious potential applications in neuromuscular rehabilitation: to increase strength and control, decrease interfering hypertonicity, improve range of motion, etc. Although these problems could be attacked with position or force feedback, EMG feedback has certain advantages. It is exquisitely sensitive to tiny vestiges of activity in a paralyzed muscle too small to produce measurable motion or force. It permits a patient to focus his efforts on specific muscles rather than on the entire limb, which may facilitate his overcoming co-contraction or maladaptive combinations of muscle activity.

Here we describe two approaches to EMG biofeedback which represent extremes of conceptual and equipment complexity. One is based on an inexpensive device soon available commercially, the Mini-trainer (Biofeedback Technology, Inc., Garden Grove, CA.). When this device was first conceived, design goals were set as follows. It was to be battery powered and small enough to be held in the hand or looped on a belt, so physiatrists, therapists, and patients were not encumbered or tied down by wires. It was to be extremely simple, safe, and straight-forward to use, so that patients could learn to practice with it at home. No technological frills were added so that cost would be minimized. A basic decision was made to provide a binary "yes-no" EMG feedback signal rather than an analog or "how much" signal such as a meter or frequency modulated tone.

Electronically the device consists of a differential amplifier, a high-pass filter to reduce 60 Hz., a rectifier, an integrator, a level detector to relate the integrated EMG to the criterion set by the operator, a light emitting diode for visual feedback, and a multivibrator and speaker for auditory feedback. A switch selects the feedback mode; when the integrated EMG exceeds the criterion level, the light or tone turns on.
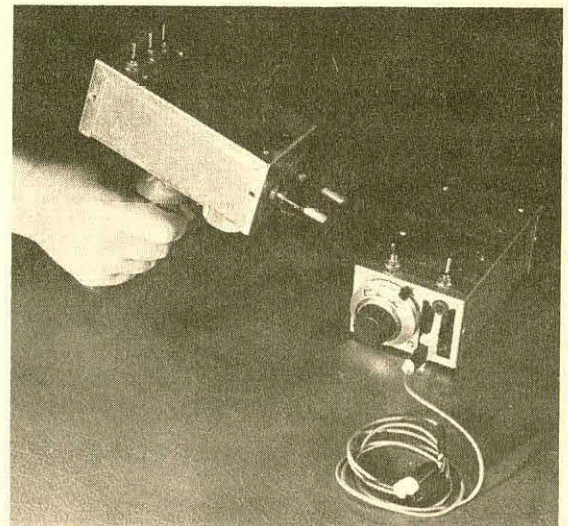

Fig. 1. A pistol-grip Mini-trainer and a more recent table-top version for research.

The early devices resembled a pistol with two electrode probes for the barrel. In place of a trigger was a knob for varying the criterion where the therapist could turn it with the index finger. The therapist grounded the unit by touching the patient with his other hand. While this was a good arrangement for hopping from place to place on various muscles, it was unsatisfactory for lengthy training at one site. Later versions and the commercial model consist of a small box which can either be held in the hand, hang on one's belt, or sit on a table, with one meter of shielded cable ending in a jack for two active electrodes and a ground. To this a probe can be attached for roving examination, or conventional Beckman surface electrodes for long-term training of one muscle.

The simplicity of this device does not imply a lack of sensitivity or internal sophistication. It will detect and trigger on single motor units recorded through skin surface electrodes (see Fig. 2). Simply tapping into intermediate stages of the circuit, as we did in the "research unit" (Fig. 1) yields excellent "raw" and analog-integrated EMG. For clinical users, the most useful form of output remains the simple light or tone indicating whether the subject's muscle activity is exceeding a threshold set by the therapist.

SMU

EMG integ.

feedback

Fig. 2. The Mini-trainer triggering from a single motor unit picked up through surface electrodes. The raw and integrated EMG were both recorded from the device's internal circuitry.

The first formal investigation of the effectiveness of this device involved training normal volunteers to increase the strength of contraction of the abductor hallucis (one of the few skeletal muscles which normal subjects find a little difficult to control voluntarily) and to use the increased strength to improve abduction of the big toe[1]. Eleven of thirteen subjects

learned to increase the range of toe abduction. A second study[2] consisted of a clinical comparison of biofeedback training and conventional physical therapy in twenty adult hemiparetic patients with chronic foot-drop. Subjects were divided randomly into two groups of 10. Group 1 received 40 minutes of therapeutic exercise 3 times a week for 5 weeks. Group 2 received 20 minutes of therapeutic exercise and 20 minutes of biofeedback training of the tibialis anterior muscle over the same 5 week schedule. Group 2 gained about two times as great an increase in ROM and strength of dorsiflexion as group 1. Four patients in the biofeedback group achieved and retained voluntary control of dorsiflexion sufficient to yield a more normal heel-toe gait pattern; three of them were able to walk well without short leg braces. In general the outcome of the study is similar to that achieved by Johnson and Garton[3] in their application of EMG biofeedback to tibialis anterior.

For increasing strength, subjects generally preferred the tone to the light, although learning and performance did not differ significantly for the two modes of feedback. (Conceivably the light might work better for training muscle relaxation than the stuttering tone, and would be useful for pre-testing muscle performance without providing feedback to a patient.) When subjects were required to attend to motion and EMG feedback simultaneously, their performance was disrupted. Thus in both studies, they worked in alternation, first to increase the muscle trainer threshold, and then to transfer gains in strength of muscle activation in efforts to achieve a greater range of motion. Frequent changes of the muscle trainer threshold helped keep subjects trying and kept a gentle pressure on them to increase muscle performance. Frequent rest periods were necessary to avoid fatigue. Subjects preferred a rhythmical cadence of commands and practice; interruptions would often disrupt performance.

The foregoing experiments demonstrate the feasibility of using a simple feedback device in the clinical setting. But they also reveal a failing common to all commercial feedback devices: to get reliable recorded data they require accessory recording equipment. Even if a clinician had a polygraph for response recording, he might lack time to review the resulting data between therapy sessions, and it would compromise the intended portability of the muscle trainer. Yet since biofeedback is a modified form of operant conditioning, it demands response records, even in a clinical setting. Otherwise the therapist cannot know how and when he is succeeding.

A satisfactory solution is to use the criterion knob setting as the response strength measure. This requires a numbered scale on the knob and some procedures for setting the criterion with acceptable reliability

relative to the patient's muscular efforts. To improve phasic control and strength in a paretic muscle, the patient can be required to produce brief (2 or 3 sec.) on-off feedback tones without tone stuttering. Once the patient has learned to do this consistently for a very low criterion setting (the initial step in retraining a paretic muscle), the criterion can be incremented gradually until the subject fails on two effort trials in succession. (Other standards such as three out of five failed efforts would also be feasible.) This new criterion level is then recorded as an operational measure of current response mastery. To train relaxation in an overactive muscle, the therapist reduces the criterion gradually until the feedback signal beeps or flashes only intermittently (roughly a third of the time), records the value and allows the patient to practice at that criterion level to get the feedback signal off entirely.

A training session will alternate between practice and test periods. In a test period the therapist adjusts the criterion systematically as outlined above and then records the setting so obtained on graph paper. During the next practice period the subject strives to improve his control of the feedback signal against a constant criterion setting, on a regular schedule of effort and rest. Practice can continue either for a standard time, perhaps 3 minutes, or until a run of correct or incorrect responses indicates the criterion needs revision. Then the test period yields a new criterion for the patient's efforts and a new value for the graph. Successive values are simply graphed against the minute of the training session when a practice period resumes. The resulting graph of progress, while inadequate for formal research purposes, is just right for tracking progress in the clinic. Most patients would be able to learn all of the above procedures for home practice. Obviously many variations might be necessary to suit particular training needs.

The second system we will describe is being developed primarily as a research and development tool to discover the ultimate effectiveness and limitations of EMG biofeedback in treatment of spasticity and paresis. It is based conceptually on a training task hierarchy and technologically on a PDP-8E computer.

The training hierarchy evolved because no single training task would suffice for a crucial test of biofeedback effectiveness in treating a spastic limb. Just training basic resting relaxation was too easy; spastic muscles usually relax anyway in a resting patient, and resting relaxation has little functional significance for most activities of daily living. But any training situation sufficiently challenging that mastery would be impressive might be too difficult a starting point for subjects inexperienced in using biofeedback

to relax. Furthermore one cannot train all the subskills needed to improve the everyday functioning of a spastic limb with any single training paradigm. Finally, preliminary studies have shown that overtly similar spastic hemiplegics can differ markedly when abnormal activity is analyzed electromyographically. These differences imply individual training needs which would require several different training paradigms. Thus we have organized a number of training tasks into a sequence of gradually increasing difficulty. Subjects first practice relaxing normal and then spastic muscles in the resting state where we can be fairly confident of their success. They are then reinforced for using feedback to maintain control of spasticity while being introduced to gradually more difficult and challenging task requirements, such as distracting noise, concurrent use of a contralateral limb, passive stretch of the spastic muscle under training, or even voluntary contraction of its "antagonist". Since training of each subskill begins only after prerequisites have been mastered, the probability is maximized that a subject will succeed at each task.

The training task hierarchy is grouped into three sequences which will be used for separate experiments. In the first sequence the spastic arm rests unused; the subject masters resting relaxation and then learns to maintain it during distracting noise and/or concurrent use of a contralateral limb. Neurophysiologically speaking, stretch stimuli are factored out while the subject learns to handle overflow or arousal stimuli. This corresponds to the minimal level of useful improvement biofeedback might provide, the ability to keep a spastic arm relaxed while resting or sitting engaged in deskwork, reading, conversation, etc.

In the second training sequence the focus changes to passive stretch stimuli. Control of resting relaxation is again established and then passive stretch of the spastic muscles being trained is gradually introduced at increasing rates. Subjects may also undergo training to inhibit excessive reflex responses provoked by an automated reflex hammer striking the tendon of a spastic muscle at regular intervals. This sequence assesses the effectiveness of biofeedback in overcoming spasticity as classically defined, this being an important prerequisite to major improvements in functional use of a spastic limb in locomotion or other activities.

The third training sequence is directed at training spastic and paretic co-synergists to flex and extend a limb through its range of motion. To do this the subject must overcome paresis and co-contraction as well as spasticity. Training starts with alternating production of graded isometric contraction and rapid relaxation in each synergist and proceeds through several intermediate steps toward reciprocal flexion and extension.

There is no task in the hierarchy which could not be approached with simple feedback devices, even with Mini-trainers, but there are two basic advantages to using an on-line computer: its superiority as a "teaching machine" and as a data recording and processing device. Spastic subjects may require intensive response shaping to produce the desired control, followed by extended practice to achieve response stabilization and over-learning. A computer can detect and categorize very subtle and complex EMG responses and generate complex feedback displays illustrating aspects of performance which a subject cannot perceive in more conventional auditory or visual feedback. It is quicker and more consistent in delivering reinforcement, tireless in carrying out complex shaping schedules, switches instantaneously from one training subroutine to another, and can be reprogrammed easily to adapt to unforeseen training needs. It is also far superior to any combination of human trainer and analog recording system in objectively recording what happens during training. EMG activity, force, and position data can be instantaneously quantified and recorded together with an exact coded record of moment-to-moment changes in training conditions. Data readout can be obtained immediately. Finally, the experimenter is freed to provide the subject with supplementary help if necessary, and to keep notes on behavior complexities to which, without the computer, he might be unable to attend.

An example of a computer-controlled biofeedback program is one developed for training subjects to overcome co-contraction of spastic flexors and extensors. Others have treated co-contraction successfully by presenting subjects with separate EMG biofeedback signals for flexors and extensors; but this may slow learning by requiring subjects to juggle two feedback signals simultaneously. In the present case, activity from the muscle to be strengthened and from the antagonist to be inhibited are integrated separately and converted to digital values. The computer multiples the ratio of these values by their difference and displays the result as a bar moving on the feedback display screen. Both the ratio and the difference are used because the use of either parameter alone would permit subjects to arrive at maladaptive solutions.

The general experimental situation is illustrated in Fig. 3. The computer-controlled feedback display is an Owens-Illinois Digiview; different in mode of operation from the more common CRT-tube device, its display need not be periodically refreshed by the computer program. Written instructions, numbers, and graphic displays can be shown simultaneously. Feedback displays include a criterion level which will be revised by the program in terms of the subject's most recent performance. When the subject surpasses the criterion, a numerical score on the screen is incremented. Previous studies[4,5] have shown that money is a
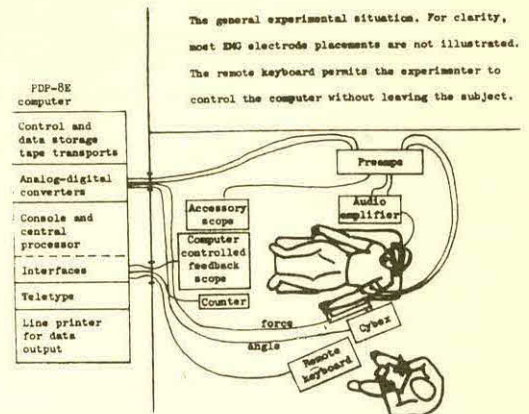

Figure 3

powerful reinforcer in biofeedback training, so the score is used as a basis of monetary incentive payments.

When training subjects to master spasticity provoked by passive stretch, or to actively flex and extend the affected limb, a means of controlling the rate of motion is needed, e.g., a Cybex Isokinetic Dynamometer or a computer controlled hydraulic limb manipulator.

This training system will be applied primarily to adolescent and adult spastic hemiparetic victims of stroke, accidental brain injury, or cerebral palsy. Some paraplegic victims of spinal cord injury may be included also. Biofeedback training will be directed at spastic and paretic synergist systems controlling flexion/extension at the ankle, knee, elbow, or wrist. Surface electrodes must be used since fine-wire electrodes, normally to be preferred for their selectivity, do not yield an EMG/force relationship which is stable over long periods of time, and can be neither left nor reinserted repetitively into the same site over numerous training sessions.

We anticipate that the power and flexibility of this research system will gain the understanding of EMG biofeedback training necessary to optimal design of simple, practical devices such as the Mini-trainer and to more effective procedures for their clinical use.

References

1. Kukulka, C.G. and Basmajian, J.V. Assessment of an audio-visual feedback device used in motor training. American Journal of Physical Medicine. In press, 1975.

2. Basmajian, J.V., Kukulka, C.G., Narayan, M.G. and Takebe, K. Biofeedback treatment of foot-drop after stroke compared with standard rehabilitation technique. Part 1. Effects on voluntary control and strength. Archives of Physical Medicine and Rehabilitation. In press, 1975.

3. Johnson, H.E. and Garton, W.H. Muscle re-
    education in hemiplegia by use of elec-
    tromyographic device. Archives of Phys-
    ical Medicine and Rehabilitation 54:320-
    322, 1973.

4. DeBacher, G.A. Operant shaping of local
    muscular relaxation in normal children.
    Doctoral dissertation. Order No. 73-1372.
    Ann Arbor, Michigan: Xerox University
    Microfilms, 1972.

5. Lang, P.J. Learned control of human heart
    rate in a computer directed environment.
    In P. Obrist, A. Black, J. Brener and L.
    DiCara (Eds.), Cardiovascular Psychophysi-
    ology: Current Issues in Response Mecha-
    nisms, Biofeedback and Methodology.
    Chicago: Aldine Publishing Co., 1974.

A SYSTEM FOR MULTI-SENSORY PROCESSING IN
Title of Paper: READING-RETARDED CHILDREN

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: A multi-sensory display device which provides tactile-visual-kinesthetic conditions for learning. The incorporation of computer control within the device enables regulation of the temporal-spatial dimensions of display.

Intended User Group: Children (and adults) who have learning deficiences and have neurological damage, dyslexia, reading disabilities, autism, deafness, cerebral palsy or are mentally retarded.

Stage of Development: (Check all that are applicable)

    A. Device

        Prototype Development   /X/

        Feasibility Testing   /X/

        Clinical Testing   /X/

        Available for Sale (check one)   Yes /X/   No / /

            Price per unit $ dependent on configuration and application
                ($8,000 - $9,500 minimum - will decrease with increased
        Availability of constructional details: / production)
                / Inquire of authors.

    B. Research Study

        Intended Utilization: _____

        Intended Device Application: _____

        Availability of Intended Device: _____

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                                 Philadelphia, Penna. 19141

A SYSTEM FOR ENHANCEMENT OF MULTI-SENSORY PROCESSING IN READING-RETARDED CHILDREN

by

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Summary - A multi-sensory, tactile-visual-kinesthetic learning device has been developed; it permits the learning disabled to enhance their sensory processing of lines, letters and letter sequences. This device has been used with the learning disabled for both diagnostic and remedial purposes. Incorporation of computer control within the device enables regulation of the temporal-spatial dimensionality of the tactile display, and also provides a basis for rhythmic finger tracing. This type of tactile-visual-kinesthetic approach to learning has potential application in programs for children with varied sensory deficits.

Introduction

Two characteristics of children with reading disabilities are their difficulty in: 1) associating the proper sounds with printed words; and 2) associating meanings with the words once they are slowly decoded. An acceptable approach to overcoming this difficulty in disabled readers has been the multi-sensory (visual-auditory-kinesthetic-tactile or VAKT) method where the child finger traces specific words that he and his teacher have selected and written on small cards (Johnson, 1966;[1] Slingerland, 1971[2]). The hypothesis of those who utilize this technique is that the additional movement of the finger and hand serves to enhance the conceptualization and integration of form and symbol in the auditory and visual modalities.

Children with learning disabilities are often characterized by a deficiency in one or more of the following perceptual functions: visual processing, visuo-motor coordination, auditory sequencing or auditory synthesis, and blending. While auditory, visual, and visuo-motor deficiencies in learning disabled children have been studied, little information has been available on the ability of these youngsters to discriminate tactile information provided on their skin, or whether their tactile sensitivity is less acute than that of normal readers. Interest in tactile discrimination leads one to inquire about laterality development, especially among non-right handers, and about hemispheric specialization and integration of brain function as it is related to tactile sensitivity.

There has been a need to study, experimentally, the diagnostic and correlative aspects of tactile discrimination in learning disabled children. There is also a still greater need to find means of helping these children to learn basic decoding skills by enhancing their sensory awareness and processing. The failure of large numbers of school children to learn the basic skills of reading and spelling is a major and unsolved problem in education. An approach to the solution of this problem would be to integrate tactile and kinesthetic practice drill into the learning sequence for reading-disabled and slow-blooming youngsters.

The purpose of this report is to describe the development and evolution of a computer controlled tactile and visual display system

for use in diagnosis and reading remediation of the reading disabled child.

The concept of using the surface of the skin as a receptor system for sensory augmentation evolved from work at the Smith-Kettlewell Institute of the Visual Sciences. The work of Bach-y-Rita, et al ,[3] resulted in the development of a vibro-tactile device to be used by the blind in the discrimination of concrete forms or objects. Their system consisted of a matrix of vibrating solenoids as the output device and a television camera as the input device. The small subject-mounted, or carried, television camera was interfaced with the electronics to decode visual environmental information and to translate this information into a temporal-spatial tactile representation. The outline and contour of objects placed within the viewing range of the camera were well represented on the skin by the temporal-spatial display. An adaptation of this vibro-tactile display was used in the initial phases of the current investigations of tactile processing in children.

The tactile display in this early system was a matrix of ten points by ten points. Each tactor in the array was a blunt plastic tip attached to a driving solenoid. The display was limited to three horizontal lines, three vertical lines, and two oblique lines at an angle of 45 degrees to the vertical. This limitation made possible the construction of only 14 upper case letters. The particular scanning (display) technique used to generate these letters was not suitable for ease of character recognition. Manual operations which were very complex and time consuming were necessary to generate a single character display. In tests with children, this prototype system was shown to lack the flexibility to display a sequence of letters, to alter the timing between stimulus points, and to address a particular stimulus point in the array.

Description of Current Tactile/Visual Display System

A review of the results of the early testing and the discussion of future requirements for a tactile/visual display led to the development of a completely new system (Figure 1). The system provides the display of a symbol in a point by point temporal sequence simultaneously on both a tactile and a visual 7 x 7 point matrix. The display

is provided in response to the selection of a keyboard element representing that particular symbol. The use of a small general purpose, digital computer as the basic system element enables functional expansion of the system. Additional input or output devices may be included to change the mode of symbol selection or display. Currently, the system is configured with two tactile displays so that two children can exercise with the same information display at any one time.

The system is configured with four basic components: a) two solenoid actuated tactile displays each with 49 tactors arranged in a 7 x 7 matrix with a center-to-center spacing of .5 inches; b) a two part visual display with a larger matrix of 49 light-emitting diodes (LED) arranged as in the tactile display with the same element spacing, and a group of ten smaller (1.0" x 1.0") LED matrices (each 7 x 7 points); c) a PDP-8L minicomputer for system control and generation of the displays; and d) a silent keyboard for operator control of system operation and selection of display symbols.

Figure 1. Tactile/Visual Display System

Any point in the 7 x 7 display array may be addressed and selected at any time (Figure 2). Thus, a symbol may be generated using any sequence of points in any specified order. The software for display control is vector oriented resulting in compactness of

memory storage. The computer provides the display controller with two digital words conveying the x, y address of the point to be displayed, and information about the way in which the display is to be carried out. In the large visual and the tactile matrices, points are displayed one at a time. The coordinates of the points displayed during the construction of a symbol are also stored in a portion of a random access memory (RAM) in the display subsystem. At the end of symbol generation, the constructed symbol may be displayed in one of the ten smaller LED displays. These are continuously refreshed from the RAM in the display subsystem.

Three basic timing controls are available for specification by the user: a) the time between point stimuli; b) the time between vector or line segments used in constructing a symbol; c) the time between display of symbols in a "string" output mode. Each of these timing values may be varied from 1 msec. to 4,096 msec. in 1 msec. increments. The string output mode permits the user to display a sequence of up to thirty symbols preselected from the keyboard, at a specified inter-symbol rate. This is useful in creating words, phrases, and sentences. Modification of the timing sequences as well as several other controls, such as specifying the mode of display on the large and small displays, is also controlled from the keyboard. Only the keyboard structure limits the number of defined symbols at any one time.
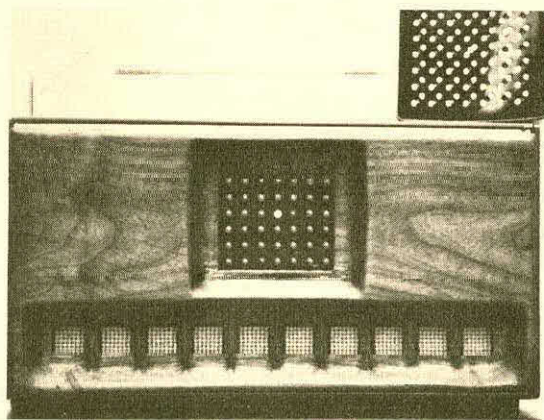

Figure 2. Display of a Single Array Element

Various symbol sets have been developed during the continuing research program. The initial symbol set was developed to evaluate tactile reception of horizontal, vertical,

horizontal and vertical, oblique, and curved lines. Examples of this set are shown in Figure 3. Several symbol sets were developed to study upper case alphabet letter processing (Figure 4). The current symbol set comprises the lower case alphabet and several special symbols such as those included in the original symbol set. The programmable properties of the computer driven display permit rapid and relatively simple construction and additions of any symbol set.
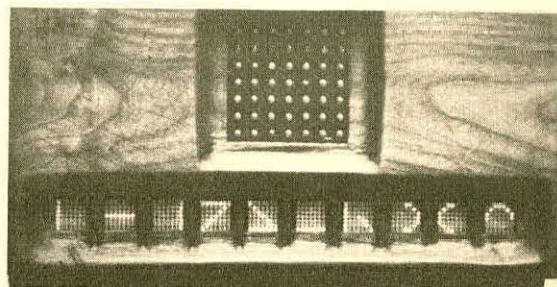

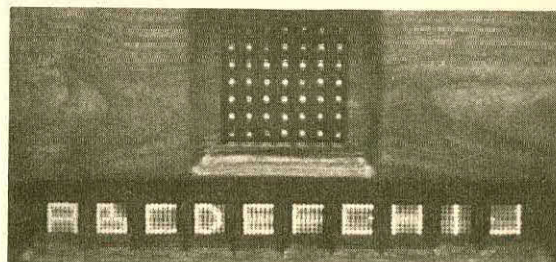Figure 3. Various Symbols Used in an Early Alphabet for Studying Tactile Perception

Figure 4. Upper Case Letters from a Recent Alphabet

An additional tactile display matrix of 10 points by 10 points (with only the center horizontal row active) was constructed to:

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1) evaluate the differences in processing between the newer system and the early vibro-tactile system; 2) evaluate the processing of lines of longer length (longer than 7 points = 3.5 inches); 3) investigate the horizontal movement of stimuli across the midline as it relates to bilateral integration of the two cerebral hemispheres; 4) assess, using shorter lines (5 points), differences in performance between the right and left sides of the body. These last two studies were reported recently (Schevill [4]), illustrating that use of a single horizontal tactile movement across the abdomen will reflect minor hemispheric processing and inadequate integration between the two hemispheres in children with learning disabilities. This particular test will not reflect inadequate functioning of the left hemisphere, which is often the case in children with specific reading disabilities. The implication is that each child processes information differently, according to the nature of his cerebral functioning. The diversity of tactile response in these children must be taken into account in a remediation program. An effective tactile integration program must use the child's learning strengths in conjunction with his weaknesses.

Status of Research

Since early 1973, when these studies were initiated, research has been concentrated in two areas. The earlier studies were concerned with the ability of normal, learning disabled and reading retarded children to discriminate tactile information provided on their skin (Schevill [4, 8]) (Figure 5). Of interest in this study was laterality development, hemispheric specialization, and integration of brain function as it relates to tactile sensitivity. One outcome of this investigation was that children with severe learning disabilities were deficient in a seven point horizontal linear movement task, more than those with a specific reading disability, especially when the temporal order of the points was slow, and when the tactile display was presented on the left side of the body.

The second area of study has been to investigate discrimination of letters and short term memory for the sequential ordering of letters. This relates directly to the overall goal of the program: to develop and assess an automated system of tactile-visual-auditory training that would improve word recognition, retention, and word attack skills in children who are severely retarded in reading ability. Several investigations have been undertaken in this phase of the program. One study (Schevill [5])

describes the significant progress in word recognition and spelling skills of a group of reading deficient children. In this case, the children were paired and divided into two groups. One group received tactile training and the other received non-tactile (visual) instruction, utilizing only the visual display of the tactile/visual display system. The effects of the tactile training were significant.

Figure 5. Child Holding a Tactile Display Matrix Against Chest/Abdomen During a Testing Situation.

A second study (Schevill [6]) described the significant improvement in word attack skills of first, second, and third graders who were slightly retarded in reading skills. A third study (Schevill [7]) demonstrated the difference between children with minimal brain damage and normal readers in the speed of decoding one letter after another in timed sequences of three and four letters.

In a study currently underway, kinesthetic aspects are being used to augment the tactile display in the practice drill sessions. To illustrate the integration of kinesthetic and tactile aspects of perception into the learning sequence, the following lesson plan has been developed:

a. Before each daily drill, the child is told which pattern he will be working on during that period. For example, if the pattern is "ee," four words are selected and printed in large letters in the child's notebook ("feel," "keep," "peep," "meet,").

b. After the child and teacher compose sentences illustrating the use of the words, the daily instruction begins.

· c. The daily instruction includes finger tracing of each letter on the tactile display matrix as it is being constructed. This is repeated in sequence, three times. Following the kinesthetic drill, the child holds the tactile display against his abdomen and, with eyes closed, orally identifies the letter or its sound equivalent following its tactile presentation. He then draws the perceived letter in the air. The third part of this drill is to combine the kinesthetic and tactile aspects by having the child trace the letter in his notebook as he feels the tactile tracing against his body.

This latest stage of the tactile program makes use of the tactile display for both the tactile transmission of information to the child's body and active kinesthetic finger tracing of each letter as it is being constructed.

System Enhancements

During the one and one-half years that the current tactile/visual display system has been in use, it has met all of our current experimental designs reliably, with only occasional minor programming or alphabet modifications. There are minor mechanical modifications which could be made to insure against certain minor malfunctions due to the enthusiastic participation of students. The system is only semi-portable in that it weighs approximately 80 pounds. A system redesign has taken place to incorporate our experiences. The new device will utilize a cathode ray tube (CRT) visual display. This display will be divided into two sections. The upper one-half of the screen will be used to display a large 7 x 9 point matrix (approximately .5 inch spacing). This will be activated during the construction of a symbol. The lower half of the screen will contain three or four lines of thirty or forty symbols each. Symbols will be stored in the lower position of the screen, in sequence as they are constructed. This will function as the 10 small LED arrays in the current system. Each of these small symbols will be constructed on a 7 x 9 array. The tactile displays (there will be four or five per system) will be increased to 7 x 9 points and will operate simultaneously with the large visual display. A 7 x 9 point array was chosen because a larger variety of symbols (upper and lower case alphabet, for example) may be more easily constructed. The system will be inte-

grated and controlled by a micro-computer, thus creating a smaller and considerably lighter, more portable package.

A kinesthetic input device has been under consideration. This device would permit the child to trace, with his finger, the previous symbol on a plate identical to the output matrix. The computer would interpret the temporal-spatial input sequence, compare this to the output, and provide visual feedback of the accuracy of the response.

Conclusion

When the present tactile/visual display system is used with kinesthetic instruction, it is applicable to children with severe learning dysfunctions, as well as to those with a specific reading disability. The active tracing of letters, combined with a focus on the motion of each character as it is represented on the child's body, would help to augment sensory awareness and decoding abilities in sensory-impaired children, such as those with neurological damage, immaturity, dyslexia, cerebral palsy, deafness, and autism. It would also be of use with perceptually impaired adults, such as those who have suffered a cerebrovascular accident. This instrument would thus find applicability in clinics, hospitals and special schools for the neurologically handicapped and learning disabled.

References

1. Johnson, M. S. Tracing and Kinesthetic Techniques. In: J. Money (ed), The Disabled Reader. Baltimore: Johns Hopkins Press, 1966.
2. Slingerland, B. A Multi-Sensory Approach to Language Arts for Specific Disability Children. Cambridge: Educators Publishing Service, 1971.
3. Bach-y-Rita, P., Collins, C., Scadden, L., Saunders, F., and White, B. Vision substitution by tactile image projection. Nature 221:963-964, 1969.
4. Schevill, H. Tactile discrimination and learning disabilities. Smith-Kettlewell Institute of Visual Sciences. Paper read at International Neuropsychology Society, Tampa, February 1975.
5. Schevill, H. Evaluation of a tactile decoding program for reading disabled children. In press, 1974.

6. Schevill, H. Tactile Decoding for Late Bloomers. Report to National Science Foundation (RANN), Grant No. GI 36118, March 1975.

7. Schevill, H. Tactile Discrimination in Dyslexic Children. Report to National Science Foundation (RANN), Grant No. GI 36118, May 1974.

8. Schevill, H.   Tactile Discrimination and Learning Disabilities - Prototypes of Cerebral Dysfunction and Suggestions for Remediation. Presented at Second Congress of the International Rehabilitation Medicine Association, Mexico City, October 1974.

AIDS FOR THE DEAF AND HEARING IMPAIRED

Chairman, Phillip Rosenberg, Ph.D.
Department of Audiology,
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Title of Paper:
Sensory Training Aids and Communication Devices for the
Hearing Impaired in the United States and Sweden

Category: (check one)   Device Development /✓/   Research Study / /

Brief Description: This is a report on the devices available in the United
States and Sweden for sensory training and reducing communication barriers
for deaf and hard of hearing persons, and on the effectiveness of systems for
delivery of such devices in the two countries

Intended User Group: Health care agencies, rehabilitation specialists,
                        educators of the hearing impaired.

Stage of Development: (Check all that are applicable)

    A. Device

            Prototype Development   / /

            Feasibility Testing   / /

            Clinical Testing   / /

            Available for Sale (check one)   Yes /✓/   No / /

                Price per unit $ Various .

        Availability of constructional details:

    B. Research Study

        Intended Utilization: Enabling improved speech and utilization
        of residual hearing by deaf and hard of hearing persons.

        Intended Device Application: Hearing impaired children and
        adults - for speech and hearing training and for communication purposes.

        Availability of Intended Device: Most all are currently available

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SENSORY TRAINING AIDS AND COMMUNICATION DEVICES FOR THE HEARING IMPAIRED IN THE UNITED STATES AND SWEDEN

by

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Summary - In view of the importance of early intervention to reduce the impact of hearing loss in young children, and to minimize such impact on adults, communication aids and training in their use should be provided promptly to those in need. The Swedish system for providing training and communication aids appears to be superior to that of the United States. In addition to the government controlled and funded health care system, the role of the hearing care consultant (horselvardskonsulent) in Sweden seems to assure that proper and timely services reach all hearing impaired citizens.

The development of both language and communication skills of children who have suffered a severe, prelingual hearing loss is drastically impeded even with early diagnosis and intervention. If diagnosis is delayed and late intervention fails to maximize the child's use of residual hearing, however, the impact on his language and speech may be irreversible. Thus, great emphasis in the education of hearing impaired children is placed on early diagnosis and early appropriate intervention to assure the best use of the auditory, visual, and tactile senses. To the extent possible, one tries to replicate for the hearing impaired child the same chronological growth and development patterns that are experienced by the normally hearing child.

Individuals whose hearing loss has occurred after normal language and speech have been acquired have problems in both expressive and receptive communication. However, their difficulties in no way match those of the child who has never heard spontaneously the sound of a normal human voice.

Types of Sensory Aids and Devices. One system for categorization of sensory training aids and communication devices is that proposed by Boothroyd (1,2):

1. Alerting and warning devices
2. Devices for face-to-face communication.
3. Devices for long distance communication.
4. Devices used primarily in educational settings.

The reader is referred to these references of Boothroyd's for more detailed descriptions as well as for sources from which to obtain those aids and devices that are currently available. Also of interest to the reader concerned with reviews of specific aids and devices including those now in the research phase, are the work of Connor (3), Levitt and Nye (4), Levitt (5), Ling (6), Nickerson (7), and Pickett (8).

The personal hearing aid, of course, is one device that if maintained in working order and consistently worn will meet many of the needs of the hearing impaired child and adult in the situation described above. Other instruments which have been demonstrated to be helpful in meeting one or more of the needs of the hearing impaired include: simple alerting

devices like flashing lights or loud bells attached to telephone and door-bells, and electronic vibrator paging devices; inductive or acoustic devices to couple hearing aids to telephones, telephone amplifiers, teletypewriters for use with normal telephones; wired audio, induction and FM systems designed to be used in classrooms in which there are one or more hearing impaired students, overhead projectors, teaching machines, and computer-assisted instruction systems, nasality indicators, pitch indicators, and sibilant indicators. All these and more are not only within the state of the art, but are being manufactured for sale in the United States.

But are these commercially available aids and devices being used by those in the United States who could benefit from them? The answer is essentially, "No".

Delivery Systems in the United States and Sweden. While the research and development of biomedical devices in the United States, including those for the hearing impaired, is often financed by the federal government, the transition from the laboratory to the consumer market generally has to meet and overcome the test of profitability. If the market for the device is not sufficiently large or financially sound to support the necessary manufacturing, marketing and servicing costs, the device tends to find its final resting place in a final report rather than in the hands of a consumer. Except for the efforts of a few government agencies like the Veterans' Administration, the Rehabilitation Services Administration and in some heavily supported schools for the handicapped, there is little support for a comprehensive system of delivery of appropriate sensory aids to U.S. citizens in need of them.

Hearing aids are sold to private customers by hearing aid dealers for amounts varying from $200 to $500. Frequently the price varies in inverse proportion to the negotiating skill of the handicapped consumer. Hearing aid dealers need demonstrate no technical knowledge or skill in fitting to begin business in many states though

a trend toward licensing of dealers has begun.

Technical aids such as those to facilitate use of the telephone, door bell flashers, baby cry alarm systems for deaf parents, group aids for class-rooms and teletypewriter terminals are all sold by different outlets. Except for those obtained from the telephone company (or regulated by the F.C.C.), none of these devices are controlled as to performance, servicing or marketing practices.

In Sweden, a modern industrial nation that is similar in standard of living and in the incidence of hearing loss to the United States, the situation is quite different. Evidence of these differences can be seen in Table 1 where there is shown the percentage of respondents which indicated that they had various types of technical aids for their preschool aged hearing impaired children in their homes.(9)

Table 1

Technical Aids Used in Homes of Pre-school Children - U.S. & Sweden

(N = 597 United States,
 N = 371 Sweden)

Tech.Aid	U.S.%	Sweden%
Desk Amplifier	1.3	19.9
Loop System	6.5	53.9
Doorbell light signal	5.0	44.5
Telephone light signal	5.0	34.2

In the same study by Fellendorf, questions were asked about the cost of hearing aids and ear molds for pre-school aged children and also where these vitally important Eduhealth (education and health) components of an auditory enhancement system had been obtained. The results as shown in Table 2 reveal the differing role of the hearing aid dealer in the United States and Swedish delivery systems as well as the differences in cost to the parents of babies and preschool aged children for essential sensory aids.

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Table 2

Hearing Aids and Ear Molds for Pre-school Hearing Impaired Children

(N = 597 United States
N = 371 Sweden)

	U.S.%	Sweden %
1. How much was paid for the child's last earmold?		
a) $10 or more	30	0
b) Nothing	14	71
2. Where was the ear-mold prepared?		
a) Doctor's office	1	7
b) Hearing & Speech Center	6	60
c) Hearing Aid Dealer	39	0
d) School	7	3
3. Where was child's current hearing aid obtained?		
a) Doctor	1	13
b) Hearing & Speech Center	16	76
c) Hearing Aid Dealer	63	0
4. How much was paid for the child's last hearing aid?		
a) Less than $100	4	0
b) $100 or more	38	0
c) Nothing	33	87
d) On Loan	7	1

While specific data on the delivery of services and aids to adults in the United States and Sweden was not collected as it was for children, it is evident that information on adult experiences probably would have been similar to those of children. Furthermore, while in the United States the placement of the hearing aid is frequently the final step in the servicing of a hearing impaired client, in Sweden it is seen as the first step. The newly fitted hearing impaired adult is encouraged to take an extended course in auditory training and lip-reading at the hearing and speech center to help him adjust to the aid. He is shown an array of technical aids available to be placed in his home and/or office at government expense, and with the engineer and audiologist a selection is made of those aids most appropriate.

One of the most significant factors in the system in Sweden is the horselvardskonsulent, a position which exists in the delivery system of each of Sweden's 22 regions. Generally filled by a teacher of the deaf or a speech therapist, the horselvardskonsulent, or hearing care consultant, is the coordinator of services for clients in his jurisdiction. He or she is responsible for seeing that all hearing impaired clients, young or old, are made aware of their rights under the Swedish social benefit system and equally important, to assist such clients in gaining prompt access to the services and devices that could help them.

In the United States there are few, if any, such consultants and perhaps this fact accounts in large measure for the fragmentation of services to the hearing impaired.

Conclusion

Though Sweden is considerably smaller in area and population than the United States, its organization for the delivery of Eduhealth services, including sensory and communication aids to the hearing impaired, may well be applied in the United States. An investment in the improvement of delivery of existing services and devices at this time may be a sounder investment than further research on new services and devices.

References

1. Boothroyd, A. The deaf in an advanced technology. Review of Sensory Disability.18:1-3, 1974

2. Boothroyd, A. Technology and deafness. The Volta Review. 77:27-34, 1974

3. Connor, L. Speech for the deaf child: knowledge and use.Washington, D.C. Alexander Graham Bell Association for the Deaf. 1972

4. Levitt, H. & Nye, P. Sensory aids for the hearing impaired: Proceedings of a National Academy of Engineering Conference, November 15-17, 1970. Washington, D.C. Alexander Graham Bell Association for the Deaf, 1971

5. Levitt, H. et al. Special section on speech analyzing aids for the deaf. IEEE Transactions on Audio and Electroacoustics. New York. AU-20 No.1. pp 2-41. 1972

6. Ling, D. Conventional hearing aids: an overview. The Volta Review. 73 #6 pp 343-352, 1971

7. Nickerson, R.S. & Stevens, K.N. Teaching speech to the deaf: can a computer help? Audio and Electroacoustics. AU-21 No.5, 445-455, 1973

8. Pickett, J.M. Recent research on speech analyzing aids for the deaf. IEEE Transactions on Audio and Electroacoustics. AU-16 #2, 1968

9. Fellendorf, G.W. An Eduhealth delivery service index: a profile of education and health care services to young hearing impaired children and their parents. Washington, D.C. Alexander Graham Bell Association for the Deaf,1974

Title of Paper: EVALUATION OF AN ELECTRONIC SYSTEM FOR REMOTE SIGNALLING OF DEAF AND DEAF-BLIND PERSONS

Category: (check one)　Device Development /x/　Research Study /_/

Brief Description: This paper is the result of a study conducted jointly by the Deafness Research & Training Center and the National Center for Deaf-Blind Youth and Adults of two types of remote signaling devices for deaf-blind people. (Additional appendix materials will be available at the conference.

Intended User Group: Deaf-blind people and organizations serving deaf-blind people.

Stage of Development:　(Check all that are applicable)

A. Device

Prototype Development　/X/

Feasibility Testing　/X/

Clinical Testing　/X/

Available for Sale (check one)　Yes /X/　No /_/

Price per unit $ _____

Availability of constructional details: _____

B. Research Study

Intended Utilization: _____

Intended Device Application: _____

Availability of Intended Device: _____

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EVALUATION OF AN ELECTRONIC SYSTEM FOR REMOTE
SIGNALLING OF DEAF AND DEAF-BLIND PERSONS

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with
Thomas Freebairn
Coordinator, Telecommunications Projects

Summary. Deaf-blind people find it extremely difficult to communicate over distances which make direct physical contact impossible. Deaf people, when out of direct line of sight with the people with whom they wish to communicate experience similar difficulties. Jointly, the Deafness Research & Training Center and the National Center for Deaf-Blind Youth and Adults explored the utility of two electronic devices which permit rudimentary signalling to deaf and deaf-blind people from remote locations.

Because of their mutual interest in the device to be tested, the National Center for Deaf-Blind Youth and Adults joined with the Deafness Research & Training Center to test an electronic signalling device for use by deaf and deaf-blind persons.

Behavioral and engineering tests were conducted in the field and laboratory in order to assess the effectiveness of the Bell & Howell Vibralert for maintaining contact with deaf and deaf-blind persons. Deaf and hearing parents of deaf youngsters used the portable vibrating signal system (Vibralert) to contact their deaf children at a distance. For two-month trial periods the devices were provided to 24 families who used them in a variety of outdoor settings, primarily for summoning the children home or to prearranged places. Similar testing was done with deaf-blind adults, using the Vibralert in the domestic setting, and both the MIT TAC-COM and the Vibralert in the industrial setting.

Both the deaf and deaf-blind users agreed that the electronic signaling device is valuable --- in principle. The ability to contact a deaf or deaf-blind person at a distance has many advantages, both for deaf children and deaf-blind adults.

Deaf children at play can be contacted by their parents with virtually no inconvenience to either; the parents need only activate the vibrators by pushing a button. Compared to physically moving to a position where the child's eye can be caught or he can be touched, the use of electronic signaling represents a marked improvement. It is not difficult, furthermore, to envision circumstances in which the Vibralert could be more than a convenience: it could save the child from serious danger. This idea apparently occured to participants who thought the device would be even more valuable with younger children than with older children and adults.

Parents invented many specialized uses. Placed under the child's pillow, the Vibralert can function as an alarm clock. A bedridden deaf child can reverse this procedure, signaling his mother when he needs her. The possibilities are numerous.

For the deaf-blind person, the Vibralert can act in place of the doorbell to advise when a visitor has arrived. The deaf-blind couple who tested the system found it was a means for contacting each other --- a problem for them, even when they are in the same apartment. The TAC-COM system tried in the work situation also proved of value. It signaled starting time, lunchtime, coffee breaks, and quitting time. The system could also be modified to advise the deaf-blind person that he is wanted in the office, etc.

The two systems tested were found to have numerous flaws. Carelessness in manufacture and design were evidenced. Both the National Center and the Deafness Center technicians produced long lists of recommended changes in the equipment. Most of their recommendations can be accomplished at small cost. The effect of the changes insofar as instrument utility is concerned would be correspondingly great.

To the deaf and deaf-blind persons, miniaturization appears highly desirable. Children and adolescents, especially, would better accept the receiver were it fashioned like a Dick Tracy wristwatch or a lavaliere.

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Summertime use particularly demands a less bulky instrument, because the user's fewer, lighter clothes offer reduced carrying capacity. Belts and harnesses to hold the receivers could be tried, but they are frequently uncomfortable in hot weather.

Increased effective range was another requested improvement in the Vibralert. No technical barriers prevent this condition being met. Along with it must go greater reliability. Confidence in the system is a requisite for its wider acceptance.

In spite of the Vibralert's limited performance, the majority of families liked it. Ninety percent of hearing parents, 75 per cent of deaf parents, and 89 percent of the deaf children so stated. What is more, a third of each parent group expressed a willingness to purchase the system, if it sold for as much as a week's salary (approximately $100 to $200). Fifteen percent would spend two weeks' salary for the system; none would give a month's salary.

An instrument that combined the modifications suggested --- smaller, lighter, waterproof, more powerful, more reliable --- would probably meet wide acceptance from deaf and deaf-blind groups. Hearing parents seemed more accepting of the signaling system than deaf parents, principally because of negative attitudes toward dependence on an electro-mechanical device. The modifications suggested should overcome the relatively small resistance shown by some deaf parents and children.

Less crucial would be changes directed toward increasing communication. By eliminating the 30-second time-out feature, the Vibralert could be used to send a code --- Morse or a simple, ad hoc series of pulses. Thus, a child could easily learn that one pulse means "dinnertime", two pulses mean "you have a visitor," etc. Two-way communication with the Vibralert system is also possible, if the parties at each end had both a transmitter and a receiver. Obviously, in its present form the equipment does not lend itself to such use. The suggested changes, however would make this service feasible.

Aside from the assessment of on-the-shelf equipment, this project has tested the concept of electronic signaling. The results vigorously support the idea, despite inadequacies in the equipment. In view of the potential uncovered by the studies reported herein, encouragement has been given manufacturers to complete the development steps needed to make a system that meets the recommendations put forth by engineers, parents, and children.

Follow-up information gathered after the formal research was concluded revealed continued acceptance of the equipment. However, obtaining batteries and repair service cropped up as additional problems, since the manufacturer could afford to make parts more available.

A very positive aspect of the project was the manufacturers acceptance of the criticisms. Recent conversations with a representative of Bell & Howell indicates that many of the suggested modifications in the Vibralert have already been made. (Additional materials describing the current models of the Vibralert will be available during the presentation of this paper April 29, 1975. Actual equipment will also be available for demonstration at this time.)

An important condition for gaining these commitments from Bell & Howell seems to have been the apparent marketability indicated by the high level of consumer acceptance uncovered by the research.

For a detailed listing of the recommendations made by project staff and a summary of engineering and performance tests, see _Electronic Communication with Deaf and Deaf-Blind Persons_ (Schein, Jerome D. (Ed.) New York: Deafness Research & Training Center, New York University, 1973).

* * * * * *

NOTE: Complete results of the analysis of the modified device were not available at the time the Proceedings went to press. These data will be presented at the conference.

Title of Paper: Let Your Fingers Do the Talking

Category: (check one)   Device Development / /   Research Study /X/

Brief Description: A new method for using the Touch-Tone Telephone
System for communication between people with hearing impairments and
their friends.

_____

_____
_____

Intended User Group: Those with all degrees of hearing impairment.

_____

Stage of Development: (Check all that are applicable)

A.   Device

Prototype Development   /X/

Feasibility Testing   /X/

Clinical Testing   ·   / /

Available for Sale (check one)   Yes / /   No /X/

Price per unit $ _____

Availability of constructional details: Complete

B.   Research Study

Intended Utilization: Communication by telephone by people
with hearing impairment. _____

_____

_____

Intended Device Application: Component parts for construction
are readily available. _____

_____

_____

Availability of Intended Device: _____

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                                    _____

LET YOUR FINGERS DO THE TALKING

by

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Summary - This paper describes a system which will enable a person who is profoundly deaf, but still able to speak and see, to conduct a two-way telephone communication with any friend who has a 12 button touch-tone phone. The only special equipment used in this communication is a small, relatively inexpensive, electronic device upon which the deaf person places his telephone handset. The other party requires no additional equipment and nothing is electrically connected to either telephone, eliminating the need for a special permit from the telephone company. A message sent to the deaf person is spelled out on the touch-tone dial and it is displayed to the deaf person as a series of alphanumeric characters. A message sent by the deaf person uses the standard voice system.

Introduction

The telephone is a vital component in the modern social structure, yet to a deaf person its main function is a paperweight. This paper may improve this situation for as many as 10,000 of this "silent minority" in the United States who qualify by having sufficient vocal ability to be understood by their friends, enough visual ability to read alphanumeric characters displayed on a screen, and the social ability to have friends outside the "silent minority" with whom they can establish bilateral communication.

One authority on deafness has written, "...they live in a world with other people, and they and whoever wishes to communicate with them, must find mutually acceptable means of communication. ...While it is important to define one's objectives in communication according to the person and the situation, perhaps the chief obstacle to effective communication is one of attitude. If you really want to get an idea across to someone, and to understand him, you BOTH must try. If you do not respect him, neither of you will try very hard, and communication will be poor regardless of the mode employed. ...Which is more important, the person or the mode? Respect must come first, regardless of individual differences, regardless of mode. If respect is there, the differences can be overcome. If it isn't, why bother? And if it isn't, aren't we saying something very important about ourselves?"[1]

Acknowledgement

As an engineer, I can do very little about the respect, but I think that I can provide a better mode.

The System

In telephone communication in which only one of the two parties has auditory impairment it is desirable that the unimpaired communicator should not be required to own or use special equipment. A number of systems based on the touch-tone telephone system satisfy this requirement, and they, and other systems, with their advantages and disadvantages, will be discussed in a paper by Steven L. Jamison, which is also scheduled for presentation during this session of this Conference.

The main advantage of the system I am proposing over similar previous systems is that it takes advantage of the added flexibility of the 12 button touch-tone system over the early 10 button system. All touch-tone phones manufactured since the end of 1973 have the 12 buttom system. Chicago, Illinois and New Jersey, being the first areas to achieve substantial penetration of the touch-tone system, are the only two major markets in which the 10 button system is widely used. At the present time throughout the United States 15% of the telephones are touch-tone and Bell Telephone expects this figure to increase to 50% by 1980.[2]

In a telephone communication between an unimpaired individual and one who has an auditory impairment, using the system proposed in this paper, messages to the unimpaired person are via normal vocalization, while messages sent by the unimpaired person are spelled out.

To send the spelled-out message the lower left, (*), and the lower right, (#), touch-tone pushbuttons are used as preselectors to choose either the left or the right letter of a set of three letters printed on the other buttons. If the letter one wishes to send is the left letter of the set he first pushes the lower left button, (*), then the button on which the desired letter appears. For example, the letter G is the left letter on the 4 button and to send G one would first push (*), then (4). If the lower right button (#), had been pushed instead of (*) the right letter of this set, (I), would have been displayed to the deaf person. If neither of these preselector buttons have been pushed the center letter on the button being pushed will be displayed, (H in this example). To send a number both preselector buttons must be pushed, in either order, before the number button is pushed.

The set is expanded by adding three characters to the (1) button, which presently has only a number on it. These characters are Q on the left, Z on the right, and a blank space in the center for separating words. In the present model the letter O is sent for the number 0 to complete the set of all letters, all digits, and a blank space to separate words. Button number 0 is still unused and available for future expansion of the system.

The system continues to display each character until enough information has been received to form the next character. It then resets its preselector memory so that each new character is independent of previous information.

Performance Data

In the English language each letter of the alphabet can be assigned a probability of occurrence and the average word length is four and one-half characters and one blank space. Therefore, on non-numeric material transmitted by this system 47% of the characters can be sent by a single key stroke with an average of 1.53 key strokes per character and 8.5 key strokes per word. In testing this system word rates have been determined by dividing the key strokes per minute by 8.5. This method has two minor sources of error, variability in word length and a change in the message entropy.

Nine subjects were used to determine the word rate capacity of the system. Practice time for each subject ranged from 2 minutes to 55 minutes. Mean effective word rate during the first 2 minutes was 4.43 words per minute with a standard deviation of .428 words per minute. Only two subjects accumulated more than 30 minutes of practice time and

their maximum rates were 9.38 words per minute and 9.92 words per minute. At a word rate of 9.5 words per minute the average time per key stroke is three-fourths of a second. If this is compared to a typing speed of 60 words per minute the required key stroke rate would indicate an upper limit to the system transmission rate of about 40 words per minute. This is still less than one-fourth of the limitation imposed by the electronic circuitry and it is the same order of magnitude of the maximum comprehension rate for this type of visual presentation.

No discussion of any form of information transmission is complete without a brief examination using information theory of communication engineering.

The amount of information is measured in units called bits. One bit of information is the amount of information that we need to make a decision between two equally likely alternatives, while two bits of information enable us to decide among four equally likely alternatives, and every time the number of alternatives is increased by a factor of two, one bit of information is added.

1. Pollack[3] found that the absolute judgment of the unidimensional stimulus of pitch by humans (between 100 and 8,000 cps) is 2.5 bits as shown in Fig. 1. W. R. Garner[4] conducted similar tests for loudness discrimination between 15 and 110 DB and obtained 2.3 bits as shown in Fig. 2. G. A. Miller[5] indicates that in multidimensional situations up to at least 10 dimensions the channel capacity of the total stimuli is increased by the addition of each dimension, but not as much as the total sum of the single dimension channel capacities.
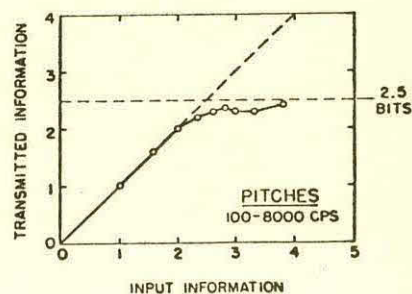

Fig. 1. Data from Pollack (3) on the amount of information that is transmitted by listeners who make absolute judgments of auditory pitch.

Miller[5] also states, "According to the linguistic analysis of the sounds of human speech, there are about eight or ten dimensions - the linguists call them distinctive

features - that distinguish one phoneme from another. ...Pollack and Ficks conducted a test on a set of tonal stimuli that varied in eight dimensions, but required only a binary decision on each dimension. With these tones they measured the transmitted information at 6.9 bits. ...There is a limit, however, at about eight or nine distinctive features in every language that has been studied, and so when we talk we must resort to still another trick for increasing our channel capacity. Language uses sequences of phonemes, so we make several judgments successively when we listen to words and sentences. That is to say, we use both simultaneous and successive discriminations in order to expand the rather rigid limits imposed by the inaccuracy of our...(unidimensional) judgments." These sequences include rhythm and syntax.
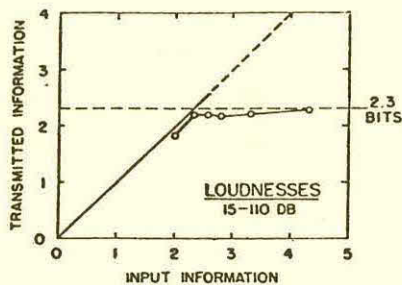
Fig. 2. Data from Garner (4) on the channel capacity for absolute judgments of auditory loudness.

P. W. Nye[6] adds, "The perceptual processes operate on discreet bundles of information which are segmented within the short-term memory of the listener. On what basis this segmentation is achieved is not clear, but it is of more than passing significance that segmentation processes appear to be reflected in the structure of natural language and the production of speech."

H. Levitt[7] nicely summarizes the significance of all this information to the present project by stating, "Experiments in human perception have shown that, with the exception of highly specialized coding systems such as speech, the rate of information processing by the human perceptual system, whatever the modality, is severely limited. It is thus not surprising that despite many years of research virtually all of the attempts to transmit speech information by non-speech like signals...have either not succeeded or have produced rates of information transfer that are substantially less than that for speech."

The alphanumeric display system is, of course, only two dimensional and its sequencial rate is limited primarily by the manual

dexterity of the unimpaired individual and the spelling skill of both individuals. The information transfer rate is therefore severely restricted. However, as compensation for this low rate, we have a system which can be used by a great many people with an absolute minimum of training at a reasonable rate.
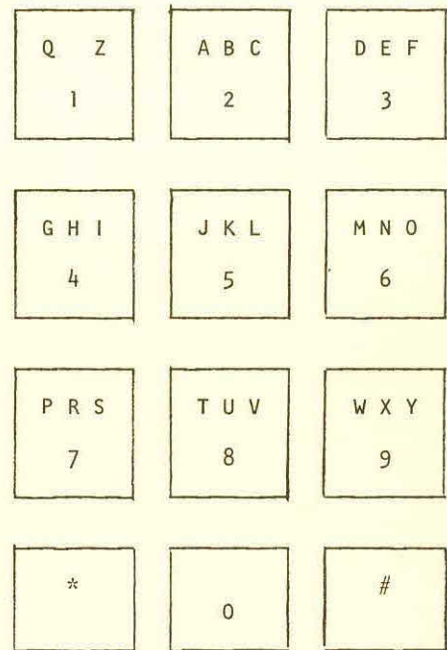

Fig. 3
TOUCH-TONE KEYBOARD

Fig. 4. Device Prototype

Cost Estimate

The unit price of each of the components purchased separately or in 100 unit lots is given in Table 1, below.

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TABLE   1

COST   ESTIMATE

ITEM	Unit Cost (1-10)	Unit Cost (100-up)
Telephone Amplifier	$ 17.	$ 14.
Detector, Decoder (SSC 301-12)	135.	120.
Digital Logic Board	70.	50.
Display (Monsanto MDA111)	74.	43.
Power Supply	90.	50.
Case and Hardware	25.	20.
Total:	$ 411.	$ 297.

Circuit Description

The circuit used to implement this system converts the series-parallel combinations of audio tones generated by the touch-tone telephone into the appropriate visual display for the deaf person. The initial processing is performed by a standard commercial Telephone Amplifier which uses an inductive pick-up coil and amplifier to sense the incoming signals and convert them into electrical signals capable of driving a touch-tone detector and decoder circuit board purchased from Solid State Communications, Inc., 21060 Corsair Blvd., Hayward, California 94545. This system uses 13 outputs from this circuit board, one to indicate each tone-pair combination generated by each of the 12 telephone pushbuttons and one to indicate that one of the pushbuttons in the upper three rows has been pushed. This latter function required a minor modification of the circuit board as it was purchased. These 13 signals drive a digital logic processing board which produces a properly timed standard ASCII set of outputs to drive a Monsanto MDA111 single character alphanumeric light emitting diode display module.

This digital logic processing board contains a set of three PROMs with bussed outputs which are latched by a delayed pulse from the 13th output of the touch-tone decoder board. The preselector outputs of this decoder board set respective bistable memories, which produce two of the five address bits for the PROMs. These preselector memories are reset by another delayed pulse from the 13th touch-tone decoder output, so that each new character begins with no memory of previous events.

The nine inputs to the digital logic processing board which correspond to dial digits 1 through 9 are "or gated" into three sets of digits 1, 4, and 7; 2, 5, and 8; and 3, 6, and 9; and each set output then enables one of the bussed PROMs, with each set also forming the remaining three of the five address bits for the PROM enabled by that set. This permits a considerable saving in the cost of the PROMs.

Alternatives

Two-way telephone communication with a deaf person has been possible for some time by a variety of methods. The most commonly used method at this time involves a system similar to teletype with a sending and receiving unit for each communicator. These units print the message which has been transmitted from a typewriter-like keyboard, so that it can be used by a deaf person who also has a speech problem. However, this system greatly restricts the population with which the deaf person can communicate. This is an extremely important consideration which directly affects the entire social structure and attitude of the deaf subject. In this situation, as in all continuous natural phenomena, it is difficult to differentiate between cause and effect. Because present physical restraints tend to isolate the deaf into a closed community, there is a natural reluctance among most deaf people to accept any concept which might open them to exposure emphasizing their handicap. Technically, this is social entropy. The introduction of the system described in this report is intended for the individual who has the neces-
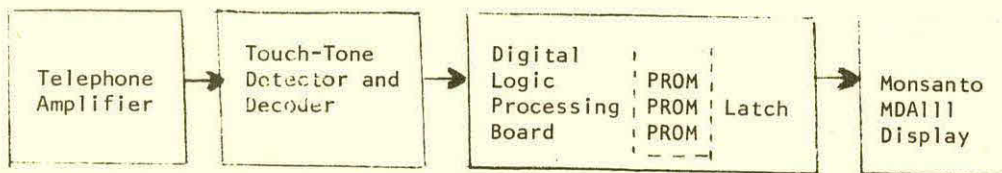

Fig. 5.   Block Diagram

sary physical abilities, and who has already broken the traditional pattern. This person has a number of friends who are not members of the deaf community, but he (or she) is not likely to seek a system like this unless he (or she) is aware that it can be done.

Another alternative is the use of the Morse Code with a visual readout. This system can be implemented for less than $25. Transmission rates for such a system would probably range from five to twenty words per minute based on the FCC minimum requirements for various grades of licenses. However the skill required to operate such equipment would impose another barrier restricting the population with which the deaf person can communicate.

There has also been considerable research into the possibility of electronically processing speech into a display format which a deaf person could visually interpret but these efforts have not yet produced practical results and the system cost is several thousand dollars.

Several years ago Bell Laboratory studied the possibility of using the touch-tone system for communication with a deaf person. They investigated two possible display formats and two possible transmitting techniques, both based on the ten pushbutton dial system. Their results were published in IEEE Transactions on Audio and Electroacoustics, Volume AU-18, Number 1, March, 1970, pp 2-6.

I have found no further published material to indicate that this research has been continued. At that time this goal may have been impractical and/or too expensive. Also, any market research would indicate that the expected monetary return on investment in this type of research would not justify it's expense.

The system proposed in this report uses a more efficient transmitting method made possible by the two additional pushbuttons on the dial. Also, the system cost has been drastically reduced by technological advances such as the development of the digital logic integrated circuits and the display techniques for pocket calculators and other similar devices.

Another important factor is the changing emphasis by a few individuals from monetary return on investment to the personal satisfaction of giving a helping hand to another human being, if he (or she) wants it. The developer of this system is willing to help anyone who wants to build such a system by providing, free of charge, any and all details on the construction of the present pro-

totype, the sources of component parts, and any advice necessary to help build similar devices, as long as this activity does not consume an unreasonable portion of the developer's time and/or resources.

References

1. Gustason, G. The Languages of Communication. Deafness Annual -- 1973: NTIS #PB-235 174.

2. Private Communication from a friend at Bell Labs.

3. Pollack, I. The information of elementary auditory displays. J. Acoust. Soc. Amer. 24:745-749, 1952.

4. Garner, W. R. An informational analysis of absolute judgments of loudness. J. Exp. Psychol. 46:373-380, 1953.

5. Miller, G. A. The magical number seven, plus or minus two: some limits on our capacity for processing information. The Psychol. Rev. 63:81-97, 1956.

6. Nye, P. W. Human factors underlying the design of reading aids for the blind. IEEE Trans. BME-17:97-100, 1970.

7. Levitt, H. Speech processing aids for the deaf: an overview. IEEE Trans. AU-21:269-273, 1973.

Title of Paper: A Visual Vocoder Using A Conventional TV As The Display

Category: (check one)   Device Development /x/   Research Study / /

Brief Description: A visual speech vocoder using 12 spectral channels and
an unmodified TV receiver as the output display has been designed and con-
constructed.   Three of the spectral channels are wide-band for looking at fast
speech parts such as fricatives and stop consonants.   The display is capable
of 1⁷4-2 seconds of information at any one time.   The display can either operate
continuously or store information, and it can be split in order to store on one-half
of the screen while the second half is used for comparison purposes.

Intended User Group: Speech Therapists
                       Speech Teachers for Deaf Students

Stage of Development: (Check all that are applicable)

A.   Device

        Prototype Development   /x/

        Feasibility Testing   /x/

        Clinical Testing   /x/

        Available for Sale (check one)   Yes / /   No /x/

            Price per unit $ _____

        Availability of constructional details:

B.   Research Study

        Intended Utilization: _____

        _____

        _____

        Intended Device Application: _____

        _____

        _____

        Availability of Intended Device: _____

        _____

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A VISUAL VOCODER USING A CONVENTIONAL TV AS THE DISPLAY

by

Richard M. Campbell
Herman R. Weed
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The Ohio State University Bio-Medical Engineering Center

Summary - A visual speech vocoder using an
unmodified TV receiver as the output display
has been designed and constructed. This vocoder
which uses 12 frequency spectral channels and
provides for either continuous or stored display
of one-half to four seconds of speech spectrum
in 32 increments has a brightness which is
considerably better than that of an array of
small incandescent lamps used in a previously
constructed display. Preliminary tests for
communality of ten vowel and nine fricative sounds
shows their average communalities to be 0.43 and
0.80 respectively. Since the vocoder has 12
spectral channels any communality less that 0.92
means the sounds are distinguishable when viewed.

A visual vocoder utilizing an unmodified
TV receiver as the output display unit
has been designed and constructed at The Ohio
State University. The TV receiver display in
this vocoder unit use a 19 inch black and white
receiver and has provided a much brighter
display than an older array of small incandes-
cent lamps. This TV display can be viewed
in a normally lighted room while it was usually
necessary to view the older display in a par-
tially darkened room. A picture of the TV
display unit along with the original array of
lamps is shown in Figure 1. The box to the
right of the lamp array contains the memories
for storing the information and the necessary
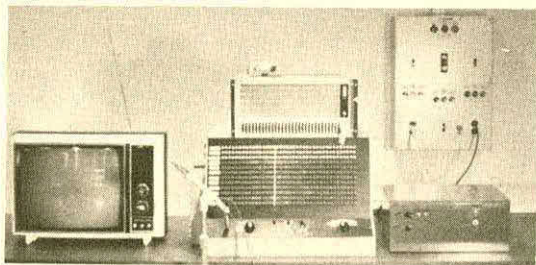electronics for generating the TV signals.

Figure 1 Vocoders

Acknowledgement

The vocoder is a speech frequency
spectrum analyzer which displays a finite
period of time of the spectrum. The display
can either run continuously or store and dis-
play a fixed time period of signal. The fre-
quency spectrum is divided into 12 channels
which are the horizontal rows of the display.
The bottom nine rows utilize one-third octave
filters and cover the frequency range of
200-2800Hz. The upper three rows use wide
band filters of one octave or greater and cover
the range of 500-10000Hz. These wide band
filters with their faster response time are
utilized to obtain fricative and stop consonant
information while the narrow band filters with
their increased resolution but slower time
response are used to obtain vowel information.

There are 32 descrete verticle columns
in the display, each one corresponding to a
different time period of the speech. The
total time displayed is variable between one-
half and four seconds in four steps. The
corresponding time periods for the individual
columns then are 15.6-125 milliseconds. The
spectral information can be put on either from
left-to-right or right-to-left. Information put
on from left-to-right always remains in the
same column until it is removed during a next
pass so that one tends to read it like the pages
of a book with each new pass of information
corresponding to a new page. The information

put on from right-to-left moves from column
to column as new information is added on the
right side so that it always reads left-to-right
in a normal fashion. A storage mode is also
provided so that a phoneme or a word can be
stopped for a long observation. In this mode
of operation, the display can be started auto-
matically with the first sound or manually as
desired. The display can also be stopped
either automatically when the time slots are
all full or manually at any time. The screen
can also be split to allow a storage mode on
one-half while the other half is used as de-
sired. This feature allows a teacher to display
a sound which a student can then attempt to
duplicate.

The amplitude of the signal in each band
of frequencies is indicated by the width of the
horizontal bar on the TV display with maximum
width corresponding to maximum intensity.
The intensities are divided into four descrete
levels.

Figures 2 and 3 show some of the
features of the display. Figure 2 shows the
word "photo" displayed on the entire screen.
The separation between the two syllables is
clearly shown in this figure. The word "tip"
is shown twice on the display of Figure 3. To
create this latter display, the split screen
mode was used. The "tip" on the left side of
the screen was placed on the vocoder and then
the screen was split in order to preserve this
word and the right side of the screen was then
used for the second "tip." In this case both
words were spoken by the same individual and
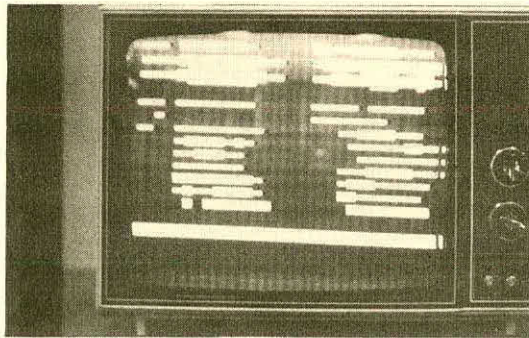the correlation is very good.

Figure 2 "Photo"

Block diagrams for the vocoder operation
are shown in Figures 4 and 5. Tracing the
signal through the diagram of Figure 4 one can
see that the speech passes through a preampli-
fier and then to the filters. The filters con-
sist of 12 parallel filters, one for each row of
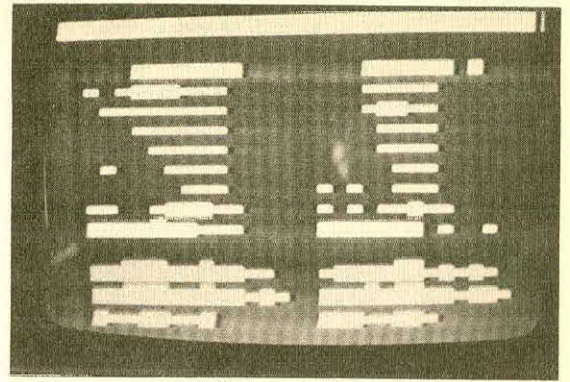the vocoder. The signals from each of the

Figure 3 "Tip" twice

filters pass through 12 parallel peak detectors
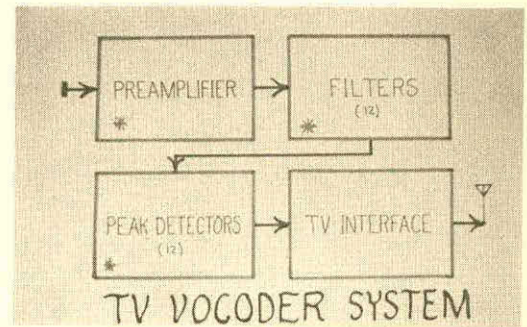and then to the TV interface.

TV VOCODER SYSTEM

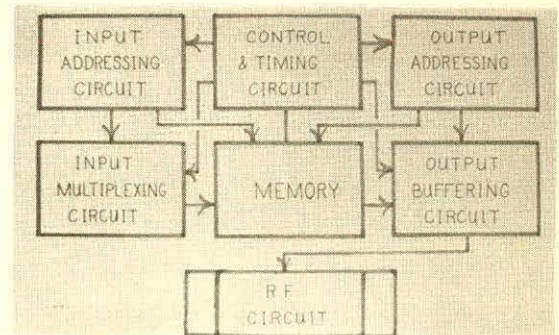Figure 4 Block Diagram of Entire Instrument

Figure 5 Block Diagram of TV Interface

The details of the TV interface are
shown in Figure 5. The signals from the
peak detectors of Figure 4 enter the input
addressing circuit from which they can be
placed in the memory. The memory then is
addressed in proper synchronism as the
electron beam sweeps across and down the TV
display. The signals taken from the memory
are used to modulate the RF carrier of a
small transmitter which transmits the signals
to the TV receiver. This transmitter-receiver
combination will operate over a range of
approximately three meters and it should be
quite possible to drive a number of receivers
if desired.

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A preliminary evaluation of the vocoder has been performed by using a short list of vowel and fricative phonemes. Table 1 shows the list used. Each phoneme was spoken by two male speakers and the average communality for the vowels and fricatives was measured independently on the vocoder. The average cross communality was also measured for the two speakers.

Table 1
List of Phonemes

Vowel Phoneme	Environment
/i/	team
/I/	tip
/E/	ten
/ /	tap
/ɔ/	talk
/U/	took
/u/	tool
/ʌ/	ton
/e/	tape
/o/	tone

Fricative Phoneme	Environment
/f/	fun
/v/	eve
/s/	sing
/z/	zoo
/ /	ship
/ /	azure
/ᴖ/	thin
/ /	then
/h/	how

Communality is defined for these measurements (1) as the fraction of the rows which agree exactly in intensities for the different phonemes. A single column corresponding to the middle of the time period of the spoken phoneme was used in each individual case and taken as the average value for that phoneme. If the levels differed by at least one unit of the four available, they were considered as not agreeing for this analysis. A small communality then means that the phonemes appear different on the vocoder and a large communality means that two different phonemes look alike. This communality can vary between 0 and 1.0 with a maximum value of 0.917 being required for any detectable difference. (There are 12 rows and a minimum detectable difference

will have a communality of $\frac{11}{12}$.)

The results of these communality tests are shown in Table 2 along with similar tests on the original vocoder using the array of miniature lamps as the display. In the original unit, only two intensity levels were considered i.e. lamps on or off.

Table 2
Communality Results

TV Display Vocoder
(4 amplitude levels)

	Average Communality For Vowels	Average Cross Communality For Vowels
Speaker 1	0.39	0.70
Speaker 2	0.46	

	Average Communality For Fricatives	Average Cross Communality For Fricatives
Speaker 1	0.83	0.94
Speaker 2	0.78	

Lamp Array Vocoder
(2 amplitude levels)

	Average Communality For Vowels	Average Cross Communality For Vowels
Speaker 3	0.67	0.84
Speaker 4	0.68	

	Average Communality For Fricatives	Average Cross Communality For Fricatives
Speaker 3	0.78	0.95
Speaker 4	0.76	

These results then show about a two to one improvement in communality for vowel phonemes as compared to the original vocoder with only a small loss in the cross communality between the subjects. The communalities for the fricative's remained about the same.

The speech vocoder using the TV display has given us an instrument with both a brighter output which can be viewed in normal room light and greater visual differences between phonemes as viewed on the screen.

References

1. Reich, Sanford. Design and Evaluation of
    a Dual Function Visual Vocoder in Speech
    Therapy, Ph.D. dissertation, The Ohio
    State University, 1972.

Title of Paper: TELEPHONE DEVICES FOR DEAF PEOPLE

Category: (check one)   Device Development / /   Research Study /x/

Brief Description: This paper is the result of a survey of telephone accessory aids and devices which permit deaf people to use the telephone. Descrived in the paper are a variety of stationary and portable teletypewriter devices which permit people with compatible equipment to communicate through standard telephone equipment. Also described are special codes and devices for using the touch-tone ^{R} telephone.

Intended User Group: Deaf consumers, government officials, organizations serving deaf people.

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   / /

    Feasibility Testing   / /

    Clinical Testing   / /

    Available for Sale (check one)   Yes /x/   No / /

      Price per unit $ _____

    Availability of constructional details:

B. Research Study

    Intended Utilization: The paper was prepared to provide basic information to deaf consumers, to government officials, and to industrial organizations interested in telephone accessory devices for deaf people.

    Intended Device Application: According to Teletypewriters for the Deaf, Inc., accessory telephone devices are currently used by deaf people in over 5,000 locations in the country.

    Availability of Intended Device: Most of the devices discussed in the paper are commercially available.

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by

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Without special assistance, deaf people are unable to use a standard telephone. However, several special techniques (such as tapped-out codes) and special devices (such as the teletypewriter) make the telephone accessible to deaf people. A major breakthrough was the development of an acoustic modem/ coupler which permits the attachment of keyboard devices to the standard telephone receiver. Using compatible equipment, two people can "converse" by typing messages back and forth. Also discussed briefly are devices for sending and receiving graphic displays such as the Electrowriter system and the Picturephone.

It is ironic that the development of each major new communications medium seems to have placed deaf people at an ever greater communications disadvantage with hearing people. The telephone is no exception.

Dependence on telephone usage is typically so casual that it is difficult for a hearing person to fully comprehend the isolation caused by being permanently without a telephone. The impact on social, vocational, educational and emergency aspects of living can be profound. Imagine the alternatives: to walk or drive to where a person is, to send a letter or telegram, or to ask a hearing person to handle the call for you. At best, these alternatives represent excessive delay, inconvenience and expense. And third party assistance, of course, makes privacy impossible. Frequently, none of these alternatives will be possible and the result will be no communication at all. When the situation requires emergency services, such as police or medical assistance, the inability to use the telephone could result in major physical harm or even death.

There are two basic alternatives for providing telephone or telephone-like communication services for deaf people. The primary requirement in each case is a sophisticated, interconnected communications network. And because deaf people are dispersed geographically, the network in either case must be a national one.

In the first alternative we would construct a new national network from scratch, which would link together all deaf people in the country and, where possible, would interface with the existing communications networks currently used by hearing people. Such a system would of course be economically infeasible. In the second --- and more realistic --- alternative, we would devise methods for deaf people to use existing telephone facilities. This would include nontraditional uses of standard equipment (such as tapping out morse code messages) as well as the addition of accessory equipment to existing telephone terminals (so that messages could be typed out on a keyboard and transmitted much like Western Union telegrams).

This paper describes several methods and accessory devices which permit deaf people to use the existing telephone network.

Third Party Assistance

For deaf people, the vast majority of telephone usage involves the assistance of a hearing family member, neighbor, or associate. If the deaf person has adequate speech he or she may wish to do the speaking. An additional earpiece, called the Watchcase receiver, can be obtained from the telephone company so that the third party can hear what is being said. The third party then communicates the message to the deaf person visually: lipreading, written notes, or manual signs.

Many deaf people, however, will require assistance in speaking on the phone as well as in listening. In this type of interaction, in which the hearing person acts as intermediary for speaking as well as for listening.

The usual opportunities for con-
fusion or misunderstanding are, of course,
compounded by the use of a third party.

Simple Solutions

In some cases, a telephone amplifier,
built into the actual earpiece, is enough to
permit rudimentary communication even for peo-
ple with severe hearing impairments. Such am-
plified receivers are available directly from
local telephone companies.

For most deaf people, however, this am-
plification is ineffective. For these people
spoken communication is impossible. Never-
theless, with few exceptions, they can detect the
presence of a loudly spoken, low frequency
syllable (like "tap") or the sound when a hard
object (like a coin) is struck against the
telephone microphone. This makes possible the
use of Morse Code or other codes --- assuming,
of course, that both parties know the code or
have access to a card defining it. [1]

Several years ago, Bell Telephone Lab-
oratories developed a number of different pro-
totype units to aid this type of simple tele-
phone communication for deaf people. [2] One
such unit, the Code-Com* set, is now readily
available from local telephone companies.
This device facilitates the use of codes by
providing a blinking light or vibrating button
so that the deaf person is not forced to
strain to hear the signals. A telegraph-like
key can also be used in the sending operation,
but the light or vibrator can also be activa-
ted by a voice on the line. Rather than tap-
ping, the hearing party can say "no," "yes,
yes" or "please repeat" and the light will glow
for the deaf receiver 1, 2, or 3 times, res-
pectively.

A similarly functioning device has been
developed and tested by personnel at Califor-
nia State University at Northridge (CSUN). [3]
Its small size (about the same as a pack of
cigarettes) and its battery power make it
fully portable, thus permitting the unit to be
used by deaf people with any standard tele-
phone. They are therefore not tied to the use
of one specific telephone. If the deaf person
has intelligible speech and if he or she is
calling a hearing person, the process can be
speeded up considerably. First of all, the
deaf person can speak much faster than he or
she can send code. Secondly, if the deaf par-
ty can predict the conclusion of a sentence
from the first part of the coded message being
received, then he or she can verbally complete
the sentence and simply ask the hearing party
for confirmation. In fact, the conversation
can be accelerated to a form similar to twenty
questions, where the deaf person takes the
initiative in making statements and asking

questions. The hearing person taps once for
"no," twice for "yes" and three times for
"repeat."

These simple techniques permit communi-
cation with hearing people, and do not require
the hearing person to have special telephone
equipment. Nevertheless, the associated ex-
penditure of time in using these techniques
is typically so large as to effectively limit
their use to fairly simple exchanges.

Touch-Tone Telephone Accessories

The increasing availability of the
Touch Tone* telephone offers the possibility
that the buttons on this telephone could be
used as a keyboard by deaf people to send and
receive messages. Since this keyboard is bas-
ically numeric, a coding scheme is needed to
transmit alphabetic characters and special
equipment is needed on the receiving end to
convert the code into readable alphabetic
characters. So, in 1968, Bell Telephone Lab-
oratories announced[4] an experimental device
which attaches to the phone and displays each
character as it is received (plus the two
preceding characters as well). A functionally
similar, but completely portable prototype
unit, called the Cybertone*, was also devel-
oped in the late sixties. Two portable,
battery-powered units, the Telelator[6]
and the Cyberphone*[7] have also been pro-
duced in prototype form. They display only
one character at a time.

A remote-controlled typewriter, called
the Cybertype* and an expanded alphanumeric
light display, called a Cyberlex*, can be at-
tached to the Cybertone to provide for the
display of several letters at one time, thus
easing the visual and mental fatigue of con-
centrating on one, or at most, three letters
at a time. These additions, however,
compromise portability.

None of these devices (Telelator, Cyber-
phone, Cybertone, and the Bell Labs unit)
are currently available commercially. In any
case, all are incompatible with the teletype-
writers which are discussed below.

The Teletypewriter

To date, the most significant develop-
ment facilitating telephone communication with
and between deaf people has been the teletype-
writer. The term "teletypewriter" is used
here in a generic sense to cover a wide range
of equipment and model numbers from both U.S.
and European firms. Usually, they are key-
board send/receive (KSR) units, having a key-
board for input and providing typed hard-copy
output. When this equipment is interfaced to

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*Code-Com, Trademark of AT&T Company

*Touch-Tone, Registered Service Mark of AT&T
Company
*Cybertone, Cyberlex, Cyberphone, Trademarks
of Cyber Corporation[5]

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standard telephones, the conversing parties alternately type their portions of the conversation. Whatever is typed on one end of the line appears on both the sender's and the receiver's unit, thus providing each with a record of the call. There are nearly 5,000 such units presently in use in the homes and offices of deaf people, in schools, churches, rehabilitation agencies and other public and private organizations serving the deaf, and at police stations and other locations equipped to provide emergency services. (See Table 1, Telephone-Teletypewriter Installations)

In 1965, Mr. Robert Weitbrecht, a deaf physicist, developed a modem/coupler[8] that would permit a teletypewriter to be acoustically attached to a standard telephone receiver. The unit performs two related functions. The electrical signals that are generated when the keys of a teletypewriter are depressed are converted (modulated) into audible tones and entered into the mouthpiece of the telephone handset. A similar unit at the other end of the line converts (demodulates) these special tones back into the electrical pulses necessary to activate the printing mechanisms of the receiving teletypewriter. The teletypewriter is thus acoustically coupled to the telephone without being electrically or mechanically attached to it.

Teletypewriters used in this way are, for the most part, older models which have been supplied by the American Telephone and Telegraph Company, the Bell Telephone System, Western Union Telegraph Company, various military and governmental agencies, and amateur radio operators. In 1968, Teletypewriters for the Deaf, Inc. (TDI) was formed as a not-for-profit corporation[9] for coordinating the acquisition and distribution of these surplus teletypewriters to deaf people and for providing an up-to-date directory of locations where teletypewriters have been installed.

All of the teletypewriters listed in the TDI directory are "compatible," and therefore can be used to contact any of the other teletypewriters in the directory. They all use the same code (the 5 bit Baudot code), operate at the same rate (45.5 bits per second). This compatibility is assured by the modem/coupler which interfaces the teletypewriter to the telephone and thus to the telephone line[10]. These modem/coupler units are available through several firms.[11]

Typical teletypewriter installations cost about $250 to $300 but can certainly cost up to $1000 depending upon whether the teletypewriter is purchased or donated, the model of modem/coupler purchased, and the optional special features if any. These features may include signaling devices which cause selected house lights to flash when there is an incoming call, or automatic answering units, or punched paper tape devices to speed the transmission of lengthy messages. In addition, of course, there are continuing operating expenses: the telephone company's regular monthly service charge, long distance toll calls, paper and ribbon supplies, and equipment maintenance.

Other Keyboard Devices

TVphone

The TVphone* is similar in many ways to the teletypewriters discussed above. Each has a full alpha-numeric keyboard and the TVphone is fully compatible with the teletypewriters in the TDI network; i.e., same communication code, frequency levels, and signaling rate. The primary difference is that the messages of the TVphone are displayed on a standard television set, to which it must be connected. The display is a generous eight lines, 32 characters to a line. If a record of the conversation is desired, a tape cassette recorder can be added.

Since the TVphone weighs only eight pounds, it can be regarded as portable, a major advantage over the typical teletypewriter. However, unless a person also wishes to carry a television set, his or her use of the TVphone is limited by the need to have a television set in close proximity to the phone that is to be used. This factor, coupled with the need for a convenient power outlet, compromises portability. It would be difficult, for instance, to use the TVphone in a public telephone booth.

The base purchase price of the TVphone, exclusive of television set, tape cassette unit, or other special features, is approximately $1000. The unit may also be obtained on a lease basis for approximately $20 per month and perhaps at a lesser rate in the foreseeable future.[13]

MCM Communication System

The MCM Communication System* was announced in July of 1973; a completely self-contained unit emphasizing portability, measuring 10 inches by 8.5 inches by 3 inches, it weighs less than 4 pounds, including rechargeable batteries. The unit, therefore, can be easily carried from place to place and used at home, at work, or even in a phone booth--virtually anywhere there is a telephone.

The MCM, like the teletypewriter, has three rows of keys rather than four (as on the TVphone), with the numerics sharing the top row of alphabetic keys. Special characters double up with each of the other alphabetic keys and thus provide for punctuation marks and other symbols. A 32-position register, that extends across the unit just above the

*TVphone, Trademark of Phonics Corporation[12]
*MCM Communication System, Trademark of Sico Corporation[14]

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top row of keys, serves as the unit's display.
Light emitting diode (LED) segments permit
each register position to display any of the
alphabetic, numeric or special characters that
appear on the keyboard. As each key is de-
pressed, the corresponding character appears
in the right-most position of the register,
shifting the remaining register contents one
position to the left. As keying (typing) pro-
gresses, the message moves across the display
and disappears off the left-hand end. Unlike
the Times Square display, which moves smooth-
ly and continuously, the MCM display bumps
along irregularly depending on the keying
characteristics of the sender.

The MCM's self-contained modem/coupler
provides an interface that is compatible with
the teletypewriter network, using the same
codes, frequency levels, and data rates.
The MCM also automatically
generates and transmits the Return and Line
Feed signals at appropriate times.

The favorable weight and size character-
istics of the MCM make it particularly attrac-
tive for travel and other applications re-
quiring easy portability. These characteris-
tics are largely a consequence of its use of
modern integrated circuit technology --- a
technology which should also contribute to
reduced maintenance. The MCM sells for about
$600.

Full Graphics Displays

Another approach, quite different from
those already discussed, involves "graphic"
transmission. Such systems have an inherent
advantage in that they can transmit not only
words, but also diagrams, maps, and other
drawings that are impossible to generate from
a keyboard.

Electrowriter ®
For example, an Electrowriter* system,
currently in use between the Rochester School
for the Deaf and the Mathematics Learning
Center at the National Technical Institute
for the Deaf, makes it possible to clarify
a mathematical concept or problem by means of
an appropriate graph or figure. As the mes-
sage or drawing is being created by the send-
er, it is simultaneously being duplicated at
the receiving end. Similar units, which are
available from other firms,(16) utilize built-
in acoustic couplers, making them usable with
any standard telephone. However, it is doubt-
ful that these graphic units will ever be
widely used by the deaf community since they
are fairly expensive (about $50 per month) and
since they are incompatible with the TDI net-
work equipment discussed earlier. Neverthe-
less, installations of these graphic units in
hospitals, manufacturing firms, and other
businesses for such applications as requisi-

tioning and reporting, could open up new em-
ployment opportunities for qualified deaf
applicants.

Picturephone ®
Finally, the telephone companies have,
for many years, alluded to the prospect of
telephone communication combining video with
audio --- a Picturephone* system giving the
ability to actually see the person with whom
one is conversing. Assuming good quality pic-
tures, the usual modes of speechreading (lip-
reading), fingerspelling, and manual signs
would be applicable. If necessary, pads of
paper containing written notes could also be
held up for viewing.

A prototype system was installed at the
National Technical Institute for the Deaf in
1969. The original system of six Vistaphone*
sets has now been expanded to thirty-two and
receives enthusiastic use on campus because of
the immediate and spontaneous communication
which it affords.(18) The use of manual signs
and fingerspelling fall well within the re-
solving capabilities of this equipment. And,
although there may be some reduction in a per-
son's ability to interpret the subtleties of
lip movements during speech reception (lip-
reading), facial expressions not only commun-
icate mood and feeling but also contribute
significantly to the overall process of
speechreading. Written messages or typed copy,
however, are currently beyond the power of the
equipment to resolve without the use of a spe-
cial lens adaptor.

Although using standard telephone wire,
the system is presently intramural with no
connection to outside telephone lines. It
utilizes a special dial-activated switching
system that can handle both video and audio
signals. It is clear, though, that such
equipment, including the necessary central
switching systems, will not be available soon
outside the few specialized installations such
as the NTID campus.

Summary

Although not an exhaustive survey, those
devices which have been discussed here are
thought to be representative. There has been
no intent to endorse any product. Each has
several characteristics that are particularly
well suited to assisting deaf people in their
use of the telephone. As such equipment be-
comes increasingly available to them and to
their families, friends and associates, deaf
people will experience reduced dependence on
others in making telephone contacts, enhanced
flexibility in business and social interac-
tions and the added peace of mind that comes
from the ability to obtain help in emergencies.
These benefits, so widely enjoyed by hearing
people, should be shared by deaf people.

---

*Electrowriter, Registered Trademark of
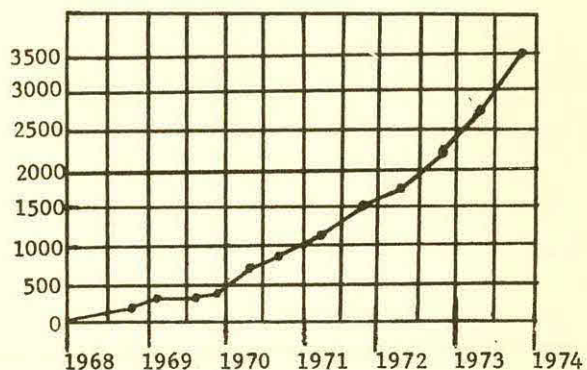Victor Graphic Systems, Inc.(15)

*Picturephone, Registered Service Mark of AT&T.
*Vistaphone, Trademark of Stromberg-Carlson
Corporation. (17)

1. Smith, Gale M. What Hath God Wrought?
    Volta Review, 67:505-7, September 1965.

2. Smith, Gale M. Telephone Service for the
    Totally Deaf, Volta Review, 65:579-83,
    December 1963.

3. Center on Deafness, California State
    University, Northridge, California 91324.

4. Experimental Device May Extend Use of
    Touch-Tone Telephone to the Deaf, Bell
    Laboratories Record, January 1968, p.34.

5. Cyber Corp. 2233 Wisconsin Avenue, N.W.,
    Washington, D.C. 20007.

6. Gydesen, Frederick R. and Still, Clyde N.,
    The Telelator: Telephone Telemetry for
    the Deaf, Fifth Annual Rocky Mountain
    Bioengineering Symposium, IEEE Conference
    Record, pp. 34-37, May 1968.

7. Cyber Corp. 2233 Wisconsin Avenue N.W.,
    Washington, D.C. 20007.

8. Breunig, H. Latham Teletypewriters: A
    Way for the Deaf to Make Telephone Calls,
    Hearing and Speech News, 37:8-9, September
    -October 1969.

9. Teletypewriters for the Deaf, Inc.,
    P.O. Box 622, Indianapolis, Indiana 46206.

10. Breunig, H. Latham Teletypewriters: A
    Way for the Deaf to Make Telephone Calls,
    Hearing and Speech News, 37:8-9, September
    -October 1969.

11. Applied Communications Corporation
    P.O. Box 555, Belmont, California 94002.

    EESCO Communications, Inc., 14-25 Plaza
    Road, Fair Lawn, New Jersey 07410.

    Ivy Electronics, Inc. P.O. Box 1325,
    Alvin, Texas 77511.

12. Phonics Corporation
    814 Thayer Avenue, Silver Spring, Maryland
    20910.

13. Sachs, Reynold M. Technology Comes to
    Telecommunications for the Hearing Impair-
    ed, Highlights, 52:16-18, Fall 1973.

14. Silent Communications, Inc., 1440 29th
    Avenue, Oakland, California 94601.

15. Victor Graphics Systems, Inc., 3900 North
    Rockwell Avenue, Chicago, Illinois 60618.

16. Talos Systems, Inc., 7311 East Evans Road,
    Scottsdale, Arizona 85260.

    Telautograph Corporation, 8700 Bellanca
    Avenue, Los Angeles, California 90045.

17. Stromberg Carlson Corporation, 100 Carl-
    son Road, Rochester, New York 14603.

18. NTID Focus, September-October 1973, p. 2
    A publication of the National Technical
    Institute for the Deaf, Rochester
    Institute of Technology, One Lomb
    Memorial Drive, Rochester, New York 14623

TABLE 1
TELEPHONE-TYPEWRITER INSTALLATIONS

VERBAL AND NON-VERBAL COMMUNICATION

Chairman, Eugene Kwatny, Ph.D.
Department of Rehabilitation Medicine,
Temple University School of Medicine &
Krusen Center for Research and
Engineering

Title of Paper: "Synthetic Speech Comprehension: A simple test applied to Reading Machine outputs."

Category: (check one)   Device Development / /   Research Study /X/

Brief Description: The paper describes the results of a comprehension test applied to the speech output of a prototype computer-based Reading Machine. Three stages are involved in the text conversion. An optical character reader converts the text into machine readable form; a dictionary is used to convert the orthographic spelling to phonetics and a speech synthesis algorithm calculates the control parameters required to drive a hardware synthesizer.

Intended User Group: The Reading Machine is intended to operate in a central library location and to provide recordings of books or articles at high speed in response to requests made by blind and other reading handicapped persons.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   / /

Feasibility Testing   / /

Clinical Testing   / /

Available for Sale (check one)   Yes / /   No / /

Price per unit $ _____

Availability of constructional details:

B. Research Study

Intended Utilization: To provide a supplementary supply of reading matter in "Talking Book" form in circumstances where readers will be prepared to sacrifice the quality of real speech in return for fast access.

Intended Device Application: _____

_____
_____
_____

Availability of Intended Device: _____

For further information, contact: Name Dr. P. W. Nye
HASKINS LABORATORIES
Address 270 Crown Street
New Haven, Conn. 06510
Telephone: (203)436-1774

SYNTHETIC SPEECH COMPREHENSION

A SIMPLE TEST APPLIED TO READING MACHINE OUTPUTS

by

Patrick W. Nye
Haskins Laboratories, 270 Crown St., New Haven, Ct. 06510

Frances Ingemann
Haskins Laboratories and University of Kansas, Lawrence, Kansas

Lea Donald
Haskins Laboratories and University of Connecticut, Storrs, Ct.

Summary - Different types of synthetic speech generated by a computer from printed texts have been compared for comprehensibility with a text read by a human speaker. Two groups of listeners were timed in two stages as they answered questionnaires; one on a synthetically and one on a naturally spoken text. The first stage covered the time taken to respond after hearing the texts through once, while the second stage covered a period when the subjects replayed all or portions of the tapes to complete the answers omitted at the first hearing. The length of these times was assumed to represent the relative difficulty of comprehension and they were later compared with the results of a paired-comparison preference test. The results indicate a direct relationship between listener preference and listener performance.

INTRODUCTION

Listeners such as the blind, many of whom depend almost entirely on speech as a means of acquiring information, are particularly concerned about speaker "quality"—where the term quality is used in a broad sense to cover such factors as the speaker's intonation patterns and accent or dialect. However, the availability of good quality readers is restricted and this is one of the many reasons why the process of producing spoken recordings for the blind is extremely slow. Several months can elapse between the publication of a new book or periodical and its availability in spoken form to blind subscribers. It is this fact which argues most strongly the need for an automatic reading system.

As a part of basic research on speech, Haskins Laboratories have been working for several years on the development of a Reading Machine for use by the blind and reading handicapped. During this period, with the objective of improving the speech quality, several different versions of a Synthesis-by-Rule program[1] have been designed by Kuhn to control two types of synthesizer--one of the Laboratories' own design and the other an OVE-III[2]. Using these programs a prototype Reading Machine system has been assembled[3] which is capable of reading typewritten texts and converting them to synthetic speech with only occasional editorial intervention by a human operator. During the past two years, the Laboratories have been conducting evaluation studies to assess the quality of synthetic speech and to determine its potential for early application to the problem of providing blind people with faster access to printed information. Previously reported work on the intelligibility of synthetic speech[4,5] has shown that several synthetic phonemes--particularly the fricatives--are poorly identified compared with their counterparts in natural speech. From these data, which yield error rates differing by as much as a factor of ten, it is apparent that, a priori, one could expect that a listener's comprehension of synthetic speech would lie below his comprehension of natural speech. However, there still remain the crucial questions: "Compared with natural speech, how good is the comprehension of a long text where natural redundancy is likely to compensate for losses in phonetic intelligibility?" and "Will blind listeners be tolerant of the deficiencies of synthetic speech in return for faster access to printed matter?"

To begin answering the first of these questions, a simple experiment was designed to derive a measure of the comprehensibility of synthetic versus naturally spoken text passages. Secondary objectives were 1) to determine the degree of improvement in speech quality contributed by successive speech synthesis programs and different synthesizers. 2) to assess the relative performance of synthesis programs using hand prepared versus purely automatically derived phonetic input, and 3) to compare the comprehensibility measurements with the results of a speech quality

preference test.

METHOD

A test was designed to compare the comprehensibility of texts generated by three synthesis programs, employing two different synthesizers and two sources of phonetic input. The synthesis programs differed from one another in terms of either the tabular phonetic values used, or the calculations which they perform to derive the control parameters fed to one of two speech synthesizers.

Chosen as the input were two text passages on the subject of "tunnels." These texts were obtained from a published reading test[6] and were matched for reading difficulty and designed for college-bound and college students. Text A contained roughly 2000 words while text B contained about 1700 words. Copies of both texts were then converted from their orthographic form into phonetic strings by means of the Reading Machine program and then synthesized.[7] No human intervention beyond ensuring that all the necessary words were contained in the computer stored dictionary was involved. Subsequently, the same two texts were also synthesized from a phonetic transcription prepared by a linguist. The hand prepared and automatically produced input strings differed principally in the placement of prosodic markers and the use of reduced versus full forms. The two synthesizers differed primarily in the circuitry of their formant resonators: in the first, an OVE-III, the resonators are connected in series; whereas in the Haskins Laboratories Synthesizer the resonators are connected in parallel.

A total of four "synthesis combinations" (i.e., combinations of algorithm, synthesizer and text) were examined. These different speech forms are identified as follows:

a) DEC71-HO - An algorithm first made available by Kuhn in December, 1971. The extension HO signifies that it employs the Haskins Laboratories Synthesizer with a phonetic input derived automatically from the orthographic (ordinarily spelled) versions of the two text passages.

b) DEC73-OO - An algorithm designed by Kuhn for use with the OVE-III synthesizer--with the input derived automatically from orthography. [This algorithm has been used in recent studies by Ingemann[8].]

c) DEC73-OE - The same algorithm as above, employing the OVE-III synthesizer and hand prepared phonetic texts created by Frances Ingemann (see below).

d) JUN74-OE - A slightly modified version of the DEC73 algorithm combined with an entirely new set of phonetic tables designed by Ingemann[8]. The phonetic texts used with this routine were prepared by Frances Ingemann specifically to match its capabilities and those of the OVE-III synthesizer.

Each of these "synthesis combinations" was applied to both text A and B to yield a total of eight recordings. The speaking rate varied slightly among the different synthesis routines from a low of 133 words per minute (wpm) (DEC71-HO) to a maximum of 154 wpm (JUN 74-OE). To provide a "control" condition, natural speech recordings of texts A and B were made by a male speaker in a moderate New York dialect, fully familiar to all the listeners who completed the test. His speaking rate was 170 wpm.

Twenty-four college students were employed as 'experimental' listeners. Half of the students heard text A in one of the four forms of synthetic speech and then text B in natural speech. The remainder heard text B in synthetic speech and text A spoken naturally. Text A, in either synthetic or normal speech form, was always heard before text B. (A natural speech pilot experiment in which text B preceded text A for half of the trials provided no evidence that the order of presentation had any bearing on the difficulty that a subject experienced on a particular text.) After hearing a text played through once without interruption, the listeners were required to answer fourteen multiple-choice questions. These questions sought factual information from the texts and offered four possible answers to each question. One question on each text was concerned with numerical data and a further ten questions required answers which were either direct quotations or close paraphrases of short statements contained in the text. Answers to the remaining four questions were less direct and required the synthesis of facts distributed over a paragraph of text (average length about fifty words).

Two factors were assumed to govern the listeners' performances on the questionnaire; the degree to which they had succeeded in interpreting and understanding the speech content and the amount of prior knowledge they may have had about the subject matter. With the objective of assessing the prior knowledge factor, the two questionnaires were presented to a new group of twelve student 'readers' who, without hearing the texts, attempted to select the most plausible answer to each question or, failing that, picked an answer at random. These students were of comparable academic status and background to the twenty-four 'experimental' listeners.

The results of the prior knowledge test are shown in Table 1. Adopting the null hypo-

thesis that all of the answers were selected at random, the binomial distribution was used to predict the number of students who could be expected to correctly select the answers of up to eight questions out of the total of fourteen. These predicted data also appear in Table 1. To test the hypothesis a Chi squared test was made of the expected numbers versus the actual numbers of students choosing correct answers. The result indicated that the actual data are consistent with the null hypothesis at a confidence level in excess of five percent. Thus the phrasing of the questions or the reader's general knowledge provided scant help in choosing the correct answers.

TABLE 1

Number of correct answers	Number of students Texts		Expected number of students
	A	B	
0	0	1	0.3
1	0	2	1.2
2	3	1	2.5
3	1	6	3.4
4	5	1	3.1
5	0	0	2.1
6	3	1	1.0
7	0	0	0.4

Text A, Chi squared = 10.9 (6 deg. of freedom)
Text B, Chi squared = 8.5

Each student from the 'experimental' group listened to the recordings in the presence of an experimenter equipped with a stopwatch. At the end of each recording the stopwatch was started and the listeners immediately turned their attention to the questions and answered them at their own pace. However, in nearly all instances, at the end of one pass some of the questions were left unanswered. After noting the time which had elapsed up to that point (T_1) and after rewinding the tape, the stop-watch was restarted. The listeners were then allowed to selectively replay passages and check off answers until they were confident that all the questions had been answered correctly. The time taken in this second phase of question-answering was also recorded (T_2). Exactly the same procedure was followed for the second text.

Upon completing the answers for both texts, each listener was given a short passage in two synthetic speech forms and asked to state which one he or she preferred. All possible pairings of the four speech forms were examined and their relative distance on an arbitrary preference scale (labeled from 0-7) was computed by the method of pair comparisons[9].

The goals of the data analysis were to assess listener's performances on synthetic and naturally spoken texts and their preferences among different speech forms. Tests for these differences were made statistically. Once again, in accordance with basic principles, a null hypothesis was adopted, namely, that the data were drawn from the same distribution, i.e., no differences were anticipated. However, individual differences in listening skills were likely and their effect was offset where possible by applying tests to differences between individual performances with synthetic and natural speech.

Differences between Synthetic and Natural Speech

An analysis of the observations listed in Table 2 reveals that as regards the time T_1 taken to complete the first pass through the questionnaires, the null hypothesis is confirmed and no differences emerge between pooled synthetic and natural data. However, the same treatment applied to T_2 shows that the second period (needed to complete the questionnaire) is an average of 4.5 minutes in length for natural speech and one minute and 45 seconds longer when the listener works with a synthetic speech text. The probability that this difference arises by chance is small ($p \approx 0.025$) and suggests that the listener requires 23% more time to understand the synthetic speech passage. A comparison of the number of erroneous answers in the two conditions shows, however, no significant differences. This finding was not unexpected because the instructions given to the listeners stressed that they were to continue working until they were satisfied that all of their answers were correct. Thus verification of the null hypothesis in this case merely indicates that the listeners followed their instructions with equal consistency in the two conditions.

TABLE 2

AVERAGE DATA OBTAINED PER SPEECH FORM

Speech Form	T_1	T_2	Errors
DEC71-HO	2.87	8.29	2.0
DEC73-OO	2.71	7.20	2.17
DEC73-OE	3.41	5.31	3.33
JUN74-OE	2.85	4.30	2.0

AVERAGES: SYNTHETIC VS. NATURAL SPEECH DATA

Speech Form	T_1	T_2	Errors
Synthetic	2.96	6.27	2.37
Natural	2.97	4.52	2.29

TABLE 2 (cont'd)

AVERAGE DATA PER TEXT

Speech Form	Text	T_1	T_2	Errors
Synthetic	A	3.05	6.17	2.5
"	B	2.87	6.38	2.25
Natural	A	3.20	5.72	2.5
"	B	2.78	3.31	2.08

Differences between Particular Speech Forms

Results from the pair comparison study were analyzed and relative distances were computed on a seven-point scale. These values are plotted in Fig. 1. The JUN74-OE combination (of synthesizer program and input) ranks highest with the DEC73-OE and DEC73-OO combinations occupying the next two positions respectively at equal intervals of about 1.6 scale points. The DEC71-HO algorithm was rated lowest—well below the other three.

LISTENER'S RELATIVE PREFERENCES
AMONG DIFFERENT SPEECH FORMS
(VALUES SCALED FROM 0-7)
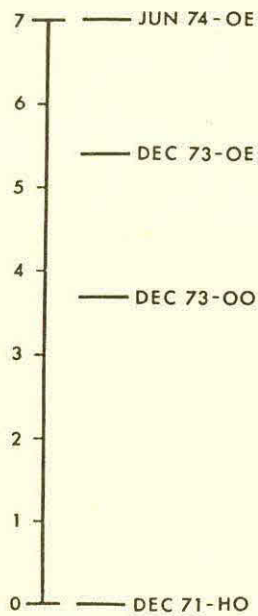
Fig. 1

Analysis of the parameter T_2 among the different synthetic speech forms does not yield sufficiently low values of probability to justify rejecting the null hypothesis although p is always less than 0.5. However, the number of samples available in each case is very small and the variance of the measurements is high due to large individual differences among listeners. Given these circumstances it is quite likely that more data would enable a statistical test to discriminate between each of the synthetic speech forms. Meanwhile, it is of significant

interest that the average values of T_2 for the four versions of synthetic speech correlate closely with the rank order derived from the preference text. These results, plotted in Fig. 2, show that the synthetic speech forms requiring the shortest period T_2 to fully complete the questionnaire are also those which are placed highest on the preference scale.

Fig. 2
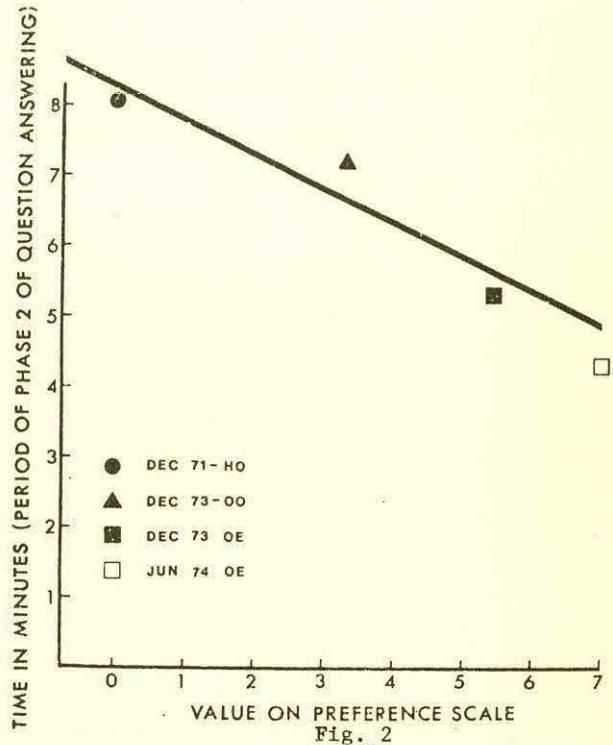
DISCUSSION

Comparing Natural Versus Synthetic Speech Comprehension: Conclusions.

Comparison of the performances on natural and synthetic speech passages reveals a surprisingly small difference in favor of natural speech. The reasons for this finding, which was not expected on the basis of earlier intelligibility tests, may stem from weaknesses in the method of the comprehension test itself or in its administration. Such possible weaknesses include the simplicity of the text (a more intellectually demanding text might have revealed a greater difference) and the speaking rate. That comprehension is affected by speaking rate is well known[10,11], although its affects on synthetic speech comprehension have yet to be explored. However, there is one side effect of speaking rate that may have specifically favored natural speech. The natural speech tape, being physically shorter, could be scanned at a slightly faster rate than any of the synthetic speech tapes, and this would be expected to have a tendency to reduce the natural-speech parameter T_2.

Concerning the question of research progress, the results in Table 2 suggest that the combination of input, synthesizer and algorithm represented by DEC73-00 is an improvement over DEC71-HO. Both algorithms received the same phonetic input derived from the stored dictionary of the Reading Machine program but the earlier routine employs the Laboratories' synthesizer while the later version uses the OVE-III.

The effects of the hand prepared phonetic text are illustrated by the results of DEC73-00 and DEC73-OE outputs. These favor the hand prepared texts and indicate that the linguist's knowledge of phonology, syntax and semantics, which is brought to bear when applying adjustments, gives a measurable advantage over the computer which applies contextual adjustments at only a very superficial level.

Finally, it is reassuring that the average times obtained on each speech form rank in a logical order--the most recent algorithms and the most carefully prepared inputs yielding the best performances. Moreover, these times agree well with the results of the pair comparison test (see Fig. 2). Taken together the data indicate that at the present stage of synthetic speech research, there is a direct relationship between listener preference and listener performance and that efforts to make the speech sound more natural (i.e., attractive) will be likely to result in significant gains in comprehensibility.

References

1. Mattingly, I. G. Synthesis by Rule of General American English. Ph.D. dissertation, Yale University. Issued as Supplement to Haskins Laboratories Status Report on Speech Research SR-33, 1968.

2. Liljencrants, J.D.W.A. The OVE-III Speech Synthesizer. IEEE Trans. Audio and Electroacoustics. Vol. AU16, pp. 137-140, 1968.

3. Cooper, F. S., Gaitenby, J.H., Mattingly, I.G., Nye, P.W. and Sholes, G.N. Audible Outputs of a Reading Machine for the Blind. Haskins Laboratories Status Report on Speech Research SR-29/30, pp. 91-95, 1972.

4. Nye, P.W. and Gaitenby, J.H. Consonant Intelligibility in Synthetic Speech and in a Natural Speech Control (Modified Rhyme Test Results) Haskins Laboratories Status Report on Speech Research, SR-33, pp. 77-91, 1973.

5. Nye, P.W. and Gaitenby, J.H. The Intelligibility of Synthetic Monosyllabic Words in Short, Syntactically Normal Sentences. Haskins Laboratories Status Report on Speech Research, SR-37/38, pp. 169-190, 1974.

6. Nye, P.W., Hankins, J.D., Rand, T. Mattingly, I.G. and Cooper, F.S. A plan for the field evaluation of an automated reading system for the blind. IEEE Trans. on Audio and Electroacoustics. Vol. AU-21, pp. 265-268, 1973.

7. Raygor, A.L. Reading Test. New York: McGraw-Hill Basic Skills System, pp. 7-9A, pp. 6-9B, 1970.

8. Ingemann, F. Testing Synthesis-by-Rule with the OVEBORD Program. Haskins Laboratories Status Report on Speech Research SR-39/40, 1975.

9. Guilford, J.P. Psychometric Methods, Chap. 7. New York: McGraw-Hill Book Company, 1954.

10. Fairbanks, G. Effects of Time Compression of Connected Speech. Journal of Speech and Hearing Disorders. 22, pp. 10-19, 1957.

11. Fairbanks, G. Auditory Comprehension of Repeated High Speed Messages. Journal of Speech and Hearing Disorders. 22 pp. 20-22, 1957.

Title of Paper: SPEECH COMPRESSION AND BLINDED VETERANS

Category: (check one) Device Development /__/ Research Study /X/

Brief Description: Because of the important role played by "Talking Books" in the life of the majority of blind people, this study attempted to assess the feasibility of using speech compression systems currently available as more efficient processors of verbal material than those currently in use. Some attempt was made to assess the relationships between numerous physical and psychological variables and successful performance in the speech compression task.

Intended User Group: Primarily the visually impaired, but applicable to other groups unable to process textual material in the normal ink-print format.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development /__/

Feasibility Testing /__/

Clinical Testing /__/

Available for Sale (check one) Yes /X/ No /__/

Price per unit $ 500 - 1,000

Availability of constructional details:

B. Research Study

Intended Utilization: This particular study should provide information to individuals working with the blind and/or physically handicapped in regard to the feasibility of using speech compression systems for vocational or avocational reading by their clients.

Intended Device Application: Primarily the visually impaired, but applicable to other groups unable to process textual material in the normal ink-print format.

Availability of Intended Device: A number of speech compression systems are currently available.

For further information, contact: Name William R. De l'Aune, Ph.D.
                                     Address Eastern Blind Rehabilitation Center
                                              V.A. Hospital
                                              West Haven, CT 06516

SPEECH COMPRESSION AND BLINDED VETERANS

by

W. De l'Aune, Ph.D., W. Needham, Ph.D., C. Lewis, and J. Nelson
Eastern Blind Rehabilitation Center and Psychology Service
Veterans Administration Hospital
West Haven, Connecticut 06516

Summary - Seventy-five blinded veterans were asked to listen to four sections of a seventh grade level biographical sketch which had been recorded at progressively faster rates (1.0, 1.5, 2.0 and 2.5 times the initial rate of 194 words per minute) through use of a commercially available electronic discrete time compressed speech device. After each section (approximately 847 words), multiple choice questions were asked. The highest rate at which 60% were answered correctly was taken as the maximum comprehensible compression rate for that Subject. It was found that over half of the veterans tested could meet the criterion level of comprehension at the 2.5 compression rate. Variables such as age, use of hearing aid, education level, Wechsler Adult Intelligence Scale Verbal IQ, average monthly talking book use, brain damage, extent of visual impairment, response to speech compression (liked or disliked), and scale scores of the Minnesota Multiphasic Personality Inventory and the California Psychological Inventory were analyzed for possible relationship with the Subject's maximum comprehended compression rate. The results indicate that younger veterans whose personality tests indicated better psychological adjustment tended to be more successful in comprehending compressed speech.

INTRODUCTION

The American Foundation for the Blind estimates that there are approximately 550,000 people in the United States today whose vision is rated at less than 20/200 or have a visual field of less than 20°. These people are considered legally blind and their use of written material is either absent or severely restricted. To compensate for this factor, several alternative ways of processing this type of material are currently available, at least in advanced experimental form. These include Braille, modality transformation systems (Optacon and Stereotoner), speech synthesis systems, and human readers, either live or on tape. Especially in the case of the once sighted blind, all of these methods, except those utilizing speech, have the disadvantage of forcing the visually impaired individual to process the information at rates much slower than his sighted counterparts. Even the methods using speech produced by human readers proceed at normal speech rates (reading aloud) averaging 176.5 words per minute (Johnson, 1961). In contrast, the average sighted reader (reading silently) can cover from 300 to 500 words in the same period of time.

There have been many attempts to increase speech rate by various means but most have distinct problems. Simply asking the reader to speak faster creates only minimal stable increases in rate but unacceptable changes in inflection (Harwood, 1955). Changing the playing speed of a recording also creates problems in terms of a frequency shift of one octave each time the playing rate is doubled. This change in pitch causes the familiar "chipmunk" effect and renders the recording unintelligible prior to most viable increases in rate.

It was not until 1950 that Miller and Licklider discovered that monosyllabic words remained 90% intelligible when up to 50% of the speech signal was interrupted by switching the signal on and off at a rapid rate. Using this principle Gary (1953) made a compressed speech tape by cutting and discarding alternate ¼ inch sections, then splicing the remaining pieces together. The first actual compressed time speech machines based on this sampling method were electromechanical devices designed by Fairbanks et al. (1954) in the United States and Schliesser (1949) in Germany.

These early compressors were complicated, cumbersome and expensive. In 1965 Scott began mating compressors to computers and through advances in electronic technology the current compressors are smaller, simpler and less expensive. There are presently four compressors of two basic types on the market: the VOCOM and the TELEX are selective electro-mechanical devices. The Varispeech (VS) and the Variable Speech Control (VSC) are discrete electronic instruments. The most significant difference between these two types is the sampling method used. The selective machines nominally select and discard pauses, shorten the duration of vowels and other "redundancies" by means of a high-speed bypass system (VOCOM) or a clutch-type device (TELEX) to compress speech. The manufacturers of selective machines claim higher compression rates but in the authors' opinion these machines tend to be mechanically complicated for unsophisticated users. Most important, however, it is difficult or impossible

for the listener or, for the purposes of this project, the tester, to vary the compression rate at will. This lack of versatility limits training strategies, research methodologies and utilization of an individual's maximum compression rate for the specific type of material being read. For these reasons the selective machines were judged unacceptable for this study.

The second type or electronic discrete compressors, VS and VSC, nominally segment and store the original speech signal. The segments are then discarded at a preprogrammed rate which corresponds to the desired rate of compression. One would be hard pressed to point out any significant differences between the two examples of discrete compressors. Informally, several people, whose hearing was within normal limits, were asked to listen to both the VS and VSC machines. The group was unable to determine any consistent differences in their quality of compression. Therefore, although the VS unit was used in the preparation of the test tapes, the authors would not feel any significant difference in performance would occur with any other discrete time-compression system.

How the discrete compression systems work.

Using the VSC unit as an example, one would double the speech rate of a prerecorded tape in the following manner. Adjusting the VSC knob to the 2.0 compression level would automatically set the variable speed motor of the tape playback system to double the normal playback speed. With this speed doubled, the tape playback head processes the original speech signal at double its original frequency. This "chipmunk" speech signal then passes through the pre amp into the frequency processor which is preprogrammed and set by the control circuit to nominally segment and delete sections on a 2:1 ratio and then "stretch" and reunite the retained sections to restore the original frequency characteristics. The compressed speech signal then enters the amplifier where adjustments for tone and volume can be made by the listener as the compressed speech is heard through speakers or earphones.

The compression rate can be varied at will from normal playback speed to a rate 2.5 times as fast on both the VS and VSC units, however the VS also expands speech to the 0.5 level. Both units are most commonly used in conjunction with cassette tapes, but can be readily adapted to process material from either a variable speed phonograph or reel-to-reel tape system.

Variables effecting use of compressed speech.

Prior investigations of time-compressed speech are concerned primarily with the developmental aspects of the compression equipment and recorded materials. Generally these studies are of three basic types. First are the purely electronic-technical studies typified by the early works of Fairbanks and Jaeger (1954). Second are the intelligibility studies in which the

clarity of compression is assessed by having subjects listen to compressed words or short phrases and then asking them to repeat the stimuli. An example of this type of study is Kurtzrock's (1957) work. Third are the comprehension studies which not only assess the clarity of the presentation but have subjects listen to relatively long compressed speech passages and and answer questions about them. The present study uses this technique. All three types of investigations have contributed to the development and validation of compressors and compressed speech listening materials to a point where their value as a means to viably increase the speed of intelligible speech is generally accepted.

Although the primary purpose of most of these studies has been the development of equipment, several of them have provided useful data on listener variables. These data have proved very useful in the selection of variables for the present research. The following studies, although few in number, have established differences in subject performance, indicating some of the possible significant effects of the human factor on the comprehension of compressed speech.

Foulke (1964) demonstrated that at 350 wpm some naive subjects had good comprehension while others showed poor comprehension initially and made no significant improvement even after prolonged exposure to compressed speech. His conclusion was that "These marked and persistent individual differences are undoubtedly the consequence of the interaction of a host of organismic variables." Calearo and Lazzaroni (1957) demonstrated that old age, presbycusis, hearing disorders, and temporal lobe tumors limit the subjects' ability to understand time-compressed words in intelligibility tests significantly. On the basis of the Calearo study, brain damage, age, and hearing aid use were included as variables in this project to determine their effects, if any, on compressed speech comprehension rates of blinded veterans.

Orr and Freeman (1964) reported no sex-related differences in the comprehension rates of male and female subjects and were supported in their findings by Foulke and Sticht (1967). This evidence would seem to allow the generalization of the results of this project to female blinded veterans although only a very limited number were available for testing.

Conflicting evidence exists on the relationship between intelligence and comprehension. Studies by Wood (1965) demonstrated no significant relationship while studies by Fairbanks et al. (1957) showed a positive relationship. Because of this unresolved issue, WAIS IQ scores of the subjects were included as variables in the present study.

In studies of school children by Fergen (1955) and Wood (1965) a positive relation between level of education and comprehension was found. To determine the effect of education level without the obvious confounding with age, this variable was included in the present experiment.

Due to the lack of further relevant data on other listener variables and the human factor in general, certain assumptions had to be made by the experimenters in regard to other a priori human variables which could foreseeably affect performance in a compressed speech comprehension task. It seemed reasonable to believe that performance could be affected by a number of variables not yet considered, particularly those of a psychological nature. For instance, if a person is subject to easily stimulated anxiety his performance in a task requiring the assimilation of aural information at an accelerated rate, could easily be adversely affected. Therefore personality scale variables from two commonly used psychodiagnostic tests, the California Psychological Inventory (CPI) and the Minnesota Multiphasic Personality Inventory (MMPI), were added to the analysis.

METHOD

To investigate blinded veterans' comprehension of discrete electronic time-compressed speech and its relationship to various variables it was first necessary to develop a test to quantitatively assess performance. Dr. Emerson Foulke at the Center for Rate Controlled Recordings at the University of Louisville supplied the experimenters with a professionally recorded biographical sketch of Mary Bethune which was 3390 words long and read at approximately 194 wpm. The transcript of the test was divided, to the nearest paragraph, into four approximately equal sections. The tape was then divided in accordance with the transcripts and rerecorded from a VS unit, with each section played at a progressively faster rate. The consecutive sections were recorded at rates of 1.0 (194 wpm), 1.5 (291 wpm), 2.0 (388 wpm), and 2.5 (485 wpm). The original test questions, numbering 25, were randomly distributed throughout the entire test. As a result, the questions covering each of the four sections differed in number. To remedy this problem those sections having more than five questions had questions deleted, and those having fewer than five were given additional questions, following the original format of exerpting each question and the correct answer directly from the text. All questions were pretested at normal rates prior to the actual experiment.

The subjects were randomly selected from the patient population of the Veterans Administration's Eastern Blind Rehabilitation Center in West Haven, Connecticut. All subjects were legally blind and varied in employment experience educational level, and age.

The subjects were told that the test they were about to take was not an indication of their ability but was simply a measure of the technique of speech compression in an effort to alleviate any tension which could accompany performance. However, to impress them with the seriousness of the test, they were also told to do their best since their performance could influence the Veterans Administration's future decisions to issue such devices to blinded veterans. Subjects

were then instructed to listen carefully to each of the four sections (in ascending compression rate) and told they would be expected to answer five multiple choice questions immediately after each section. Each question was repeated twice. Each subject was given a pad and pencil and asked to record his answer by writing the number of the question and the letter identifying which of the four multiple choice alternatives he thought was correct. Because of the subjects' visual impairments, a sighted monitor checked the legibility of the answer sheets during the question period and assisted subjects who had difficulty in writing.

Comprehension rate was determined by scoring the number of correct answers per section. Any subject having three answers out of five correct was deemed to have satisfactorily comprehended that section. The highest speech rate comprehended according to this criterion was then recorded as the subject's Maximum Comprehended Compression Rate (MCCR) score. After testing, the subjects were asked to indicate their name, age, the average monthly use of talking book machines (assuming each book to take seven hours), and whether or not they liked the concept of a machine to speed up recordings on their answer sheet. These data were supplemented by psychological records which gave information about the presence of brain damage, WAIS verbal IQ scores, years of formal education, and scale scores from MMPI and CPI.

The data were then subjected to statistical analysis utilizing descriptive statistics, independent t-tests, and linear regressions whenever appropriate.

RESULTS

It was found that 52.8% of the subjects (n=36) were able to comprehend the test material at approximately 485 wpm (2.5 times the original rate of 194 wpm). At approximately 388 wpm (2.0 rate) 77.8% were able to understand the material, and 88.9% met criterion levels of comprehension at approximately 291 wpm (1.5 rate). At the original rate of 194 wpm (1.0 rate) 94.4% were able to comprehend the material while 5.6% were unable to understand it to criterion levels even at this "normal" rate.

Linear regressions of MCCR scores and the available (n=23) veterans' scores from the CPI revealed statistically significant (p≤.05) positive correlations between MCCR and Flexibility (Fx), Tolerance (To), and Psychological mindedness (Py). It should be noted, however, that 17 out of the 18 CPI scales were positively correlated with performance (See Table 1). When the sample was divided into those subjects not able to meet criteria at the 2.5 rate (n=11) and those subjects successfully meeting criteria at this level (n=12) with t-tests used to determine if the CPI scale scores were different for the two groups, it was found that the Responsibility (Re), Tolerance (To), Communality (Cm), Achievement via Independence (Ai), and Flexibility (Fx) scales were significantly different at the .05 level and the Psychological-

mindedness (Py) scale was significant at the .01 level. Figure 1 shows the relationship of these test scores for the two groups.

Table 1.
Linear Regressions between
CPI Scales and MCCR scores.

	r
Do (Dominance)	0.3046
Cs (Capacity for Status)	0.2177
Sy (Sociability)	0.1726
Sp (Social Presence)	0.2522
Sa (Self-acceptance)	0.0273
Wb (Well-being)	0.1556
Re (Responsibility)	0.1958
So (Socialization)	0.1111
Sc (Self-control)	0.2047
To (Tolerance)	0.3532*
Gi (Good Impression)	0.2126
Cm (Communality)	0.2508
Ac (Achiev. Conform.)	0.2003
Ai (Achiev. Indep.)	0.2391
Ie (Intell. Efficiency)	0.2740
Py (Psychol. mindedness)	0.4832*
Fx (Flexibility)	0.4465*
Fe (Femininity)	-0.1055
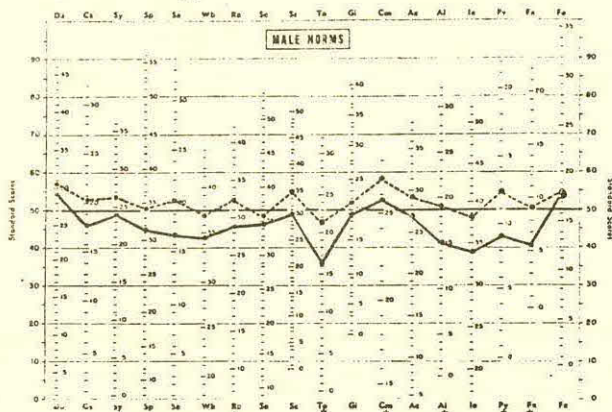
Figure 1. CPI Scale Means for High (---) and Low (——) Performance Groups.

Linear regression of MCCR and the available (n=20) veterans' scores from the Minnesota Multiphasic Personality Inventory (MMPI) revealed no significant relationships, but all ten clinical MMPI personality scales were negatively correlated with performance. When this group was divided by the performance criterion level (high, n=10; low, n=10), the F scale, a measure of validity although not one of the ten clinical scales, showed a significant difference between group means at the .05 level of significance. Table 2 displays the results of linear regression analysis for the MMPI scale scores and MCCR and Figure 2 shows the relationships of the mean test scores for the two groups.

Age (n=36) significantly correlated with maximum compression rate at the .05 level. The Wechsler Adult Intelligence Scale Verbal IQ (n=35), education level (n=36), brain damage and monthly average talking book use (n=32) were not significantly related to MCCR. Sight level (totally blind, n=4; low vision, n=31), hearing

aid use (with aid, n=4; without aid, n=31) and response to speech compression technique (liked, n=23; disliked, n=9) were not found to provide significantly different performance scores between subgroups when subjected to t-tests.

Table 2.
Linear Regressions between
MMPI Scales and MCCR scores.

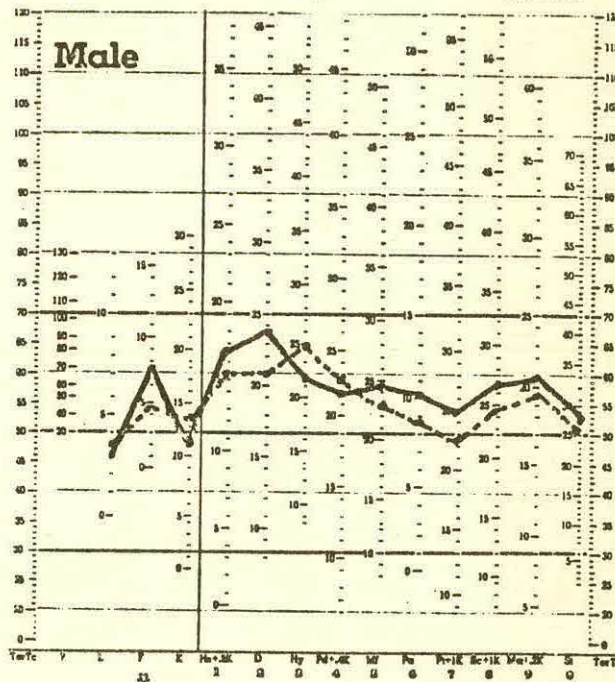|	r
L (Lie)	-0.1820
F (Frequency)	-0.2350
K (Correction)	0.2121
Hs (Hypochondriasis)	-0.2644
D (Depression)	-0.2087
Hy (Hysteria)	-0.0073
Pd (Psychopathic deviate)	-0.0339
Mf (Masculinity/femininity)	-0.2349
Pa (Paranoia)	-0.2604
Pt (Psychoasthenia)	-0.1921
Sc (Schizophrenia)	-0.0781
Ma (Hypomania)	-0.0645
Si (Social introversion)	-0.0381

Figure 2. MMPI Scale Means for High (---) and Low (——) Performance Groups.

DISCUSSION

On the basis of the data analyzed in the preceeding section of this paper, several series of conclusions can be drawn both in regard to the overall level of performance and certain factors influencing the performance of blinded veterans in the comprehension of discrete time-compressed speech.

The first of these concerns the percentages of blinded veterans capable of comprehending recorded materials at rates faster than presently available with standard sound reproduction equip-

ment. The finding that 77.8% of the veterans tested were able to comprehend the material at a rate of 2.0 or above indicates that discrete time-compressed speech devices are of very broad applicability and may serve a viable role in providing veterans with a comprehensible, time saving means of aural reproduction of printed materials. In recent evaluations of a narrower range of blinded veterans, those who expressed an interest in speech compression devices because of vocational or avocational reading needs (n=39), it was found that 79.5% could meet criterion levels of comprehension at a compression rate of 2.5 times (485 wpm). This more recent finding adds even more strength to the concept of speech compression being a very important prosthetic device for the blind individual in need of processing verbal material.

The second conclusions concern the possible indicators of performance in the speech compression task. Subjects who were younger tended to do better in this experiment. None of the other "non-psychological" variables were significantly related with performance in the task, but two gave inconclusive but interesting trends. Although the sample of hearing aid users was very small the trend was for those with hearing impairment to perform at a lower level than the population not wearing hearing aids in this obviously auditory task. A follow-up study with a larger population of hearing aid users would seem indicated to determine the effect of hearing aid use on compressed speech comprehension.

Although liking versus disliking the idea of compressed speech did not prove significant when subjected to statistical analysis, it was found that 66% of the subjects who performed at the 1.0 level of comprehension disliked the concept, 50% of the subjects performing at the 1.5 level expressed dislike, 22% of those at the 2.0 level disliked the concept and only 18.8% disliked the concept and met criterion at the 2.5 level. Thus there would be a distinct trend for subjects more open to this unusual form of presenting verbal material to do better at comprehending the material.

The scale scores of the two personality tests were much better predictors of performance on the speech compression task. The CPI personality scales which were significantly related to successful comprehension of compressed speech include those that reflect positive socialization, maturity and responsibility, achievement potential, a sensitivity to psychological variables and cognitive-behavioral adaptability. The MMPI F scale is composed of frequently unanswered items and, although used primarily as a validity scale, high scores on it are at times associated with emotional pathology. Accordingly, its significant negative relationship with understanding of compressed speech is consistent with the above, as traits associated with successful emotional and behavioral adjustment in general seem to covary with successful speech comprehension. This conclusion is also supported by the fact that all of the MMPI clinical scales, which indicate maladjustment, were negatively correl-

ated (although not significantly on an individual basis) and 17 of the 18 CPI scales which measure favorable characteristics in general being positively related (although only some of them were significantly so on an individual basis) to successful speech comprehension.

The finding that presence or absence of "psychological health" is associated with positive sensory and intellectual characteristics in the blind (despite a lack of relationship with WAIS IQ) is consistent with other studies. Psychological state has been found to be related to ability to detect open and closed spaces by ambient sound (De l'Aune, et al., 1974), mobility variables such as velocity and veer (De l'Aune et al., 1975; Needham et al., 1975) and acquisition of Optacon skill (Gadbaw and De l'Aune, 1974). Accordingly, in the blind, or at least blinded veterans, there appears to be a global trait which could be termed "functional" or "dysfunctional overflow," whereby psychological adjustment relates to a wide variety of abilities and skills.

BIBLIOGRAPHY

Calearo, C. and Lazzaroni, A. Speech intelligibility in relation to the speed of the message, Laryngoscope, 1957, G 7.

De l'Aune, W., Needham, W., and Kevorkian, G. Relationships between indices of mobility and personality factors in the blind: I. Minnesota Multiphasic Personality Inventory. Journal of the International Research Communications Service, 3, 80, 1975.

De l'Aune, W., Scheel, P., Needham, W., and Kevorkian, G. Evaluation of a methodology for training indoor acoustic environmental analysis in blinded veterans. Proceedings of the 1974 Conference on Engineering Devices in Rehabilitation, Tufts-New England Med School, Boston, 1974, 26.

Fairbanks, G., Everitt, W., and Jaeger, R. Methods for time or frequency compression-expansion of speech. Transactions of the Institute of Radio Engineers Profession Group on Audio, Jan.-Feb., 1954.

Fairbanks, G., Guttman, N. and Miron, M. Effects of time compression of connected speech. Journal of Speech and Hearing Disorders, 22, 1957, 10.

Fergen, G. Listening comprehension at controlled rates for children in grades IV, V, VI. (Unpublished doctoral dissertation, Univ. Missouri, 1954), Dissertation Abstracts, 14, 1955, 89.

Foulke, E. The comprehension of rapid speech by the blind - Part II, cooperative research project #1370, Office of Education, Washington, D.C., U. S. Department of Health Education and Welfare, 1964.

Foulke, E., and Sticht, T. The intelligibility and comprehension of accelerated speech, Proceedings of the Louisville Conference on Time Compressed Speech, University of Louisville, 1964.

Gadbaw, P. and De l'Aune, W. Correlates of Successful Optacon learning. Presented at Experienced Optacon Teacher's Seminar, Palo Alto, California, November, 1974.

Garvey, W. The intelligibility of speeded speech. Journal of Experimental Psychology, 45, 1953, 102.

Harwood, K. Listenability and rate of presentation, Speech Monographs, 22, 1955.

Johnson, W. Measurement of oral reading and speaking and disfluency of adult male and female stutterers and non stutterers. Journal of Speech and Hearing Disorders Monogram Supplement, 1961, No. 7.

Kurtzrock, G. The effects of time and frequency distortion upon word intelligibility. Speech Monogram, 24, 1957.

Megargee, E. The California Psychological Inventory Handbook, Jossey-Baso, Inc., San Francisco, 1972.

Miller, G. and Licklider, J. The intelligibility of interrupted speech, Journal of the Acoustical Society of America, 22, 1950.

Needham, W., De l'Aune, W., and Kevorkian, G. Relationships between indices of mobility and personality factors in the blind: II. California Personality Inventory. Journal of the International Research Communications Service, 3, 81, 1975.

Orr, D., Friedman, H. and Williams, J. Trainability of listening compression of speeded discourse. Journal of Educational Psychology, 56, 3, 1965.

Schliesser, H. A device for time expansion used in sound recording, Funk und Ton, 3, 1949.

Scott, R. Temporal effects in speech analysis and synthesis (unpublished doctoral dissertation, University of Michigan), 1965.

Title of Paper: THE PRACTICAL APPLICATION OF AN ELECTRONIC COMMUNICATION DEVICE IN THE SPECIAL NEEDS CLASSROOM

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: This device is a scanning communicator that allows a severely motor impaired non-verbal individual to print any desired message using a single type muscular movement. .

Intended User Group: Non-verbal severely motor impaired individuals.

Stage of Development: (Check all that are applicable)

    A.   Device

            Prototype Development   / /

            Feasibility Testing   / /

            Clinical Testing   /X/

            Available for Sale (check one)   Yes /X/   No / /

               Price per unit $ 2300.00

            Availability of constructional details: Yes

    B.   Research Study

            Intended Utilization: _____

            Intended Device Application: _____

            Availability of Intended Device: _____

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THE PRACTICAL APPLICATION OF AN ELECTRONIC COMMUNICATION
DEVICE IN THE SPECIAL NEEDS CLASSROOM

by

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Summary - This paper discusses a cooperative effort be-
tween an engineering research laboratory and two state
service agencies. The joint project involves the in-
stallation of eleven communication devices in special
needs classrooms.

Possibly the most pleasing and satisfy-
ing outcome of a research project is the
practical application of the research ef-
forts. The sometimes laborious process of
removing a device from the prototype stage
to a level of clinical usefulness is certain-
ly as important as the initial concept de-
velopment. Without this practical effort,
those for whom the research was intended may
not receive their proper benefits.

The Biomedical Engineering Center has
spent the past four years developing a com-
municative assist for the non-verbal se-
verely motor disabled. The TIC, as the de-
vice is called, allows such a person to type
using one residual muscular movement. It
has been demonstrated that the TIC offers
the opportunity for an individual to commun-
icate in an original and possibly abstract
manner. This is contrasted with the only
available alternative of "twenty questions."

During the first three of the four
years of development, only three TIC's were
produced. This was partially due to the re-
search emphasis placed on the project. An-
other major drawback was the inability of
the Biomedical Engineering Center to fund
additional units with research money.

The need for a device such as the TIC
made it essential to find a way of making
the device available. While the relatively
small market and high component cost virtu-
ally eliminated the possibilities of a com-
mercial venture, the B.M.E.C. found that the
service could be provided by a close cooper-
ation between non-profit and public agencies.

The Biomedical Engineering Center feels
that it has an obligation, as well as the
technical capabilities, to produce TIC's on
a regular basis, even if only in a limited
quantity at first. Production of ten to
twenty units per year is a reasonable goal
that is within the economic means available
and will not obstruct the research efforts
of the B.M.E.C. The B.M.E.C. is a portion
of the Tufts-New England Medical Center.
The New England Medical Center Hospital has
sanctioned non-profit sale of TIC's as a
service of the Hospital, and the Hospital
administration has waived overhead charges
during the initial stages of the project.
In late 1974 the first two units of the
latest-model TIC were shipped. Two addi-
tional TIC's are now on order.

In a major cooperative effort, the
Massachusetts Developmental Disabilities
Commission and the Massachusetts Department
of Education have funded the construction and
installation of eleven more TIC's in special
needs classrooms in Massachusetts. In addi-
tion to building these communicators, the
B.M.E.C. has been given the responsibility
of developing appropriate training materials,
providing in-service training to teachers
and clinicians, and assembling curriculum
materials.

The TIC and Related Devices

Before continuing with a description of
the project, it is important to describe the
TIC and its relationship to similar devices.
The TIC is essentially a one-key typewriter
with a scanning visual keyboard. The char-
acters are selected from the keyboard by ap-
propriate switch closures.

The TIC offers one row at a time, by
lighting all the characters within the row;
the scanning moves steadily down the key-
board from top to bottom. Choice of a row
is made by depressing the switch when the
desired row lights up. The TIC then offers

each character within the row by illuminating them from left to right. Selection of the desired character is made by pressing the switch again. The chosen character flashes four times, and then is printed on the output devices. Scanning then resumes with the top row, and the user repeats the process to select his next letter.
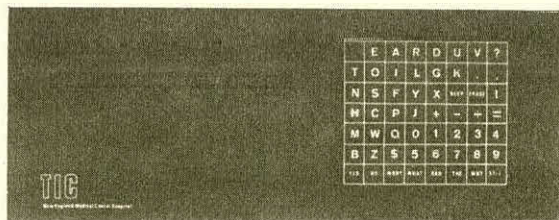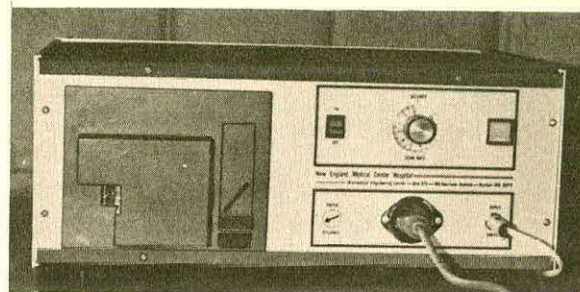

Front View of the TIC
Figure 1

Two output devices are provided in the basic TIC. The front panel contains a 32-character gas discharge display which presents the user's message in softly glowing letters. This provides easily readable feedback to the user. The output is simultaneously printed on a strip printer in the rear of the unit. This allows for hardcopy storage which can be used for homework assignments, correspondence, or long messages.

The TIC will print all alphabetic and numeric characters, punctuation, and arithmetic symbols. In addition to these, it has a vocabulary of eight short, commonly used words that can each be printed with a single actuation, such as "WANT", "AND", "THE", or--when circumstances occasionally require it--"#?*!".[1]

The TIC is not alone in the area of communication devices. An early predecessor is the "Elcode"[2] which was developed by the Telephone Pioneers of America (Bell System). This offered no printing capability. The Possum[3] is an English device that prints characters on an IBM typewriter by means of a scanned keyboard or coded input. The AutoCom[4] is a relatively new device that is under development at the University of Wisconsin. It requires more hand control than do the scanning units, but offers a faster

Rear View of the TIC
Figure 2

rate of output. There are a number of other devices that have also been well received by the clinical community. The Cybernetics Research Institute of Washington, D.C.[5] and Bush Electric Company of San Francisco[6] have probably produced the largest number of communicative assists. Only recently has Bush Electric Company suspended its involvement in this area. Their difficulties do not give encouragement to the possibilities of commercial success. This is by no means an attempt to survey the entire field. It is meant to put the TIC in its proper perspective. The B.M.E.C. does not operate in a vacuum, but makes all possible effort to maintain a thorough knowledge of the state of the art.

Chapter 766

The interest that has been generated in aiding the non-verbal population in Massachusetts can be related to recent legislation passed by the State Legislature. Chapter 766 was passed in July 1972, and became effective in September 1974. This addition to the laws of the Commonwealth guarantees every child the right to free and public education regardless of handicaps. The result of this has been an emphasis upon education rather than custodial care. New classrooms have been opened. State schools are being re-examined. A major effort is underway to provide the necessary facilities and equipment to implement the law. Since the severely handicapped have most often been neglected, they are being given considerable attention. Educators and clinicians are aware that they can not be totally effective without technical assistance, just as the B.M.E.C. is aware that it can not adequately demonstrate the usefulness of its equipment without input from those dealing

directly with the disabled individuals. Through the statewide effort to provide the best possible service, the cooperation between the three agencies has flourished.

The Cooperative Project

The potential population involved in the project includes any person who lacks conventional communication skills (both spoken and written) due to a motor disability. These include cerebral palsy and traumatic brain injury. The B.M.E.C. staff for the project includes engineering, occupational therapy, and educational personnel. Candidates were first identified by their respective school systems and were referred to the State Department of Education. After an initial screening, a modified list was submitted to the B.M.E.C. whose staff members interviewed each candidate. From that list were chosen the eleven users. The decision was based upon the child's need for a TIC, his willingness to cooperate, and permission from his parents.

Once the initial commitments were made, each candidate was fitted with a custom designed switch. Since each child is afflicted in a different way, his switch must be personal. A training kit was then provided so that the user could master the operation of his switch while the construction of the TIC's proceeded. The training kit does not assume any particular intellectual development. It is designed to provide training in the physical movement necessary to operate the TIC. (It must be remembered that most of these children have never operated any electronic device, radio and television included.) The training procedure begins with very simple steps and progresses to a simulation of TIC operation using a manual scan keyboard and an instructor. Exercise material to be included is provided by the classroom teachers so as to insure compatability with current educational experiences of the individual.

Originally, it was planned to deliver a TIC to a student once he had reached a level in the training where he could make use of it. However, difficulties in obtaining some of the components delayed shipment of all units until early March of 1975. As of this writing it is too early to assess the impact of the TIC upon the classroom. One teenager who was educated before a brain injury is now able to spell quite well and operate the TIC at the maximum scan rate. The opposite end of the range is a 7 year old cerebral palsy girl who has had no previous schooling and is just now learning the alphabet. Her problem is compounded by the noise and confusion of her classroom, which has a tendency to distract her. This will be improved with the arrival of a language specialist and a small acoustical partition.
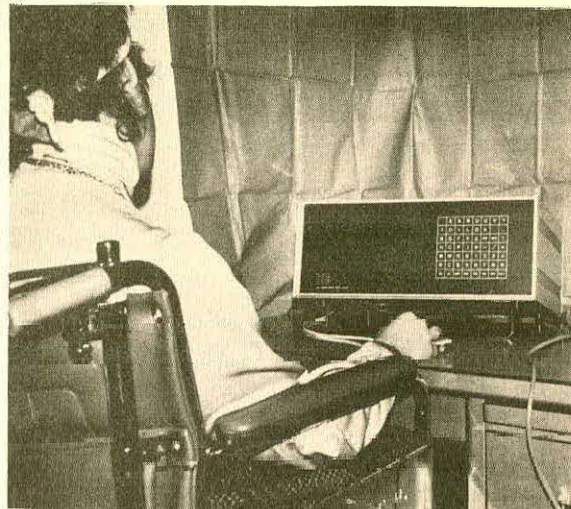
R.H., 12 years old, is a severely involved spastic-athetoid, male child with basically spastic lower extremities, and an athetoid component in the upper extremities. He has some head control, but no meaningful speech. Physically, he has developed to a 6-month level. Intellectually, he has been tested by psychologists at Children's Hospital, Boston, and in language development by our Speech Therapists; and has been found to have intellectual development comparable to his chronological age. He is enrolled at the Special Educational Classroom at our Clinic and attends classes five days a week, five hours a day.

***

J.P., 13 years old, is a severely involved basically athetoid, male child who has good sitting balance and head control, but no meaningful speech. Physically, he has reached the developmental level of 9 months. His intellectual level, although not adequately tested, is felt to be near his chronological age. He attends the Special Class at the Clinic five days a week, five hours a day.

Figure 3

The project will continue with both monitoring of the existing devices and provision of additional TIC's in later years. The Department of Education will retain ownership of the units through its "Resource Center for Devices of Exceptional Expense." The TIC's will, however, be on permanent loan to the users for as long as they remain in the state of Massachusetts and have need for them.

The cooperation has extended beyond the B.M.E.C. and the two state agencies. Each school system has committed time and effort to the project. In many cases the introduction of the TIC has brought about an increase in the interest shown in the user. More time of both teacher and specialist is being brought to bear on the child's problem.

The Future

The Biomedical Engineering Center is continuing to pursue the effective design and development of communication devices. The most recent prototypes have been an anticipatory communicator (described elsewhere in these Proceedings) and a battery-powered device. The battery-powered TIC is approximately one-third the size of the existing TIC; it can run for an excess of four hours without recharge.

Alternatives to the single switch input will be a two-switch system and a placemat-thin 56-switch keyboard. These will make the TIC a more versatile device suitable for use with various levels and types of disability. Optional outputs will be a video display, a page printer, and a voice synthesizer that produces spoken words. Other features currently being developed and evaluated include a built-in calculator, a "dictionary" mode, and dual speed scanning.

References

1. TIC Operating Manual. Tufts-New England Medical Center, Boston, Mass., 1975.

2. Personal Communication with Telephone Pioneers of America.

3. Demonstration by Miss Muriel Zimmerman, O.T.R. New York University Medical Canter.

4. Vanderheiden, G., Lamers, D.F., Volk, A.M., Geisler, C.D.: "A new means of communication for the severely handicapped: the Auto-Monitoring Communication Board (AutoCom)." Proceedings of the Annual Meeting, Biomedical Engineering Society. 4, 15, 3 (Abstract) 1973.

5. Kafafian, H.: "Study of man-machine communication systems for the handicapped." Cybernetics Research Institute, 1970.

6. Personal Communication with Bush Electric Co.

Title of Paper: THE EFFECTIVENESS OF LANGUAGE REDUNDANCY IN
NON-VERBAL COMMUNICATION

Category: (check one)   Device Development /X/   Research Study /_/

Brief Description: This device is an anticipatory communicator for non-
verbal severely motor impaired individuals . It permits faster communi-
cation by taking advantage of the statistical characteristics of the English
language to anticipate the letters most likely to follow those already printed.

Intended User Group: Non-verbal severely motor impaired individuals.

Stage of Development: (Check all that are applicable)

   A.   Device

            Prototype Development   /X/

            Feasibility Testing   /_/

            Clinical Testing   /_/

            Available for Sale (check one)   Yes /_/   No /X/

                Price per unit $ _____

            Availability of constructional details:

   B.   Research Study

            Intended Utilization: _____

            Intended Device Application: _____

            Availability of Intended Device: _____

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THE EFFECTIVENESS OF LANGUAGE REDUNDANCY IN NON-VERBAL COMMUNICATION

by

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Summary - This paper describes investigations conducted at the Tufts-New England Medical Center in the use of the statistical nature of the English language as an aid to improving the communication speed of non-verbal individuals.

Introduction

In recent years the communication difficulties of non-verbal severely motor impaired individuals have given rise to a number of electronic communication devices. The methods of operation vary according to the severity of the disability of the potential user. The Biomedical Engineering Center has concentrated its efforts on serving the very severely impaired through the development of the TIC. This requires only one controllable ON-OFF movement.

While the TIC has achieved considerable success in providing a communication medium to its users, we recognize that it has severe limitations in terms of the speed at which a person can type his output. This is not a problem for the developmentally disabled child who is initially learning to read and spell, in spite of his disability; but as the educational level of the user increases, he will be faced with long periods of time during which he will already know his desired letter, but must wait for the TIC to reach that letter. The need for a faster communicator, requiring no additional physical exertion, has become apparent.

In studying various types of communication we began to observe what circumstances would lead to a faster communication rate. It was then that we noted an incident that was extremely significant. An opportunity arose to communicate with an individual whose only means of "speaking" was through eye movements. His sister, having a great deal of rapport with her brother, scanned individual letters on a letter board. When she pointed to the letter he wished to communicate, he would signal her by looking up and to the

left. It was noticed that the sister would present a different order of characters throughout a somewhat labored conversation. It became clear that she was anticipating the next characters and even the remainder of the message with a high degree of success. In effect she was serving as an intelligent communication processor.

As a result of this experience, the question arose as to whether a machine could be built to perform this anticipatory function. Research was conducted into the statistical behavior of English. It was discovered that there is a great wealth of literature on the statistics of the language. Much of the work was done by cryptographers.

It is common knowledge that English does exhibit certain statistical properties. Samuel Morse sought to optimize his code by assigning the shorter, easier designations to the more frequently occurring characters. He visited a printer's shop to examine the type box. By counting the number of pieces of type for each character, he was able to approximate the rank order of characters used in English text. The rank order of characters varies from source to source, depending upon the sample text from which it was drawn. The order does, however, seem to fall into groupings. Within these, letters may change order, but rarely change groups. These are shown in Table 1.[1]

Redundancy

The use of the statistical nature of English in improving communication speed is directly related to the amount of predictability evident in the language. If all letters were equally likely to occur there would be no opportunity to predict any particular letter other than by chance. The extent to which the characters are not equiprobable is a measure of the redundancy in the spelling of a language. In a case where there is no predictability beyond chance,

Group	Characters Within Group
I	SPACE
II	E
III	T
IV	A,O,N,R,I,S
V	H
VI	D,L,F,C,M,U
VII	G,Y,P,W,B
VIII	V,K,X,J,Q,Z

Groupings of the Rank Order
of Occurrence of Letters
in the English Language

TABLE 1

there is 0% redundancy. Continuing this ap-
proach to the rank order of characters, there
is approximately 15% redundancy. By increas-
ing the statistical knowledge, one can find
that the language approaches 60% redundancy.[2]

Use of Rank Order in the TIC

The earliest model of the TIC featured
an alphabetically arranged visual keyboard.
This seemed appropriate since the academic
world of the original client population was
structured alphabetically. This offered ex-
tremely slow communication speeds.

The scanning method of the TIC favors
certain entries on the visual keyboard. The
keyboard locations are shown in Figure 1 with
an "iterative value" assigned to them. An
iterative value is a measure used by the BMEC
to indicate the number of scanning steps or
iterations (either vertical or horizontal)
needed to reach a designated location. The
upper left square of the keyboard, for ex-
ample, has an iterative value of 2. This in-
dicates that one iteration is required to
offer the row, and a second iteration is
needed to offer the square once the row is
chosen. (Please refer to the previous paper
for an explanation of the method of character
selection on the TIC.) The positions with a
value of 5 all require combinations of row-
scans and position-scans which total to five.

From this analysis we recognize that
the most easily accessible locations on the
TIC are in the upper left of the keyboard.
The loci of descending accessibility are di-
agonal lines located farther and farther from
the upper left corner. By arranging the
characters on the TIC according to rank order,
the communication rate can be substantially
improved. The final keyboard layout, arrived
at in this manner, is shown in Figure 2.

Beyond Rank Order

The rank order of characters indicates
some of the statistical behavior of the lan-
guage. From our experience with the man and

2	3	4	5	6	7	8
3	4	5	6	7	8	
4	5	6	7	8		
5	6	7	8			
6	7	8				
7	8					

Iterative Values of the
TIC Visual Keyboard

Figure 1

SPACE	E	A	R	D	U	V
T	O	I	L	G	K	
N	S	F	Y	X		
H	C	P	J			
M	W	Q				
B	Z					

Arrangement of Characters on
the TIC Visual Keyboard

Figure 2

his sister, we felt that by considering the
frequency of occurrence of groups of letters
rather than simply individual letters, the
rate might be further increased. The liter-
ature describes such groupings as "n-grams."
Individual letters are designated monograms;
pairs of letters are digrams; and groups of
three and four characters are described as
trigrams and quadgrams, respectively.

We suggest a tabulation of n-grams based upon a 27-character alphabet (space plus A-Z). Since most cryptographers eliminate space from their codes, we found their n-gram tables unacceptable. Several months of correspondence led us to Dr. E. Newman at Harvard University who had compiled trigram and quadgram information during his research in the 1960's. Dr. Newman provided us with his data from which we extracted digram and monogram information.

The first task was to assure that the data we had available were truly representative of common written English. Newman's work had used a sample of 250,000 letters of text taken equally from the writings of E.B. White, Henry James, Saturday Review Magazine, and the Holy Bible. Our tests included evaluating much smaller samples of first-, third-, and sixth-grade texts, "Time Magazine" and the Encyclopaedia Britanica. Tests of the mean, variance, and the Student's "t" distribution indicated that in all likelihood our small samples were from the "normal" population (i.e. Newman's data). This told us that we could make predictions of the next most likely character within any reasonably common text using one standard data base.

In addition to deriving the monogram and digram data from Newman's tables, we rearranged the presentation of the information. Whereas the tabulated information would tell us that the trigram "ECH" occurred 48 times in the total text of 250,000 characters, we interpret this to mean that out of the 613 times the pair "EC" occurred, it was followed 48 times by "H". This then allowed us to derive the rank order of characters following any existing pair of characters and calculate the probabilities. An example of this is again the pair "EC" which has a rank order as follows:

$$"EC": \quad T,E,O,A,I,H,U,K,L,R,C,D,S$$

It should be noticed that not all 27 characters are likely to follow the pair "EC". This is true of most trigrams. Table 3 indicates the theoretical number of possible letter combinations versus the number of actual combinations in our statistical tables.

		Theoretical Combinations		Actual Combinations
Monogram	27^1		27	27
Digram	27^2		729	520
Trigram	27^3	19,683		5,000
Quadgram	27^4	531,441		18,500

Combinations of Characters
Both Theoretical and Actual

TABLE 2

The Usefulness of Statistical Information

Having established that there is a statistical behavior evident in the spelling of the language, we sought to demonstrate the usefulness of that feature. We have looked at the average probability of occurrence of each position in the 27 character string in monograms, digrams, and trigrams. The probabilities are shown in Figure 3.
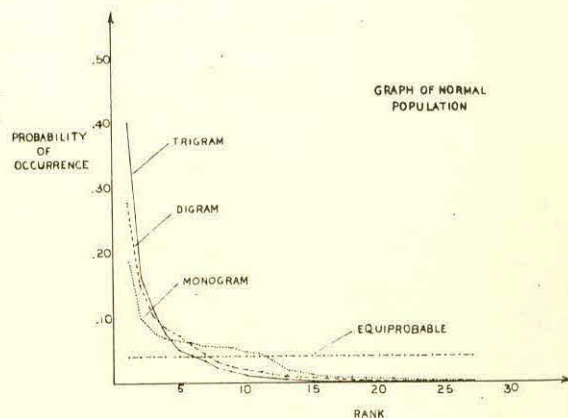
Probability vs. Rank Order of N-Grams

Figure 3

An illustrative example of the effect of probabilities upon the selection of characters is the case where the string of characters HAPP has been selected and the user wishes to spell HAPPY. The "n-gram" strings are shown in Table 3 and the position of the "Y" is indicated.

The desired character keeps appearing earlier in the string as we progress toward higher-order tabulations beyond quadgrams. Estimates have been made that strings beyond the 16th-gram level offer little if any additional advantage.[2]

Preliminary tests have suggested that a fully-dynamic keyboard requires so much concentration and contributes to so many errors that this would not be a desirable method to use.

The most effective technique seems to be a compromise between the fully-dynamic and fully-static visual keyboards. We chose to offer only six dynamic elements in the

		18th
Monogram String	(SP) E T A O I N S D H R L U C F M W Y P G B V K X J Q Z	
Digram String (Following "P")	13th E R O A L (SP) I U T P S H Y M W N F G	
Trigram String (Following "PP")	5th E O R L Y A I S	
Quadgram String (Following "APP")	4th E R L Y A O I	

TABLE 3

six squares in the upper left of the key-board. The entire alphabet would then be of-fered, in a fixed layout, on the remainder of the keyboard. Again using trigram infor-mation, the first six positions of the aver-age rank order constitute 84% of the occur-rences. We then have a communicator that will assign iterative values of 2, 3, or 4 to 84% of the characters typed. The order of the static part of the keyboard will not be the rank order of characters in English. We modified the trigram strings to eliminate the six most likely characters in each string; a tabulation was made to determine the rank order of characters remaining in all of the strings. This new rank order was found to be:

D,SPACE,M,C,O,L,U,B,F,N,H,E,R,
G,S,W,A,Y,T,I,P,V,K,J,X,Q,Z

The entire 27 character alphabet will be in-cluded in the static portion of the keyboard in this order. Figure 4 shows the keyboard arrangement.

The Practical Implementation of Redundancy

The Biomedical Engineering Center has begun a project to simulate on a computer the various methods in which this informa-tion can be presented to a user. Presently five such methods are under study. One of these is a natural extension of the develop-ment of the TIC. If the TIC could remember the most recently typed letter, or letters, it could modify its visual keyboard to place the appropriate n-gram string along the di-agonals referred to earlier.

A fully dynamic TIC with trigram infor-mation was simulated, and the ideal, error-free rate of communication was computed. This is compared to the static monogram TIC:

Trigram TIC:
    3.1 iterations/character

Monogram (standard) TIC:
    4.5 iterations/character

This is a sizable improvement when one considers that the fastest possible rate would be 2 iterations/character. (Each of the two switch closures requires one itera-tion.) The difficulty that arises with this

arrangement is that a fully-dynamic visual keyboard--in which the arrangement of let-ters on the keyboard changes each time a letter is printed--can be very confusing to the user.

d	d	d	D	O	N	W	K
d	d	SPACE	L	H	A	J
d	M	U	E	Y	X
C	B	R	T	Q
F	G	I	Z
S	P
V

"d" — Indicates DYNAMIC ELEMENT

Keyboard Arrangement for a
Partially Dynamic TIC

Figure 4

The ideal rate of communication was again calculated and was found to be 3.3 iterations/character. This is very near to the value for a fully-dynamic communicator.

An explanation for this can be found by plotting (Figure 5) the probabilities of occurrence of the average rank positions 1-27 in the fully-dynamic keyboard versus those of 1-6 (dynamic) and 7-33 (static) of the partially-dynamic arrangement. The first six positions will be identical. The remainder of the graph shows surprising sim-ilarity in probability between the dynamic and static positions. After the sixth posi-tion the probability tables offer very lit-tle.

Probability vs. Rank Order for
Trigram and Modified Trigram Data

Figure 5

Conclusion

We have shown that by taking advantage
of the redundancy within English spelling,
we can predict (with accuracy beyond that of
chance) the characters most likely to follow
known characters. The improvement in ideal
communication rate is on the order of 50%
of the maximum possible gain. Our prototype
communicator will be fully evaluated to de-
termine how this ideal rate is affected by
human interaction.

References

1. Pratt, F.: Secret and Urgent. Bobbs-
    Merrill Co., 1939.

2. Edwards, E.: Information Transmission.
    Chapman and Hall, London, 1969.

3. Crochetiere, W., Foulds, R., Sterne, R.:
    Computer Aided Motor Communication.
    Proceedings of the 1974 Conference on
    Engineering Devices in Rehabilitation,
    Boston, Mass., 1974.

PROSTHETICS/ORTHOTICS

Chairman, A. Bennett Wilson, Jr.
Committee on Prosthetics Research
and Development,
National Academy of Sciences

Title of Paper: Unique Design and Fabrication of Aids for the Mentally and Physically Handicapped

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: Reclining chairs, stand-up tables, trays for wheelchairs, communication devices, training devices, etc.

Intended User Group: Disabled

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   /X/

Feasibility Testing   / /

Clinical Testing   / /

Available for Sale (check one)   Yes /X/   No / /

Price per unit $ Cost of materials only

Availability of constructional details:

B. Research Study

Intended Utilization:

Intended Device Application:

Availability of Intended Device: Custom built to suit individual need.

For further information, contact: Name   Flauma Service Society
Address 108 W. Clearfield Road
Havertown, Penna.   19083

UNIQUE DESIGN AND FABRICATION OF AIDS FOR THE
MENTALLY AND PHYSICALLY HANDICAPPED

by

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Summary - For seven years a small group of dedicated engineers, housewives, executives and craftsmen have volunteered their time and effort to design and construct prosthetic devices, teaching aids and specialized toys for the mentally and physically handicapped. These items are produced only on order by the professional therapist, doctor, or teacher, to their specifications, for the particular child requiring them. Charge for the service is approximately the material cost. Hence, this service and the aids produced are unique. Membership in the Flauma Service Society is open to all who wish to donate their time and talents to further the work.

This paper is the story of a group of dedicated people who chose to apply their skills, time and energy to help the handicapped to perform their day-to-day tasks.

The group came into being about seven years ago and formally established themselves into a society incorporated in the State of Pennsylvania as a non-profit organization. For identification purposes the name Flauma Service Society was adopted. The name Flauma is an acronym composed of the initial letters of a Masonic organization. However, many of its members do not have a Masonic affiliation.

The members are composed of persons representing many skills and professions, including housewives, school teachers, accountants, technicians, salesmen, a lawyer magistrate, a physicist, and engineers in the fields of chemistry, electricity and mechanics. Several of the latter are registered professional engineers. The proficiency of the group is further enhanced by their avocations, including home workshops, painting, photography and dressmaking - to mention a few.

The Society meets periodically to conduct its general business and to listen to guest speakers on subjects related to the mission of the Society. Additional meetings are held by various committees to implement the work of the Society. Much of the real effort is handled by the Research and Development Committee and the Production Committee.

It might be well to state at this point that all work performed by the members is voluntary, and all completed projects are sold at cost. The work of the Society is dependent entirely on contributions for its operations and there are no paid employees. Clearance has been obtained from the Internal Revenue Service and all contributions are tax deductible.

An undertaking of this nature could have no meaning without proper guidance and direction. It was this idea that prompted the founding members to draw up the necessary guiding principles to attain the desired mission. Essentially, this calls for a close working relationship of the Flauma Service Society with those responsible for the rehabilitation of the disabled and handicapped.

The Society, under no circumstances, prescribes nor recommends any therapeutic devices, aids or programs. Its primary function is to provide the technical skill in the design of the devices using engineering criteria, and to build the devices with the concurrence and approval of those responsible for its application. The operation and specifications are prescribed by doctors, surgeons, therapists or clinicians. Every effort is taken to make all items safe in both the mechanical design and in the choice of materials.

In actual practice, the method of contact is two-fold. In the first case, a member or group of members will visit an institution and offer its services. In the second case, an institution may contact the Society after having learned of its existence from another source. In either case, a joint meeting is held to discuss the details of what is wanted and compared with blue prints, sketches and pictures of similar objects. Normal devices present no problem; however, complicated, involved, or extraordinary problems are referred to the Research and Development Committee for evaluation and solution. This is followed by additional meetings until there is a concurrance by all concerned as to its merits, and then initial steps are taken to produce the item.

Due to the limited production facilities and the personnel available for work, the Society has restricted its efforts to the specialized projects normally not obtainable from other suppliers. The trend has been toward the "custom made". Only those projects requiring special use and unique adaptation to the individual patient are the chief concern of the Society.

The following examples are cited to illustrate what has been done in the past: Jig saw puzzles of various kinds were produced with raised knobs and protruberances for patients with terminal devices; checker boards with pins and checkers with corresponding holes to prevent them from falling off; ordinary scissors attached in an upright position on a steel plate to be used by hands without normal dexterity; numerous peg boards of different sizes and shapes - both painted in various colors and unpainted - each for a specific therapeutic effect.

An interesting example was a board mounted on a base with a conventional door knob in the lower right hand corner. In the center and at the top of the board was an opening through which could be seen a picture. The picture itself was one of several on a rotating disc activated by the door knob. The purpose of this item was to train patients with terminal devices in the operation of a normal doorknob. A spring adjustment was provided behind the board to vary the force necessary to turn the knob.

Self-help and training aids for dressing were made in various styles including lacing boards and button belts with different sizes of buttons and textures of fabrics. Communication aids are a vital necessity and several were produced to meet specific needs. One type consisted of the usual tray attached to a chair. Along the edge opposite to the patient were a series of wooden buttons identified by the biological needs of the patient who could not talk. When a button was depressed, an alarm was sounded and a small light was shown, indicating which button was activated. Switches were also provided for each button for control by the nurse.

Another interesting device for children was developed as an original idea by one of the members of the Society. During post operative care a child was required to blow into a tygon hose attached to several bottles of colored water as a deterrent against pneumonia. A better device was made by painting a Walt Disney character (Mickey Mouse, Pluto or Woody the Woodpecker) on the face of a one foot square piece of plywood mounted on a base. A metal tube was secured through the mouth of the character and a rubber balloon was attached to the front. A tygon hose was attached to the rear for the child to blow into. From the child's point of view this was a much more interesting pastime.

One of the more productive projects of the Society has been the design and construction of chairs and stand-up tables. These items are available and can be purchased on the open market; however, they are built to standard specifications and in many instances do not quite meet the needs of specific cases. It is this field that Flauma has tackled.

Out of the many chairs that have been built to date there are very few that could be classified as identical. They range over many sizes and configurations. Practically all of them are made adjustable in the seat, the back, the foot rest - including provisions for inclining the entire chair backward. Adjustable head rests and supports are also incorporated to confine the head where muscular control is lacking. Some chairs are equipped with separators for knees or feet. Casters of various types for moving the chairs are supplied to order. Padding is installed whenever necessary to prevent chafing and injury. Feeding trays are made either plain or arranged with communication devices as mentioned previously. They are also made to tilt to compensate for the tilt of the chair and to maintain an even keel. There is no limit as to what can be accomplished since

all trays are made to be removable. Special replaceable trays can be constructed to provide for educational programs.

An interesting case of the value of a chair is worth repeating for its effect upon the patient as well as the people responsible for his care. A disabled child had spent a large portion of his life confined to the floor for lack of suitable furniture. A chair was designed and built expressly to meet the needs of this child, and on the day that he was placed into this chair there was an immediate change in his outlook. For the first time this child was able to look at the world in the same plane as other human beings, and the reaction was dynamic. The child showed greater interest in the world about him and took a more lively interest in learning. Needless to say, the reaction was very encouraging to the people entrusted with his care.

A few years ago a surgeon presented the Society with the problem of developing a blood filter for recovering the blood lost during a surgical operation. The task of removing the solids was not difficult, but removing the fats was another matter. The project was referred to the Research and Development Committee for analysis and study. The final outcome was the development of a plastic throw-away cartridge containing a fibrous material which had the property of absorbing oils and fats. The recovered blood could then be used for self-transfusion.

Curvature of the spine can be corrected by surgically implanting a stainless steel rod known as a Harrington Rod. The rod is arranged with two hooks, one at each end, for engaging into the vertebra of the spine. The hook at one end is fixed, whereas, the opposite one is adjustable by means of a series of grooves cut into the rod proper. After implantation, the hooks are forced apart by a special tool similar to forceps to provide the necessary compression to straighten the spine. Several weeks later a similar operation is performed to expand the rod as the spine assumes a more normal position. The problem as presented to Flauma was to find a method of extending the rod without the necessity of another drastic surgical procedure. Once again, this problem was referred to the Research and Development Committee for solution.

The final result was the develop-

ment of a new rod having an acme thread with a suitable nut attached to the adjustable hook. It is now a simple matter to insert a small key for rotating the nut to provide the necessary compressive force. An advantage of this method is that infinite adjustment is available, whereas the former rod required large increments due to the spacing of the grooves. The final and real advantage is that only a minor surgical opening is necessary to insert the key for subsequent adjustments of the rod. In this way the trauma of a more serious surgical operation is avoided.

It has been a fond hope of this Society that other similar organizations can be formed throughout the United States. The knowledge, drawings, and ideas accumulated by this Society are available to anyone interested in similar endeavors. The only stipulation is that all material received will be used at no profit to any one or any group. There is no doubt that a free exchange of ideas can be of great benefit to the handicapped and certainly to those responsible for their nurture, care, and rehabilitation.

Title of Paper: ORTHOTIC MANAGEMENT TODAY

Category: (check one)   Device Development /X/   Research Study /__/

Brief Description: This paper is intended to describe orthotic systems that are developed from thermoplastic materials and are fabricated by using vacuum forming techniques. These systems have been clinically tested and have been found to meet the physical needs of the patient.

Intended User Group: Persons who require external systems of support, immobilization, and assistance.

Stage of Development: (Check all that are applicable)

   A.   Device

         Prototype Development   /__/

         Feasibility Testing   /__/

         Clinical Testing   /__/

         Available for Sale (check one)   Yes /X/   No /__/

                  Price per unit $ Cost varies according to design and materials,
                                     geographic area, and facility that is providing
         Availability of constructional details: the service.

   B.   Research Study

         Intended Utilization: _____

         Intended Device Application: _____

         Availability of Intended Device: _____

For further information, contact: Name   Melvin L. Stills, C.O.
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ORTHOTICS MANAGEMENT TODAY

by

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Temple University - Moss Rehabilitation Hospital
Philadelphia, Pennsylvania

Summary- The development of new plastic materials such as polyethylene and polypropylene has made it feasible and economical to fabricate orthotics systems which are durable, lightweight, cosmetically acceptable, and designed to meet the individual needs of the patient. The purpose of this paper is to describe the orthotics designs which have been fabricated from these materials, using vacuum forming techniques. These techniques have been employed in the fitting and bracing of 700 patients in the Krusen Research Center Orthotics Clinic.

Introduction

Orthotics systems are usually fabricated from leather and metal components, and they are similar, in function, to systems that were utilized over 50 years ago.[1] Although advancements have been made in the materials utilized, and the fabrication techniques and delivery, the overall intended function of the orthotics systems has not been modified. Standard metal systems do not adapt easily to accommodate the individual functional status of patients with locomotor disabilities; this is due, in part, to the physical characteristics of the materials.

Plastics were introduced several years ago as a possible solution to this problem. However, because of the poor characteristics of the available materials, they were not readily utilized. In recent years, newer forms of thermoplastics and thermosets have become available, and the time has come to revitalize and update some of the old techniques. The advantages of these newer materials over metal include their light weight, durability, cosmesis, and flexibility in design application. In addition, vacuum forming, as a fabrication technique, and the new materials provide an infinite number of possibilities for orthotics design and development.

In 1972, the Krusen Research Center initiated a program to study the use of thermoplastics and vacuum forming to fabricate an orthosis to meet the individual patient's needs without compromising function, weight, cosmesis, and cost.[2]

Molded Ankle-Foot Orthosis (MAFO)

This orthosis is fabricated by vacuum forming standard polypropylene over a positive model of the lower limb. Polypropylene was chosen for use in lower limb orthotics due to its durability, flexibility in design, and formability. It is not totally cosmetically acceptable due to its opaque white color, but it can be easily covered by stockings, shoes, or clothing. An attempt is being made to obtain a transparent material that has the same characteristics as polypropylene. To date, this type of material has not been found.

The MAFO is designed to be in total contact with the posterior aspect of the shank of the leg and the plantar surface of the foot (Figure 1). It extends from 3.8 cm (1½") distal to the apex of the fibular head to the apex of the metatarsal heads. The medial and lateral trim lines of the orthosis are determined by the amount of rigidity required in the orthosis. The foot trim line on the medial side extends through the apex of the navicular, or slightly above and laterally. The trim line extends slightly above the shaft of the fifth metatarsal. If the trim line extends
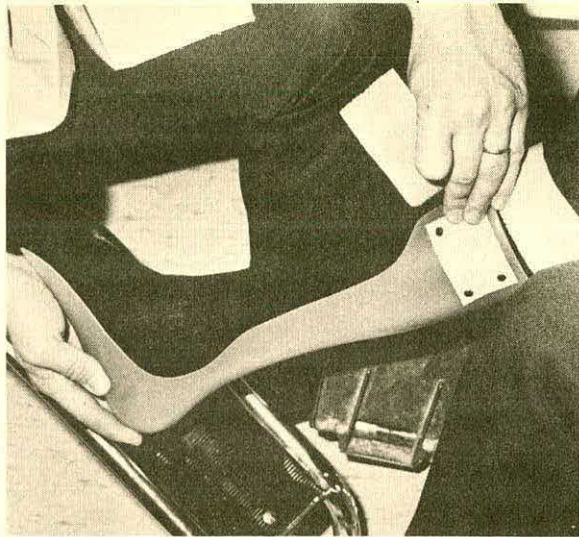
Figure 1. MAFO in total contact with posterior aspect of shank of leg and plantar surface of the foot.

below a bony prominence, this area may become a pressure area. The overall weight of the completed MAFO is approximately 115-170 grams, depending upon the size of the patient being braced, and the placement of the trim lines.

Rigidity is a function of three major variables: material, geometric shape, and cross-sectional area. Since polypropylene is generally used, its effect upon rigidity remains constant, but geometric shape and cross-sectional area can, and do, vary among patients. The anatomical configuration of the limb to be braced directs the geometric shape of the orthosis.

An MAFO fabricated over a model with prominent surface anatomical markings will be more rigid, due to its shape, than an orthosis formed to a model that lacks definite anatomical markings. The cross-sectional area of the orthosis is determined by the thickness of the material utilized and the placement of the trim lines. A completed MAFO should be no more than 4 mm thick and should taper down to approximately 2 mm.

After the orthosis is formed, the placement of the trim lines is the only method available to alter its rigidity. The degree of rigidity determines the overall function. The orthosis is secured to the leg proximally by a Velcro closure about the calf and distally by non-orthopedic type shoes (Fig. 2).

Figure 2. MAFO secured to leg by Velcro closure about calf, and by non-orthopedic shoes.

The MAFO has been used in the treatment of approximately 600 patients. The functional needs of the patient, not the etiology of the disability, determined which orthotic design was utilized. This orthosis has been found to be an effective means of controlling the ankle and foot and is accepted by the patient.

The MAFO has been used effectively with children when control of the ankle and foot is required. The patient in Figure 3 is two weeks post-tendo-Achilles lengthening (TAL) and the MAFO is utilized only to prevent equinus position of the foot. The total weight of each orthosis is approximately 2 - 3 oz (80 grams). The patient can wear tennis shoes or standard street shoes. The patient can be braced in this manner thus, eliminating the need for prolonged casting and standard metal bracing which is the normal routine following a TAL procedure.

Fracture Bracing

An MAFO is in total contact with the posterior aspect of the leg and by extending it to the level of the knee and adding an anterior shell, circumferential control of the long bones of the lower leg can be gained (Figures 4 and 5). Many of the problems commonly associated with standard plaster casts are greatly reduced by use of this method.

Weight is reduced from 2.3 - 4.1 kilograms (5-9 lbs) to 230 -280 grams (8-10 oz). Pressure areas can be easily noted should there be any. Open fractures can be cared for without any difficulty since the orthosis can be removed easily. Needless to say, this system would not be used if the patient could not be trusted to exercise care in its handling and proper use. Mobility is not compromised because the system is light in weight, water does not affect it, there is no leg length discrepancy, and the patient utilizes conventional footwear. Hygiene is not a problem since dressing changes are readily accomplished and the patient can bathe and not be concerned about damaging the orthosis. Cosmetic appearance is greatly improved (Figure 6).

The system has only been utilized in the treatment of non-union fractures and has been worn over a period ranging from 4-13 months. The patients are fully weightbearing in this unit, and, to date, there has been no record of orthosis breakage. All of the non-union fractures have healed completely without complication.

By adding conventional polycentric knee joints to the orthosis, medial/lateral control of the knee is achieved (Figure 7). This permits the treatment of proximal tibia and distal femoral fractures. Experience in fitting 20 patients with non-union fractures has led to the belief that the system may be useful in other clinics.

Figure 4. Fracture orthosis with anterior shell hinged proximally.
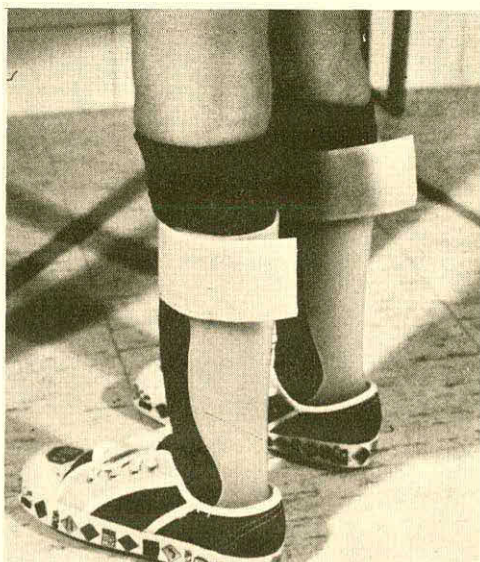
Figure 3. MAFO utilized to maintain positioning following TAL procedure.
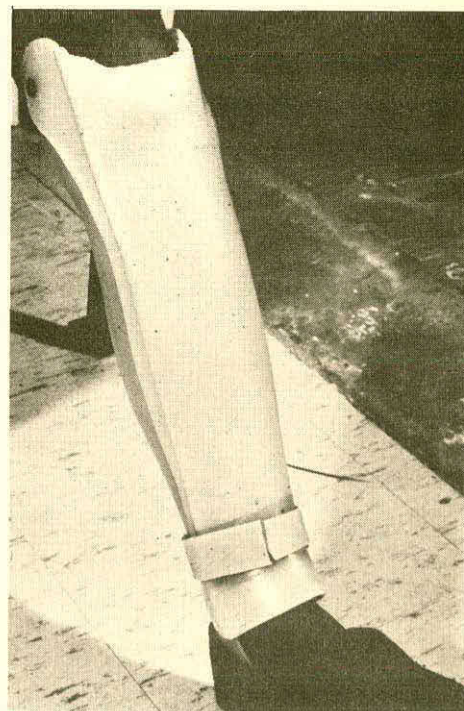
Figure 5. Fracture orthosis secured distally with Velcro closure for circumferential control of long bones of lower leg.

Figure 6. Patient wearing molded fracture orthosis.

Knee-Ankle-Foot Orthosis (KAFO) - Anterior Quadriceps Shell

This system has been utilized with two patients having quadriceps rupture secondary to chronic renal failure (Figure 8). Each patient required knee immobilization to prevent knee flexion and flexibility in the medial/lateral plane to permit volume fluctuation which frequently occurred. Wound dressings were changed daily and standard plaster casts were impractical.

Low density polyethylene was used to fabricate the modified KAFO. It was flexible enough to permit the volume changes without creating pressure areas along the trim lines. The geometric shape caused it to be totally rigid in the anterior/posterior direction (Figure 9). Polyethylene is impervious to body fluids; the dressing changes are accomplished easily and the orthosis is cleaned by using standard septic techniques.

Figure 7. Fracture orthosis with medial/lateral control of the knee.

Figure 8. KAFO used for knee stability following quadriceps rupture.
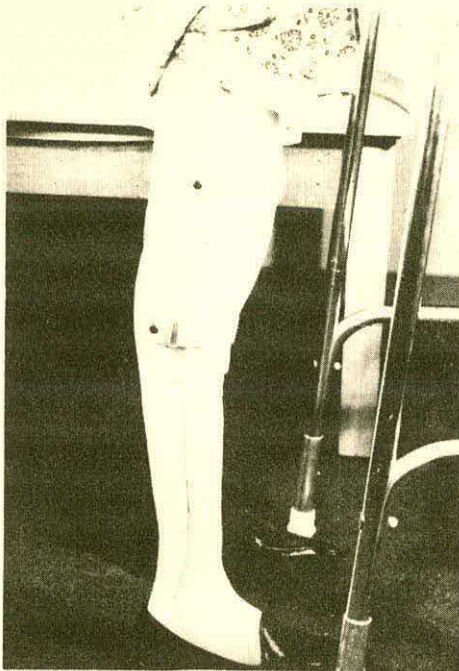
Figure 9.   KAFO with anterior qua-
driceps shell in place.

Many types of orthoses have been
developed with numerous modifications in
design. It would be impossible to present
all of them in this paper. It is hoped that
the reader will understand that, using
knowledge of the actual needs of the patient
along with present day technology, an ortho-
tist, as part of a rehabilitation team, can
develop systems which are unique in design
and function. These systems cannot be
pre-designed and stocked as "off-the-shelf"
items with the assumption that a patient
will fit into any given design criteria. With
available materials and fabrication tech-
niques, definitive orthotics systems can be
provided on an individual basis.

References

1.   Orthopedic Appliances Atlas. Volume I.
      J. W. Edwards. Ann Arbor, Michigan,
      1952.
2.   Rehabilitation Engineering Center,
      Progress Report No. 3, Krusen Center
      for Research and Engineering, Phila.,
      Pa., pp 34-50, December 1, 1973 -
      November 30, 1974.

Title of Paper: A NOVEL SUPPORT SYSTEM FOR UNSTABLE SPINES

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: The spinal support system is a seat which is shaped such that it provides comfortable and correct support for an unstable spine in a wheelchair-bound person. It is a light weight unit which incorporates adjustable and detachable supports for arms, legs and head. The unit is easily detached from the wheelchair frame for use as a car seat or in the home. A conventional wheelchair requires minor modifications to accept the support system.

Intended User Group:
Post-ambulatory children with Duchenne Muscular Dystrophy.

Stage of Development: (Check all that are applicable)

A.   Device

Prototype Development   / /

Feasibility Testing   / /

Clinical Testing   /X/

Available for Sale (check one)   Yes / /   No /X/

Price per unit $ _____

Availability of constructional details: A manual is being prepared and will be available by September, 1975.

B.   Research Study

Intended Utilization: _____

_____

Intended Device Application: _____

_____

Availability of Intended Device: _____

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A NOVEL SUPPORT SYSTEM FOR UNSTABLE SPINES

by

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SUMMARY - Post-ambulatory Muscular Dystrophy patients develop progressively
weakened and unstable spines which collapse in spite of various attempts at
conventional bracing. A multi-disciplinary team of investigators at The
Hospital for Sick Children in Toronto have developed a support system, a
seat which acts as a brace, that appears to prevent the relentless progression
of spinal deformities during the wheelchair-bound stage of this disease, a
period representing up to 50% of the patients life span.

In approximately twelve months of continuous use by ten patients for average
periods of 9 to 14 hours each day, no indications of pressure sores have
appeared. These children all claim to feel "very comfortable". Evaluation
of A-P and lateral radiographs taken at intervals of 3 months show conclusively
that progression of spinal deformities is prevented and the kyphotic posture
usually seen in the lateral view is significantly improved.

INTRODUCTION

Clinical management in the post-ambulatory phase
of many paralytic diseases has long been diffi-
cult and frought with associated complications.
Such patients often develop serious problems
with their spines which may become unstable and
collapse for lack of sufficient and proper
support while the patient is attempting to sit
upright in the wheelchair.

Associated with the problem of spinal support,
or lack of support, is the pattern of distri-
bution and magnitude of supporting forces on the
tissues. Paralyzed patients confined to sitting
in a standard wheelchair seat, frequently and
with few exceptions develop local thermal or
anoxic necroses, particularly in the regions of
the ischial tuberosities. These problems are
particularly relevent to children with Duchenne
muscular dystrophy whose post-ambulatory period
is about 10 years duration or 50% of their ex-
pected life span. These children, and their
parents, require a service beyond that normally
offered in a hospital clinic, a service which
requires the expertise not only of a clinical
specialist but also professional consultation
of physiotherapists and medical engineers.

The purpose of this article is to emphasize the
coordinated engineering input into this type of
multidisciplinary effort, to describe the
philosophy behind a total spinal support system
to prevent spinal deformities and to outline in
general the engineering design and material
selection for such a device.

A deformed spine in a muscular dystrophy child
is classified as a form of paralytic scoliosis.

The literature describes a number of attempts
over the past decade of managing the deformities
clinically by using a variety of back braces,
which generally evolved as aids in the management
of other back problems (Dorando, et al, 1957).
None of these attempts, as might have been expec-
ted, were very successful in achieving the goal
intended and in many cases the deformities pro-
gressed relentlessly to the point where the only
alternative treatment available was surgery and
spinal fusion by the techniques of either
Harrington or Dwyer, depending on the classifi-
cation of the deformity. Effective as these
corrective procedures are in reducing the spinal
deformities, there are serious problems and risks
associated with this treatment and it is often
denied the patient simply because he or she is
too weak to safely survive the operation.

THE DEFINITION OF THE PROBLEM

Firstly, the paralytic nature of Duchenne Dystrophy
manifests itself as a progressive symmetric weaken-
ing of muscles. With loss of muscular support
the spine collapses.

Secondly, surgery does not appear to be the best
answer to this problem. Some form of external
support is desirable, but this support must be
designed on the basis of a thorough structural
analysis of the problem of the unsupported spine.
This is not an easy task for a structural engineer;
the geometry and material properties of the spine
are complex and many assumptions and approxima-
tions have to be made based on extensive clinical
observations and experience in structural design.

Thirdly, there is a great need for classifying the types of spinal instability and collapse based on accurate assessment of sequential standardized clinical radiographs of the relaxed sitting patient as well as evaluations by physical and occupational therapists.

One of the most successful attempts at bracing spinal deformities in muscular dystrophy children was the result of the work of Wilkins et al (1972) at this Hospital. They developed a tightly fitting moulded body jacket designed to meet the specific needs of this type of patient. In spite of its intelligent design it met with two practical difficulties; it was difficult to put on properly and the patient often complained of discomfort and in some cases rejected the brace completely. So, a fourth pair of criteria to consider in the design of a device of this type is comfort and ease of application.

SPINAL SUPPORT SYSTEM

It was on the basis of this definition of the problem that the concept of a total spinal support system evolved. The orthosis was designed to fit onto a modified wheelchair frame to form a special seat which acts as an open spinal brace together with additional integrated supports for head, arms and feet, each designed specifically to meet the need of the muscular dystrophy patient. The overriding priorities which governed the design included maximizing the efficiency of the structural support of the spine, and allowing the patient to attain the highest level of comfort and freedom to use his remaining muscle strength. This was achieved by the combination of an optimum shape and the selection of materials with suitable mechanical characteristics to satisfy the requirements for both support and comfort (see Figures 1 and 2).

Another important criteria for the support system was, that it should be an independent self-contained portable unit of minimum possible weight.

The support system is built on a sheet of high density polyethylene formed into the basic desired lateral curvature. Contours of the seat are then built up with an elastic foam according to custom measurements of each patient. These contours are then overlaid with a visco-elastic foam (Koreska et al, 1975) which ensures a good fit and an evenly distributed pressure between the patient and the support system. Finally, the entire seat is covered with a double-knit tricot fabric. Armrests, footrests and headrest are standardized components which are detachable and adjustable for the individual needs and maximum comfort. The whole unit fits directly onto a modified wheelchair. It is inclined from straight upright position by approximately 15° which is sufficient to make the patient "fall" into the shape of the seat. The resulting posture reduces kyphosis, emphasizes lumbar lordosis and provides continuous lateral support for the spine, rendering it structurally stable. The inclined position also reduces the axial load carried by the spinal column, thereby reducing the possibility of structural collapse. This inclination may be gradually increased, as the weakness in the patient's back muscles progresses with the combined effect of increasing the efficiency of the structural support and at the same time reducing the axial load on the spinal column.

Other features related to the modifications of the electrically powered wheelchair include a telescopic spring support at the back which allows the patient to rock, thus exercising his abdominal muscles which seem to maintain their strength somewhat longer. These muscles are important in maintaining lateral stability of the lumbar spine (Bartelink, 1957). Another feature is the racing stripes on the back of the support system, a feature which is difficult to measure in terms of need, but with obvious positive results. The control box on these powered chairs has been mounted on a swing arm directly in front of the patient instead of in the usual side location. The purpose of this is twofold; it allows the patient to use both hands to control the wheelchair and it encourages the child to assume a more erect, balanced posture.

THE PROBLEM OF STANDARDIZED X-RAYS

Systematic evaluation of the performance of a system such as described here or any device designed for patient care, is important to ensure that the device is fulfilling the job it was designed to do. Since this particular device was designed to prevent spinal deformities, systematic spinal radiographs must be taken in 2 directions, A-P and lateral.

For most routine clinical radiological assessments the patients sit in a more or less arbitrary position dictated by the severity of their deformity, with someone holding their arms or torso since they are most often unable to support themselves in a sitting position. The resulting lack of reproducibility makes comparison of sequential radiographs impossible. Distortions in the X-ray image of the spine thus vary considerably and render quantitative measurement, comparison and analysis almost meaningless. To compensate for these deficiencies, we developed a device which allows us to obtain systematic and far more reproducable orthogonal X-ray images on a standard frame of reference. The device has been named "The Throne" (see Figure 3) and incorporates a soft and comfortable seat. Elevated panels along one side and the back contain metal strips which show up on the X-ray picture as horizontal reference lines. A horizontal metal cross-bar adjusts to a tight fit under the knees and ensures that the pelvis remains in a fixed position, parallel to the bar. Vertical acrylic rods at the back are adjustable to suit the individual patient. These rods contain wires which serve as vertical reference axes on the X-ray images and calibrations which allow us to correct for dimensional distortions. These rods also support the patient at the scapulae only with the assurance of a safety belt around the upper thorax. In short, the throne simply fixes the position of the shoulders parallel with the spines of the pelvis while the thoracolumbar spine remains unsupported in the A-P and lateral planes.

The introduction of this throne has been very

successful. It is simple to use and for a trained radiographer, A-P and lateral X-ray images can be obtained quickly, conveniently and accurately in a routine procedure.

RESULTS

Figure 4 illustrates a set of A-P and lateral radiographs of a patient sitting on the "Throne". The horizontal and vertical reference axes are identified and parameters such as pelvic obliquity (P.O.), sacral angle (S.A.) and kyphotic index (K.I.) are indicated and defined. The values shown on these radiographs are typical of the ten patients presently using the spinal support system. Spinal curvatures measured on the A-P radiographs (indicating instability of the spine) have increased by less than five degrees in five patients and decreased by up to 5 degrees in four patients. In one child the curve remained at its mild curvature of ten degrees over the twelve month study period. Similar patients confined to a normal wheelchair and supported by a conventional body brace are frequently observed to develop spinal curvatures over a similar period of time which measure an order of magnitude higher. During twelve months of use for average periods of 9 to 14 hours continuously each day, compared to a maximum of 2-3 hours at a time in the standard wheelchair, no indications of pressure sores have appeared and the children claim to feel "very comfortable".

CONCLUSIONS

The concept of a spinal support system for unstable spines has been applied to Muscular Dystrophy patients suffering from paralytic scoliosis. The designed combination of form and material to provide optimum support and comfort has proven successful. No significant progression in spinal collapse has occurred.

A procedure for accurate and reproducable assessment of the support system with respect to its ability to prevent spinal deformities has been described. This includes standardized and calibrated X-ray images which are essential for evaluating a spinal support system.

FIGURE 1. Spinal Support System on modified powered wheelchair base. Front view. Armrests and footrests are adjustable and removable.
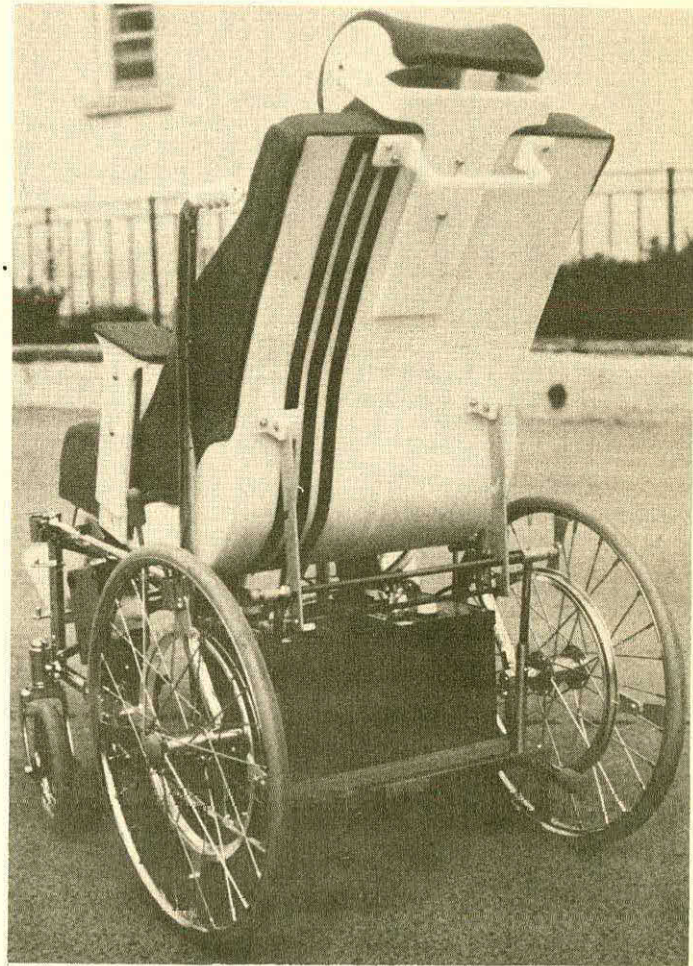
Figure 2. Spinal support system seen from rear. Modifications to the wheelchair frame include telescopic springs supporting the system which may be inclined from 15° to 30° and 45° respectively.
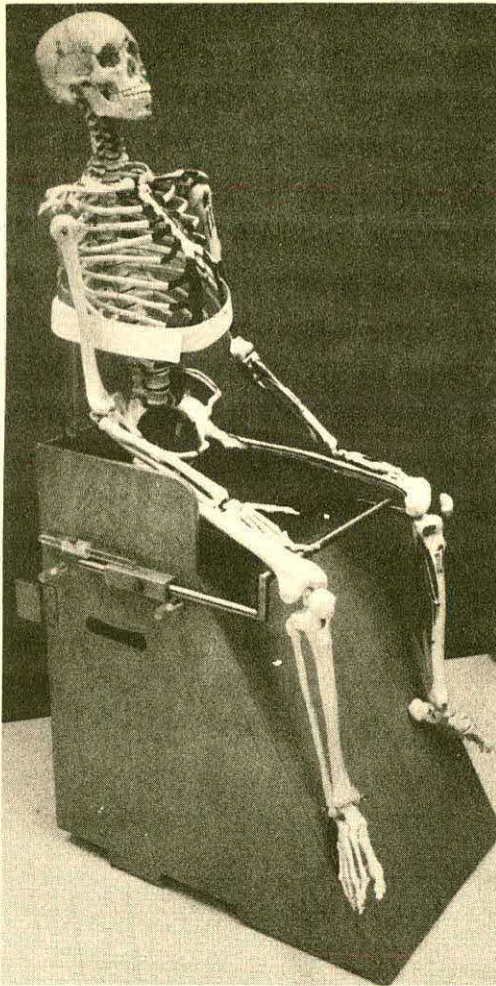
FIGURE 3. The "Throne" supporting a "patient".
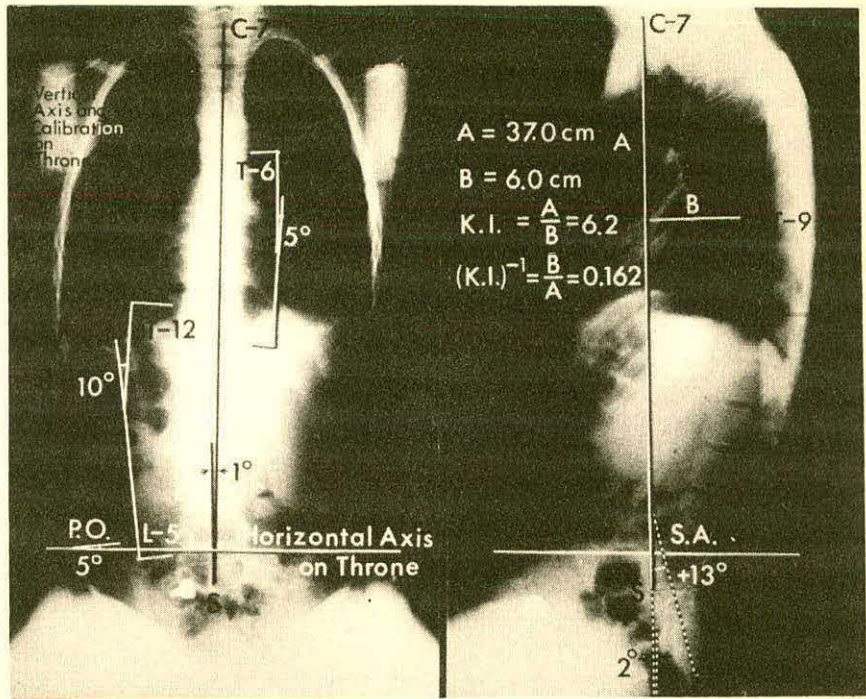
FIGURE 4. Typical A-P and lateral radiographs of a patient sitting on the Throne. See text for explanation.

REFERENCES

Bartelink, D.L., "The Role of Abdominal Pressure in Relieving the Pressure on the Lumbar Intervertebral Discs", J. Bone Joint Surgery (Brit) 39-B: 718 (1957).

Dorando, C. and M.K. Newman, "Bracing for Severe Scoliosis of Muscular Dystrophy Patients". The Physical Therapy Review, Vol. 37, No. 4, 1957, pp. 230.

Koreska, J. and A.M. Albisser, "A New Foam for Support of the Physically Handicapped", Biomedical Engineering, Vol. 10, No.2, 1975.

Wilkins, K.E. and D.A. Gibson, "The Patterns of Spinal Deformity in Duchenne Muscular Dystrophy", J.Bone Joint Surgery, in print.

ACKNOWLEDGMENTS

Title of Paper: Clinical Field Trials of the Emory Detachable Electric Powered Drive for the Standard Wheelchair

Category: (check one) Device Development /xx/ Research Study / /

Brief Description: A prototype of a battery powered drive unit has been developed that can be easily attached to most standard non-powered wheelchairs to convert them to powered chairs. Attachment and detachment can easily be done by the wheelchair user while sitting in the wheelchair. This paper contains a description of the unit, criteria used to develop it, and the clinical and laboratory testing procedures used in testing it.

Intended User Group: Any wheelchair user requiring full time or intermittent use of a powered wheelchair.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   /x /

Feasibility Testing   / /

Clinical Testing   / x/

Available for Sale (check one)   Yes / /   No /x /

Price per unit $ _____

Availability of constructional details: Prototype drawings of the unit can be obtained upon request.

B. Research Study

Intended Utilization: _____

_____
_____
_____

Intended Device Application: _____

_____
_____
_____

Availability of Intended Device: _____

_____

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CLINICAL FIELD TRIALS OF THE

EMORY DETACHABLE ELECTRIC POWERED DRIVE FOR THE STANDARD WHEELCHAIR

by

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Summary - Emory University Regional Rehabilitation Research and Training Center (RR&TC) has developed a battery powered drive unit that can be easily attached to a standard wheelchair to convert it to a powered wheelchair. While powered units are available that can be attached to or detached from a wheelchair, this unit is unique in that its attachment can easily be done by the wheelchair user while he is sitting in the chair, if he has at least some use of his upper extremities. This unit will enable the user to enjoy the advantages of having both a powered and a standard wheelchair. Presently three prototype units have been built for clinical testing of their effectiveness.

Relevance of Unit

Users of conventional powered chairs face several problems that this unit may help them overcome because of the ease of detachment and attachment of the unit. For instance, a powered wheelchair is often difficult to transport. However, with this unit detached and the standard chair folded, the client will be able to travel in automobiles that could not normally transport a powered chair. If a situation occurs where the powered chair must be pushed by someone else, which is the case if the power drive should malfunction or if the client wants to go somewhere a powered chair cannot easily go, the power drive acts as a drag on the chair wheels and as extra weight. The Emory drive unit can easily be detached in these situations so that the chair can be pushed as a standard wheelchair.

Many clients who presently do not use a powered chair could benefit from intermittent use of power for long distance wheeling; those with partial quadriplegia, paraplegic clients with other involvement in their upper extremities, hemiplegic clients confined to a wheelchair, and any wheelchair user who suffers from a disease that prohibits any significant exertion. Generally, a client in this category has chosen a standard chair because of its greater portability and versatility. A powered chair would increase his endurance

and long distance wheeling capabilities but would decrease his overall independence because they are more cumbersome than standard chairs. However, use of the Emory unit with a standard chair will provide the standard wheelchair client the option of power when it is needed.

This unit may also be useful in a rehabilitation center or clinic as an evaluation tool for deciding what patients would benefit from use of a powered chair and also as a teaching device for those soon to receive powered chairs. In this situation a single unit can serve many patients.

Design Criteria

The original prototype for this unit was developed by Dr. M. B. Ewing (formerly of the Emory University RR&TC), a physician with a background in mechanical engineering. Dr. Ewing was confined to a wheelchair because of polio which had also affected his upper extremities; he was unable to wheel his standard wheelchair for long distances without producing excessive muscle fatigue. He developed this unit to meet his own personal needs of a wheelchair with intermittent power.

The design criteria originally established by Dr. Ewing[1] for a detachable wheelchair motor unit are the following:
1) Should be adaptable to fit varying sizes of standard wheelchairs and not require wheelchair alteration.
2) Must not decrease stability of chair, particularly in backward tilting, i.e., in

climbing ramps.

3) Should support its own weight and not place undue stress on the wheelchair.

4) Must not increase the size of the wheelchair.

5) Should allow normal use of wheelchair when detached.

6) Should be attachable and detachable by the user.

7) Controls should be adaptable to meet the needs of severest disabilities and safe for independent use, permitting precise maneuverability in all directions.

8) Should permit transfer of user from either side.

9) Must be smooth and tractable to prevent precipitation of muscle spasm or other discomfort.

10) Should be capable of climbing reasonable inclines.

11) Should be quiet in operation.

12) Should have sufficient braking capabilities to provide safe control on inclines and smooth stops on the level.

13) Should permit close approach to and withdrawal from a desk or table.

14) Should be easy to transport.

15) Should require minimal maintenance and have maximal durability.

The criteria established for evaluating powered wheelchairs at the Veterans Administration Prosthetics Center[2] are the following:

1) Should be adjustable to a low speed of 1 mile per hour.

2) Should be capable of climbing a 1 inch curb.

3) Should be capable of climbing a 10% slope.

4) Should have a 30 inch turning radius.

5) Should be capable of withstanding a normal day's use without recharging of the power supply.

6) Should not increase the overall dimensions of the chair if it is to be used in the house.

The present prototype units have been developed from Dr. Ewing's original prototype with these criteria as standards.

Technical Data and Description

The unit complete with battery weighs approximately 100 pounds and is 15 inches high, 15 inches wide, and 20 inches long. To prevent any increase in the stresses on the wheelchair because of additional weight, the power unit rests on the ground instead of on the wheelchair frame. When connected to the wheelchair, it exerts no vertical force on the chair; it is completely supported by its own three wheels -- two hard rubber drive wheels at the front of the unit and one supporting wheel at the rear. Power is not supplied to the large wheels of the wheelchair; instead this unit will push or pull the wheelchair by means of its two drive wheels which are in contact with the ground.

The unit will fit completely between the rear wheels of a narrow adult or regular size adult chair. Locking mechanisms on each side of the unit are designed to attach to the vertical portions of the wheelchair frame directly beneath the rear wheel axes. No modification to the wheelchair is needed for attachment of the unit.

To attach the unit the user backs his chair up to the unit and uses a lever on the unit to activate the locking mechanism. To detach from the unit the lever is used to open the locking mechanism and the user wheels away from the unit. To prevent any wheel skidding during turns, the drive wheel axes are located directly beneath the chair's rear wheel axes upon attachment of the unit, and the rear wheel of the unit is free to pivot during turns.

Each drive wheel of the unit is powered independently by a 1/8 HP permanent magnet DC motor, which is standard for other powered wheelchairs also. Each motor and therefore each drive wheel can be run forward or backward at any speed between zero and full speed. The motor speeds are regulated by the control unit, which is a pulse width modulator utilizing silicon controlled rectifiers (SCR). At full power, 12 volts DC from the battery are being supplied continuously to a motor, and at anything less than full power, DC pulses of 12 volts are being supplied. Motor speed is proportional to pulse duration. The pulse durations (width) are varied by the control unit in response to the wheelchair controls. With the controls, the user selects the speed and direction of both motors and, therefore, of his chair.

The type of controls needed by the user of the unit will depend on the user's disabilities. To be completely independent in attaching and detaching the unit and the controls, the client must have functional control of muscles across his shoulder and elbow joints. Clients with greater disabilities will not be independent in the use of the unit, but they may still benefit from its detachability. A "joy-stick" type of control, which permits the client to turn the chair in any direction and travel at any speed between zero and full, is being used on the three prototype units. Wheelchair clients who can attach the unit independently also have enough use of the upper extremities to use the joy-stick control. For easy attachment and detachment of the joy-stick, a metal plate was fastened to one arm of a user's wheelchair. The joy-stick control could then be connected to this plate with a metal clip by the wheelchair user. When the joy-stick control and the unit are detached from the chair, the chair will function as usual.

In case of failure of the pulse width modulator, the joy-stick control returns to the off position, but the motors can still be

run in an on-off fashion. With the joy-stick at the center location the motors are off, and with the joy-stick at any other location the motors would be receiving 12 volts DC continuously and would be full on. It would be possible to run the chair in this manner until the control unit could be repaired.

The 12 volt DC automotive battery will be able to run these motors for at least one day and probably several days' use between battery charges. Recharging can be done overnight with a battery charger that can be plugged into a socket connected to the battery terminals.

The price of this powered unit plus a standard wheelchair is expected to be competitive with that of other powered wheelchairs on the market.

Testing

A. Pre-patient
Before these units can be evaluated in the field by wheelchair users under normal operating conditions, they must be evaluated for safety and performance in the laboratory. The initial evaluation consists of the following items:
1. Safety
   a. Determination of stability of unit and chair when making turns of various degrees at high speeds and when accelerating on a slope or on a level surface.
   b. Testing of braking ability of unit on a slope and at high speeds.
   c. Evaluation of speed control continuity.
2. Performance
   a. Determination of what degree slope the unit can climb while pushing a chair and occupant.
   b. Determination of maximum speed.
   c. Determination of turning radius of unit and chair.
   d. Surface variability--testing of effects of uneven surfaces, curbs, and surfaces of various consistencies on performance.
   e. Determination of power supply longevity.
   f. Testing for excess noise and vibration.

B. Patient Testing
Clients recruited to test this unit on their own wheelchairs were limited to those who had enough function of their upper extremities to use a joy-stick type of control. Users with various degrees of upper extremity involvement were obtained as volunteers.

For four weeks prior to being given a powered unit for testing, the client volunteers had odometers attached to their wheelchairs to measure how much they actually used their chairs. They were then taught the use of the powered unit in a short training session lasting less than one-half day, after which they were given the powered units to use for the next four weeks.

The odometers were left attached to their wheelchairs for this four week period also to see if any change in the amount of use of the wheelchair occurred. The first few days or weeks may not be indicative of normal use because of the novelty of having this unit. Therefore the clients were asked to keep a record each week of the odometer reading. No special instructions on how much to use the unit were given with one exception: those who were using it in place of their own powered chairs were asked not to use their own units unless they found that the test unit interferred with their activities.

At the end of this four week period of using the unit, the clients were given a questionnaire covering any changes they observed in their own endurance, independence, and activities of daily living. They were asked also if there were any instances in their opinions in which the design criteria were not fulfilled by the unit. In addition, they were given a series of tasks to perform using the unit that required a combination of wheelchair maneuverability and user control of the wheelchair. This performance test was done because of the possibility that many situations requiring high performance were not available in the testers' natural environments.

The performance tasks included many which are often difficult for a person in a wheelchair to perform, such as (1) opening and going through a series of doors, (2) going up and down a ramp, both forward and backward, stopping at the half-way point and then continuing on up or down, (3) maneuvering forward and backward in confined areas, (4) turning around in confined areas, and (5) traveling over various types of surfaces.

These tasks were also done by the testers using their own normal means of propulsion as a means of comparison with the performance of the Emory unit. Performance was judged in two ways--the ability to complete the task safely and amount of time needed to complete the task.

Results and Discussion

At the time of submission of this paper, we are still in the testing stage. Results will be discussed during the conference.

References

1. Ewing, M.B. Project Report, Emory University Regional Rehabilitation Research and Training Center, 1969.

2. Peizer, E. and Wright, D.W. Five years of wheelchair evaluation. Bulletin of Prosthetics Research 9:37, Spring 1969.

AIDS FOR THE BLIND

Chairman, Gustav F. Haas, Ph.D.
Committee on Prosthetics Research
and Development,
National Academy of Sciences

Title of Paper: The Commercialization of Sensory Aids

Category: (check one) Device Development /X/ Research Study / /

Brief Description: A description of the multi-phase process by which technological devices evolve from the planning stage to commercial availability.

Intended User Group: Consumers, counselors, clinicians, and those persons not engaged in research and development.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development / /

Feasibility Testing / /

Clinical Testing / /

Available for Sale (check one) Yes / / No / /

Price per unit $_____

Availability of constructional details:

B. Research Study

Intended Utilization: _____

Intended Device Application: _____

Availability of Intended Device: _____

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THE COMMERCIALIZATION OF SENSORY AIDS

by

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New York, New York

Summary - Many potentially useful sensory aids
never reach the commercial market place because
of a break in continuity between the research and
deployment phases. A series of discrete steps and
careful planning are required to insure the prop-
er development and testing of new products so as
to attract private investors, manufacturers and
consumers. The Office Of Sensory Aids Development
of the American Foundation For The Blind was rec-
ently created to act as a catalyst and assist in
the commercialization of worthwhile sensory aids
for blind and visually impaired persons.

For more than fifteen years the American Foundation For The Blind (AFB), and its Research Department in particular, has been wrestling with the problem of the transfer of technology to the blind and visually impaired consumer. Many potentially useful sensory aids for the visually impaired have been developed by individuals, companies, universities and laboratories, and now exist in prototype form. However, few ever advance beyond the prototype stage and even fewer are currently available.

The commercialization of these devices is too often difficult to achieve due to the small serial production runs needed for the target user population. Large manufacturing organizations usually avoid involvement in these situations on economic grounds alone. Small manufacturers and laboratories, while they may express interest in these devices, often do not have the investment capital required for further development, testing, evaluation, tooling, production and distribution.

In October, 1971 the AFB sponsored an international symposium on science and blindness. One of the major topics discussed was the possibility of AFB bridging the existing gap between the research phase and the availability of commercial products for blind persons. By acting as a catalyst it was thought that AFB might begin to get some of the current biomedical research into the hands of blind users. AFB staff and consultants collected basic data, analyzed the issues and worked up a report which was submitted to our Board of Trustees.*

As a result, The American Foundation For The Blind created the Office Of Sensory Aids Development. Currently, the three basic areas of activity are:

MARKET RESEARCH - where we develop information and market data on the visually impaired and on specific types of sensory aids, provide information and guidance to developers and potential investors or manufacturers of sensory aids; issue reports and prepare articles on sensory aids and markets; and assist in conducting conferences on specific aids.

MARKET DEVELOPMENT - where we attempt to assist developers and manufacturers of sensory aids with problems in securing funding, manufacturing, market development, advertising, sales and service. We plan to conduct a job develop-

* = Graham, Milton D., editor, Science and Blindness: Retrospective and Prospective, American Foundation For The Blind, New York, 1972.

ment program to explore new areas of employment for the visually impaired which might be made possible by specialized sensory aids.

PRODUCT INFORMATION AND DISTRIBUTION - we serve as a source for public information on commercially available sensory aids for the visually impaired; disseminate information on aids and services through catalogs, information sheets and media releases; and serve as agent for sensory aids, which may otherwise not reach the visually impaired market, by recommending the sale of certain devices through the Aids & Appliances sales program here at AFB.

After the initial preparation in 1972 by our Research Department and the printing of the first edition in 1973, the Office Of Sensory Aids Development accepted the responsibility for up-dating and preparing new editions of the International Catalog Of Aids And Appliances For Blind And Visually Impaired Persons. This 214 page inkprint catalog lists about twelve hundred (1200) commercially available aids, manufactured throughout the world, for blind persons. The acceptance of this reference book has been so successful that AFB is planning to publish a new, illustrated edition late in 1975.

The systematic assessment and evaluation (the general commercialization process) for sensory aids has been recommended, discussed and written about for quite some time. This approach is necessary in order to; set goals, obtain information for design improvement, develop valid training procedures and establish viable production and marketing techniques. We believe that the participation of visually impaired consumers and consumer groups should be sought during the developmental stages of any device intended for that group.

There are approximately 1.7 million persons in the United States who appear to function at the level of "severe visual impairment". Severe visual impairment, blindness, or legal blindness usually refer to persons with a "corrected" binocular or better-monocular distance visual acuity of approximately 20/200 or below. About 3% of the severely visually impaired (approximately 60,000 persons) are in school or of pre-school age, and about 12% (approximately 200,000) are in the labor force.**

Figure A, GENERAL COMMERCIALIZATION PROCESS, illustrates our general concept for the commercialization process. During the planning and goal setting step one might be faced with the task of solving a particular problem by "inventing" a new device. On the other hand, new technology may have resulted in a device or system for sighted persons, but which may have special applications for blind or visually impaired persons.

Note that funding is indicated as the step following planning and goal setting. Funding could be indicated at any point or at several points throughout the process.

Once the plans and goals are set (and funding is provided) research and development work proceeds and results in a rough first prototype or "breadboard model". This first prototype is tested and demonstrated in order to obtain initial reactions from other researchers and potential users.

A decision to proceed must then be reached so that a second series of prototypes may then be strategically placed for preliminary field trials. Input, from consumers and researchers, may be helpful for possible revisions in design.

A market study should be conducted to guide further development and aid in reaching a decision based on cost/benefit. One of my colleagues suggests substituting "cost-value" and "effectiveness-value" for "cost/benefit". Nevertheless, one of the economic facts of life is that cost/benefit is a consideration in planning the production and development of sensory aids.

The next step is to produce a series of pre-production prototypes and place them for field tests and

** = Goldish, Louis H. The Severely Visually Impaired Population As A Market for Sensory Aids & Services: Part One. New Outlook For The Blind, 66: 183-190, June 1972.

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FIGURE A - GENERAL COMMERCIALIZATION PROCESS

Flowchart of the general commercialization process.

RESEARCH & DEVELOPMENT PHASE:
PLANNING & GOAL SETTING → FUNDING → RESEARCH & DEVELOPMENT → FIRST PROTOTYPE → PRELIMINARY TEST DEMONSTRATION → DECISION (TO PROCEED)

PROTOTYPE TESTING PHASE:
RE-DESIGN PROTOTYPE → SECOND SERIES PROTOTYPES → PRELIMINARY FIELD TRIALS → MARKET STUDY → DECISION (COST/BENEFIT) → PRE-PRODUCTION PROTOTYPES → FIELD TESTS - PERFORMANCE ASSESSMENT → DECISION (FINAL DESIGN)

POSSIBLE REVISIONS

PRODUCTION & MARKETING PHASE:
PRODUCT DEVELOPMENT → PRODUCTION

MARKET DEVELOPMENT → PRODUCT DISTRIBUTION

TRAINING PROGRAM DEVELOPMENT

SERVICE & MAINTENANCE PROGRAM

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performance assessment. These tests
should be monitored and the results
analyzed in order to reach a decision
on the final design of the device.

At this point, the production and
marketing phase is entered by simul-
taneously conducting product develop-
ment, which then leads to actual pro-
duction; market development, which
leads into product distribution; train-
ing program development and a service
and maintenance program.

The development process for sen-
sory aids closely parallels that which
is used for commercial products for
the general marketplace. New tech-
nology and resulting hardware are
financially expensive and many times
the funds for the commercialization
of these products comes from private
or venture capital sectors. Locating
potential sources for the production
of sensory aids, establishing priority
order for emerging devices, deter-
mining possible financial returns for
investors are only a few of the
problems for which the AFB Office Of
Sensory Aids Development hopes to
provide solutions or assistance.

*   *   *   *

Title of Paper: Electronic Calculators for the Blind

Category: (check one)   Device Development /x/   Research Study / /

Brief Description: Various displays for an electronic calculator for
        the blind were studied and evaluated. Spoken speech was determined
        to be optimum. A voice-output calculator is now being engineered.

Intended User Group: Blind and partially sighted, students

Stage of Development: (Check all that are applicable)

    A.   Device

            Prototype Development   /x/

            Feasibility Testing   / /

            Clinical Testing   / /

            Available for Sale (check one)   Yes / /   No /x/

                Price per unit $ less than $500 in less than one year

            Availability of constructional details: no

    B.   Research Study

            Intended Utilization: _____

            Intended Device Application: _____

            Availability of Intended Device: _____

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ELECTRONIC CALCULATORS FOR THE BLIND

by

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Summary - With the help of a survey of potential users, important design features needed in an electronic calculator for the blind were identified. Different display alternatives were ranked with respect to the desired features. Four breadboard calculators with different displays were evaluated. Spoken speech was determined to be the preferred display modality for an electronic calculator for the blind.

I.   INTRODUCTION

The ubiquitous pocket electronic calculator has been one of the few truly innovative products of recent years and a success of American technology made possible by Large-Scale-Integration (LSI) electronic circuitry. New and improved calculators are being introduced almost daily by various manufacturers. Thus far, the blind have largely not benefited from this technological advance because pocket calculator displays are visual. To overcome this lack, many organizations, including our company, are actively developing special calculators suitable for use by the blind. Our work has been directed toward defining the desirable features of a pocket calculator for the blind, studying the various display options, constructing several breadboard calculators for evaluation and, finally, selection of what we feel to be the best configuration for further development.

II.   DESIRED FEATURES OF A CALCULATOR FOR THE BLIND

Blind persons' computational needs cover the same wide spectrum as that of the general public. In order to accurately assess interest from the blind community in an electronic calculator, we conducted an informal survey of 180 blind people throughout the country. We were pleased that 75% of those questioned expressed a desire to own an electronic calculator. The results of the survey, together with our own opinion, led to the following list of key important features needed in any calculator we should develop for the blind.

1.   At least four-function (add, subtract, multiply, and divide), floating point calculation plus automatic constant, memory and square root. Nearly half of the survey respondents indicated

that they would use a calculator primarily for personal use, and only 5% needed full scientific capability. The above features would therefore cover most of the expected usage.

2.   Easy usage by the sighted and partially sighted. Many potential blind users have sighted spouses and children who would also use the calculator. The utility of a calculator would also be increased considerably if those partially sighted who cannot read ordinary calculators would be able to use it.

3.   Easy portability and battery operation. About half of our survey respondents indicated a firm desire to have a portable unit as close as possible to pocket size.

4.   Immediate confirmation of keyboard entry. The operator needs instant feedback to confirm each key-press to insure easy learning and fast, accurate computation.

5.   A display that is easily learned. To enable widespread usage there should be no undue burden on the operator, other than learning how to operate the calculator. Additionaly, the calculator should be easy to teach and demonstrate.

6.   Minimum human error in display readout. Calculators do not make mistakes. Human operators do. The display technique chosen should be sufficiently clear and unambiguous to minimize the inevitable human error.

7.   Low "user frustration". This subjective parameter relates to the others, and means basically that the display is easy to use. The operator should be able to concentrate on the mathematical problem at hand, not

on just reading the display.

The critical problem in meeting the above goals is to choose the proper display. The computation itself is easy, due to the recent availability of inexpensive LSI calculator circuits. Our work has therefore been directed toward the display problem, with the hope that the same LSI technology could lead us to an effective display. Since we were searching for "pocket" calculator displays, we did not consider displays providing permanent hard copy.

III. DISPLAY ALTERNATIVES

Choice of a display that meets the above requirements is not easy, and is the subject of considerable effort throughout the world. A recent report by J. M. Gill of the University of Warwick, Coventry, England lists 27 different digital displays either available or proposed. We have encountered several additional displays during our investigations. Most of these displays, it should be noted, are useful for digital information whether from a calculator or not.

In Table 1 we present a listing of the important pocket calculator displays that we know, along with a comparison with respect to the various desired features described above plus calculation speed and cost. Displays are ranked within each category, with lowest numbers the best. To the right, scores of each column are added to give a rough ranking of the various display options. Our listing of the relative display merits are, of course, subject to debate and revision as time progresses.

The abacus must not be overlooked as calculator for the blind, especially because of its very low cost. However, it lacks the accuracy and speed given by electronic computation and requires considerable operator training and skill.

The Optacon reading aid for the blind, combined with a special calculator lens module, is effectively used by many blind persons. The calculator lens module allows the user to read directly light-emitting-diode displays. The digits of the display are reproduced in magnified tactile form, one digit at a time, as the user scans the display. The calculator lens module was specially designed for Hewlett-Packard scientific calculators, but it is useful for many other calculators as well. The biggest drawback of this calculator system is cost, at least for those not owning an Optacon.

Tactile Parallel refers to displays, generally braille coded, that present the readout register contents in a line of output cells. In essence, these displays simply replace the calculator visual readout with a tactile readout. At first glance, such displays seem quite attractive. However, their use is limited to braille readers, and they are mechanically difficult to fabricate.

Tactile Serial displays utilize only a single display cell, again usually braille, that dynamically presents the digits, one at a time, to the reader. The display usually scans from most to least significant digit upon user command. Physical construction is simplified, since only a single display cell is required, in trade for more complex electronics. Tactile skill is unfortunately still required from the reader.

Audio Coded displays present the digits to the user auditorily in time sequence. Each digit is represented by a unique sound pattern that can include tones of different pitch and/or duration. Much ingenuity has been applied to such displays. Examples are Morse and Binary-Coded Decimal codes. The principle disadvantage is that any such rather arbitrary code requires considerable training and practice to master, and many who attempt will never achieve a sufficiently low error rate.

Audio Speech displays are a special case of Audio Coded, where synthetic speech is the output code. The learning problem is thereby eliminated. However, speech is much more difficult to generate electronically than tones, presenting a significant engineering obstacle. Nevertheless, speech is seen to give by far the best score in our ranking.

Audio-Keyboard Scan displays were recently devised and evaluated in our laboratory. The basic idea behind such displays is to use the calculator keyboard itself to perform the digital readout. In one embodiment, the user scans the keyboard by sequentially pressing the numeric keys. An audio tone is generated when the key corresponding to the most significant digit is depressed. At successive scans, successive digits are determined on down to the least significant digit. Of course, the calculator itself is disabled during the scanning process.

Audio-Matrix Scan displays use, instead of the keyboard, a number of side-by-side columns of braille readout cells, one column for each display digit. The user scans each column of cells vertically with his fingertip. A tone is provided when the correct cell is touched (the final paper of this session describes such a display in detail).

IV. TSI'S CALCULATOR EVALUATION

One can appreciate that the display problem is really one of too many choices. All of the display techniques described in the previous section work. Undoubtedly, any one of the displays could be happily and successfully used by many people. Faced with this dilemma, we decided to construct or obtain several different calculators having the display techniques we liked the best, and conduct a comparative evaluation as objectively as possible. Following this plan, we evaluated four different calculators.

1. <u>Tactile Serial.</u> The display of this calculator utilized four vibratory piezo-electric "bimorphs" like those used in the Optacon tactile display. The display points were arranged as dots 1, 2, 4, and 5 of a braille cell, and the appropriate combinations were excited to present a dynamic braille presentation to the subject's fingertip. During entry of a problem, the braille displays corresponded to the key being depressed. When the problem was completed, closure of a display switch caused the digits of the answer to be presented sequentially. The display rate was variable.

2. <u>Audio-Keyboard Scan.</u> The preferred type of audio-keyboard scan calculator was described in Section III of this paper. Several other variants were also tried, one utilizing a second keyboard that selected the column to be scanned, which allowed parallel access to any display digit, but required two-handed operation.

3. <u>Audio-Speech.</u> This calculator used an electronic speech synthesizer. During problem entry, a voice response confirmed closure of all digit and function calculator keys. The result was spoken automatically when the "equals" key was depressed.

4. <u>Audio-Matrix Scan.</u> The calculator display evaluated was described in Section III. The contents of the calculator readout register were always displayed, allowing immediate access to any digit.

The evaluation was conducted in two phases: in the first phase, the braille serial and keyboard scanned calculators were compared by fifteen blind persons. The procedure with each subject was the same. After being taught how to use the calculators, the subjects worked sample problems and answered questions.

The braille serial display calculator was evaluated with two different methods of cycling through the output display digits. In the first method, the braille display was advanced from column to column on command with a push button switch. The second method automatically cycled through the display at a user-selected rate. The two keyboard types of scan calculators were tried having the same cycling schemes as the braille. A third keyboard scan calculator utilized the two-handed, two keyboard scheme described above. Physically, all of the above calculators were combined in a single simulator box. The salient results are given below.

1. Braille serial display preferences:

    . 4 for push button step, 11 for automatic step.

2. Keyboard display preferences:

    . 3 for push button step, 12 for automatic step

. 15 prefer one-handed, 0 prefer two-handed.

3. Braille vs Keyboard:

    . 11 prefer one-handed, 4 prefer keyboard

In summary, most subjects preferred the braille display, and wanted a display mode that minimized user effort by automatically scanning. An additional feature that we determined to be necessary was the suppression of leading zeros on output.

The second phase of the evaluation compared the braille calculator preferred from the first evaluation round with the matrix scan and voice output units. The seven evaluators were first introduced to each calculator and allowed to practice. Next, they were timed for speed and accuracy doing sample problems. Finally, their subjective preferences were solicited. The results are tabulated below:

Display Type	Av. Time/ Problem	Total No. Errors	Preferred by
Matrix Scan	66 sec	13	0
Braille Serial	38 sec	14	1
Audio Speech	26 sec	0	6

In this final runoff, speech was preferred by 6 of the 7 subjects, and proved also to be faster and more accurate.

V. SUMMARY AND CONCLUSIONS

We have determined the important features felt necessary for a calculator designed for the blind, with the help of a survey of nearly 200 blind persons. Consideration of the available types of displays, ranked according to the desired feature, pointed out the many advantages of speech. A hardware evaluation with four different displays confirmed that spoken speech was preferred using both subjective and objective measures. Speech, as the natural human communication means, uniquely needs no learning, can be used by the sighted, causes minimum user error and frustration, and provides immediate feedback identifying key depression. Another advantage of voice for the calculator application is that additional required display parameters, such as "overflow", "minus" and "point" are provided in a natural way. All of the other display techniques become awkward when faced with these extra functions.

Our conclusions is therefore that audible speech is the best display modality for an electronic calculator for the blind. The principle drawback of speech is its cost, which we feel can be mitigated using LSI electronics.

Table 1. RANKING OF CALCULATOR DISPLAYS

Display Type	Learning Effort Required	Sighted Use	Computation Throughput Speed	Porta-bility	Confir-mation on Entry	Overall Error Rate	Cost	User Frus-tration	Unweighted Total Score
Abacus	2	2	4	1	4	2	1	2	18
Optacon	5	1	1	2	3	2	5	2	21
Tactile-Parallel	3	3	1	2	2	2	4	2	19
Tactile-Serial	3	3	2	1	2	2	3	3	19
Audio Tones	4	3	2	1	3	4	2	3	22
Speech	1	1	2	1	1	1	4	1	12
Audio-Keyboard Scan	2	2	3	1	2	3	2	3	18
Audio-Matrix Scan	2	2	3	2	2	3	2	3	19

Title of Paper: Evaluation of a Sonic Urinimeter for Blind Diabetics

Category: (check one)   Device Development /x/   Research Study /_/

Brief Description: Development of a device to enable blind diabetics
    to measure sugar in the urine and receive a sonic indication of sugar level.
    _____
    _____
    _____
    _____

Intended User Group: Blind diabetics _____
    _____
    _____

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   /x/

    Feasibility Testing   /_/

    Clinical Testing   /_/

    Available for Sale (check one)   Yes /_/   No /_/

        Price per unit $ _____

    Availability of constructional details:

B. Research Study

    Intended Utilization: _____
    _____
    _____
    _____

    Intended Device Application: _____
    _____
    _____
    _____

    Availability of Intended Device: _____
    _____

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EVALUATION OF A SONIC URINIMETER FOR BLIND DIABETICS

by

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Summary - There is at present no device available which will
enable a blind diabetic to measure the glucose content of
urine. All such tests at present are chemical reactions
with a color change as indicator of glucose contained.
There is a population of approximately 250,000 blind diabet-
ics that could benefit by having such a device with reason-
able reliability and cost. The sonic urinimeter is a device
that measures glucose content of urine by means of its elec-
trical resistance change. The output is a tone indicating
the presence of sugar at that measured resistance level.
Field testing of this unit is needed to determine its relia-
bility.

The sonic urinimeter is a device which
measures changes in electrical resistance of
urine as caused by changes in sugar level and
sonically indicates the change. The device
is intended for use by blind diabetics though
sighted diabetics may find its use advanta-
geous.

There are more than 1.7 million diabet-
ics in the U.S. today and approximately
250,000 are blind (see Table 1). Blindness
due to diabetes is now at a rate of about
18.4% as opposed to about 4.3% in 1940.
These figures are from 1962 and may well
underestimate the problem.

TABLE 1. Using the figures from Newell's
"Prevalence Diabetes" table, with 1.7
million diabetics, assuming 15% blind, then
approximately 250,000 are blind diabetics.

Prevalence Diabetes[1]

Known	1,764,000 (9 per 1000)
Unsuspected	1,587,000 (8.1 per 1000)
	150,000 New cases annually
	31,350 New cases blindness annually
	4,400 New cases due to diabetes

There are then about 250,000 people who
could benefit from this device. There is an
additional population (sighted diabetics) of
more than 1.5 million that might find it use-
ful.

This device is useful because it is not
color dependent. All present tests of glu-
cose level in urine involve a color change of
a solution or a strip of paper (Clini-test or
Testape). This device requires no vision for
its operation or use. Blind diabetics have
always required the aid of a sighted person
to conduct a glucose check which most of them
must do at least three to four times a day.
If they reside alone or have an occupation
that takes them away from usual friends and
family, they may operate the sonic urinimeter
without any additional aid.

If a severe diabetic (and many who are
blind are severe cases) does not check his
sugar level periodically, insulin shots may
not be administered when necessary and diabet-
ic coma can result. If the diabetic is not
then given immediate emergency treatment this
results in death.

The sonic urinimeter is being designed
to sell at less than $25.00 and therefore may
be available to all diabetics. The device
should have a lifetime of years if properly
maintained and may prove to be more economi-
cal than Testape or Clini-test tablets.

In addition it is designed to be rela-
tively pocket-sized for easy transport. This
device is intended as an individual instrument
rather than a clinical device because at this
point in our research its measurements seem
qualitative rather than quantitative.

Development of the Prototype

In the development of the prototype, it
was necessary to establish that changes in
electrical resistance of urine did indeed vary
with glucose changes and second that the

resistance varied with sugar level changes
only. In other words resistance did not
change due to potassium or sodium salt change
as well as sugar changes.

The first question I answered in two
separate studies: one conducted at Georgia
Institute of Technology and a nearly identi-
cal study conducted at the Emory University
Regional Rehabilitation Research and Training
Center. In the first study normal (non-dia-
betic) urine was used, a standard power sup-
ply, a test cell with aluminum electrodes
and standard Clini-test tablets and glucose.
The Clini-test was used to determine that the
urine of 30 subjects was normal and again
later in the experiment to determine a change
in sugar level.

A standard amount of normal urine
(50 ml) was placed in the test cell, a
voltage applied across the cell and a D.C.
current reading obtained. Then 200 mg glu-
cose were introduced into the 50 ml solution,
a clini-test performed with a few drops of
this solution in a separate test tube and a
current reading taken of current flow in the
50 ml solution. Then 300 mg glucose were
added and another reading taken of the cur-
rent and another clini-test performed as
before. (The solution was agitated vigorously
after glucose was added in order to obtain a
good solution.)

The clini-test showed a maximum change
of 0% (normal urine) sugar to almost 1% or
just under +3 on the diabetic scale of 0,
+1, +2, +3, and +4. These readings corres-
pond to 0%, .5%, .75%, 1.0%, and 2.0%
respectively.

Resistance changes amounted to about 10%
from 0 to +3. These changes were approximate-
ly the same for all subjects though the resist-
ance "norm" was individual. The subjects were
donating samples at random under a variety of
circumstances but for any one subject the
resistance norm was approximately the same
at any given time.

This experiment was repeated at Emory
University Regional Rehabilitation Research
and Training Center in very nearly the same
manner. Stainless electrodes are now being
used with great success. There had been a
problem with bronze and aluminum electrodes
corroding.

Testing was carried out at various volt-
ages so as to get different currents through
the solution. For currents in excess of 10
milliamps the resistance of urine is linear
with respect to voltage. At very low cur-
rents, 100 microamps, the uric acid present
seems to cause a "battery effect" and
measurements become unreliable.

In the next phase of testing, to aid in
calibration of the sonic urinimeter, the
electrical resistance of urine from an actual
diabetic was obtained.

This decision was prompted by a look at
laboratory test results on normal urine with
glucose added to form "synthetic" diabetic
urine. The tests showed that the current
flow in urine with respect to voltage rose
linearly. This was true on normal and syn-
thetically prepared diabetic urine, even with
varying glucose levels.

The question arose as to whether the
"synthetic" diabetic urine really displayed
the electrical properties of real diabetic
urine. To answer this question, our subject
was a male approximately 25 years old and
only recently diabetic. His condition was
controlled by injections of "slow" insulin,
and his sugar range was from 0 to +4. Data
were collected over approximately a three
week period.

A comparison of his data gathered at
random over this period does not show the
expected agreement with previous laboratory
data.

The figures obtained were current flow
at ten volts and current flow at fifteen
volts for each sample tested. All samples
were checked against the Clini-test and/or
Testape measures, normal measurement tech-
niques.

The figures obtained were converted to
electrical resistance (application of Ohm's
Law, $R = E/I$
where R = resistance in ohms,
       E = volts in volts,
       I = current in amps).
The resistance for no sugar samples (0 on
Clini-test) showed reliably as 148 ohms ± 1
ohm on any sample at ten and fifteen volts.
This slight error could easily be measurement
error. This agreed with lab results of ap-
proximately 150 ohms with slight variability
among subjects. (Note: the same test dish
with stainless steel [type 818] electrodes
and the same power supply with meters were
used in both lab and subject tests.) I found
with our diabetic subject that as sugar in-
creased, resistance first decreased then in-
creased (see Fig. 1); whereas lab tests had
shown a linear increase (see Fig. 2). The
overall range was 18 ohms in our diabetic and
is to 20 ohms in our synthetic lab samples.

As can be seen from Fig. 1, the curve
for diabetic urine has two x-intercepts, one
at 0 sugar and one at a higher sugar level
(just below +3 or 1% sugar). If the second
intercept is found to be always below +3 for
diabetics (assuming a second intercept is
even present for all diabetics), the sonic
urinimeter could act as an alarm system for
high sugar levels (above +3 or near +4).

ACTUAL DIABETIC SAMPLES
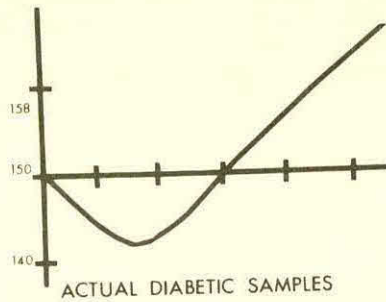
FIG. 1. Samples taken from male diabetic showing resistance changes in ohms vs. sugar level changes.

SYNTHETIC SAMPLES
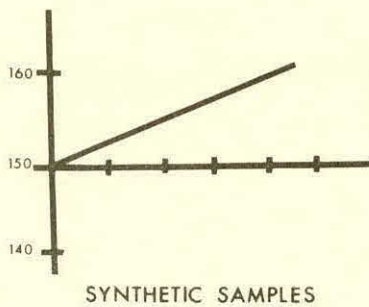
FIG. 2. "Normal" urine with glucose added artificially in amounts necessary to obtain desired sugar level range so resistance could be measured.

Our subject explained that he developed a "feel" for the readings and could "tell pretty closely" what his level was.

Further data on actual diabetics must be gathered in order to determine the calibration for any prototype device if indeed calibration is possible for all diabetics.

A program at Grady Hospital Diabetic Day Care Center is being established for gathering more data on the electrical properties of urine for real diabetic urine.

The same procedure will be used in gathering data there as was done with our one diabetic subject. When the data needed for calibration are gathered and processed, a prototype sonic urinimeter will be constructed which will measure the resistance change in urine; if this resistance change is within a range of a particular level a continuous tone will sound; if the reading is beyond this range, the tone will not be emitted. This method provides a quick check of the instrument since if the instrument is at all operable it will emit a tone at the zero level. A switch is provided labeled 0, +1, +2, +3, +4. If the tone is heard continuously at all readings, the patient will know that his sugar

level is +4 or greater. If a short circuit were suspected, disconnection of a lead should silence the device on all readings except the zero level. This device lends itself readily for calibration ("fine tuning") for each individual and when constructed will undergo tests at Grady Hospital and by individual diabetics.

References

1. Newell, F. W. The problem of diabetic retinopathy from Vascular Complications of Diabetes Mellitus, p. 36, (eds.) Kimura & Caygill. St. Louis: C. V. Mosby Co., 1967.

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Title of Paper: A TACTILE DEVICE FOR THE BLIND

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: A sophisticated device which allows sighted or blind to draw or write on paper and gain immediate raised line impression. Much learning opportunity is thus newly available.

Intended User Group: Partially sighted, congenital and adventitious blind, dyslexic.

Stage of Development: (Check all that are applicable)

    A. Device

        Prototype Development   /X/

        Feasibility Testing   /X/

        Clinical Testing   /X/

        Available for Sale (check one)   Yes / /   No /X/

          Price per unit $_____

        Availability of constructional details:

    B. Research Study

        Intended Utilization: Teaching spatial and other concepts, mobility, job related applications.

        Intended Device Application: _____

        Availability of Intended Device: _____
Not commercially available.

For further information, contact: Name   D. Reginald Traylor
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                                  University of Houston Victoria
                                  Center

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A TACTILE DEVICE FOR THE BLIND

by

D. Reginald Traylor
University of Houston Victoria Center
Victoria, Texas

Summary - A recently developed instrument offers much pro-
mise to those who are visually impaired, including totally
blind, partially sighted, and sufferers of dyslexia. The
device is designed to allow anyone to write or draw on
paper, causing an immediate raised line image to occur.
The height and breadth of the line can be altered. More-
over, the device is adaptable to "master" and "slave" units,
offering substantial classroom potential.

Anyone who has had the experience of teaching blind students in a sighted setting understands well the inadequacy of existing devices which are purported to provide a tactual substitute for the images seen by a sighted person. What often is not understood is the rather common position of many agencies for the blind whose staff hold fast to the notion that the crude devices which generally are available indeed are adequate.

The research project herein reported presupposes, at the outset, that existing devices for use by the blind are inadequate. It is assumed that no technological device answers all needs, but that each person's needs, being different, might be best met by a choice of a variety of methods, techniques, and instruments.

Contrary to the position taken by several of the national organizations for the blind, there today do not exist adequate devices by which a blind person may generate a raised line drawing or script. Those who visit schools for the blind or who have themselves taught students understand this totally. On the one hand those in national offices state that raised line drawing kits either are adequate or not needed, and still they or their blind colleagues offer extremely difficult and time consuming (to prepare) mock-ups which substitute as maps. These sometimes are patiently constructed with balsa wood or by glued plastic, or some other ingenious, but time-consuming preparation.

The device which is reported in this paper is simply a sophisticated mechanical device allowing both sighted and blind to draw, on paper, with a stylus, causing a raised impression to immediately occur wherever the point of the stylus is moved. The history of the device is short.

In Fall 1971, need was first felt at the University of Houston that there was absolutely no effective device that lent itself to classroom activity of a nature beneficial to the blind student who sought to observe what occurred on the chalkboard. Existing devices were evaluated and discarded. Efforts were begun to develop a device that had several characteristics:

(1) the drawing or writing surface needed to offer deformation potential, to allow a raised line impression of any nature,

(2) the drawing or writing surface should be paper, to allow permanent deformation for later study and evaluation by the student,

(3) the drawing or writing motion should be normal, with no inversion or "mirror-image" required in the process,

(4) the drawing surface should be large to allow tactile evaluation effectively made of detailed work.

The initial effort was to design and construct such an instrument for use in classroom setting to allow, for instance, a blind student to have before him whatever drawing might occur on a chalkboard to a sighted student. However, as attempts were made to gain funding for the project, the purpose of the device was modified.

Several facts became apparent at the outset. First, the University of Houston, and the persons involved from the University, were without reputation of having any dealings with the blind. Accordingly, those agencies charged with responsibility of aiding the blind were non-responsive to the proposers of the project. Generally, the response from potential funding agencies was that such a device could not be constructed. In a few instances, representatives of potential funding agencies felt that if it could

be built at all, it would be done at sophisticated university research centers, but certainly not in Texas.

With such staunch encouragement from funding agencies, the University of Houston task force, consisting of one mathematics faculty member, one staff person, and one blind student, set out to develop the desired device. After the initial efforts were begun in Fall 1971, a small firm, Richmond Instruments, in Richmond, Texas was identified as a possible design and construction resource. By July of 1972, the device had been built and was in use. Called the Heugel Quill, carrying the name of Robert Heugel, the machinist who accomplished that which could only be done at major, sophisticated, research centers outside Texas, the instrument has proved to have much effective application and offers much potential benefit which, as yet, is undeveloped.

The Heugel Quill is a device which allows a person sighted or blind, to draw or write freely, holding a stylus which moves across a paper surface. The sheet of paper is held in place by a sophisticated clamping lid which both clamps and stretches taut the paper. Immediately beneath the foot of the stylus, on the other side of the paper, is a small motor driven reciprocating pin which, by use of arms attaching the stylus and the motor driven pin, remains directly beneath the stylus regardless of its position above the paper. The foot of the stylus has a narrow channel in its base to receive the impact of the reciprocating pin, hammering the paper upward, leaving deformation as a result.

Using the Heugel Quill, anyone can produce, in almost any detail desired, a writing or drawing which could otherwise be produced on chalkboard or on paper.

The applications already determined are several. First, it may be true that most advantage of the instrument will accrue those of preteen years, though much potential exists for mature people. The opportunity for children or youths is that of expression of their own concepts or ideas in a manner which can be illustrated to others. Now, a visually handicapped student has little opportunity to give rise to his own image of a given concept, evaluate it himself and then show it to a sighted person for discussion or evaluation. Examples:

(a) Handwriting skills: Those who now must employ very crude devices can easily practice script, evaluating instantly in a tactile sense, that which was just written.

(b) Spatial concepts: Now much of that taught about spatial concepts such as parallel lines, circles, rectangles, squares, distance, etc., is done by tactile evaluation of objects made from wood, plastic, or other materials. With the Heugel Quill the visually disabled can be required additionally to draw his own concept of the notion being dealt with, evaluate it tactually until satisfied, and then have it effectively criticized. This will do much to remove the dependence of today on vocabulary, with little real opportunity to evaluate actual grasp of the notion.

(c) Mobility aid: Actual experience teaches the value of easy access to quickly sketched, hand-drawn maps, to offer a visually disabled person. Less is known of the learnings of mobility skills, though each method has its staunch cadre of supporting disciples. Lacking, without the Heugel Quill, is an effective opportunity to require, after the student has mastered mobility skills, the learner to demonstrate by effectively drawing his own map of the route to be taken that he understands it well enough to perform it.

(d) Job related applications: These are immense. Consider the actual plight of a blinded owner of a printing company who must bid on advertising spreads requiring art work which he cannot see. With the Heugel Quill, he has capability to better evaluate and thus, bid on such work. Or consider the engineer or architect, who loses capability as sight diminishes, and who could effectively function if the drawings could be reinforced with raised lines.

(e) Dyslexia: Such impairments as represented by those suffering from dyslexia can gain benefit from the Heugel Quill. Now, time consuming efforts to create felt numbers or other figures so that the student can reinforce his visual impression with a tactical one, can be reduced to fractions of the time, gaining the advantage of the student giving use to his own objects with which to work.

(f) Thought processes: If one understands that the thought processes of (congenital) blind may be quite different from that of a sighted people, there is wide potential application offered by the Quill. For instance, when a sighted person enters a room, he quickly scans the room, then focuses his attention on a small portion of the room. A blind person, entering the same room, approaches it always "in the small," being able to "scan" the room not at all, or in extremely minute form. These same thought processes, if reflected in learning situations, are hardly ever dealt with, since the teaching approach is often translated from that which was effective for sighted. The Heugel Quill, in allowing the blind an opportunity heretofore not available, for self-expression and self-evaluation of that expression, offers a substantial step forward

in the direction of developing stronger teach-
ing methods.

Other examples can be offered to suggest
the wide applicability of the Heugel Quill.
Stark difficulties obstructing its wide usage
include
(i) cost of the unit,
(ii) reluctance of professionals to
attempt new approaches to teaching the visu-
ally handicapped, and
(iii) reluctance of funding agencies to
fund projects or equipment to be produced or
developed by others than those with whom the
agencies have developed past association.

For additional information refer to the
proceedings of the 1972 Carnahan Conference
on Electronic Prosthetics held at the
University of Kentucky, Lexington, Kentucky.

Title of Paper: AN AUDIO-TACTILE DISPLAY

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: The authors have conceived, prototyped and evaluated a display enabling the blind to read numeric information from virtually any type of electronic display. Prototypes have included displays for electronic calculators and electronic stopwatches.

_____

_____

Intended User Group: Rehabilitation organizations, educational Institutions, Blind individuals.

_____

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   /X/

    Feasibility Testing   / /

    Clinical Testing   / /

    Available for Sale (check one)   Yes / /   No /X/

        Price per unit $ _____

    Availability of constructional details:

B. Research Study

    Intended Utilization: _____

    _____

    _____

    _____

    Intended Device Application: _____

    _____

    _____

    _____

    Availability of Intended Device: _____

For further information, contact: Name ____ Deane B. Blazie _____
                                     Address ____ US Army Human Engineering Laboratory
                                     _____ Aberdeen Proving Ground, MD 21005

AN AUDIO-TACTILE DISPLAY

by

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T. V. Cranmer
Director of Services for the Blind
Frankfort, KY

Abstract - From modern electronics has evolved the digital display
using Nixie's, LCD's, LED's, Incandescent's and a variety of other
visual displays. Several devices have been developed for enabling
the blind to adapt to this type of display. Most require extended
training for the blind and all (except one) are relatively expensive.
The Audio-Tactile Display described in this paper requires very
little training and promises to be inexpensive. Prototypes of the
display have been developed for a digital stopwatch and several
electronic calculators, and have been well received by the blind
community. The ultimately low cost of this display and associated
electronics will enable every blind individual to own his own
electronic calculator.

The device is based on a panel containing columns of Braille digits
which are made active through a logic circuit interfacing the Braille
display with the calculator or other device. The blind person scans
the Braille columns and discovers the digits active in each column
when tones are produced simultaneous with the finger contacting the
Braille digit.

Introduction

The recent editorial in HAM magazine re-
ported that there had been produced to date
70,000,000 pocket calculators using digital
displays with an anticipated 35,000,000 new
units to be sold this year. This is an indi-
cation of the level of interest and public
acceptance of digital displays for calculators
and by inference other types of equipment, i.e.
clocks, timers, counters, voltmeters, thermom-
eters, etc. Simultaneous with public interest
in these devices has been an all out search for
that adaptation which would best make available
to blind people the information available from
these devices. Dr. Kelly of the University of
New Mexico, successfully modified the Hewlett-
Packard HP-45 calculator by interfacing it with
a solenoid driven Braille display. Science for
the Blind successfully produced a prototype of
another device that serially interrogates a
calculator and produces a Braille print-out on
paper tape.

It is beyond the scope of this paper to
review and evaluate these and the score or more
other approaches that have been reported in
literature. They are cited only to indicate
the magnitude of the problem and the widespread
nature of efforts to find solutions.

To our thinking, one of the most promising
approaches is one conceived by Mr. T. V. Cranmer,
Director of Services for the Blind, Frankfort,

Kentucky. It allows a blind user to have ran-
dom access to digital information by purely
electrical means.

At the heart of the Audio-Tactile Display
is a metallic plate with holes in the pattern
of the Braille digits 0-9. These digits are
arranged in vertical columns (see photograph).
The number of columns equals the number of
digits on the visual display to be read. Each
hole in the metal-faced plate has had a small
ring of metal removed from around it. Metal
pins are pressed into the holes, thus forming
the raised Braille digits. The digits them-
selves, thus are insulated from the metal
material of the surrounding plate. The act of
touching the Braille digits with the finger
necessarily causes the finger tip simultane-
ously to touch the Braille digits and the
surrounding metal thus completing the
electrical circuit.

In each column there will be nine passive
digits and one having an electrical charge.
When this digit is touched with the finger, the
audio alarm is triggered, allowing the blind
person to know that the digit he is touching is
to be read as an active part of the calculator's
display. To read the display, he scans each
column for a tone and compiles the number, a
digit at a time. This arrangement may be
likened to a visual display in which a vertical
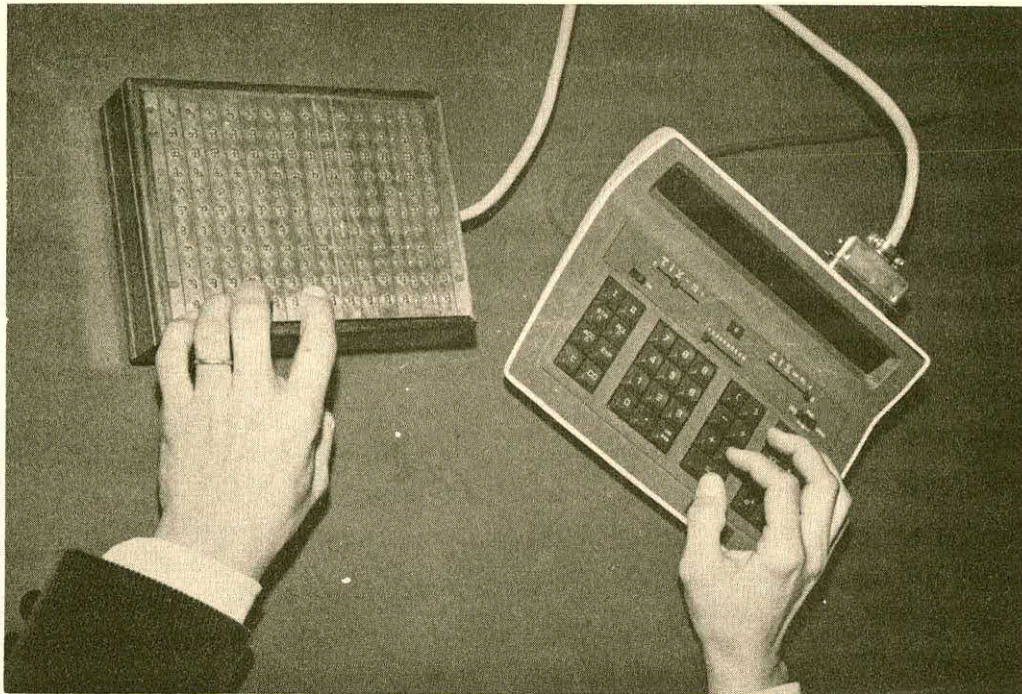
column of digits carries behind it a row of
lights only one of which is turned on at a
given time, thus the observer quickly under-
stands that he is to read only the lighted
digits. This scheme was used in many early
electronic counters before the NIXIE tube and
other numeric displays became popular.

The Audio-Tactile Display has been incor-
porated into prototypes of an electronic stop
watch, an 8-digit pocket calculator, a scien-
tific calculator (shown in the photograph) and
a telephone switch panel. These devices have
been shown at the convention of the National
Federation of the Blind, Chicago 1974, and the
Association for the Education of Visually
Handicapped, San Francisco, June 1974. More
recently the evaluation of the calculator has
been undertaken by Telesensory Systems, Inc.,
Palo Alto, California. There seems to be con-
siderable agreement that the Audio-Tactile
Display may be a practical, reasonably priced
approach to interfacing the blind with a
variety of digital devices.

In cooperation with Mr. Cranmer, I have
played a major roll in the development of these
prototypes. In the following paragraphs I will
outline the design philosophy, and the basic
circuitry employed.

Technical Description

As mentioned earlier in this paper, the
Audio-Tactile Display can be used in a variety
of different ways. While calculators, stop
watches and digital test instruments are the
first uses to come to mind, other uses may in-
clude non-numeric information display. For
example, a color indicator may display a
Braille color wheel with dots in a circular
fashion. The active dot would indicate the
relative color a sensor is responding to.

The point to be made is that the display
is simply a touch sensitive switch which has
been adapted to a Braille system. This touch
sensitive switch is the heart of the Audio-
Tactile Display. How the switch 'contacts'
are used depends upon the particular use made
of the display. Some examples will be dis-
cussed later in this paper.

Touch Sensitive Switch

The switch is required to operate when the
two sensor contacts are touched by a finger.
There are no moving parts, and switch activa-
tion requires skin conductance to be sensed
by the switch circuit so that the switch state
can be changed. Using a 3/8 inch square
plated Braille cell and substrate the skin
resistance can vary from a few megohms for

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moist fingers to over 50 megohms for very dry fingers. This means that the switch circuit must be sensitive enough to detect a 50 megohm resistance across the sensor contacts.

The switch consists of a specially fabricated Braille cell coupled to an electronic circuit.

The physical display consists of Braille cells representing items of information (in the case of a stop watch, the digits 0-9). A cell is based on a conductive substrate such as a printed circuit board (see Figure 1). The raised dots are electrically conductive pins implanted in the pattern of the Braille digit and protruding through the board. Each dot is insulated from the conductive substrate by removing the conductive coating in the vicinity of each dot. The dots are electrically tied together on the underside of the display. This point represents one terminal of the switch sensor and the substrate represents the other. These are the sensor contacts mentioned above.

The electronic portion of the switch is shown schematically in Figure 2. It consists of a single CMOS (Complementary MOS) inverter with a pull-up resistor on the input. The input resistance of a typical CMOS inverter is on the order of a million megohms which makes it ideally suited for our application. The pull-up resistor insures the state of the switch when it is not being touched. This resistor may be connected to Vcc when a logical low signal is being used to activate the display or it can be connected to ground when a logical high is driving the display. This resistor controls the sensitivity of the touch switch and can be made variable should the need arise to change the sensitivity.

A Simple Counter

As an example of using the touch sensitive switch, Figure 3 shows a decade counter (RCA CD4017 CMOS integrated circuit). The 10 output lines go to the cells on the Braille display panel. Each of the ten output lines on the counter goes to a Braille cell corresponding to the digit on the counter. Referring to Figure 3, each time the count reaches a certain value, 5 for example, line 5 on the CD4017 goes high and if the Braille cell representing the numeral 5 is touched at that time, the substrate receives this high level through the skin resistance and causes the inverter to change state and the Sonalert to sound. The alert will sound as long as the cell is touched and the count is 5.

This simple circuit has enabled us to read a single digit counter. If we want to display a two digit counter, we would add another column of Braille cells to our substrate and connect the lines from the second counter to

the new column of cells. Now a touch on an active cell in either column will produce an audible signal. In this way any number of digits can be displayed with a single switch circuit.

An Eight-Digit Calculator

Figure 4 is a functional block diagram of a calculator using the Audio-Tactile Display. The actual calculator used was the 'Cannon Palmtronic LE-80'. It incorporates an 8-digit visual display containing an overflow and minus sign indicator. The 8-digits are made visible by 7-segment LED displays and the minus and overflow indicators by LED dot displays.

The seven segment to decimal converter changes the calculators 7-segment display format into a decimal format used on the Audio-Tactile Display. The ten outputs connect directly to the Braille cells on the display panel. The digit selection logic circuit contains the electronic portion of the touch switch and circuits to handle the de-multiplexing and the overflow and minus indication.

The calculator display is time multiplexed, as is common with multi-digit displays. Each digit is energized for a short time (several microseconds) and off for a longer time (several milliseconds) while the other digits are being energized. This scheme reduces the number of connections from the calculator to the display, but poses a problem to the simple Braille circuit just described. We no longer have 10 digit lines for each column but only 10 lines for all columns. The 7-segment signals must be directed to the proper Braille columns at the right instant in time, that is, they must be de-multiplexed.

While this could require a considerable amount of logic circuitry, advantage can be taken of the mechanical layout of the Braille panel shown in Figure 5. Note the 8 columns of Braille cells representing the 8 digits in the calculator's visual display. Each column contains the digits 9 through 0 from top to bottom followed by a decimal point at the bottom. The vertical bars between columns represent insulation between the conductive substrate of each column. This electrically breaks up the display into eight separate one-digit (one column) Audio-Tactile Displays.

This may seem to complicate the design by requiring eight touch sensitive switch circuits. While it does require eight separate touch circuits, it actually simplifies the logic required to do the de-multiplexing.

The seven segment to decimal decoder takes as input the seven segment lines with the multiplexed information for all eight digits. At

sequential periods in time, these lines represent the seven segment code of the eight digits being displayed. Eight digit select lines, also from the calculator logic circuits, tell at which point in time each digit is to be turned on. Since there is one line for each digit, each time that line is active we can assume the seven segments represent that digit to be displayed.

Now if we gate the eight touch switch inverters with the corresponding digit select lines, we will have successfully decoded the multiplexed display information. Now all we must do is logically 'OR' the eight gated column signals and appropriately drive the audio output device!

Although the decimal point is on the display panel, it was not mentioned in the above description because it can be treated exactly as a numeral with the exception that it need not be converted from seven segment format, for there is a separate decimal point signal available in the calculator.

The above discussion also ignores mention of the sign and overflow indicators. While separate Braille cells could have been included to display this information, from a human factors standpoint, this was not desirable. Instead, logic circuits were implemented in the display interface to provide a continuous tone whenever overflow occurs. This tone will be activated without touching the display and will be sustained until the condition is cleared on the calculator. When a negative number is read, touching an active Braille numeral will produce a beeping tone instead of the normal continuous tone produced on positive numbers. This scheme requires no operator attention yet keeps him informed of the appropriate condition.

Summary

To date, the Audio-Tactile Display has been successfully used with calculators, stop watches and telephone switch panels. Future plans include digital voltmeters, counters, thermometers and color indicators. The display is easy to use and requires very little training. It promises to be relatively inexpensive and could be sold with a calculator for under $200.00.

Having been shown at two major conventions and having been reviewed by many in the blind community, it is felt that the display is a practical, reasonably priced approach to interfacing the blind with a variety of visual displays.
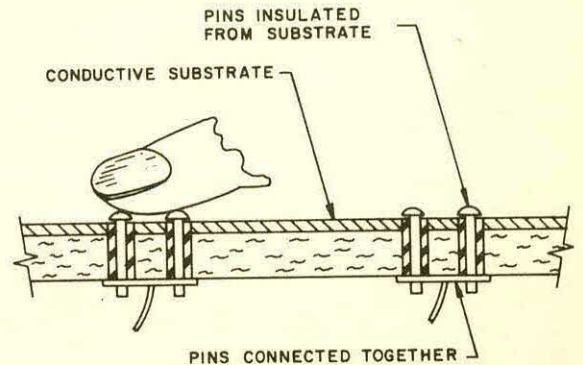
FIGURE 1 CROSS SECTION OF BRAILLE PANEL
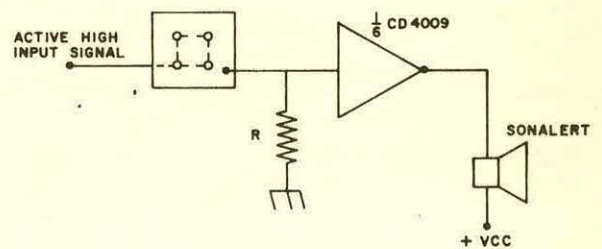
FIGURE 2 TOUCH SENSITIVE SWITCH
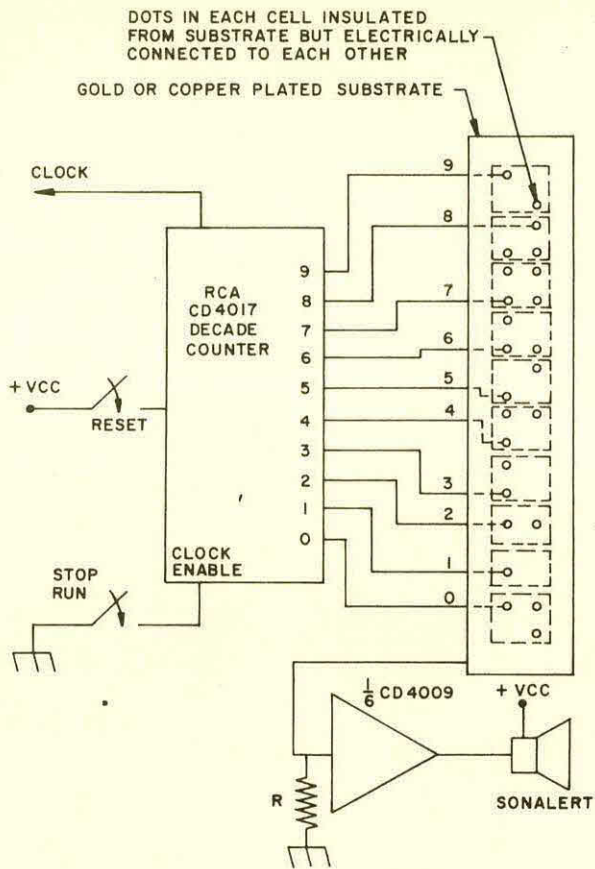
FIGURE 3 A SIMPLE COUNTER
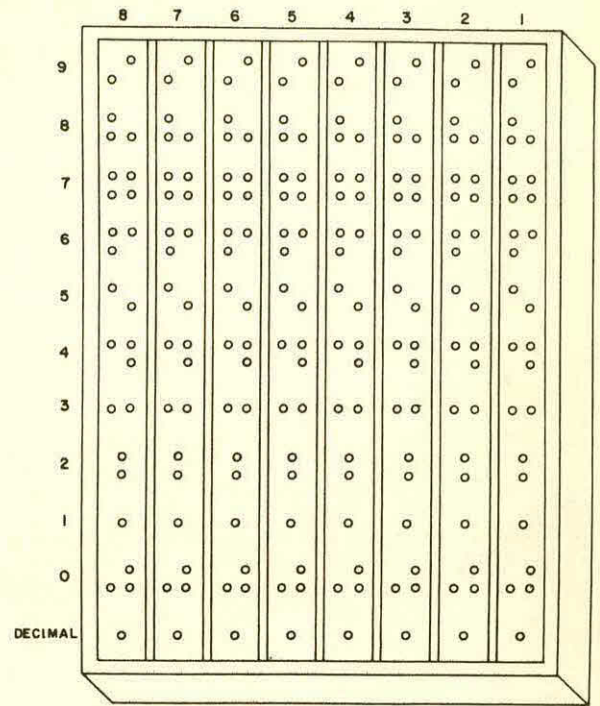
FIGURE 5 BRAILLE PANEL
FOR 8 DIGIT CALCULATION
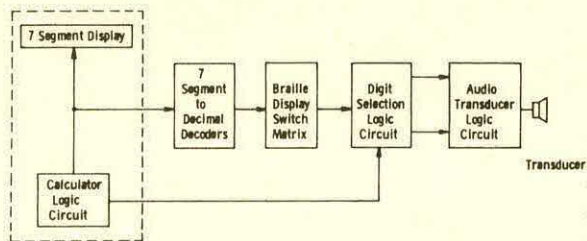
Figure 4
Block Diagram of 8-Digit Calculator

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INVESTIGATORY STUDIES

Chairman, F. Ray Finley, Ph.D.
Department of Rehabilitation Medicine,
Temple University School of Medicine &
Krusen Center for Research and
Engineering

Title of Paper: LOCALIZATION OF SOUNDS USING CUTANEOUS CUES

Category: (check one)   Device Development /X/   Research Study /__/

Brief Description: This device is intended to be part of a sound processing unit for the profoundly deaf. It allows the user to localize sounds using cues presented to the skin by means of electrocutaneous stimulation.

_____

_____
_____
_____

Intended User Group: Profoundly deaf.
_____

_____
_____

Stage of Development: (Check all that are applicable)

   A. Device

       Prototype Development   /X/

       Feasibility Testing   /X/

       Clinical Testing   /__/

       Available for Sale (check one)   Yes /__/   No /X/

          Price per unit $_____

       Availability of constructional details:

   B. Research Study

       Intended Utilization: _____

_____
_____
_____

       Intended Device Application: _____

_____
_____
_____

       Availability of Intended Device: _____

_____

For further information, contact: Name ____ James Mason ____
                             Address ____ Queen's University ____
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LOCALIZATION OF SOUNDS USING CUTANEOUS CUES

by

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Summary - An experiment has been performed to measure the ability of subjects to localize sound sources in the horizontal plane using only information presented to the skin. The outputs from two ear-mounted microphones were processed and fed to two electrocutaneous stimulators on the user's forearm. The user was blindfolded and asked to localize a movable sound source with this equipment. His task consisted of rotating his head until he was directly facing the sound source located approximately two feet away. Comparisons between the results of this experiment (tactile sound localization) and those of a similar version in which the subject localized the sound using normal auditory feedback produced some surprising results. Although the latency of response for tactile sound localization was worse than that observed for auditory localization, the accuracy of localization for either case was essentially the same.

Introduction

Recent advances in electronic technology and in knowledge of the functioning of the cutaneous sensory system have increased the interest in development of devices to help the profoundly deaf overcome some of the many serious handicaps they face. The most generalized of such devices fall into the category of sensory substitution systems in which some other still functioning sense is substituted for the defective auditory sense. The tactile sense is commonly chosen as the surrogate auditory channel since it is generally not heavily utilized for other tasks.

The substitution device samples the auditory field and presents to the user some function of the field in the form of vibrational or electrocutaneous patterns. In the past, because of better stimulus control, mechanical devices in the form of miniature solenoids or cantilevered piezoelectric reeds have been chosen over electrocutaneous stimulators as the means for producing a tactile sensation. However, because of their inherently lower power requirements, small size and ease of fitting, electrocutaneous stimulators would be favoured if enough were known about the complex interactions that occur at the electrode-skin interface to adequately control the quality and strength of the perceived sensation. The first stage of the overall development program was designed to investigate this problem of stimulus control. This phase of the project has been completed and the results have been reported elsewhere[1]. The conclusion reached was that electrocutaneous stimulation is a satisfactory substitute for mechanical stimulation as long as a few simple precautions are taken.

In the second stage of the program the use of electrocutaneous stimulation in actual laboratory models of particular sensory substitution systems was investigated. The results of an experiment with an electro-tactile sound localizer are reported in this paper.

Experimental Set-Up

The subject was seated in the center of a small room in a comfortable position and was fitted with a blindfold and a pair of tight fitting earphones. On each earpiece of the headphones, a miniature electret microphone was mounted in a foam rubber cushion. The output from the microphones was processed in a fashion to

be described below and fed to a pair of silver plated concentric electrodes mounted 6 cm apart on the subject's right medial forearm. A speaker, mounted on a boom, could be rotated through an arc of 120 degrees about the centre of rotation of the subject's head. This speaker which provided the target sound stimulus for the experiment was driven by a train of 0.3 msec pulses at a frequency of 100 Hz. Throughout the experiment, white noise was played through the headphones to effectively mask any normal auditory cues as to the speaker's position and the subject's task was to rotate his head, using only the information provided by the electrocutaneous stimulators, until he was directly facing the speaker.
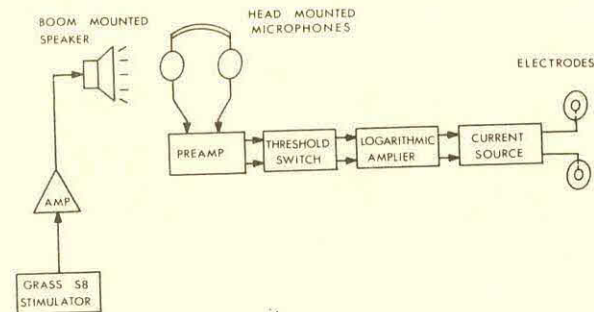
Fig.1: Block Diagram of Sound Localization Equipment

A block diagram of the equipment is shown in Fig.1. The signal produced by the microphones was amplifed and fed to a threshold switch. The inclusion of the threshold switch was necessitated by the rather severe reverberations which occured in the small room in which the experiment was conducted. These echoes were found to be a source of confusion to the subjects and their effects were removed from the stimulating waveform by adjusting the threshold level so that the switch passed the initial signal but blocked the reverberations. Following the threshold switch, a logarithmic amplifier was included in the signal path to reduce the dynamic range of the electrocutaneous stimulation. The comfortable range for electrical stimulation is about 4 dB yet the intensity of the sound at each ear can change by as much as 6 dB as the source moves from one side of the head to the other due to the shadowing effect of the head. The logarithmic conversion ensures that the tactile sensation remains comfortable at all times. The final stage of the processor was a voltage controlled current source which produced the stimulus that was applied to the skin.

Results

The speed with which the subjects were able to learn to use the tactile information to locate the target sound source, was surprising. The initial training consisted of a series of trials run without the blindfold in place. After each response the subject was allowed to check his response accuracy by peeking at the speaker. Less than five minutes with this type of training was required before subjects were confident enough to proceed with the main experiment.

In the experimental session, thirteen discrete speaker positions were used, one directly on the medial plane of the subject and six others at ten degree intervals on each side. A complete session consisted of five trials at each position given in a random order. For each position, the response angle and latency were recorded. A typical set of data for one subject is plotted in Fig.2. The error bars represent ±1 standard deviation for the five responses at each point and the solid line indicates the response expected if localization were perfect. The close correspondence between the actual and the ideal responses is immediately evident.
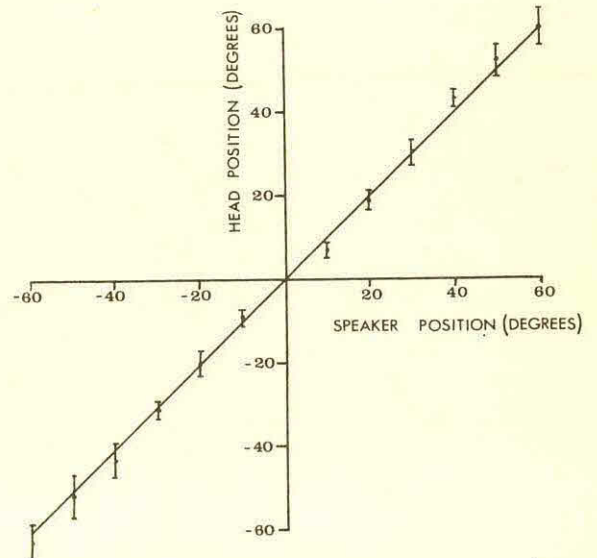
Fig.2: Typical Localization Accuracy

Table 1 gives the mean error in degrees, the average standard deviation for the five responses at each test position and the average latency for six subjects. The average error with tactile feedback ($\bar{x}=3.19°$) compares favourably with the error when the normal auditory system is used for localization under similar experimental conditions ($\bar{x}=4.44°$). However, the average latency for tactile localiza-

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tion is five to ten times the latency for auditory localization. Both the error and the latency decreased throughout the session implying that more prolonged practice with the device could reduce the time required to make the tactile judgements to the point where tactile and auditory performance would be almost equivalent. This learning process would be particularly evident if subjects were allowed immediate visual feedback of the position of the sound source as would be the case in actual field trials with a deaf subject. A correlation between the position of the sound source relative to the head and the sensation produced on the arm would be firmly established so the subjects would be able to perceive the tactile stimulus as a property of the sound source itself rather than merely as a sensation on the arm. This process of externalization of the percept has been observed by White et al[2] in a tactile substitution device for the blind and by Gescheider[3] in a tactile sound localization experiment in which the localization cues were presented to contralateral fingertips. Because of the limited amount of experience gained by the subjects during the short experimental session reported here, no externalization was reported.

TABLE 1

SUBJECT	RMS ERROR (DEGREES)	STD. DEV.	AVG. LATENCY (SECONDS)
S_1	2.95	2.94	15.8
S_2	3.68	5.95	14.1
S_3	1.92	2.88	12.7
S_4	1.19	2.15	16.0
S_5	3.10	4.14	18.3
S_6	6.30	4.93	13.9
$\bar{x}$	3.19	3.83	15.13

During the course of the experiment, normally in the training period, the subjects evolved a search strategy which could best be termed "bracketing". When the sound source was turned on in a new position the subject quickly turned his head until it was in the vicinity of the target location. The initial motion usually resulted in overshooting the target whereupon the subject reversed the direction of his head movement. This process of scanning back and forth past the target, with diminishing excursions on each

cycle, was continued until the subject was satisfied with his localization accuracy. Fig.3 is a copy of a strip chart recording of the typical head motions of a subject while searching for the target, taken at the end of a session after the subject had had approximately one and one-half hours of practice. The sophistication of the subject's performance can be seen by noting that the initial head motion was always in the proper direction whenever the speaker position was changed and that the excursions are limited to about ten degrees on either side of the target.
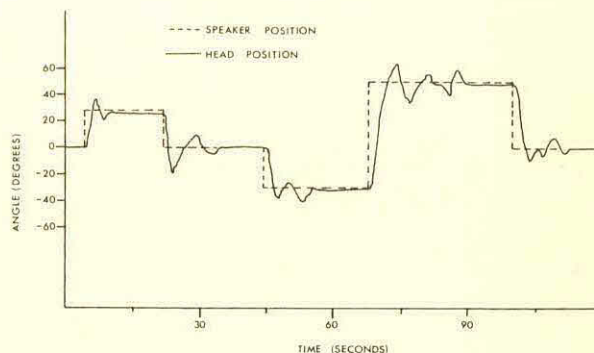
Fig.3: Head Motions during Localization

Conclusions

This experiment clearly demonstrates the ability of the skin to transduce sound localization information and the ability of the central nervous system to decipher this information. With very little practice, localization performance using tactile cues is as accurate as the performance using auditory cues although the time taken to make a judgement is an order of magnitude greater in the former case.

Richardson[4] has performed a localization experiment very similar to the one reported here with the exception that mechanical vibrators were used to produce the tactile stimuli, and the tips of the forefingers were chosen as the site of stimulation. He also found that tactile localization could be surprisingly accurate. However, since the overall objective is the development of a portable device, the many serious limitations of mechanical stimulators cannot be overlooked. Primarily, it would be an intolerable handicap to have the hands continuously occupied with receiving sound localization information. But if alternate stimulation locations are chosen larger and more powerful stimulators

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would be required because of the lower sensitivity to vibrotactile stimuli of other parts of the body. Electrocutaneous stimulators, on the other hand, are adept at producing comfortable sensations at almost any chosen site.

A more subtle but none the less important drawback of mechanical stimulators is the difficulty faced in effectively camouflaging them. Their bulk and the noise they produce make the designing of a cosmetically acceptable portable device a particularly challenging task. Electrocutaneous stimulators present no such problems; they are lightweight, small, silent and easily hidden beneath loose fitting clothing.

It is clear from this experiment that the tactile sensory system is particularly well suited to the task of supplying sound localization information to a deaf person. The final step that is required before a sound localization aid can be considered a reality is the fabrication of a self-contained portable model to replace the laboratory version used here. Such a development is presently in progress.

References

[1] Mackay, N.A.M. and Mason, J.L.. Electrocutaneous Stimulation in Sensory Aids. Proceedings of 26th Annual Conference of Engineering in Medicine and Biology, 277, 1973.

[2] White, B.W., et al. Seeing with the Skin. Perception and Psychophysics, 7, 23-27, 1970.

[3] Gescheider, G.A. Some Comparisons between Touch and Hearing. IEEE Trans. on Man-Machine Systems, MMS-11, 28-35, 1970.

[4] Richardson, B. and Frost, B. A Sound Localization Device for the Deaf. Proceedings of the 1974 Conference on Engineering Devices in Rehabilitation, 143-146, 1974.

Title of Paper: "Effects of Posture on Pressure Distribution Under Wheelchair-Bound Patients"

Category: (check one)   Device Development / /   Research Study /X/

Brief Description: This report describes a large area pressure transducer system and its use in studying the effects of posture on pressure distribution while a patient is in a wheelchair.

Intended User Group: The measurement system has been designed for use by OT, PT, and nurses who must be concerned with preventing pressure sores from developing.

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   /X/

    Feasibility Testing   /X/

    Clinical Testing   / /

    Available for Sale (check one)   Yes / /   No /X/

    Price per unit $ N/A

    Availability of constructional details:

B. Research Study

    Intended Utilization: The results of the ongoing study will be used in the design of a pressure distribution pad that affords the patient the stability of a foam pad and the pressure uniformity of a water or air pad.

    Intended Device Application: The pressure transducer system is being used in the TIRR OT program to optimize the type of pressure distribution pad that is prescribed for wheelchair-bound patients.

    Availability of Intended Device: Plans for the pressure transducer are currently available. The pressure distribution pad is not available at this time.

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EFFECTS OF POSTURE ON PRESSURE DISTRIBUTION

UNDER WHEELCHAIR-BOUND PATIENTS

by

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Summary – Knowledge of the stress distribution at the interface between the patient and an elastic support, i.e., the skin and wheelchair or bed, is necessary to predict and prevent the occurrence of ischemic-induced necrosis and subsequent ulcer formation.

This report describes the preliminary results of a study in which a large area pressure transducer was developed and used to study the effects of posture on pressure distribution while seated in a wheelchair and the pressure relief afforded by simple physical activities.

Introduction

Knowledge of the load (stress) distribution that is developed under a SCI (spinal cord injury) patient when he is in a wheelchair is needed in order to evaluate the effectiveness of commercially available support systems (pressure distribution cushions) for each individual patient. Also, the data collected will provide the base that is required to fabricate pressure-relief systems with improved effectiveness and efficiency of patient training programs.

Acknowledgement

Although it has been clinically observed for many years that decubitus ulcers occur as a result of pressure being applied for extended periods of time to the soft tissue over bony prominences, it has not been technically feasible to quantify how a patient's weight is distributed while seated in a wheelchair or when the patient is on any surface other than a rigid, planar one. Moreover, the techniques used in therapy programs to teach the patient how to sit in a wheelchair have developed as an art and depend on the patient and/or therapist to detect potential trouble spots before there is irreversible tissue damage and compensate for the problem with adjustments to the patient's posture while in the chair. Current training techniques have evolved to a level that prevents many pressure problems, but now modern engineering technology can provide the therapist and nursing staff with an aid which obviates the total reliance on past experience in assessing potential

pressure problems and postural modifications designed to effect load reduction in pressure-sensitive regions.

Previous Studies

Interest in improving the comfort of seated persons is not new. The work done by Lay and Fischer in 1940 on the effects of cushions on riding comfort served as a benchmark for many subsequent studies in the area of human engineering.[1] Similarly, Randall, et al., studied the effects of seating on aircraft pilot performance and comfort during World War II.[2] However, these early studies were based on the premise that the dimensions and geometry of the seat were the primary variables and the problem of load distribution were only given a cursory examination.

An excellent review of the early attempts to measure the pressure generated between the buttocks and the seat is given in Hertzberg's article.[3] The four-part series on transferring load to flesh by Murphy[4] and Bennett[5,6,7] provides a good summary of the conceptual problems involved in transferring loads through soft tissue. This series of articles also points out the importance of shear stresses in causing ischemia.

The work done by Frye[8] and Thornburgh[9] illustrated the state of the art in measuring and monitoring buttocks pressure prior to this study.

Finally, Houle's study of various seat cushions for use in wheelchairs is the basis from which this study has been launched.[10] Houle examined the effectiveness of seven types of seating surfaces. However, his study did not consider the effects of patient posture on pressure distribution, although the data illustrate that posture is an important variable, accounting for variations in the peak pressures of up to 30 mm Hz.

Methodology

In this study, a large area pressure transducer (Figure 1) has been developed to simultaneously monitor the pressure under the buttocks and thighs during sitting. The transducer consists of 144 pneumatically controlled contact switches which activate a matrix of lights, one light for each switch. By varying the pressure in the pad and photographically recording which lights are lit at a sequence of pressures, a pressure contour map can be constructed, permitting the therapist or clinician to detect anomalies in the seating posture that produce skewed pressure patterns.
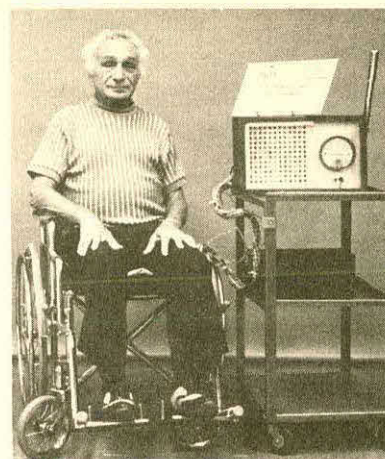
Figure 1. Buttocks area pressure transducer system

The variables which are being controlled and recorded in the study are:

1. The handedness of the patient, i.e., whether the person is right or left handed in his activities;

2. The body type of the patient, e.g., obese, heavy, average, thin;

3. The position of the wheelchair footrests;

4. The position of the patient's back in relation to the wheelchair back;

5. The type of cushion used in the wheelchair, and;

6. The patient's diagnostic group.

In the present stage of this study, the effectiveness of four types of commonly used pressure distribution cushions is being evaluated for each subject. When the most effective pad for a particular subject is determined (on the basis of lowest peak pressure), the footrests of the wheelchair are adjusted in order to make the pressure distribution as uniform as possible over the entire load-bearing area. Presently, the position of the wheelchair back is not being varied, but the effect of changing the back geometry will be studied as part of this project at a future time.

Results and Discussion

Typical results from a data collection session are given in Figures 2-7. These photographs show the light displays which correspond to pressures of 1 psi, 0.75 psi, 0.5 psi, 0.25 psi, 0.1 psi and the position of the ischial tuberosities on the pad.
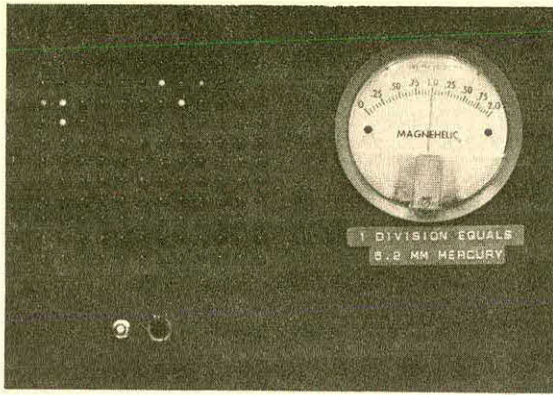
Figure 2. Typical light display at 1 psi, with feet properly elevated
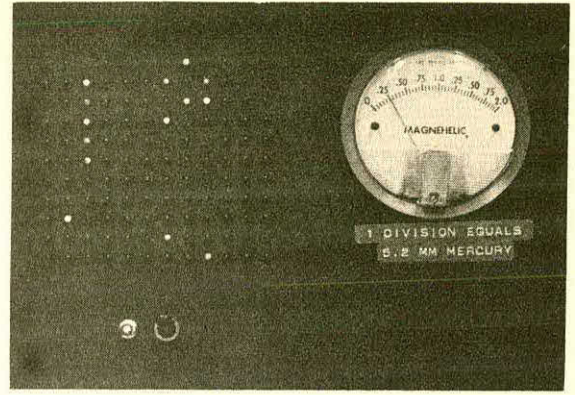
Figure 5. Typical light display at 0.25 psi, with feet properly elevated
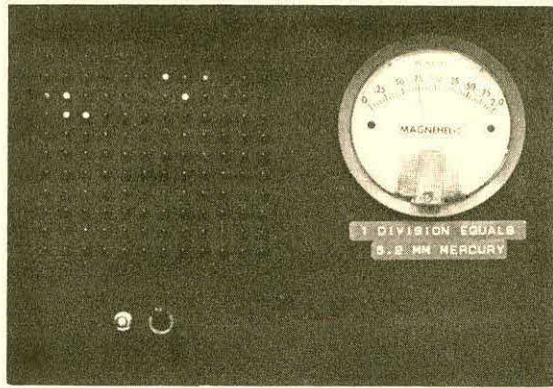
Figure 3. Typical light display at 0.75 psi, with feet properly elevated
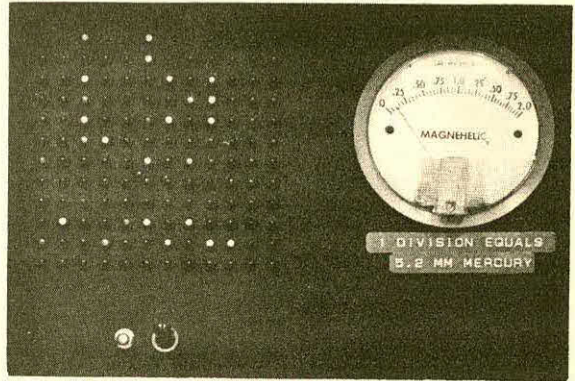
Figure 6. Typical light display at 0.1 psi, with feet properly elevated
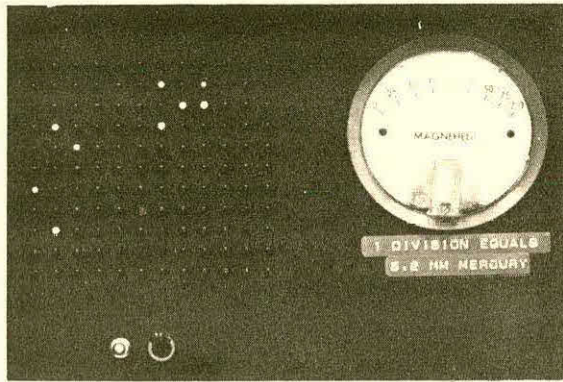
Figure 4. Typical light display at 0.5 psi, with feet properly elevated
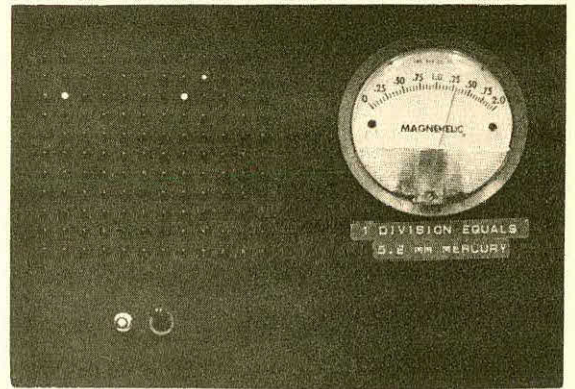
Figure 7. Typical light display showing the ischial tuberosities

From these data, a map, as illustrated in Figure 8, is developed and the most effective pressure redistribution pad is selected for the patient.
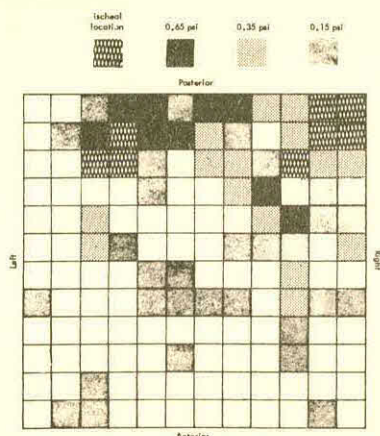
Figure 8. Typical map of the pressure distribution under a patient seated in a wheelchair

Figure 9 illustrates the effect of footrest elevation on the pressure redistribution. A comparison of Figure 5 and Figure 9 illustrates that if the footrests are not correctly installed or if the patient changes shoe styles so that the feet are not correctly elevated, the effectiveness of the cushion is severely impaired.
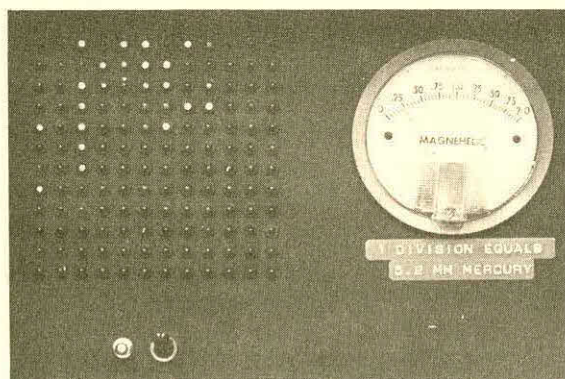
Figure 9. Pressure distribution at 0.25 psi, with footrests 3 inches too high

These results are preliminary and will require several more months of study to develop and substantiate an adequate data base. However, the effect of posture on pressure distribution is apparent and should be considered as a significant variable when training a patient to care for himself.

References

1. Lay, W.E. and Fischer, L.C. Riding comfort and cushions. SAE Journal 47(5):482-496, 1940.

2. Randell, F.C., et al. Human Body Size in Military Aircraft and Personal Equipment. American Air Force Technical Report 5501.

3. Hertzberg, H.T.E. Some contributions of applied physical anthropology to human engineering. New York Academy of Science Annals, 63:616-629, 1955.

4. Murphy, E.F. Transferring load to flesh, Part I, Concepts. Bulletin of Prosthetics Research, 10-16:38-44, Fall, 1971.

5. Bennett, L. Transferring load to flesh, Part II, Analysis of compressive stress. Bulletin of Prosthetics Research, 10-16:45-63, Fall, 1971.

6. Bennett, L. Transferring load to flesh, Part III, Analysis of shear stress. Bulletin of Prosthetics Research, 10-17:38-51, Spring, 1972.

7. Bennett, L. Transferring load to flesh, Part IV, Flesh reaction to contact curvature, Bulletin of Prosthetics Research, 10-18:60-67, Fall, 1972.

8. Frye, P.R. Design and construction of a support system for severely debilitated individuals to prevent ischemia. Master of Science Thesis, Texas A&M University, 1971.

9. Thornburgh, J.D. The measurement and management of external pressure in the prevention of bedsores. Master of Science Thesis, University of Alabama in Birmingham, 1969.

10. Houle, R.J. Evaluation of seat devices designed to prevent ischemic ulcers in paraplegic patients. Archives of Physical Medicine and Rehabilitation, 50:587-594, October, 1969.

Title of Paper: USE OF A POSTURE PLATFORM AS A DIAGNOSTIC AND THERAPEUTIC DEVICE

Category: (check one)   Device Development /X/   Research Study / /

Brief Description: ___ A moveable force plate platform system has been used to evaluate postural stability under static and dynamic conditions in various patient groups. The system allows for precise perturbations of upright stance and measurement of the patient's reactions.   Some results of a preliminary test procedure are discussed as well as possible therapeutic uses of the system.

Intended User Group: ___ Patients with impaired postural stability.

Stage of Development: (Check all that are applicable)

A. Device

  Prototype Development   /X/

  Feasibility Testing   /X/

  Clinical Testing   / /

  Available for Sale (check one)   Yes / /   No / /

    Price per unit $_____

  Availability of constructional details:

B. Research Study

  Intended Utilization: _____

  Intended Device Application: The system is intended to provide objective measures of postural stability and provide information for the evaluation of present and new therapeutic approaches.

  Availability of Intended Device: Not available.

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USE OF A POSTURE PLATFORM AS A DIAGNOSTIC AND THERAPEUTIC DEVICE

by

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Summary - A moveable force plate platform system has been used to evaluate postural stability under static and dynamic conditions in various patient groups. The system allows for precise perturbations of upright stance and measurement of the patient's reactions. A "sum of sinusoids" test procedure is described and an example of the test scores is presented for patients with hemiplegia, low back disorder, cerebellar disorder, spinocerebellar degenerative disease, and chronic poliomyelitis. Possible therapeutic uses of the system are also discussed.

Postural Evaluation Rationale

"Unsteadiness of motor control in gait and standing posture is a sign of disease or disordered function which, as a readily observable symptom, has served physicians of all times." [1] Romberg, in 1853, was one of the first to recognize and emphasize the importance of postural unsteadiness and to devise specific tests for it. [2] Although Romberg's test (standing with eyes closed and feet together) is easily applied, the fact that normal subjects also sway continuously means that the examiner has to rely heavily on personal clinical judgment to assess the degree of dysfunction. Consequently, since Romberg's time, there has been a continuing effort to measure more objectively the stability of human upright stance. [1, 3-7]

The advent of modern electronic technology has brought about the use of more sophisticated methods of measuring postural stability. The central feature of most of these methods is the use of a strain gage force plate which allows for a precise measure of the magnitude and distribution of the supportive ground

reaction forces. With such a system, the patient stands quietly on a small platform and the movements of the body's center of gravity are directly reflected in the movements of the location of the (single resultant) ground reaction force. In cases of decreased stability and increased postural sway, the resultant force location movement increases. A precise measure of this increase provides an objective assessment of the degree of dysfunction. This technique has been utilized by several investigators in the study of a variety of patients with suspected postural stability problems [8-10] and it offers a considerable advantage over relying solely on personal clinical judgment. Such measures also can provide an objective method of determining the effectiveness of specific therapeutic interventions aimed at alleviating balance problems.

Posture and equilibrium mechanisms, however, function not only under the rather static conditions of quiet standing but also under the more dynamic conditions of everyday life. Consequently, the system and tests to be described in this paper have been designed to assess dynamic postural performance, i.e., the patient's ability to maintain a reasonable equilibrium with gravity under disturbing conditions. The rationale has been that dynamic postural control is the more important functional entity and it has definite therapeutic implications.

Dynamic Postural Evaluation System

The central feature of the dynamic postural evaluation system is an hydraulically-moveable "posture platform" which contains two force plates upon which the test subject stands (see Figure 1). The platform appears as part of the laboratory floor and can be made to move: (1) anterior-posteriorly in the horizontal plane (translational mode), (2) in the sagittal plane about a frontal axis (tilt mode), and (3) in the horizontal plane about a vertical axis (rotational mode). The platform movements can be either discrete (e.g., a sudden horizontal translation), or continuous (e.g., sinusoidal), and each of these categories can be further broken down into predictable (periodic) and unpredictable (random) movements. With these capabilities, then, it is possible to produce a wide range of very precise perturbations to a patient's postural control system.
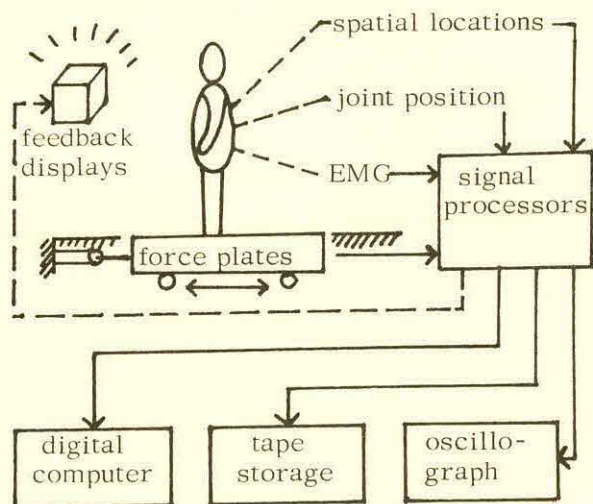
Figure 1. Posture Laboratory System.

Patient responses to these disturbances can be measured using four basic parameters: (1) floor reaction forces, (2) myoelectrical activity, (3) joint motion, and (4) spatial location of various anatomic segments. After appropriate signal conditioning, these data channels can be routed to: (1) a digital computer for analysis, (2) a tape recorder for data storage and later analysis, (3) an oscillograph for immediate interpretation, and (4) a display system which allows the patient to monitor his/her own performance using visual, auditory, or vibro-tactile feedback.

"Sum of Sinusoids" Test Description

Although several different test procedures for measuring dynamic postural control have been and are being developed, the present discussion will be limited to a consideration of patient responses to continuous unpredictable translations of the posture platform, i.e., anterior-posterior movements in the horizontal plane. The input signal to the hydraulic actuators is a summation of six (non-coherent) sine waves (0.06 - 0.6 Hz) which has been shown to be unpredictable [11-12] and, therefore, removes any possible learning effects. This "sum of sinusoids" test consists of a series of six 60-second periods with (at least) 30-second pauses after each. During the first period no platform movement occurs and during each subsequent period the maximum "random" platform movement is progressively increased, in one centimeter increments, from 2 to 6 centimeters. Measured parameters are limited to signals from the force plate strain gages so that the patient is not burdened by test apparatus. The force plate information is sampled ten times per second by a (Varian 620/f) digital computer. For each 60-second test period, the computer printout provides: (1) a measure of the magnitude and point of application (center of pressure) of the vertical force under each limb and of the resultant force between limbs for each sample; (2) the ratio of left-to-right limb load for each sample; and (3) the mean, variance, and standard deviation of these parameters for the 60-second period. The entire test procedure takes less than ten minutes, allows for ample rest periods, if necessary, and is well-tolerated by the various patient groups.

Patient Findings

To provide a comparative data base, twenty-five normal subjects have been tested. The shaded areas in Figures 2 and 3 indicate the normal ranges for two of the test parameters. (Scores are highly replicable for this normal group.)

Standard Displacement of the Resultant Center of Pressure ($X_{c s.d.}$): Although the body weight is distributed over the plantar surfaces of both feet, these many small force applications can be resolved into a single vector force, as mentioned above. The point of intersection of this force with the floor has been termed the resultant center of pressure and can be determined precisely from the force plate data. As the subject

sways in the anterior-posterior direction, the resultant center of pressure (X_c) changes. For any 60-second test period, an average center of pressure ($\overline{X}_c$) can be determined and the standard displacement (X_c s.d.) can be calculated as the square root of the average squared error from the mean. In other words, the X_c s.d. provides a measure of the amount of anterior-posterior movement about some average location. Figure 2 shows the distribution of X_c s.d. for the group of 25 normals during quiet stance and during platform movements. Also shown are the test results from several patients (see below).
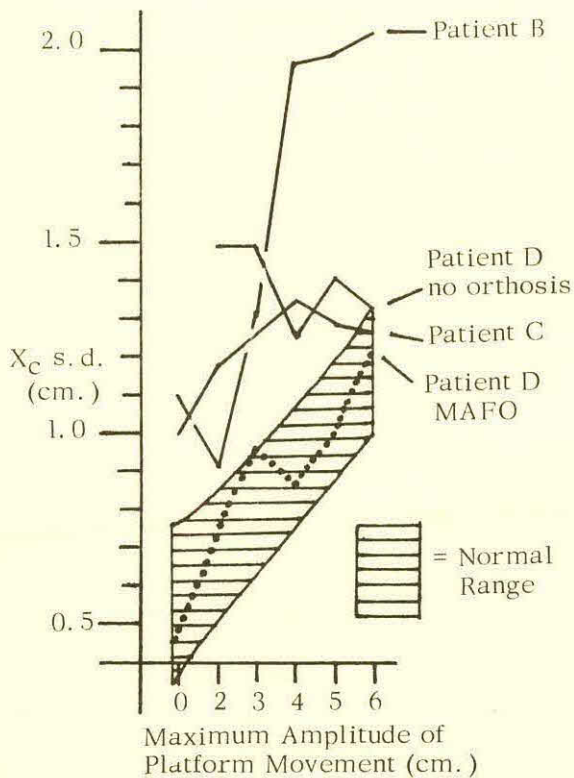
Figure 2. Standard Displacement of the Resultant Center of Pressure for a group of 25 normal subjects and several patients (see text).

Limb Load Ratio ($\overline{V1/Vr}$): The average ratio of the vertical force under the left leg to the vertical force under the right leg (for any 60-second period) is an indication of the symmetry of weightbearing. Figure 3 indicates the distribution of test scores for the normal subjects and several patients (see below).

An assessment based on just these two test parameters, i.e., anterior-posterior sway (X_c s.d.) and limb load ratio ($\overline{V1/Vr}$),

can provide significant information about a patient's postural stability. A consideration of several patients is illustrative.
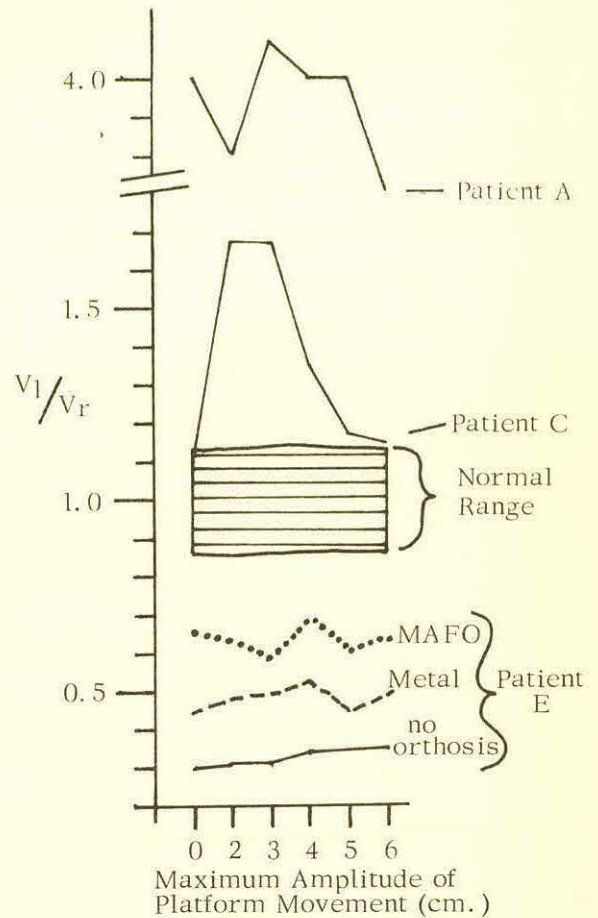
Figure 3. Left-to-Right Limb-Load Ratio for a group of 25 normal subjects and several patients (see text).

Patient A is a 57-year old hemiplegic male with right-sided involvement. He was tested in the posture laboratory eight weeks following his stroke. This patient's test scores for anterior-posterior sway (X_c s.d.) were within the normal range during quiet standing and during platform movements. However, Figure 3 shows this patient's left-to-right limb-load ratio (V1/Vr) to be markedly increased indicating that the left limb was bearing most of the body weight and, therefore, responsible for the (apparently) normal postural stability.

In contrast to patient A, patient B is a 42-year old female hospitalized for an acute low back disorder. This patient's limb-load ratio was in the normal range for all test conditions, but Figure 2 shows that postural

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sway was normal during quiet stance, but became progressively abnormal as the amplitude of platform movement increased.

Patient C is a 62-year old male who developed an ataxic gait and was diagnosed as having a unilateral cerebellar disorder. Figures 2 and 3 show that this patient was outside the normal ranges for both test parameters at low amplitude platform movements but gradually returned to the normal ranges for higher amplitude movements. (This "loading" phenomenon has been observed in other patients with cerebellar problems.)

Patient D is a 37-year old female with spino-cerebellar degenerative disease and bilateral lower extremity spasticity. Her limb-load ratio was normal during all test conditions. The solid line in Figure 2 indicates the test results for postural sway when this patient wore no orthosis, and the dotted line shows the results when the patient wore bilateral molded ankle-foot orthoses (MAFO). The data indicate a significant decrease in abnormal postural sway as a result of orthotic applications.

And finally, patient E is a 34-year old female who is 30 years post-polio. She had worn a conventional long-leg brace almost all of her life. She was fitted with a MAFO and Figure 3 shows her limb-load ratios with no orthosis (solid line), with the conventional metal orthosis (dashed line), and with the MAFO (dotted line). Her postural sway was within normal limits during all test conditions.

Significance and Applications

The test procedures and results described above are, admittedly, quite preliminary and, as yet, inconclusive. More formal studies on larger patient samples are underway to assess the validity and reliability of the "sum of sinusoids" test. The emphasis in this paper is that an objective evaluation of dynamic postural control may be a useful and necessary assessment procedure. The laboratory system which has been developed can provide a delineation of those tests and measures with the most diagnostic significance and of those which are most suitable for translation to clinical use. Once these measures have undergone rigid scientific scrutiny, they will provide a useful diagnostic tool as well as a means of determining the effectiveness of various therapeutic interventions aimed at alleviating postural control problems.

This posture laboratory equipment will also provide a means of exploring: 1) the usefulness of augmented sensory feedback to ameliorate postural control problems, 2) compensatory strategies developed by the damaged nervous system, and 3) the effects of vestibular and visual sensory inputs. It has already been shown that hemiplegic patients can learn to stand symmetrically using auditory feedback of limb load.[13] Does this symmetrical stance result in decreased stability? Can the appropriate display channels be used to improve the performance of a patient with a cerebellar disorder so that he has normal postural control even at low amplitudes of platform movement? Should a patient achieve some minimum postural control test score as a prerequisite to ambulation training? These are but a few of the many important therapy-related questions that need answering.

It is anticipated that this posture laboratory system will prove to be a useful diagnostic and therapeutic device in the near future.

References

1. Miles, C. H. Static equilibrium as a useful test of motor control. J. Indust. Hyg. & Toxicol. 3:316-331, 1922.
2. Romberg, M. H. A Manual of the Nervous Diseases of Man. Sydenham Society Transactions, London 2:396, 1853.
3. Hinsdale, G. The station of man considered physiologically and clinically. Am. J. M. Sc. 93:478-485, 1887.
4. Fearing, F. S. The factors influencing static equilibrium. J. Comp. Psychol. 5:1- , 1925.
5. Hellebrandt, F. A. Standing as a geotrophic reflex. Am. J. Physiol. 121: 471-474, 1938.
6. Travis, R. C. A new stabilometer for measuring dynamic equilibrium in the standing position. J. Exper. Psychol. 34:418-423, 1944.
7. Sheldon, J. H. The effect of age on the control of sway. Geront. Clin. 5: 129-138, 1963.
8. Kapteyn, T. S., and DeWit, G. Posturography as an auxiliary in vestibular investigations. Acta Otolaryng. 73: 104-111, 1972.
9. Sugano, H., Takeya, T., and Kodaira, N. A new approach to the analysis of body movement. Agressologie 13, B:15-19, 1972.

10. Njiokiktjien, C., and de Rijke, W. The recording of Romberg's test and its application in neurology. Aggressologie 13, C: 1-7, 1972.

11. Cox, D.R. The superposition of several strictly periodic sequences of events. Biometrika 40:1-8, 1953.

12. Stark, L., Iida, M., and Willis, P.A. Dynamic characteristics of the motor coordination system. Biophys. J. 1:270-300, 1961.

13. The Rehabilitation Engineering Center, Krusen Center for Research and Engineering, Philadelphia, Penna., Progress Report No. 3:97-108, 1974.

Title of Paper: Hearing Aid Systems for the Hard of Hearing Blind.

Category: (check one)   Device Development / /   Research Study /X/

Brief Description: Auditory localization is of paramount importance for the blind. Existing chest mounted hearing aids appear to offer little help in this respect. The relative merits of a hardware solution as compared with training subjects in the use of existing devices are assessed. The results strongly favour training.

Intended User Group: Orientation and mobility personel, audiologists, rehabilitation workers.

Stage of Development: (Check all that are applicable)

A.   Device

Prototype Development   / /

Feasibility Testing   / /

Clinical Testing   / /

Available for Sale (check one)   Yes / /   No / /

Price per unit $ _____

Availability of constructional details:

B.   Research Study

Intended Utilization: The implementation of these and subsequent findings should enable the hard of hearing blind to obtain greater benefit from existing orientation and mobility training proceedures.

Intended Device Application: _____

Availability of Intended Device: _____

For further information, contact: Name   Dr A D Heyes
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                                             Department of Psychology
                                             University of Nottingham
                                             Nottingham, — England

HEARING AID SYSTEMS FOR THE HARD OF HEARING BLIND.

by

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Blind Mobility Research Unit
Department of Psychology
University of Nottingham
Nottingham   England

Summary - A series of chest-mounted binaural
hearing aid systems, intended to aid auditory
localization for the hearing-impaired blind, are
described. The designs of these systems make
successive approximations to the 'ideal', where
the 'ideal' systems is defined as that which
perfectly mimics the normally experienced inter-
ear intensity and time differences for sound
sources in the azimuth plane. Sound localization
performance is measured both before and after
training. The effects of training are shown to
far outweigh the contribution made by sophisticated
hardware.   The extent to which the sighted deaf
can use visual confirmation to produce the necessary
adaptation of auditory space remains to be assessed.
In the case of the deaf-blind, for whom sound
localization is an important means of orientation,
training will be necessary to facilitate such
adaptation.

Introduction - In order to benefit from
training given by mobility and orientation
courses a subject must have reasonably good
hearing. In particular he should be able to
orientate himself with respect to environ-
mental sound. For the totally deaf blind
this is not possible and not only must
training be radically modified but use must
also be made of sophisticated mobility devices.
For the hard of hearing blind however an
alternative solution is possible. Provided
that the subject can be issued with a hearing
aid system which enables him to localise
sounds he may then benefit from an almost,
and I stress almost, unaltered O and M Course.
The design considerations inherent in such
a hearing aid system together with experimen-
tal results of sound localization ability
form the subject matter of this paper.

Existing hearing aid provision under the
United Kingdom National Health Service takes
no account of the special needs of subjects
who suffer the additional handicap of blind-
ness, namely the requirement for auditory
localization. The standard issue is one
chest mounted aid. We have determined that
some degree of auditory localization is
possible using only one ear, with accuracy

Acknowledgements

on the open ear side being improved if head
movements are allowed. Figure 1 shows the
stimulus/response curves for monaural local-
ization of a white noise source using the
right ear. The mean response, together with
an error bar indicating the size of the
standard deviation from the mean, is shown
for nineteen angles in the azimuth plane.
Each mean has been derived by collapsing 16
readings, 4 from each of 4 subjects. An
overall root mean square (RMS) error is
obtained by collapsing over angles and over
subjects. Figure 2 shows stimulus/response
curves obtained using two ears; a consider-
able improvement over the monaural condition
can be noted. In this case there is little
difference between the head-fixed and the
head-free condition. We have decided to
concentrate our attention on binaural systems.
We also decided to work on chest worn systems
because (a) in addition to the above evidence
for the marginal effects of head movement
there was the practical consideration that
chest worn aids were, at that time, the aids
available through the United Kingdom National
Health Service, and (b) notwithstanding the
recent decision to issue post-aural aids on
the N.H.S. there exists a large number of
people for whom these aids will not be suitable
Furthermore, our experience with blind
subjects had led us to conclude that head
movements are not used to facilitate on-going
orientation with respect to sound sources in
the field situation.

The position within the head of the sound

MONAURAL LOCALIZATION   HEAD FIXED   RMS=63.1

RESPONSE

AZIMUTH
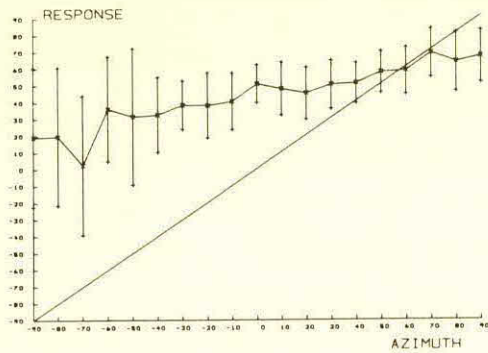
MONAURAL LOCALIZATION   HEAD FREE   RMS=39.1

RESPONSE

AZIMUTH

BINAURAL LOCALIZATION   HEAD FIXED   RMS=10.5

RESPONSE

AZIMUTH
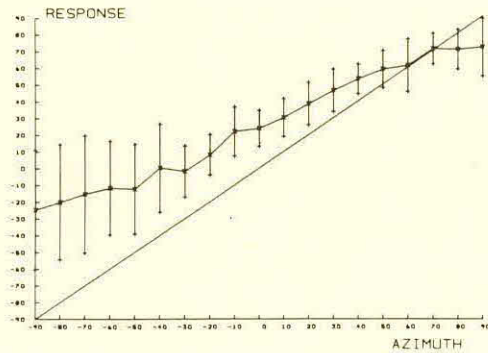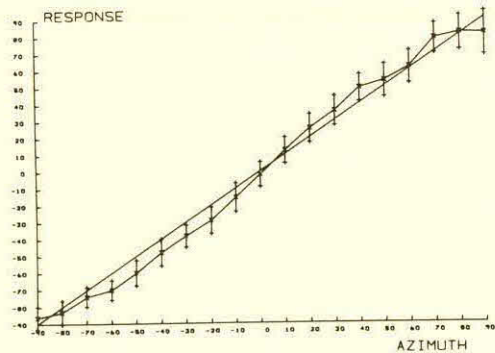
BINAURAL LOCALIZATION   HEAD FREE   RMS= 7.6
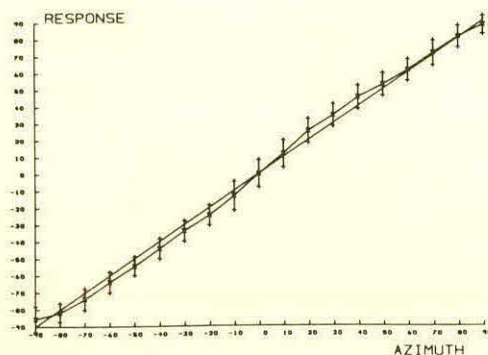
RESPONSE

AZIMUTH

Figure 1 (a) and Figure 1 (b) - Monaural localization using the right ear. The mean and standard deviation is shown for responses to stimuli ranging from far left (-90 degrees). The line of unity slope is the 'ideal' response.

Figure 2 (a) and Figure 2 (b) - Binaural localization; much superior to monaural localization. Note the little extra advantage to be obtained by allowing head movements.

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image depends upon small differences in the informational content of the sounds reaching the two ears. A brief analysis of the kinds of difference involved in the case of normal hearing should enable us to suggest methods by which we may maximise localization ability using hearing aid systems.

The origin of the small differences in the signals received by the two ears lies in the size and shape of the human head. Thus, sounds coming from sources on the left hand side arrive at the left ear before they arrive at the right ear and vice versa. Furthermore, the intensity of sound received from a source differs at the two ears depending upon both the direction of the source and the frequency of the sound (1). The frequency dependence arises from the fact that the human head diameter is approximately equal to half the wave length of a 900 Hz tone. Consequently the presence of the head between the ears has little shadowing effect on sounds of lower frequency than this, but has a progressively greater effect with increasing frequencies above this point.

Thus, both time and intensity differences play a role in auditory localization. That their role is complimentary may be seen from the experiments on time/intensity trading in which subjects presented with binaural dichotic clicks can centralize an image when the two clicks do not arrive simultaneously - provided that the later click is of greater intensity. More generally, the fused image from dichotically presented clicks having any inter-ear difference less than 2 ms. may be positioned anywhere in the azimuth by suitably changing the inter-ear intensity (2).

In designing a hearing aid system which is designed to maximise a subject's lateralization ability, one has the choice of attempting to design a 'natural' display in which both time and intensity azimuth relationships fit closely to those experienced by normally hearing subjects or of designing a 'non-natural' system which uses other combinations of these relationships. For example, one might use time information alone or alternatively intensity information alone. One might, as in the 'natural' display, use both time and intensity information, but without special precautions to fit the respective azimuthal relationships to the natural curves.

The design of a 'natural' system, which

derives a signal from two chest mounted microphones and displays the information to the ears in such a way that both the inter-ear time and inter-ear intensity differences were correct for all azimuth directions, has proved too difficult. However, several approximations to the ideal were constructed and the results obtained from experiments with these systems both before and after training are described.

The Method - Localization performance was measured for the various hearing aid systems by seating subjects at the centre, and facing, a semicircle of small loudspeakers. The nineteen speakers, which had been selected for similar frequency characteristics, were arranged at 10° intervals and at ear level. The straight ahead direction was called 0 degrees and all other angles were measured in a clock-wise direction relative to this. The stimuli were 7 second bursts of white noise at an S.P.L. of 55 dB, and the experimental sessions consisted of four presentations at each of the 19 speakers, the order of presentation being randomised. The subject was required to point in the direction of each stimulus using a long cane, the tip of which rested on a low table on which was drawn a protractor. In all the experimental conditions head movements were restricted using a hand rest and a chin rest. All the subjects were sighted, normally hearing, undergraduate volunteers who were blindfolded for the purpose of the experiment. A pilot study had shown that there was considerable learning transfer between systems and therefore since the experiments were to involve training it was necessary to use a different group of subjects for each hearing aid system. With the exception of the initial base line measurements, training sessions were carried out immediately prior to each test. The training consisted in the experimenter supplying the subject with a knowledge of his results. The subject responded to each stimulus and the experimenter then told him in which direction and by how much he should adjust his response; no attempt was made to force the pace. This proved to be quite a rapid procedure and it was found possible to give training for three presentations of every loudspeaker - 57 presentations in all - in about 20 minutes.

Analysis of Results - The data points for each test session were pooled and a new data population formed by combining the error scores for all subjects at each of the 19 target directions. Thus, a set of 19 mean error, standard deviation, and RMS scores was produced for each hearing-aid condition. The data was then further collapsed over all 19 target directions and an overall RMS score was computed for each test condition. This served to indicate the overall accuracy of performance under any one condition.

To test statistically the differences found between hearing aid conditions, or between different test sessions with the same aid system the Wilcoxon T test was applied to the 19 pairs of RMS scores for the two chosen conditions. An obtained value of T having a probability of occurrence equal to, or less than, 0.05 was then accepted as evidence of a significant difference between performances under the two conditions. When learning effects were being investigated, the assumed improvement in performance made a one-tailed version of the significance estimate appropriate. Where no such prior expectation existed (i.e. when comparing hearing aid systems), a two-tailed estimate was used.

Graphical displays of pooled data in which the mean response direction is plotted against the target direction provide a useful method of presenting summarised data; the magnitude of the standard deviation of the pooled data at each target direction being represented by a bar. Such graphs make it possible to see at a glance any systematic distortion in auditory space perception, or any systematic variation in localization accuracy. Thus, in presenting results for comparison, three complimentary sets of information are appropriate: (a) A response graph for each condition. (b) The overall collapsed RMS values. (c) An estimate of the significance or otherwise of the difference.

Experiment A. A Comparison of Localization Ability for Three Binaural Hearing Aid Systems.
- Three hearing aid systems of different complexity were considered. The systems, which represent successive approximations to an ideal 'natural' system, were as follows:-

System A.   Crossed Stereo Pair.

A pair of high quality studio microphones, both with a cardioid polar response, were crossed; each microphone making an angle of 45° to the straight ahead. In accordance with usual studio practice, the microphones were mounted with the diaphragms one above the other. This is a system which provides only intensity cues. However, a consideration of the polar response shows that this arrangement provides an interaural intensity versus azimuth relationship, the magnitude of which is less than that experienced in normal hearing (1).

System B.   Crossed Stereo Pair with
                   Out-of-Phase Cross-Talk.

This system uses the crossed stereo pair (system A), but with the stereophonic sound image artificially widened by feeding a proportion of the signal from each channel (18%) out of phase into the other channel.

This increased inter-channel intensity difference could also have been achieved by increasing the angle between the microphones. Both the techniques were used at the pilot study stage but the system B was chosen for the extended study since it used the same microphone configuration as in A, the cross-talk being achieved electronically. A description of the circuit is given in the Mullard Handbook (3).

System C.   Crossed Stereo Pair with
                 Frequency Dependent Cross-Talk.

This employed an arrangement which was
identical to system B except that the stereo-
phonic sound image was a function of
frequency. The intensity/azimuth relation-
ship obtained by Weiner was thus reproduced
quite accurately; in-phase cross-talk being
provided at low frequencies to remove inter-
channel differences and out of phase cross-talk
provided at high frequencies to artificially
enhance the inter-channel separation. The
circuit was derived directly from the
Mullard design by replacing the resistive
components in the cross-talk network by
reactive components. This system was thus
'quasi-natural' in that the intensity/azimuth
relationship was essentially correct for the
two channels but the time difference inform-
ation was absent.

Four subjects were assigned to each of the
three systems, results being recorded before
training (the base line) and after each of
two sessions on training.

Experiment A.   Results.

The base line performances for the three
hearing-aid conditions under study are shown
in Figures 3a, 3b and 3c. The overall
collapsed RMS values are also shown. In
terms of the error measures discussed in the
previous sections systems A and B are not
significantly different from each other.
However, both are significantly more
accurate than system C. The short error bars
on the graph for system C indicate that
subjects were consistant in their responses.

Clearly all systems provided enough inform-
ation to enable the subjects to associate a
particular sound with a particular direction.
The consistency of the association was best
for system C, but the correspondence between
the perceived direction of the stimuli and its
true direction was best for systems A and B.
Systems A, B and C represent successive
attempts to engineer the auditory information
into a form which enables the subject to
perceive the stimulus in the correct direction,
but these attempts have failed because,
although we have increased consistency, we
have decreased accuracy. The most sophistic-
ated system, system C, displays to the user a
well defined but distorted auditory space.

An alternative approach to the provision of
more and more sophisticated hardware is to
attempt to teach the subject to relate more
accurately the perceived sound images with the
objectively correct source direction. The base
line performance of all three systems shows a
response versus azimuth curve which is less
steep than the ideal performance line. In
terms of auditory space this means that the
perceived sound images are contained within an
arc which is centred about the medial plane
but which is somewhat smaller than the 180°
arc of sound sources. Thus, the main function
of a training procedure for all the systems is

tantamount to achieving a spreading of the
auditory space. The extent to which this has
been achieved is seen in Figures 4a, 4b and 4c
which show the results obtained after two
training sessions on each of the systems.
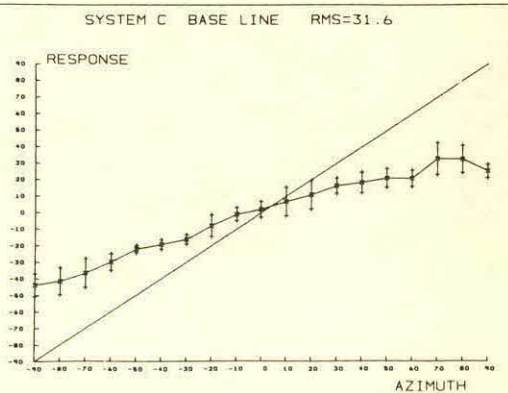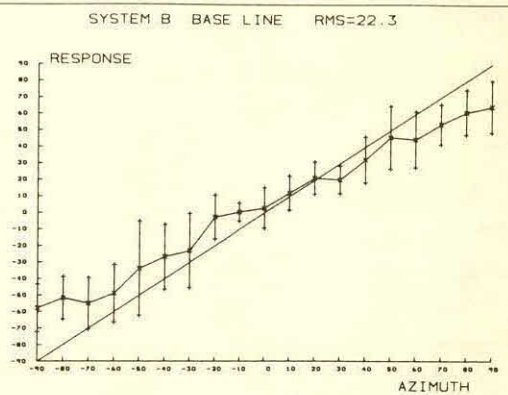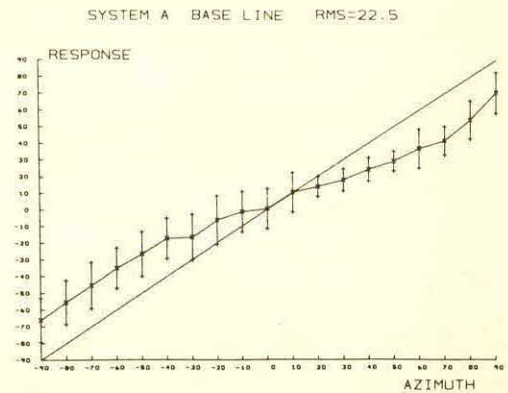
Figure 3 (a, b, c) - Base line performances
for the systems used in Experiment A.

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Table 1 shows the results of inter-test
comparisons. Each condition is represented
both by a row and a column. The results of
any two condition comparisons is shown by the
symbol at the point of intersection of the

SYSTEM A   TR.2   RMS=13.2
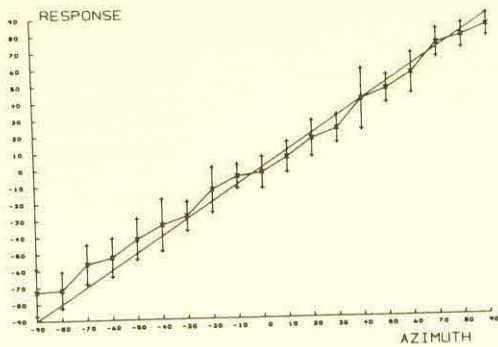
SYSTEM B   TR.2   RMS=14.5
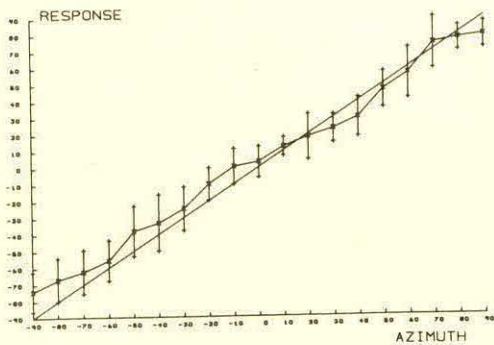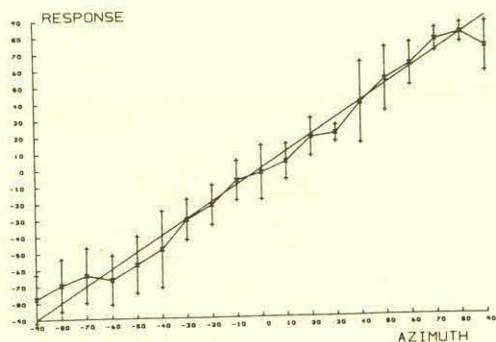

SYSTEM C   TR.2   RMS=16.5

Figure 4 (a, b, c) - Performances after two training sessions for the systems used in Experiment A.

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corresponding row and column. A zero indicates that the two conditions are not significantly different. An arrow indicates a significant difference at the 0.05 level of probability and the arrow points towards the condition which is superior. The labels A, B and C refer to the system A, B and C and the suffixes 0, 1 and 2 refer to results obtained from the base line test, and the tests after 1 or 2 periods of training.

From the table we may see that:

(a) Of the base line conditions, A and B were not significantly different but both were significantly more accurate than C.

(b) After one session of training, all systems were significantly better than their base line condition but now A1 is better than both B1 and C1; the last two being not significantly different.

(c) After the second training session none of the systems had improved over and above the levels reached after the first session.

(d) The final position after two training sessions is that B2 is not significantly different from either A2 or C2 but A2 is significantly better than C2.

(e) A2 is alone in being not significantly different from the corresponding normal hearing condition (i.e. binaural head fixed, see Figure 2).

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Table 1. Significance table for systems A, B and C.

	A_0	A_1	A_2	B_0	B_1	B_2	C_0	C_1	C_2
A_0									
A_1	←								
A_2	←	O							
B_0	O	↓	↓						
B_1	←	↓	↓	←					
B_2	←	O	O	←	O				
C_0	↓	↓	↓	↓	↓	↓			
C_1	O.	↓	↓	←	O	↓	←		
C_2	←	↓	↓	←	O	O	←	O	
	A_0	A_1	A_2	B_0	B_1	B_2	C_0	C_1	C_2

Experiment A.   Discussion.

The results show that system A not only starts off better than system C, (system C being the one incorporating the most sophisticated electronics) but responds to training in such a way that it remains so. In general base line accuracy measures were a good predictor of final performance levels although the overriding effect of the training was to lessen the difference between the systems.

Experiment B.   The Effect of Familiarization and Training on Localization Ability using Binaural Chest Mounted Medresco Hearing-Aids. (type OL 56).

In this experiment we determined the base line

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performances and the effects of training on 5 subjects each using a pair of standard National Health Service chest mounted hearing aids. The two microphones were worn at the inter-ear distance. Since the hearing-aid microphones are essentially omnidirectional this condition would seem to be an example of a test of auditory localization ability in which time cues alone were given. However, this is not the case since the effect of body shadow is to render the aids directional. Inter-channel intensity differences for two such chest worn aids rise to a maximum value of 8dB at an angle of 50 degrees from the straight ahead. Thus, this hearing-aid system is an example of a condition for which both time and intensity cues were available for sound localization judgement. Pilot study findings had suggested that such a system resulted in poor localization performance. However, in view of the striking improvements produced by training in experiment A we decided to investigate the effects of training on the use of the system.

In addition we wished to discover how such improvement was due to familiarisation alone and then finally to extend the training programme to look for evidence of a plateau in the learning curve. In all eight sessions were performed; the base line measurement, three familiarization sessions (simply repeated measurements involving no training) and lastly four sessions preceded by training.

Experiment B.   Results.

Figures 5a, 5b, 5c and 5d show the base line performance along with the results obtained after subsequent trials 3, 4 and 7.

Table 2 gives the complete list of collapsed RMS results for the eight stages in the experiment (the letters BM stand for binaural Medresco).

Table 2.

	Condition		RMS
BM0	Base-line		32.4
BM1	Familiarization	*	26.6
BM2	Familiarization		24.5
BM3	Familiarization		24.2
BM4	Training	*	17.8
BM5	Training	*	15.5
BM6	Training		14.4
BM7	Training		14.9

Significant improvements in performance were found after the 1st, 4th and 5th post base-line trials (marked by asterisks).

The results for trials 5, 6 and 7 were found to be not significantly different from the final results obtained in experiment A (i.e. system A after the training sessions). However, all of the results for the binaural Medresco system were significantly different from those obtained for normal binaural hearing.

Experiment B.   Discussion.

Base line performance, as anticipated from the

pilot study, is seen to be poor. The effect of familiarization is to produce an initial significant improvement in performance followed by little further change. Training, however, produces further performance increments until a performance plateau is reached.

BINAURAL MEDRESCO   BASE LINE   RMS=32.4

BINAURAL MEDRESCO   TR.3   RMS=24.2
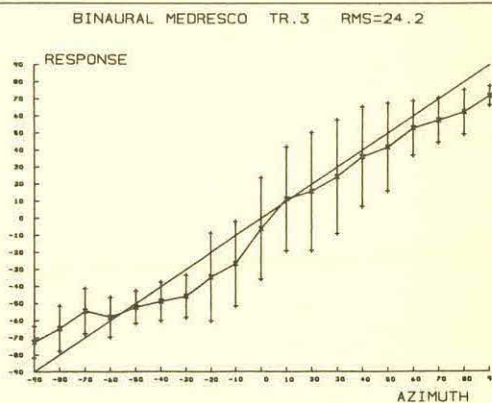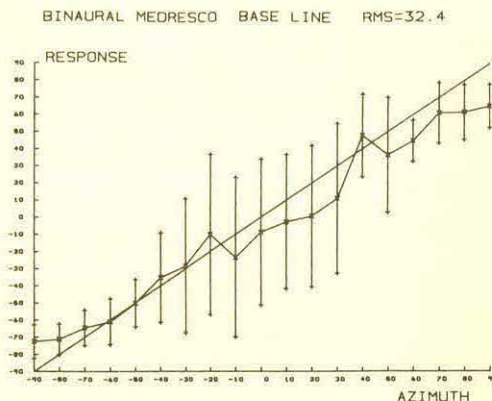
Figure 5 (a) and Figure 5 (b) - Base line performance using the Binaural Medresco system and the effect of familiarization (no training) on localization performance in Experiment B.

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Conclusion.

The volume of work involved prevented us from continuing the training sessions until we had found the plateau on all the learning curves for each system. Nevertheless, we were able to observe a similar level of auditory localization performance for all of the systems used in the two experiments. The sophisticated methods intended to match the information presented to the subjects to that experienced by a subject using normal hearing proved to be irrelevant. The human auditory system was found to be sufficiently malleable to adapt to 'non-natural' auditory presentations. Although signals containing mixed cues (i.e. time and intensity) appeared

to be less well accommodated, one such
system, binaural chest-mounted Medresco aids,
did respond well to training. This system
commends itself for future investigation
since it involves the use of instruments that
are already available from the National
Health Service. It would be incorrect to conc-
lude that this removes the necessity for
hardware research, since all the proposed
alternatives investigated in experiment A
were superior to the N.H.S. system. Neverthe-
less, it does suggest that performance
increments may be achieved in auditory
localization simply by training subjects
to make more effective use of existing
instrumentation.

BINAURAL MEDRESCO   TR.4   RMS=17.8

BINAURAL MEDRESCO   TR.7   RMS=14.9
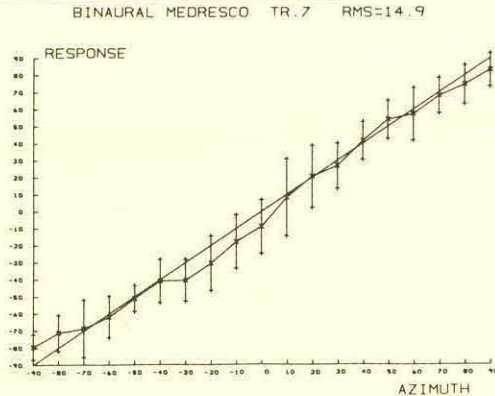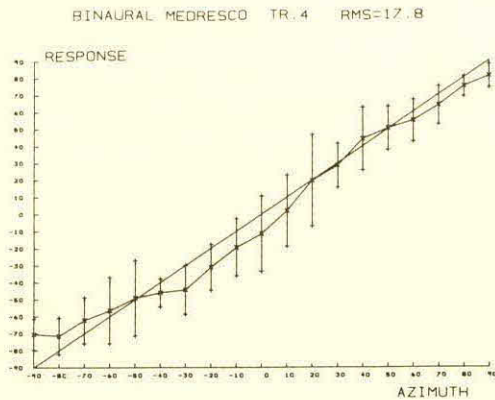
Figure 5 (c) and Figure 5 (d) - The effect of
training on the Binaural Medresco system
(Experiment B).

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References

(1) Weiner, F.M. Sound Diffraction by Rigid
     Spheres and Circular Cylinders. J.Acoust.
     Soc.Am. 19, pp 444-451.   1947

(2) David, E.E., Guttman, N. & Van Bergeijk,
     W.A. On the Mechanism of Binaural Fusion.
     J.Acoust.Soc.Am. 31, pp 774-782.   1959

(3) Mullard Handbook. Transistor Audio and
     Radio Circuits. Mullard Ltd. London. 1969

Title of Paper: A COMPUTER BASED SYSTEM FOR INVESTIGATION OF VARIOUS FORMS OF SENSORY ENHANCEMENT

Category: (check one)   Device Development /   /   Research Study /X/

Brief Description: A computer is used in a system to simulate various sensory substitution devices using electrocutaneous stimulation. This system acts as a research tool with which potential devices can be developed, studied, modified and improved before prototypes are constructed.

Intended User Group: Used on research subjects on an experimental basis, as a device for potential blind and deaf users.

Stage of Development: (Check all that are applicable)

A. Device

     Prototype Development   /   /

     Feasibility Testing   /   /

     Clinical Testing   /   /

     Available for Sale (check one)   Yes /   /   No /   /

        Price per unit $ _____

     Availability of constructional details:

B. Research Study

     Intended Utilization: It is used in research to develop prototype devices.

     Intended Device Application: Electrode arrays.

     Availability of Intended Device: _____

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A COMPUTER BASED SYSTEM FOR INVESTIGATION OF VARIOUS FORMS OF SENSORY ENHANCEMENT

by

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Summary A computer has been used to simulate various sensory substitution devices using electrocutaneous stimulation. A synthetic visual system was developed which employs the computer in image fabrication and processing and an array of electrodes to transfer visual images to the skin. Two two-dimensional tracking systems for use in localization aids have been developed, one using a large array of electrodes, the other using only four electrodes. The paper describes a computer system which enables simulation of these and other sensory substitution devices. This system acts as a tool with which potential devices can be developed, studied, modified and improved before prototypes are constructed.

Introduction

A number of synthetic visual, auditory and other environmental aids for the handicapped developed over the past few years have used the skin as a substitute input channel to replace the defective sense.[1,3-6] One difficulty concerning use of these aids has been in adequately training and testing users of these devices in a laboratory environment. For example, to perform comparisons between a number of sensory substitution techniques, it is necessary that the input information, be it auditory or visual, be identical for each test and for each user. To meet this requirement, a system for providing synthetic sensory data to the user has been developed. An important feature of this system has made it a valuable research tool; by making a synthetic sensor and processor, costs have been kept down during the development stage since modifications in sensing and processing are made through software and not hardware changes. Therefore, the system can be quickly and easily modified to take account and make use of the results obtained through subject testing.

Acknowledgements

Described in this paper is such a system with flexibility provided through the use of a programmable computer. Synthetic visual or auditory information can be generated, processed by the computer, modified in accordance with operator commands, and presented to the skin through an array of transducers. In addition, existing environmental sensors can be used as data inputs to the system, with the computer converting this data to a form suitable for transduction to the tactile sense. The paper first outlines the general functioning of the system with a description of its various components. Then three substitution systems, one visual and two auditory are examined with brief mention of some experiments performed with these systems.

Computer Controlled Stimulator Description

The system shown in block diagram form in Fig.1 and photographed in Fig. 2 can be divided into three parts: a data input section, a processing and control section and a section providing feedback to the control unit. Sensory data is read into the control section in synthetic form via tape, punched cards, disk or teletype, or real sensory information can be delivered to the system through existing sensor devices such as a television camera. The PDP-15 computer used in the control section processes this

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input data and displays it on the skin through an array of transducers. Operating in parallel with the transducer array is a light emitting diode array which visually depicts the pattern of stimulation applied to the skin. With this array the operator or subject can visually monitor the stimulation pattern and its orientation. A head position monitor detects changes in the orientation of the subject's head. This information is used by the computer to change the orientation of the pattern of stimulation, providing the subject with a feedback path to the computer. Thus with this system a pattern is created and impressed on the skin of a subject who may change its orientation by movements of his head.
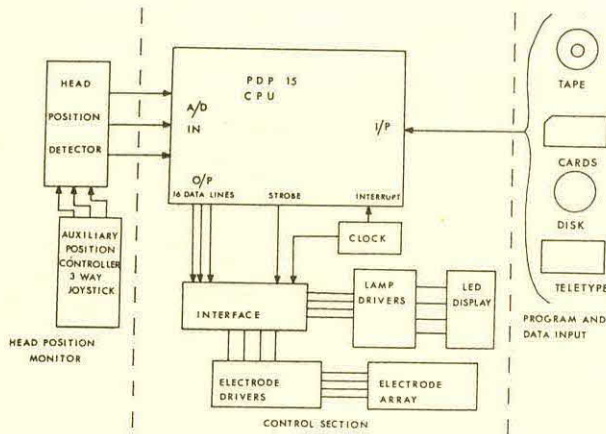
Fig.1: Computer Controlled Stimulator
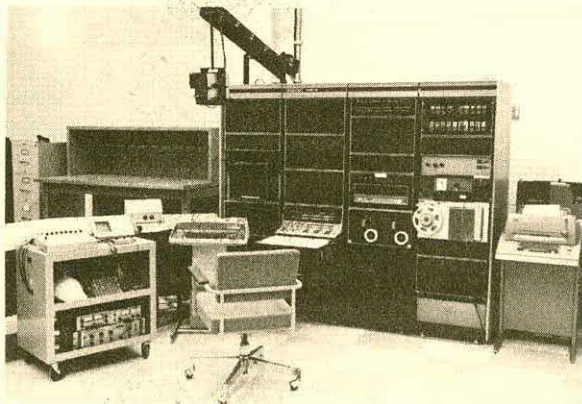
Fig.2: Computer Test Facility

Synthetic Visual System

A synthetic visual device which uses the system described above has been developed to study visual substitution by electrical stimulation of the skin. A comparable visual system would involve an image sensor, an image processor and a transducer to relay visual information to the skin. The process

under investigation is the transduction of visual information to the central nervous system. Accordingly, the front end of the visual system, namely the image sensor and processor have been replaced by the computer in the synthetic system. It therefore becomes a simple matter to generate a variety of synthetic visual patterns and process them with the computer through software programming. Then, the only remaining feature required in the synthetic system is a means of transferring the processed information to the skin. More development time and resources can therefore be spent on determining an effective method of achieving this transfer.

Electrical stimulation of the skin is provided by an eight by eight array of concentric nickle-plated electrodes (Fig.3) held against the skin by an elastic strap and velcro fasteners (Fig.4). Each column of electrodes is driven by a separate integrated circuit driver which contains eight switched constant current sources, the outputs of which are programmed by an external potentiometer. All eight output currents are matched such that each electrode in a column delivers the same current as the other electrodes in that column. The subject therefore has control over the levels of stimulation at each electrode in the array with only eight potentiometer adjustments.
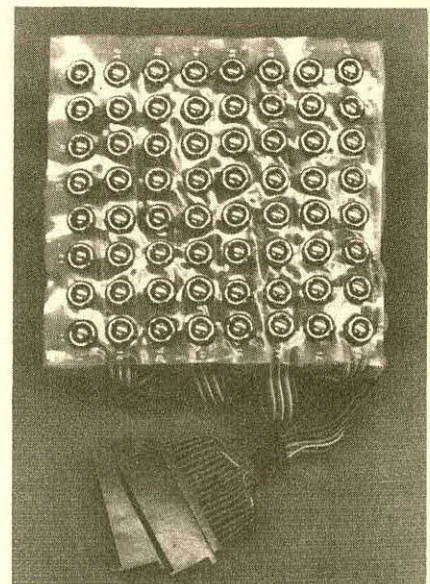
Fig.3: Concentric Electrode Array

To transfer a visual pattern to the skin through this electrode array the pattern is divided into eight rows of information by the computer. The electrodes are then stimulated in a row by row fashion from the top of the array to the bottom as follows:

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referring again to Fig.1, the computer transfers via the output data lines the first row of visual information to the electrode drivers which energize the selected electrodes in the first row of the output array. The succeeding rows of the visual pattern are transferred to the array in a similar manner. After the eight rows of electrodes have been energized, the process is repeated. In this way a visual pattern is traced over the skin of the subject.

Fig.4: Electrode Array Strapped to Subject

It is essential that the subject be able to control the positioning and orientation of the visual pattern. The head position monitor which gives him this control operates as follows: Three low friction potentiometers are mounted on the side, back and top respectively of construction helmet (Fig. 5). A gimbaled counterweight is hung from the potentiometer shafts on the side and back of the helmet. The user sits in a chair and the shaft of the potentiometer on the top of the helmet is connected to a rod suspended from four posts on a chair by elastic bands. Fig.6 shows that the three orientations of the head can be monitored independently with the shaft readings of the three potentiometers. The outputs from the potentiometers are transferred to the computer through three analog to digital channels and this information is used to shift the position of the synthetic image on the skin. Thus, by moving his head, the subject can shift the image on his skin in a manner similar to the way in which visual patterns are shifted on the retina of the eye by eye and head movements. He explores the image in various orientations to aid his recognition of the pattern. This feedback information is essential in a visual system for externalization of the image by the subject. A three way joystick is available for use by the subjects as an alternate position monitoring device, or alternately, the joystick and head position monitor can

work together in a summing circuit, thereby allowing the subject and operator independent control over orientation of the image.
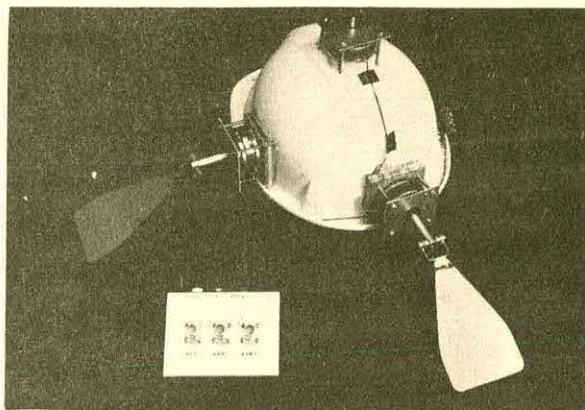
Fig.5: Construction Helmet with Mounted Potentiometers and Gimbaled Counterweights
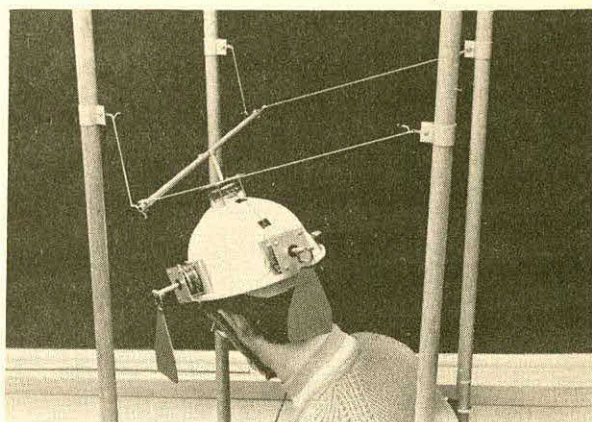
Fig.6: Head Postion Monitor showing Operation of Three Potentiometers

This synthetic visual device has been used to investigate the learning process involved in the recognition of visual patterns. Subjects are presented with simple patterns such as intersecting lines and asked to identify the patterns.

The identification procedure typically used by subjects is worthy of note. For example, if the letter L is displayed, a subject often moves his head so that the horizontal component of the letter moves off the array, at which time he became aware of only the vertical component. Similarly he isolates the horizontal component. Then with further movements of his head he determines that the horizontal and vertical components intersect at right angles. It is important to note that a vital part of the identification process is related to the head position monitor, that is, a dy-

namic display appears to be essential for effective transfer of the visual image to the subject.

An advantage of the inclusion of the computer in visual recognition experiments is that the computer can be programmed as a training device while monitoring the progress of the subject. The flexibility of the system enables stimulation parameters to be easily varied and modification of imaging techniques (such as reversal of contrast, object enlargement or contraction or outlined and solid depiction of objects) are easily accomplished, providing a basis for comparison of the merits of one technique over another with regard to recognition accuracy and learning speed. On-going research will attempt to establish optimum imaging techniques for the most effective use of electrocutaneous stimulation in a visual substitution system.

Localization with
Discrete Electrode Array

The potential use of electrocutaneous stimulation in an auditory substitution system has also been investigated. With small modifications to the system as described above a two dimensional tracking system for potential use in sound localization aids has been developed. Information which simulates the location of a sound source within a room is used to drive a single electrode in the array. The user feels localized vibrations at one point on the abdomen immediately below the driven electrode. The point of stimulation can be moved around the array by the computer to simulate motion of the sound source. As with the visual system, the user's head movement has control over the position of the pattern of stimulation so that he can counteract the movement of the spot with an appropriate movement of his head, thus providing him with a feedback mechanism for localization. If his head movements exactly counteract the computer's movement of the spot, the spot will remain in a stationary position on the output array. Thus the subject can track the source just as an individual using auditory cues can follow a sound source with his head.

Both dynamic and static tracking experiments have been performed with this device. In the static experiments the spot was moved from the centre of the matrix to a predetermined position by the computer. Then the subject moved his head to again center the spot and the computer recorded his error. The dynamic experiments involved con-

tinual movement of the spot at variable rates. The subject tracked the spot and the error was measured by the computer at fixed time intervals. Results of these experiments indicate that this method of tracking and feedback would be useful for object detection and localization, sound localization, and prosthetic limb orientation aids. However, the resolution of the system is limited by the number of electrodes in the output array. Another two dimentsional tracking system using the so-called phantom sensation overcomes this difficulty.

Two Dimensional Localization with
the Phantom Sensation

The "phantom sensation" as described by Von Bekesy[2] is a phenomenon whereby a subject perceives a single fused sensation between two spatially distinct electrodes. The phenomenon is similar to the stereo image created by two loudspeakers playing the same program in phase. The listener hears apparently only one sound source located between the two speakers. As the level of one speaker goes up while the other level correspondingly reduces, the stereo image moves in the direction of the speaker with the increasing level. The phantom sensation on the skin between two stimulating electrodes moves in the same manner with corresponding changes in amplitude at the electrodes. Thus the location of the phantom is controlled by the relative amplitudes of the stimuli. This provides a continuously variable sensation location in one dimension.

Continuing with the high fidelity analog, four speakers can produce a two dimensional sound image characteristic of quadraphonic sound. To determine whether an analogous two dimensional phantom sensation could be created with four electrodes, the output electrode array was modified so that only four electrodes were activated. The four electrodes used formed the corners of a diamond with vertical and horizontal diagonal pairs representing vertical and horizontal information respectively. Control over the level of electrode stimulation was provided through a software program which essentially simulated the sound location information associated with a quadraphonic system. Thus equal intensity of stimulation at each of the electrodes simulated a sound source at the centre of a two dimensional space in front of the user. By varying the relative intensities of each of the electrodes the apparent position of the source on the skin was

changed just as the apparent position of a sound in a room can be varied by varying the outputs of the speakers in a quadraphonic system.

A number of experiments, again in dynamic and static conditions, were conducted to investigate this effect. First the levels of stimulation by the four electrodes were adjusted by the subject to be of approximately equal value and a comfortable pulse width and repetition rate selected. Then the subject activated a sub-routine which changed the levels of stimulation lowering the intensity at one element of the electrode pair and raising it at the other element by the same amount, such that the phantom sensation moved in a horizontal or vertical direction or a combination of both. As with the discrete electrode tracking system, the head position monitor provided him with feedback which enabled him to track the phantom sensation with his head.

A two dimensional phantom was indeed perceived by several subjects. Tracking ability with this device both in terms of speed and accuracy was improved in comparison with the discrete system. Forty positions were established in each dimension and subjects were able to localize the sensation to within ±1 level in each dimension. This improvement could partly be explained by the extra information provided by this technique. The stimulation from the individual electrodes could be felt in addition to the phantom sensation and the subject quickly learned to move his head in a direction to reduce the sensation levels in the strongly stimulating electrodes thereby reducing the time to localize correctly. However, the main improvement is in resolution, for the subject could discriminate a great many more levels then with the discrete system. The results of the phantom experiments indicate that a useful two dimensional sound localization device could be developed using only the four electrodes. Such a system would have obvious advantages over the relatively complex discrete electrode tracking device both in reduced hardware and increased resolution.

It should be noted that testing subjects with the above described localization systems was simplified with the use of the computer. Programs were generated which controlled the whole experiment from start to finish, the only requirement of the operator being to activate the system program. The computer instructed the subject to perform certain tasks, monitored the sub-

jects progress and recorded the experimental results. Hence inclusion of the computer in these simulated sensory aid systems was a convenient and useful procedure.

Conclusions

The flexibility of the computer system described in this paper has made possible the simulation of a variety of sensory substitution devices. A synthetic visual system was developed and used to investigate the perception of visual patterns impressed on the skin. Two methods of two-dimensional sound localization have been investigated and results indicate that useful devices could be developed using these methods. Other simulations of sensory substitution devices can be developed with the use of this computer based system. The power of the system lies in the fact that new techniques can be tried without major hardware changes. Most changes can occur at a software level and can be done quickly and cheaply. If the results from experiments indicate more effective and better techniques of substitution, a few simple program changes will often be all that is required to implement these improved techniques. Thus, such a computer based system has proved to be a useful and valuable tool in the development of prototype sensory substitution systems.

References

1. Back-Y-Rita, P. Brain Mechanisms in Sensory Substitution. Academic Press, New York, New York, 1972.
2. Berkesy, G.von. Similarities Between Hearing and Skin Sensations. Psych. Rev., 66, 1, 1959.
3. Bliss, T.C., et al. Optical-to-Tactile Image Conversion for the Blind. IEEE Trans. on Man Machine Systems, March 1970, pp. 58-65.
4. Collins, C.C. Tactile Television - Mechanical and Electrical Image Projection. IEEE Trans. on Man Machine Systems, March 1970, pp. 65-71.
5. Mason, J.L., Mackay, N.A.M. Cutaneous Stimulation for Sound Localization Aids. Paper presented at the Carnahan Conference on Electronic Prosthetics, Lexington, Kentucky, September 1973.
6. Mason, J.L., Mackay, N.A.M. Phantom Sensation in Sound Localization Aids. Proceedings of the 5th Canadian Medical and Biological Engineering Conference, September 1974, p. 13.2a.

MOBILITY AIDS

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

Title of Paper: The Work of the Blind Mobility Research Unit.

Category: (check one)   Device Development / /   Research Study /x/

Brief Description: ___Projects covered are the development of a non-device___
__specific mobility evaluation procedure, the design of a simple ultrasonic___
__obstacle detector, and the design of tactual maps.___

Intended User Group: ___Orientation and mobility personel.___

Stage of Development: (Check all that are applicable)

    A. Device

        Prototype Development   /x/

        Feasibility Testing   /x/

        Clinical Testing   / /

        Available for Sale (check one)   Yes / /   No /x/

            Price per unit $ _____

        Availability of constructional details: Not yet published.

    B. Research Study

        Intended Utilization: ___Our work involves an on-going study___
__and appraisal of the need of the mobile visually handicapped.___

        Intended Device Application: ___The specific device described___
__in the paper is an obstacle detector intended for intermittent___
__use.___

        Availability of Intended Device: _____

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                                 Nottingham, - England

THE WORK OF THE BLIND MOBILITY RESEARCH UNIT

by

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Summary - A description is given of the major features of the research program of the Blind Mobility Research Unit. Specific projects include the development of a technique to measure mobility performance, the design and development of a simple ultrasonic obstacle detector and the design of raised maps.

The Blind Mobility Research Unit has the responsibility of delineating and investigating the problems encountered by the visually handicapped during independent mobility. It is the function of the Research Unit to attempt to find practical solutions to these problems by developing special aids and associated training programs. The Unit was established in 1970 by the late Dr J A Leonard and it is unique in Western Europe by being the only research organisation which has the resources to conduct a scientific examination of a wide range of mobility problems and to work on appropriate solutions.

Our research interests fall roughly into two areas corresponding to the two major types of problem which restrict the mobility of the visually handicapped. The first area of concern relates to the protection of the pedestrian against physical damage resulting from unintentional contact with some part of the environment. A mobile visually handicapped person usually wishes to avoid collision with lamp-posts, trees, parked cars, walls and other obstacles; he also seeks to avoid accidental departure from the side-walk which could endanger his life and the safety of other road users. At the same time, he hopes to be able to achieve a walking speed which is comparable to that of a sighted pedestrian. The second area of concern relates to the orientation of the pedestrian with respect to both the near and distant environments. When travelling independently, the visually handicapped person needs to know his current position with respect to local features such as the boundaries of the side-walk and also his position in relation to the gross geographical features of the area through which he intends to pass. If he lacks appropriate orientation information then he will lose his way and not reach his desired destination.

Pedestrian Protection: The contribution to the

field of pedestrian protection, made by the Research Unit, is twofold. First, we have attempted to develop a totally objective measure of mobility performance which would provide information on how efficacious specific mobility aids are in providing this protection. Second, we have used information gathered in this way to highlight some of the inadequacies of existing aids and to indicate the need for new developments. Our involvement in these two areas will now be considered in detail.

(1) The Objective Measurement of Mobility Performance. From the begining of the sixties onwards, the arrival of miniaturisation in electronics resulted in the appearance of a number of sophisticated electronic mobility aids which were intended to offer more to mobility than the then available sticks, canes and dogs. With the appearance of so many of these devices came the need for the development of some technique which would allow definitive statements to be made about the improvement in mobility performance which these aids would allow. The desired technique was not simply for comparison purposes but to indicate those mobility situations where the aid in question provided adequate information and those situations where it did not. Such information would allow the developer/inventor to modify the aid in order to bring about improvement or, possibly, to disband his work on it totally. Similarly, the mobility practitioner, faced with a possible range of alternatives, would need to know the advantages and disadvantages of the various aids in order to choose the most appropriate one for his client.

It is important to note that, from the outset, we considered the physical performance of the device itself to be secondary to the combined performance of man and device. After all, the essential question at practitioner level is not concerned with how well the device meets the inventor's specifications but rather the extent to which a user can improve his mobility performance with the device. This is not to say that the physical performance of the aid is unimportant, but such evaluation is the responsibility of the inventor and should be carried out at the development stage.

The development of our measurement tech-

nique has been based on the assumption that a visually handicapped person would aim toward a mobility performance which would minimise the risk of personal injury, lead directly and without time wasteage to the desired location and involved no undue psychological stress. Successful mobility was thus defined as being safe, efficient and without unacceptable stress. Dependent measures have been evolved for these three aspects of mobility performance.

Safety is measured in terms of the frequency of unintentional physical contact with various parts of the environment (eg single obstacles with an origin at ground level, overhanging obstacles, walls etc) and the frequency of unintentional departures from the side-walk, both mid-block and at the end of the block.

In measuring efficiency we have accepted that walking speed on its own is not a particularly good indicator. Although many visually handicapped people do like to maintain a walking speed which is comparable to that of sighted pedestrians, other factors such as the levels of safety and reliable orientation are important. Thus the pedestrian may well sacrifice a high walking speed in order to ensure increased safety and to avoid loss of orientation which might follow a collision. Accordingly, we measure both walking speed and smoothness or continuousness of walking. Our index of the smoothness of walking is the ratio between the length of time taken by the person to cover a specified distance and the proportion of that time during which he was actually physically moving forward. A high index of smoothness would result when the pedestrian walked continuously over the specified distance and a low index would result if time was lost due to frequent stopping and starting (resulting from collisions, disorientation etc).

For our measure of psychological stress we had hoped to use one of the well established physiological indicators such as heart rate. Unfortunately, although there is evidence that visually handicapped people do experience a higher heart rate when walking independently than when walking with sighted assistance (1), we have established that fluctuations of heart rate during mobility cannot be linked to specific environmental events (2). Thus, whereas heart rate does provide an overall indication of the psychological stress experienced, it cannot be used to isolate specific situations in which the use of a particular aid causes, or fails to alleviate, stress. However, our own observations indicate a high correlation between the pedestrian's subjective rating of psychological stress for particular parts of a route and his average stride length for that section. It would seem that, as the situation becomes more stressful, the average stride length decreases. Although this measure requires further validation, we consider that it may turn out to be a useful means of

estimating the level of psychological stress associated with specific environmental features.

To the present, this measurement technique has been used to construct performance profiles of pedestrians using, in real environments, dog guides, long canes and Binaural Sensory Aids (3)(see Fig 1) and the Swedish Laser Cane.

Fig 1: The Binaural Sensory Aid

In due course, these profiles will be made available to orientation and mobility specialists so that decisions on fitting the appropriate aid to a particular client can be made easier.

(2) Developing a new mobility aid. Our experiences in the evaluation of some existing mobility aids suggested that there was a need for a small obstacle detector which was simple to use and easy to understand. Although some of the existing electronic aids are technically capable of providing much environmental information, their displays are often too complex for many users to cope with. For example, the early Kay Sonic Aid (4) was capable of indicating distance, size and texture of obstacle, but, in complicated environments (eg a busy street situation) this information was difficult to extract from its auditory display. Our conclusions from much experimental work with this aid was that, in order to be acceptable, its display needed to be simplified in a number of ways.

First, the frequency of the Sonic Aid's auditory display varied continuously with the range of the target; a very small change in distance resulted in a small change in frequency.

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We considered that, although this system could allow very accurate judgements of distance, most visually handicapped people would not need this accuracy.

Second, the Sonic Aid signal resulted from the summation of ultrasonic reflections from all targets within range. We thought that, since blind mobility tends to be a sequential process (each environmental feature being detected and dealt with in turn), the user would be less confused if information about the nearest obstacle only was provided.

Just recently, we have finished the construction of a number of prototypes of an aid which incorporates these various considerations. The Nottingham Obstacle Detector (NOD) is a small single channel ultrasonic device.
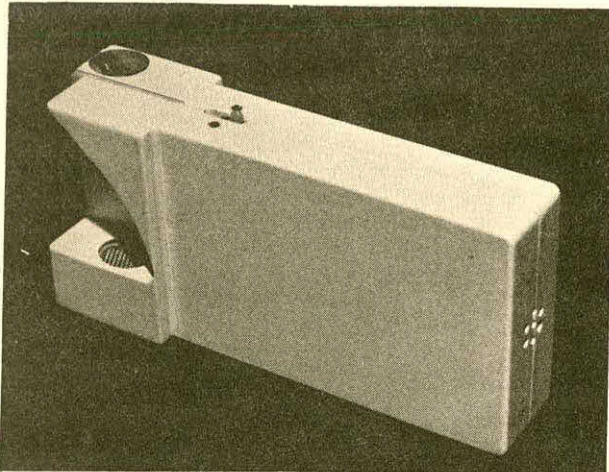
Fig 2: The Nottingham Obstacle Detector

It transmits pulses of high frequency sound (40kHz) ahead of the user and any obstacle which falls within its ultrasonic beam reflects some of this sound energy back to the receiver of the device. The distance of the obstacle is determined by the length of time that an individual sound pulse takes to travel from the aid, to the target, and back again. In the interests of achieving simplicity at the display, the device has only eight possible outputs; each corresponding to a small range of target distances. An obstacle which lies at any distance between zero and 12 inches gives a single unique output at the display. An obstacle anywhere between 12 inches and 24 inches will give another unique output, and so on. Thus, the maximum range of the device (84 inches) is subdivided into eight 12 inch zones, each of which has a unique output assigned to it. Although, in theory, it would be possible to assign any auditory signal to each of the eight outputs, we have chosen the eight notes of a musical scale (with the lowest note representing the nearest distance zone. Since most visually handicapped people are very familiar with the scale configuration, the task of assessing distance is a very easy one. Further, even if the user does not make a positive attempt to learn the association between specific notes and zones, the end of the

sequence of notes is so easy to recognise that stopping just short of collision is a very simple matter.

In order to avoid the confusion brought about by the presence of a number of targets at different distances, the aid signals the range of the nearest target only. The design of the device allows for tactual as well as auditory displays.

NOD is intended to be a secondary aid which will be kept in the user's pocket until the need to make a remote check on the presence and distance of obstacles/landmarks arises. It is hoped that the aid will be of value to long cane users, guide dog owners or individuals with some residual vision (as a means of distinguishing between solid obstacles and shadows. Alternatively, it could be used as a primary aid where movement is restricted to the inside of a building.

It is hoped that, in production, NOD could be manufactured for as little as 75 dollars.

Orientation in the Visually Handicapped: Even if the blind pedestrian is completely protected from physical injury, the success of his mobility is not guaranteed unless he is able to orientate himself with respect to both the near environment (the side-walk boundaries etc) and the more distant environment (the layout of streets, positions of buildings etc). The Blind Mobility Research Unit is attempting to provide solutions to both types of orientation problems.

(1) Orientation with respect to the near environment. Most mobile blind people are able to maintain effective orientation with respect to the near environment by utilising information derived both naturally (ie by hearing, touch and, sometimes, smell) and from their mobility aids. Normally, orientation depends predominantly on being able to localise distant sounds and sound patterns such as those produced by traffic movement. Sometimes orientation is assisted by the observation of the change in self-generated noise patterns which occurs when obstacles reflect back some of this sound. In addition, more complex mobility aids (such as the Binaural Sensory Aid),which effectively signal the relative positions of a number of targets, provide additional orientation information.

However, when the visually handicapped person has inadequate hearing for the purpose of auditory localisation, orientation with respect to the near environment becomes difficult, if not impossible. Our research into the problems of the visually handicapped with hearing loss is described by one of the authors (ADH) elsewhere in these proceedings.

(2) Orientation and movement with respect to the distant environment. When the visually handicapped person sets off for a distant destination, he needs information about the geographical layout of the area to be passed through. This information is essential in order for him to maintain the appropriate

direction towards his goal.

In 1969, Leonard (5) first demonstrated that the necessary information required to ensure continuous correct orientation with respect to the environment could be provided by various types of map. Although Leonard included both word maps and raised spacial maps in his study, subsequent work has concentrated mainly on the latter type.

Our earliest raised maps were essentially tactual versions of conventional street maps with the provision of little additional environmental information. However, it quickly became obvious that the visually handicapped person required information which specifically related to his own form of mobility. For example, the location of pedestrian crossing points, steps, underpasses, traffic signals and bus stops are rarely given on maps for the sighted but information about the location of these features is invaluable in blind mobility. Similarly, important facilities (such as public lavatories), which are easily located by a sighted person, need to be represented on the raised map.

The major problem in the design of a raised map is that of overcrowding. Since it is necessary to use letter codes (usually braille) and other symbolic representations which are large in comparison to the minimum forms capable of being read with vision, maps either become very large or, alternatively, overcrowded. Thus, there has existed a need to ensure that maximum information is conveyed by the smallest effective symbols. Our program of research (initially in conjunction with the University of Warwick, England), has resulted in the development of a working vocabulary of point symbols (for representing point features such as steps, crossing points etc), line symbols (continuous features such as roads, footpaths, railways etc) and area symbols (for parks, lakes, traffic free pedestrian areas etc)(Gill & James, 6). These various symbols are used to make up a master map from which plastic copies can be taken by a vacuum forming process (see Fig 3 for the final product).
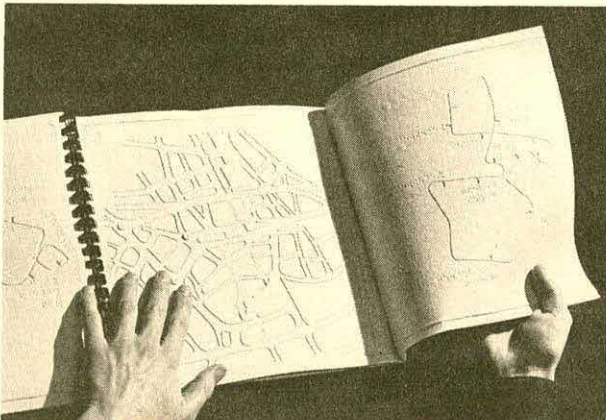
Fig 3: A completed tactual map with overlays

In order to make this manufacturing facility available to orientation and mobility specialists in the United Kingdom, we have developed a kit of parts which makes the construction of the master map a relatively easy task. Further, provision of the various symbols (Fig 4), ensures a high degree of standardisation throughout the country so that visually handicapped people can obtain maps in neighbouring towns and still recognise the symbol code being used.
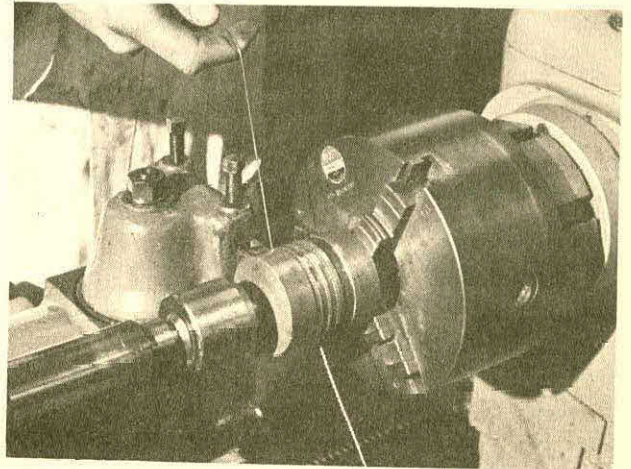
Fig 4: The production of a line symbol by rolling solder wire

Our mapping experimentation has extended beyond simple street areas into shopping complexes, public buildings and to the provision of public transport route information.

Additional Research Interests: We are currently engaged on the study of the mobility capability and requirements of a sample of 1000 visually handicapped people. Data is being obtained on current mobility status and on the potential of the individual to use more advanced mobility aids. Information on the print reading capability, tactual sensitivity and symbol recognition capacity is also being derived. The aim of the study will be to provide information to local social services departments to aid future planning.

References

1. Peake, P. and Leonard, J.A. The use of heart rate as an index of stress in blind pedestrians. Ergonomics 14:189-204, 1971.

2. Heyes, A.D., Armstrong, J.D. and Willans, P.R. A comparison of heart rates during blind mobility and car driving. Ergonomics (in press).

3. Kay, L. Sonic Glasses for the blind: a progress report. AFB Research Bulletin 25:25-58, 1973.

4. Kay, L. An ultrasonic sensing probe as a mobility aid for the blind. Ultrasonics 2:53, 1964.

5. Leonard, J.A. and Newman, R.C. Three types of 'maps' for blind travel. Ergonomics 13:165-179, 1970.

6. Gill, J.M. and James, G.A. Mobility Maps, the choice of symbols. New Beacon 58:35-38, 1974

Title of Paper: ADVANCES IN INFRARED MOBILITY AIDS

Category: (check one)   Device Development /x/   Research Study / /

Brief Description: A description of the operating mode of several electronic mobility aids is provided. A more detailed description of an eyeglass mounted infrared aid is then given. This device is unique in that the entire electronics and power supply packages weigh under 35 grams and are mounted in their entirety upon eyeglass frames. Finally, shortcomings of a prototype version of this aid are discussed and suggested improvements noted.

Intended User Group: Partially and totally blind persons. The device is intended to supplement conventional mobility techniques such as the long cane and guide dog. It's primary function is as an object detector.

Stage of Development: (Check all that are applicable)

- A. Device

     Prototype Development   /x /

     Feasibility Testing   /x/

     Clinical Testing   / /

     Available for Sale (check one)   Yes / /   No /x/

          Price per unit $_____

     Availability of constructional details: See references in this paper. The finalized device will be described in detail in a forthcoming report.

- B. Research Study

     Intended Utilization: _____

     _____
     _____
     _____

     Intended Device Application: _____

     _____
     _____
     _____

     Availability of Intended Device: _____

     _____

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ADVANCES IN ACTIVE RADIATING INFRARED MOBILITY AIDS

by

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Summary - Two commercially available electronic mobility aids, the Binaural Sensory Aid and the C-5 Laser Cane, and several experimental active radiating infrared aids developed by the author are described. The most advanced of these devices is mounted in its entirety upon eyeglass frames. Informal evaluative tests of this device by blind subjects and the Veterans Administration have resulted in the identification of several major operating deficiencies. These deficiencies have been studied at length, and operating specifications for a proposed new eyeglass aid which will overcome them are presented.

Introduction

In the past thirty years more than twenty different electronic mobility aids for the blind have been fabricated. [1,2] The most promising devices have been those which project a beam of sonic waves or infrared radiation and detect the reflected signal when the beam strikes a nearby object. Thus far, only two such active radiating aids have reached the serial production stage, the Wormald Vigilant Binaural Sensory Aid and the Bionic Instruments C-5 Laser Cane.

Both these aids, the development of which has been sponsored in large part by governmental subsidy, were preceeded by handheld units with similar operating principles. The Binaural Sensory Aid is the present version of a handheld device designed and developed by Dr. Leslie Kay in 1962. [3] The origin of the Laser Cane can be directly traced to Dr. Lawrence Cranberg's Signal Corps Obstacle Detector of 1946, a handheld device which employed a chopped beam of light and a novel triangulation scheme to detect objects. [4] Cranberg's device was followed by a series of more advanced handheld active radiating optical mobility aids developed by Bionic Instruments, Inc. under the able guidance of J. Malvern

Benjamin, Jr. and with the support of the Veterans Administration. [5]

Kay and Benjamin have both concluded that a separate handheld mobility aid is not necessarily the most desirable operating configuration. Both have advanced to other configurations, and Kay's present aid is partially installed in modified eyeglasses and Benjamin's is installed in the upper portion of a modified mobility cane.

There are several significant operating differences between the Binaural Sensory Aid and the Laser Cane, not the least of which is that the former detects objects by means of a wide cone of ultrasound and the latter by means of three narrow infrared beams. The Binaural Sensory Aid emits its ultrasound cone from an ultrasonic transducer mounted at the center of a modified spectacle frame. Reflections from objects are received by two similar transducers on either side of the first. The Laser Cane emits narrow beams of infrared (905 nanometers) from three semiconductor lasers located in a nacelle near the crook of the cane. Reflections are received by three detectors in a second nacelle nearer the cane's midpoint.

The Binaural Sensory Aid supplies information about the range to a target in the form of a complex, variable audio signal coupled to both ears of the user by means of thin plastic tubes. The pitch of the tone supplies range information (the lower the pitch the nearer

the object) and the "smoothness" or "roughness" of the tone supplies information about the surface of the object.

The Laser Cane provides indirect information about the range to a detected target in the form of both audio and tactile stimuli.[5] A tactile output in the form of a poking action against the ball of the index finger carrying the cane denotes an object directly in front of the cane. Audible tones of 2200 Hz and 1200 Hz emitted by a small speaker in the cane indicate the detection of, respectively, a target above the tip of the cane and the presence of a hole or drop-off. The latter detection mode is implemented by a detector which constantly monitors the laser beam projected downward in front of the cane. If the beam passes into a hole or drop-off (such as a curb), the detector loses the signal and triggers a 1200 Hz tone generator.

The differences in the man-machine interface employed by these two aids are particularly significant. The Binaural Sensory Aid supplies an analog signal which is rich in information about the environment it detects. The Laser Cane supplies a simpler go/no-go signal about the presence of objects. This topic will be considered in more detail later.

Both the Binaural Sensory Aid and the C-5 Laser Cane are now in serial production. The Veterans Administration has procured 35 Laser Canes from Bionic Instruments and has ordered 50 more. At least 12 of these canes are now in the field. The present cost of the Laser Cane is $1950. The Binaural Sensory Aid is in wider use. It is manufactured in New Zealand by Wormald Vigilant, Ltd. and is available from its United States distributor, Telesensory Systems, Inc., for $1850. The price for each aid does not include fees for necessary training or, in the case of the Binaural Sensory Aid, audiometric tests.

Handheld Infrared Mobility Aids

The author has undertaken the design of a series of miniaturized infrared active radiating mobility aids which differ in several fundamental respects from the Laser Cane and the Binaural Sensory Aid.[2] The first aid in this series was assembled in 1966 in the form of a miniature handheld device about the size of a pack of chewing gum (2.6 cm x 2.6 cm x 9.4 cm). The aid projected a narrow beam of near infrared radiation (905 nanometers) from a gallium arsenide light emitting diode (LED) and detected the radiation reflected from targets

with a silicon detector. The detection of a target was indicated by an audible tone. This aid was informally evaluated by more than 50 blind subjects in 1966 and 1967. The tests were conducted with blind adults in several cities in the United States, at the Texas State School for the Blind, the *Ecole des Garcons Aveugles* in Saigon, Republic of Viet-Nam, and the Saigon School for Blind Girls.

In the limited role as an obstacle detector, this aid permitted blind subjects to navigate through mazes of desks, chairs, and other obstacles with generally good success. The aid supplied a go/ no-go output with no ranging information and learning time was short. In a typical case, a subject would be given the aid, instructed about its operating principles for a few minutes, and assigned a maze task. Most subjects would complete the task with few, if any, collisions. Fig. 1 shows a student at the *Ecole des Garcons Aveugles* in Saigon using this aid to detect a chair.

Figure 1. Miniature handheld infrared mobility aid.

These early tests demonstrated that an aid employing a relatively low-powered LED could detect many types of targets within a 3 meter range. The tests also demonstrated a convincing need for some kind of range information. Accordingly, a second aid was designed which employed completely new circuitry and an adjustable triangulation ranging feature. This aid is shown in Fig. 2.

The new aid weighed 140 grams or 40 grams more than the original aid. Although it occupied twice the volume of the original aid, it was still very compact and measured 3 cm x 5.5 cm x 8 cm. The LED was installed in a movable lens tube connected to a spring and plunger. Normally the lens tube was parallel to a
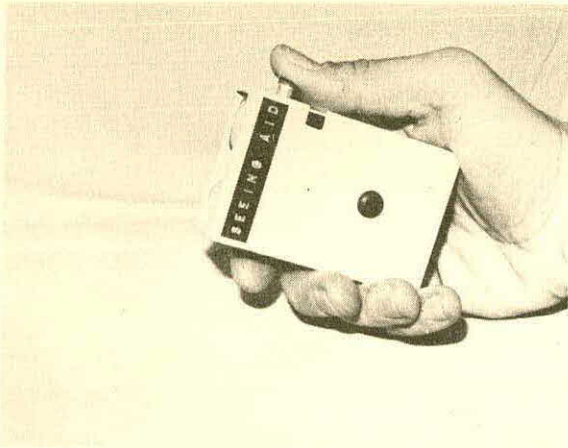
Figure 2. Miniature infrared mobility aid with adjustable triangulation ranging feature.

Figure 3. Self-contained non-ranging eyeglass-mounted infrared mobility aid.

similar but fixed lens assembly housing the detector. Depressing the plunger, however, rotated the LED lens tube and varied the intersection region of the transmitted beam and the detector's field of view. Since the signal from a target would reach an amplitude peak during the rotation of the LED lens tube, an approximation of the range to the target could be deduced from the position of the plunger. For example, a signal peak which occurred at the midpoint in the plunger's up-down cycle indicated a target range of approximately 1.5 meters.

This new aid provided substantially more information than the preceeding unit, but tests with blind subjects revealed several important drawbacks. These included the handheld operating format, the presence of the earphone cord, and the loss of ambient auditory cues caused by the presence of the earphone in one ear. It was therefore concluded that a third aid should be designed. In order to alleviate many of the drawbacks of the two handheld aids, the new aid would be housed in eyeglasses.

An Eyeglass-Mounted Mobility Aid

Three non-ranging infrared mobility aids mounted in their entirety upon eyeglass frames were assembled in 1971. One of these aids is shown in Fig. 3.

The eyeglass aids incorporated considerably improved and more miniaturized circuitry. The transmitter and receiver systems are each housed in identical

1.3 cm x 9 cm tubes on either side of the eyeglass frames. Each tube contains its own optical system, electronic circuitry, on-off switch, and battery. The combined weight of the transmitter and receiver is less than 85 grams.

The eyeglass aids employ a simple triangulation method to detect targets. As shown in Fig. 4, objects within the detection region reflect infrared from the transmitter back to the receiver. A detailed technical description of these aids is found elsewhere.[2,6]
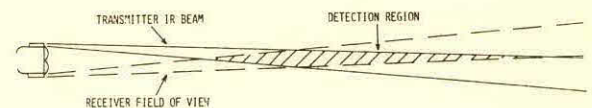
Figure 4. Triangulation detection method used by the eyeglass infrared mobility aids.

One of these eyeglass aids has been tested with several blind subjects in Albuquerque, NM, and the remaining two aids were purchased by the Veterans Administration at cost ($225 each). These aids were subsequently tested and informally evaluated at the Central Rehabilitation Center for the Visually Impaired and Blinded Veterans (Veterans Administration Hospital, Hines, Illinois).[7] This evaluation identified several important operating deficiencies and these included:

1. The aids are relatively fragile in their present form.

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2. The alignment of the transmitter and receiver optics is very critical.

3. The aids provide no range information.

4. The audible signal is difficult to hear in a moderately noisy environment.

5. The detection range of the aids is frequently less in real-world conditions than in laboratory test conditions.

Though these operating deficiencies are serious, the successful miniaturization of the aids, their laboratory performance, and results of tests with blind subjects are sufficiently encouraging to warrant further development. The man-machine and engineering considerations for a much improved version of the basic infrared eyeglass mobility aid are described next.

Proposed Eyeglass Mobility Aid

The design of a prosthetic device must involve both man-machine and engineering considerations. The evaluation of the prototype eyeglass mobility aids showed that the existing device falls short in both areas. The deficiencies of the existing prototype aids have been studied in detail, and preliminary operating specifications for a proposed new eyeglass aid have been developed and are described below.

1. Man-Machine Considerations

The primary man-machine considerations are body-mounted versus hand-carried aids, analog versus go/no-go output, and auditory versus tactile stimulus. There are other man-machine considerations (e.g. cosmetic acceptability) but these three are the most important.

a. Body-Mounted versus Hand-Carried

Many workers have shown a preference for body-mounted mobility aids with the head being the most common location.[2] Blind subjects who have tested hand-carried aids have frequently criticized the need to carry the device since it restricts the use of one hand. Additional criticisms concern the need for manual scanning to look for targets. An important exception to both these criticisms is the Laser Cane, a dualistic mobility aid.

b. Analog versus Go/No-Go Output

Since the velocity of a sonic wave is much less than that of an infrared wave, the implementation of an analog output is much easier with the former than with the latter. It is therefore easier to provide the blind user with considerably more information about his environment with the sonic approach. Whether or not a large quantity of information is needed for point-to-point traveling is altogether another question, and this topic has been discussed in detail elsewhere.[2]

c. Auditory versus Tactile Stimulus

Auditory stimulus is generally simpler to implement than tactile stimulus, but it may block part or even all of the blind user's normal acoustical cues. The blockage can be in the form of earphones, inserts, or tubes which physically obstruct all or part of one or both auditory canals or constant auditory signals which mask ambient cues.

Auditory stimulus, however, is advantaged by its increased information bandwidth. For this reason it is well suited for use with aids which provide an analog output. Tactile stimulus can also provide limited analog information by varying the rate of stimulation according to the range to a target. For example, a slow rate of stimulation may denote a far target and a fast rate a near target.

Both auditory and tactile stimuli have relative advantages and disadvantages, and at this point it is safe to say that neither has yet been proved superior to the other.

After a careful study of these man-machine considerations, it has been decided that the proposed new aid will be eyeglass mounted. Like the prototype aids, the new aid will be totally self-contained and will have no connecting wires or pocket-carried electronics and battery package. The initial device will have an audible go/no-go output. A tactile stimulus will be considered for evaluation if the tests with the proposed aid are sufficiently encouraging.

2. Engineering Considerations

The proposed new mobility aid must incorporate the following features:

1. Sturdy construction.

2. Fixed transmitter and receiver alignment.

3. A range detection method.

4. Adjustable output volume.

5. Adequate detection range.

Utilization of lightweight metal or composite frames will provide a reasonably sturdy device. Alignment problems will be alleviated by mounting the transmitter and receiver optics directly to the front of the frame instead of the sides. An adjustable output volume control will be provided by an additional stage of amplification in the receiver.

The range detection system will utilize a triangulation scheme wherein two receivers are operated in conjunction with a single transmitter to provide three tones indicative of near, medium, and far targets. A simple optical arrangement will cause the receiver's fields of view to intersect the transmitted beam in two zones 1 and 3 meters from the aid for the near and far detection zones respectively. An overlap of the two fields of view will provide the medium range detection zone.

Improving the detection range of the aid is more involved since a consideration of the reflectance of the target is required. A standard form of the optical radar range equation for a diffuse target (lambertian reflector) which intercepts the entire transmitted beam is

$$R = \sqrt{\frac{P_o}{P_{th}} \frac{A_{rec} \rho \tau}{\pi}} \qquad \text{Eq. 1}$$

where,

P_o is the transmitted optical power,
P_{th} is the receiver threshold,
A_{rec} is the area of the receiver,
ρ is the reflectance of the target,
τ is the optical attnuation.

Eq. 1 gives only approximate results and a correction factor $\rho *$ which more accurately characterizes the nature of the target's reflectance can be incorporated to give

$$R = \sqrt{\frac{P_o}{P_{th}} (A_{rec} \rho * \tau)} \qquad \text{Eq. 2}$$

It is possible to assign values for all the terms in Eq. 2 except the ratio of P_o/P_{th}. The following requirements have been imposed for the proposed aid:

1. A_{rec} is 0.785 cm^2 (1 cm dia)

2. τ is 0.85

3. The aid shall detect a worst-case target at R of not less than 1.5 meters (two paces). A worst-case target is defined as a surface at a 45° angle with respect to the oncoming beam which intercepts the entire beam and reflects 10% of the radiation into a lambertian

distribution. $\rho *$ of this target is 0.026

Solving for P_o/P_{th} gives a minimum required value of 1.3 x 10^6. The prototype aids have a P_o/P_{th} of 7.5 x 10^5 and give a detection range of 1.1 meters against the worst-case target. This value has recently increased to 3 x 10^6 by means of a phase-locked loop to reduce the adverse effects of noise. This gives a range of 2.3 meters against the worst-case target.

Conclusion

A completely self-contained infrared eyeglass-mounted mobility aid which provides range information is technologically feasible.

References

1. Nye, P.W. and Bliss, J.C. Sensory aids for the blind: A challenging problem with lessons for the future. Proceedings of the IEEE 58:1878-1898, 1970.

2. Mims, F.M. Energy radiating mobility aids for the blind: Design considerations and a progress report on an eyeglass mounted infrared aid. Research Bulletin (AFB) 27:135-158, 1974.

3. Kay, L. Ultrasonic spectacles for the blind. Proceedings of the International Conference on Sensory Devices for the Blind, London: St. Dunstan's, 275-292, 1966.

4. Cranberg, L. Sensory aids for the blind. Electronics, p. 116, March 1946.

5. Benjamin, J.M., Jr. A review of the Veterans Administration blind guidance device project. Bulletin of Prosthetics Research 10-9:63-90, 1968.

6. Mims, F.M. LED Circuits and Projects. Indianapolis: Howard W. Sams Publishing Company, 1973.

7. Farmer, L.W. and Whitehead, J.J. Preliminary Investigation and Assessment of E-2 Seeing Aid, August 23, 1973.

Title of Paper: "REHABILITATION INSTITUTE SERVO CONTROLS FOR THE SEVERELY HANDICAPPED DRIVER"

Category: (check one)   Device Development /x̄ /   Research Study / /

Brief Description: The Rehabilitation Institute has developed a low force servo operated brake and throttle control for severely handicapped drivers lacking strength and range of motion to operate presently available hand controls.   The new control utilizes existing patients covering direct connection linkage to the power brake servo valve, thus eliminating the awkward foot pedal push rods.   Other Institute Developments will include joy stick steering control, transfer aids, and wheelchair storage devices.   Emphasis is being placed on ease of installation and minimal vehicle modification to reduce cost and improve vehicle resale value.

Intended User Group: Quadraplegic drivers and all physically impaired drivers desiring low force operation, the safety of an auxiliary vacuum supply, and elimination of the awkward foot pedal push rods.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   /x /

Feasibility Testing   /x̄ /

Clinical Testing   /x /

Available for Sale (check one)   Yes /x̄ /   No / /

Price per unit $ 750.00

Availability of constructional details:

B. Research Study

Intended Utilization: _____

_____
_____
_____

Intended Device Application: _____

_____
_____
_____

Availability of Intended Device: _____

_____

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REHABILITATION INSTITUTE SERVO CONTROLS
FOR THE SEVERELY HANDICAPPED DRIVER

by

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Summary - Finger-operated servo control modules with braking force and dis-
placement adjusted to the driver's abilities offer driving capabilities to
the handicapped not able to operate conventional hand controls. Direct
connection of the servos to the power brake booster and to the carburetor
eliminate the need for conventional push rods and linkage to the foot
pedals. Safer driving is possible with this smooth positive control which
includes an auxiliary vacuum power source for operating the brakes in
case of engine stoppage and resulting vacuum failure. Addition of optional
modules for cruise control, control of lights, steering, wipers, seats,
etc., will enable this modular servo concept to offer completely independent
automobile travel to handicapped people presently unable to drive.

Purpose

The purpose of this paper is to present
our newly developed servo connected automobile
driver controls and explain how they meet the
needs of the severely handicapped driver.

Conventional Add-on Hand Controls

The automobile plays a very important role
in the total program of mobility training and
rehabilitation of a physically handicapped
person. Case studies have disclosed many
situations in which disabled persons were
given complete vocational rehabilitation and
job training only to find they could not make
use of their training because of their inabi-
lity to go to and from places of employment
independently (1).

According to the Veterans Administration,
who is evaluating the quality of performance
and safety of present driver aids (2), at least
19 makes of traditional add-on automobile hand
controls are available which enable a person
with paralyzed legs to push the foot pedals
with his hands (3). This is accomplished by
using levers and push rods which are clamped
or bolted to the normal pedals as shown in
Figure 1. The resulting system requires a
large force and displacement to operate the
controls through the normal foot pedals.

This type of control is good for a para-
plegic with strong arms or any driver with
reasonably strong arms provided the car is
equipped with power brakes. However, many

potentially able handicapped drivers lack the
strength or range of motion to use this add-
on type control. For them a control which
would bypass the normal pedals and connect
directly to the servo valve of the brake
system and to the carburetor would offer a
system matched to their capabilities. Such a
direct connection would also eliminate the
need for linkage between the hand lever and
the foot pedals, which can cause interference
to a non-handicapped driver of the vehicle (4).

An Advanced Control Concept

Dozens of hand-operated driver control
systems and prototypes have been made to
connect directly to the carburetor and brake
servo valve. Many of these sophisticated
integral systems were designed by major auto-
mobile firms for possible use on production
model cars (Figure 3). However, none of
these are now available domestically.

In addition to offering strictly hand
operation, these integral controls offer
shorter reaction time inherent in hand opera-
tions as compared to foot operations, and
decreased lost time which is caused by the
need to transfer a foot from the accelerator
to the brake and to take up any free travel
of the brake pedal. The anatomical control
and feedback loops are shorter for a hand
control. The hand is thus able to effect a
better control of the vehicle than the foot,
provided an adequate control site and
control system are available.

Conventional Power Brake System

The conventional power brake booster
uses engine vacuum as a power source. The
booster consists of a diaphragm, a servo
valve, an enclosure, and connections to the
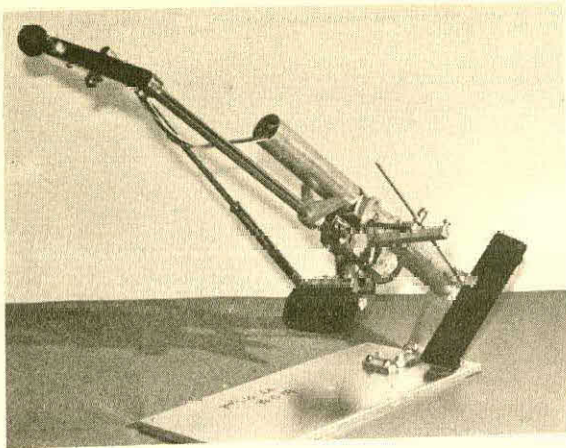brake pedal linkage and master cylinder as
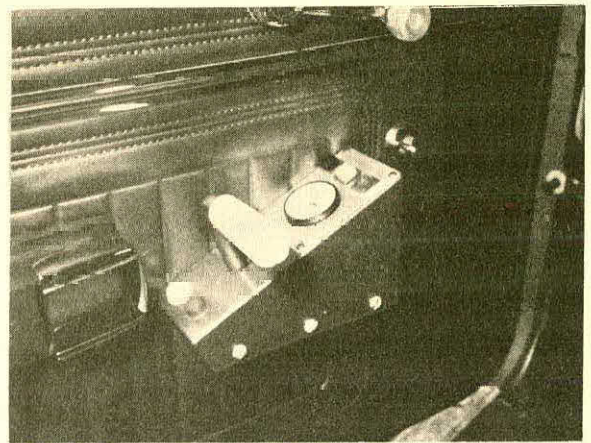
Fig. 1 Examples of typical add-on hand controls

Fig. 2 Rehabilitation Institute door mounted servo hand control module

*Photograph courtesy of Ford Motor Company

Fig. 3 Example of a pistol grip type integral hand control

shown in Figure 4. Engine vacuum is connected to both sides of the diaphragm. Atmospheric air is modulated by the servo valve to one side of the diaphragm as a direct function of foot pedal force vs. hydraulic system pressure. The pressure differential times effective diaphragm area yields the power booster force which is added to the direct foot pedal force on the master cylinder as shown in Fugure 5.

The servo valve is a floating force proportioning device between the master cylinder

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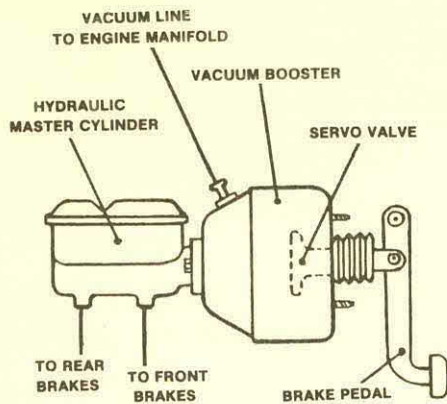
Fig. 4   Schematic of regular power brake system
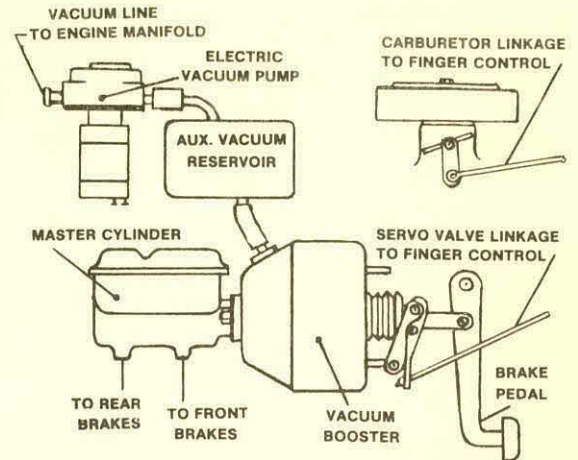
Fig. 7   Schematic of finger control brake system
with safety backup
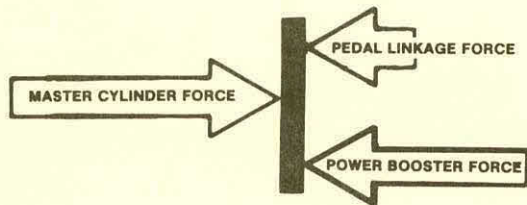
Fig. 5   Standard servo value force balance

Fig. 8   Finger control servo valve force balance
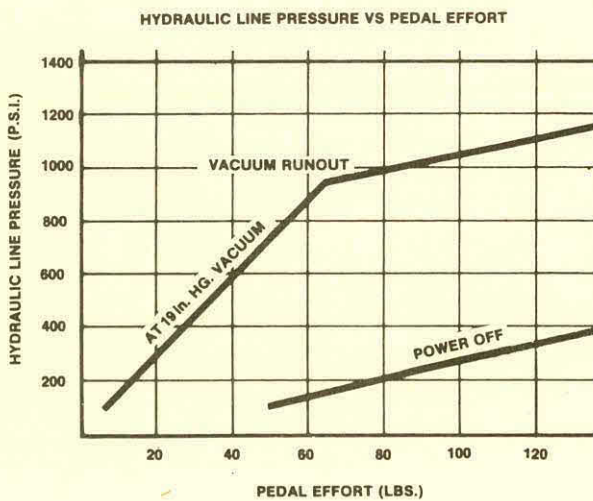
Fig. 6   Typical characteristics of standard power brakes
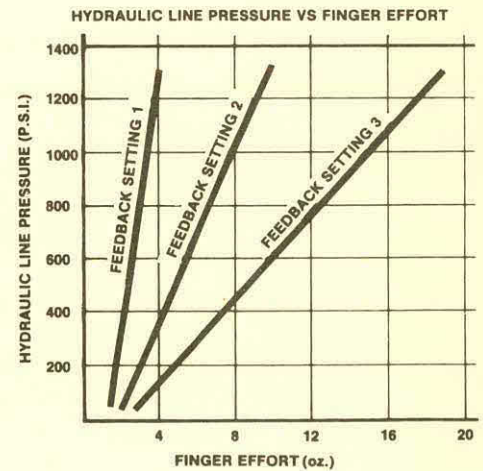
Fig. 9   Characteristics of finger control
power brakes

on one side and the foot pedal and power booster on the other side. This servo valve arrangement amplifies the foot pedal force by a constant factor until vacuum runout occurs.

At vacuum runout maximum diaphragm differential pressure and thus maximum booster force output exist. Additional hydraulic line

pressure is obtainable only from increased pedal force. Figure 6 shows the point of vacuum runout on a curve of foot pedal force vs. hydraulic line pressure. During engine failure or other no-vacuum conditions, direct force from the operator's foot pedal may be sufficient to give normal braking. A handicapped operator with weak legs or hand controls needs an auxiliary vacuum source as a

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safety feature.

It should be noted that locked wheels occured at 50 MPH on dry pavement with 900 psi of hydraulic line pressure when testing the vehicle used for the control system prototype. Figure 6 shows that this hydraulic pressure is obtained with 65 pounds of foot pedal force when 19 inches of mercury vacuum is available to the booster. This points out the need of an auxiliary vacuum source, particularly for the handicapped driver. Figure 6 also shows that under the same conditions with no vacuum, a locked wheel condition could not occur due to the excessive foot effort required to obtain 900 psi.

Rehabilitation Institute Hand or Finger Operated Power Brake System

Figure 7 is a schematic diagram of the Rehabilitation Institute's finger controlled power braking system using a mechanical servo connection. The finger control linkage is connected directly to the floating servo valve in the power brake unit. Quicker response is obtained with this integral finger control system than with the conventional foot pedal system because the free travel and dead time have been reduced. A safety back up system for the finger controlled system consists of an electric vacuum pump, reservoir, and warning lights. The safety system will provide uninterrupted braking if normal vacuum source fails. This safety feature exists for the foot pedal system as well as the finger control since either system can be used to control the brake of a vehicle equipped with the servo brake and throttle control.

A direct feedback of hydraulic system pressure and displacement are transmitted to the driver by means of the direct linkage between the servo valve and the driver's finger control lever. Countless experiments have been run in an attempt to eliminate the need for these direct feedbacks from the brake system. Artificial "feel" or feedback fails to give the driver the accurate instantaneous information required to coordinate his control action with the vehicle response to produce the desired smooth braking action.

It is extremely important that the feedback be a function of the specific characteristics of that vehicle's brake system. The non-linearities of the brake system, such as those due to temperature, brake lining wear, drum and shoe action, etc., all present an unsurmountable task in producing an artificial feedback. A Ford Motor Company patented servo valve connection linkage used in the Rehabilitation Institute control gives accurate feedback for the pressure and displacement variables. Thus an excellent "feel" is obtained even with the greatly reduced effort and travel required at the control site or driver-vehicle interface.

Practically all of the force to operate the brake master cylinder with the finger controlled servo system comes from the vacuum power booster as shown in Figure 8. The finger control lever force and displacement requirements can be independently selected without compromising either, merely by adjustments in the patented linkage. This allows a choice of characteristics to give a system matched to the handicapped driver's capabilities, Figure 9.

Driver-vehicle control interface occurs at the door, steering column, or center seat mounted finger control lever module. Figure 2 illustrates door mounting of the control module which contains the system indicator lights, a vacuum monitoring guage, and the brake and throttle lever with dimmer switch. Since all connections to the control module are flexible, the location may be easily adjusted to suit the needs and capabilities of the handicapped driver. The flexible connections permit the door mounting position which allows the driver to use the arm rest and operate the control lever with wrist or finger action. Or in the case of quadriplegia, the control can be operated with arm movement on the arm rest if wrist action is not possible.

Braking action results when the control lever is moved rearward. This choice avoids the self-energizing effect produced by a very sensitive brake control operating in the forward direction. The self-energizing action, which is considered undesirable or dangerous, is caused by the operator's body or arm inertia increasing the braking action during braking deceleration. Self-energizing action with a sensitive control system would create an unstable braking situation.

Accelerator and Dimmer Switch

The accelerator and dimmer switch are incorporated in the brake control module. The dimmer is operated by a momentary contact button on the control lever which operates the hi-low beam relay. The brake control lever advances the throttle when moved forward, opposite to the braking control action. The control lever was connected directly to the throttle linkage on the first prototype. This was found to require excessive force and travel when compared to the action required for braking. The throttle is now operated by an electrical servo which ties into the vacuum powered speed control to be furnished with the control module kit. Thus the Stop-Go controls of the adapted automobile are both servo connected, offering completely adjustable characteristics to the control lever module. The automatic speed control incorporated into the control system is helpful in maintaining uniform speed and reducing driver fatigue caused by a need to hold an accelerator in a fixed position.

Proposed Additional Control Modules

To complete a line of controls and transfer aids to enable a severely handicapped person become an independent driver, modules and devices are required to give: 1) Linear or twist steering control with variable ratio power steering (5); 2) Remote shift selection; 3) Compact, conveniently located auxiliary switch panel for use with normally mounted dash controls; 4) Driver's body restraint and stabilizing systems; and 5) Wheelchair loading and driver transfer devices (6). The Rehabilitation Institute is proceeding with the planning and design of the above driver controls and aids so that the necessary driving equipment can be prescribed and purchased to suit the requirements of each handicapped individual. Design of the equipment will be accomplished to provide the greatest mounting flexibility and vehicle transferability compatible with functional dependability. Thus equipment can easily be installed to suit the driver's needs and easily transferred to another vehicle with minimum residual effects on the vehicle.

The first production lot of Rehabilitation Institute servo connected controls has been contracted for scheduled completion in June of 1975. These first units will be laboratory and road tested by the Veterans Administration and the Rehabilitation Institute. Following test approvals the first in the series of control modules should soon be marketed by an independent manufacturer and distributor.

References

1. Charles R. Poor, "Driver Evaluation and Training in a Comprehensive Rehabilitation Center". Scand J Rehab Med 4:182-187, 1972.

2. "VA Standard Design and Test Criteria for Safety and Quality of Special Automotive Driving Aids for Standard Passenger Automobiles". VAPC-A-7502-7, Veterans Administration Prosthetics Center, New York, N.Y., Feb 1975.

3. Interview with Anton Reichenberger, Staff Engineer, Bioengineering Research, Veterans Administration Prosthetics Center, New York, N.Y. Feb 20, 1975.

4. David H. Harden and David M. Tenniswood, "Advanced Concepts in Automobile Driver Controls". Society of Automotive Engineers Technical Paper No 730472, May 14-18, 1973.

5. Peter Bray and Don M. Cunningham, "Vehicles for the Severely Disabled". Rehabilitation Literature 28:98-109, 1967.

6. David H. Harden, MSME, and Victor J. Nyboer, M.D., "Device for Loading a Wheelchair into an Automobile Trunk". Archives of Physical Medicine and Rehabilitation, Vol 53, Feb 1972.

Title of Paper: LICENSED MOTOR VEHICLES FOR HANDICAPPED DRIVERS

Category: (check one)   Device Development /✓/   Research Study /_/

Brief Description: The paper deals with a wide variety of commercially
available adaptive automotive control equipment used by handicapped drivers
in the operation of standard motor vehicles. It also covers van-type vehicles
for the handicapped, and the "newer" type control systems in development by
VAPC and other parties.

Intended User Group: Handicapped Drivers Licensed by State Authorities
to operate Motor Vehicles.

Stage of Development: (Check all that are applicable)

A. Device

Prototype Development   /✓/

Feasibility Testing   /_/

Clinical Testing   /✓/

Available for Sale (check one)   Yes /✓/   No /_/

Price per unit $ Depending on type of equipment

Availability of constructional details:

B. Research Study

Intended Utilization: _____

Intended Device Application: To provide handicapped drivers
with a wide variety of special control equipment.

Availability of Intended Device: Adaptive Automotive Control
Equipment.

For further information, contact: Name Anton J. Reichenberger, Project Manager
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LICENSED MOTOR VEHICLES FOR HANDICAPPED DRIVERS

by

Anton J. Reichenberger
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Handicapped drivers operate motor vehicles generally for reasons similar to non-handicapped drivers, they want to drive because they need to drive. By adapting special hand controlled systems to standard motor vehicles, many disabled individuals have again become productive participants of our society. Mobility usually makes the difference between doing and not doing. We examine the "state of the art" of available adaptive automotive equipment, and the need for a standard to provide devices that meet minimally acceptable levels of safety, quality, and performance. Recent congressional action prompted the development of a VA standard for adaptive automotive equipment.

Congressional action resulting in PL-666 charged the Veterans Administration with the development of a standard applicable to a wide variety of available adaptive automotive control equipment for handicapped drivers. The development of a workable document for the procurement of adaptive automotive driving aids for VA beneficiaries became an urgent request in order to assure maximum safety to handicapped drivers as well as the general public. Our correspondence with the respective state driver-licensing authorities verified the lack of standards and specifications for the assortment of adaptive automotive control equipment on the market. Surely we all agree that an industry providing useful products and services for handicapped drivers must have an equally strong interest in public safety. Consequently, the VA Standard defines minimally acceptable levels of safety, quality, and performance to provide some guidance to manufactures and installers of adaptive driving aids.

The first phase of our development program called for an evaluation of commercially available items, and we purchased driving aids from sixteen (16) known manufacturers. An engineering analysis as part of the evaluation resulted in recommending five (5) adaptive hand control systems out of seventeen (17) for road testing, conducted in conjunction with volunteer drivers from the New York Chapter of the Eastern Paralyzed Veterans Association.

To fully understand the mechanics of hand control systems used by handicapped drivers, we classify them into (4) four types, i.e., the push-pull, push-right angle pull, push-twist, and the crank type. For uniformity in description, we assume that each control is left-hand operated.

I. PUSH-PULL TYPE CONTROL SYSTEM (FIG. I)

To apply the brakes, the driver pushes the operating lever away from him or her in a direction parallel to the steering column, whereas actuation of the accelerator is achieved by pulling the same lever in exactly the opposite direction towards the driver.
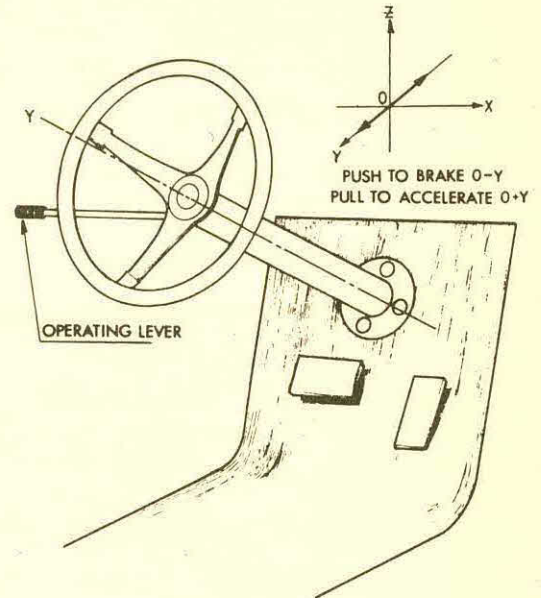

FIG. 1 PUSH-PULL TYPE CONTROL SYSTEM

2. PUSH-RIGHT ANGLE PULL TYPE CONTROL SYSTEM (FIG. 2)

To apply the brakes, the driver pushes the operating lever away from him or her in a direction parallel to the steering column, whereas actuation of the accelerator is achieved by pulling the same lever in a direction perpendicular to the steering column and towards the driver.

3. PUSH-TWIST TYPE CONTROL SYSTEM (FIG. 3)

To apply the brakes, the driver pushes the operating lever away from him or her in a direction parallel to the steering column, whereas actuation of the accelerator is

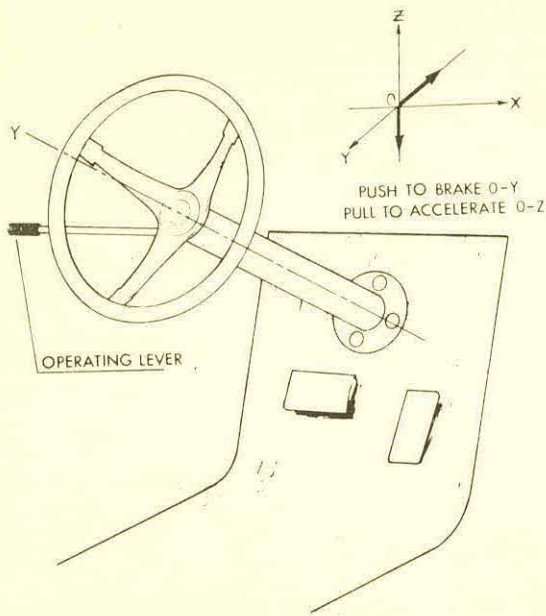achieved by counterclockwise rotation of the handgrip.

erator is achieved by cranking the handle in the opposite direction and towards the driver.
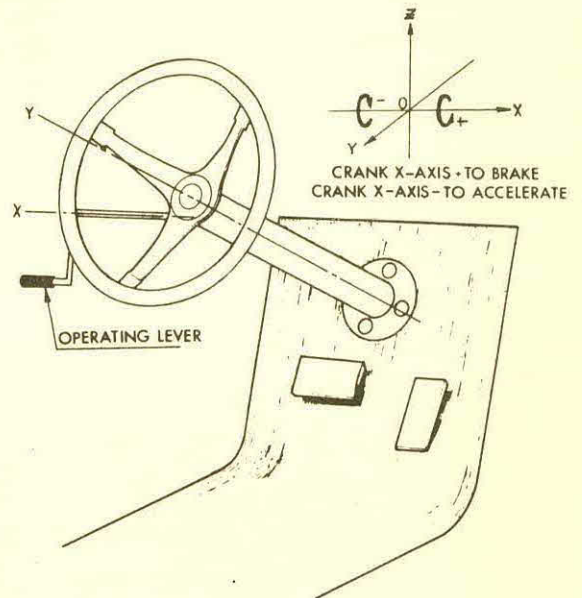

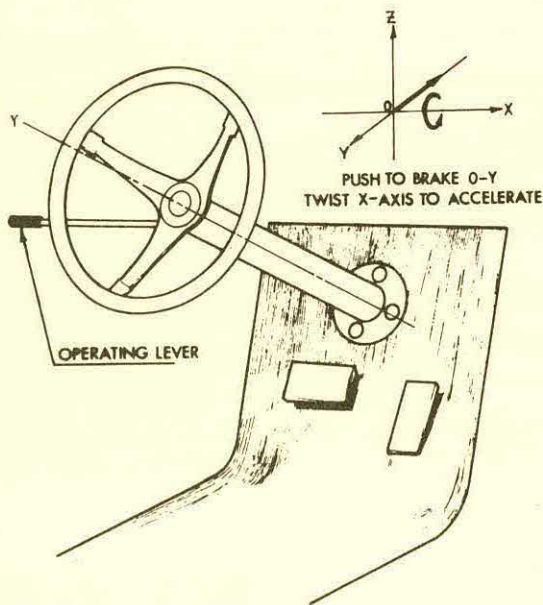FIG. 2 PUSH-RIGHT ANGLE PULL TYPE CONTROL SYSTEM

FIG. 3 PUSH-TWIST TYPE CONTROL SYSTEM

4. CRANK TYPE CONTROL SYSTEM (FIG. 4)
To apply the brakes, the driver cranks the handle in the clockwise direction away from him or her, whereas actuation of the accel-

FIG. 4 CRANK TYPE CONTROL SYSTEM

Most hand control systems are manufactured and sold supposedly to fit the entire spectrum of motor vehicles on the market, i.e., compacts, standard-size sedans, luxury-type automobiles, vans, trucks, etc., as long as the vehicle is equipped with an automatic transmission. Experience gained from working with adaptive automotive devices has taught us that this is an assumption that often leads to substantial problems. Frankly, the variety of automotive styles combined with frequent design changes of the passengers compartment interior require distinct individual considerations to complete the installation of a particular hand control system satisfactorily.

FIG. 5 shows an example of a push-pull hand control system, after installation to a road test vehicle.

It would be unrealistic to imply that a specific set of hardware fits all motor vehicles, and we can readily symphatize with a driving aid manufacturer trying to market one control system for all automobiles. Our standards address themselves to the installation of driving aids specifically, as one of many pertinent points to assure safety, quality, and performance. The development of documentation has reached a point where distribution of VA STANDARD DESIGN AND TEST CRITERIA FOR SAFETY AND QUALITY OF SPECIAL AUTOMOTIVE DRIVING AIDS (ADAPTIVE EQUIPMENT) FOR STANDARD PASSENGER AUTOMOBILES, VAPC-A-7502-7 has been made to the adaptive automotive equipment industry, as well as a number of other interested parties. In future work with driving aid manufacturers, we

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hope to inspire a free flow of information that is necessary to provide handicapped drivers with the best adaptive equipment and installation services possible. Aside from our primary mission to serve the handicapped, we also share a responsibility to protect the public from shoddy and unsafe automotive equipment.
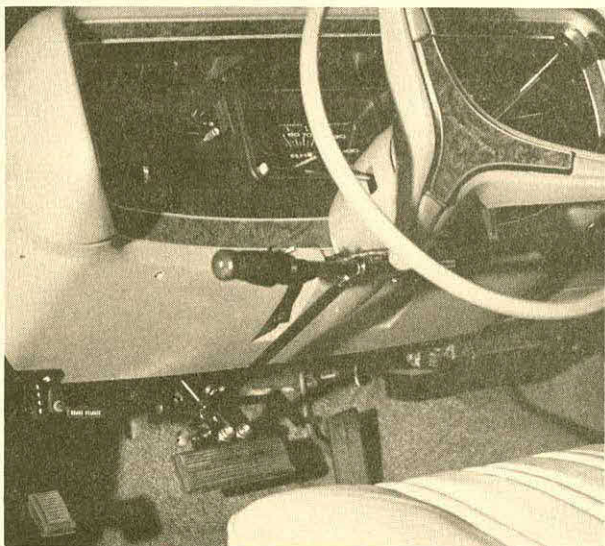

FIG. 5 PUSH-PULL HAND CONTROL AFTER INSTAL-
LATION TO A ROAD TEST VEHICLE

Without attempting to present an actual version of the VA standard here, a number of related key questions are listed below. As it is easily seen, a negative answer to any of these questions would almost always lead to rejection of the automotive aid, since components not in compliance with VA standards are not recommended for purchase by beneficiaries. Specifically, some of the questions we raise are as follows:

1. Are driving aids within reach of handicapped driver when lap and shoulder belts are securely fastened?

2. Are there reflective surfaces on the installed equipment that tend to reflect sunlight into the driver's eyes?

3. Are there sharp edges or projections on the equipment that might cause undue injury in the event of impact?

4. Does any part of the equipment deform permanently when it is used in simulating normal driving conditions?

5. Is rust or corrosion found on any part of the assembled and installed equipment?

6. Are all fasteners used in assembly and installation of the driving aid securely tightened?

7. Are all electrical components safe from accidental shock, short circuits, sparks, etc.?

8. Does the installation permit conventional use of the vehicle by normal drivers?

9. If the installed driving aid is a brake and accelerator hand-control system, does it remain in the neutral position in the hands-off mode?

10. Are the motions required to actuate brake and accelerator controls distinctly different?

11. Can the accelerator be actuated by applying a force in the forward direction away from the driver?

12. Has the driving aid manufacturer provided adequate instructions to permit proper installation of the equipment to the motor vehicle?

13. Does the installed equipment interfere with the collapsible feature of the automotive steering column?

14. Did the source of the driving aid provide instructions on its proper use in the motor vehicle?

15. Did the installation of the driving aid result in unnecessary modifications of the vehicle?

16. Was the driving aid inspected for quality and proper functioning by the manufacturer?

17. Is a statement of warranty included in the purchase of the driving aid?

To expand our discussion of licensed motor vehicles for handicapped drivers more fully, we must include the van type automobile, intended to give maximum mobility to many handicapped drivers that either cannot transfer from their wheelchairs into standard passenger automobiles, or have selected to operate a light truck type vehicle for a specific reason, e.g., business, travel, camping, etc.. There are a number of adaptive equipment manufacturers modifying standard van-type vehicles for operation by handicapped drivers. The interior of these motor vehicles can be supplied to resemble a panel truck, or can be elegantly finished for maximum utility and personal comfort, depending on the individual's preference. Naturally, each van must be equipped with a wheelchair-access system, and again there are a number of devices on the market.

There are rear-loading and side-loading wheelchair lifts. Most are fully automatic

and can be completely controlled by the handicapped driver. Manual types usually require some assistance by an attendant. Several wheelchair lift designs integrate the lifting platform into the automotive structure, lowering reinforced and hinged sidedoors of the motor vehicle for wheelchair entry and exit.

The VA Prosthetics Center is currently involved in the evaluation of several van type motor vehicles equipped with wheelchair-access systems, and although satisfactory progress has been made, it would be premature to predict the final results. We have learned a number of important details in working with vans, information necessary in the preparation of future standards and specifications.

To give some examples of the variety of equipment, we present two (2) specially modified van-type motor vehicles for handicapped drivers. Specifically, they are as follows:

FIG. NOS. 6-7
This motor vehicle is a Dodge Sportsman Van, modified to hinge the reinforced right side door for wheelchair entry and exit. Once the driver has entered the vehicle, transfer is made to a specially designed driver-chair that permits adjustments for maximum comfort.

FIG. 6 ROYCEMOBILE VAN FOR THE HANDICAPPED
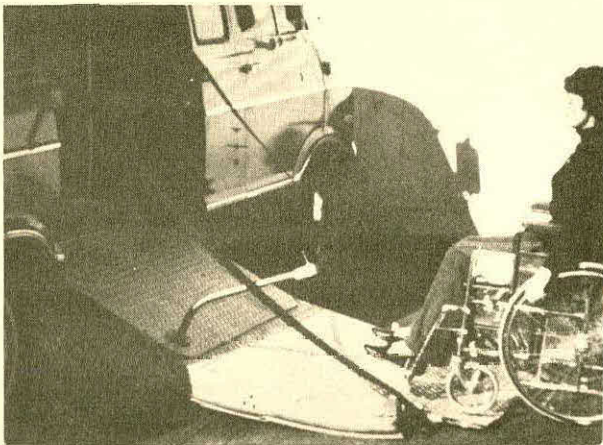
FIG. 7 WHEELCHAIR ACCESS SYSTEM (ROYCEMOBILE)

FIG. NOS. 8-10
A Ford Econoline 100 Super Van was used to provide this special vehicle for severely handicapped drivers. The standard steering mechanism and brake-accelerator control systems were removed from this vehicle, and replaced with a hydraulic servo-system that only requires very small forces to apply brakes or actuate acceleration. Steering requires very limited motion of the wrist and can be achieved with either the right or left hand. Naturally, the degree of sophistication of this vehicle requires more development to assure maximum safety to drivers as well as the general public. Efforts are continuing along this line. The motor vehicle is equipped with an experimental model of the SCAT electric wheelchair. The chair features a bucket seat, lap and shoulder belts, height adjustment, and is constructed for automotive use when locked to the motor vehicle. When not in use with the SCOTT VAN, this item is intended to take the place of a standard electric wheelchair. Obviously, there is no need to transfer from chair to chair for the seriously handicapped driver.
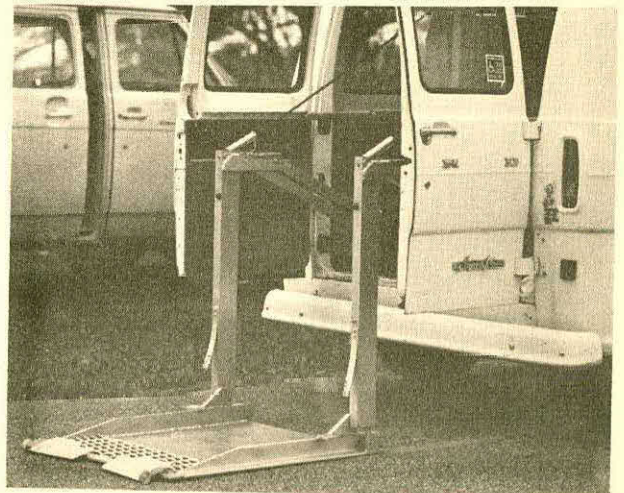

FIG. 8 SCOTT VAN FOR THE HANDICAPPED

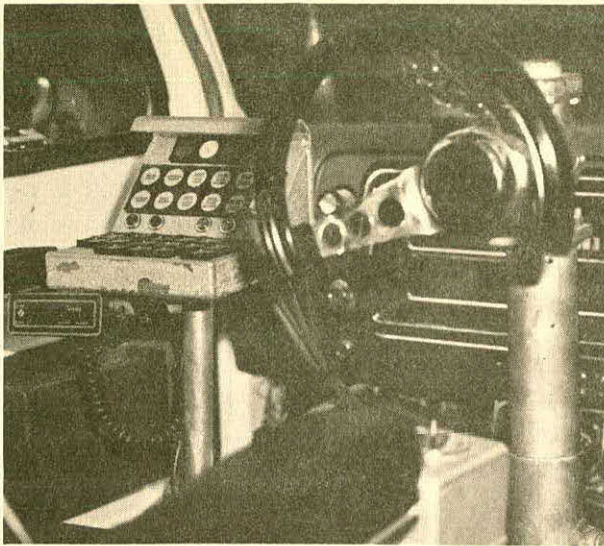FIG. 9 WHEELCHAIR ACCESS SYSTEM (SCOTT)

FIG. 10 SPECIAL CONTROL SYSTEM (SCOTT)

In summary, the evaluation of commercially available adaptive automotive control equipment indicated that the current "state of the art" is far below the level of acceptability as compared to automotive equipment for the non-handicapped driving public. Much of yesteryear's "add-on" hardware is frightfully unsafe, or no longer compatible for installation in modern passenger automobiles. In order to find these problems adequate solutions we must work closely with equipment manufacturers to improve existing devices for compliance with minimum standards, in addition to the initiation of development programs to provide a new generation of automotive control equipment for handicapped drivers.

We applaud the arrival of an experimental motor vehicle, equipped with a factory-installed pneumatic servo system for handicapped drivers. The new 1974 VOLVO 142-GL is the only motor vehicle available from an automobile manufacturer that includes equipment for drivers who do not have the use of their lower extremities. Shown in Fig. 11 is a member of the EPVA road testing the vehicle at the VOLVO OF AMERICA CORP., Rockleigh, N.J.. Naturally the automobile can be operated in the standard mode, without interfering with the pneumatic servo hand control provided for handicapped drivers. Accelerator-brake actuation is controlled by two (2) hand-grip type brackets fit-

ted between the spokes of the standard steering wheel. The brake is operated by exerting pressure with one or both thumbs away from the driver, whereas acceleration is achieved by applying finger pressure towards the driver. Handicapped drivers with nearly normal function and mobility of the upper extremities should have little difficulties in learning the operating techniques of this hand control system.

FIG. 11 HAND CONTROL SYSTEM (VOLVO 142-GL)

It is not suggested that this or any other automotive control system is the sole solution to all driving problems faced by the handicapped. We do not think that any single system can serve such a wide range of disabilities adequately. However, a new generation of automotive control systems for the handicapped is urgently needed, and the arrival of servo systems suggests a new relationship between the automotive manufacturing industry and handicapped drivers. We see our role very clearly in doing what is necessary to bring about the proper changes.

REFERENCES

VA STANDARD DESIGN AND TEST CRITERIA FOR SAFETY AND QUALITY OF SPECIAL AUTOMOTIVE DRIVING AIDS (ADAPTIVE EQUIPMENT) FOR STANDARD PASSENGER AUTOMOBILES, VAPC-A-7408-6

GENERAL SYSTEMS AND VOCATIONAL AIDS

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Temple University School of Medicine &
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Engineering

Title of Paper: Observational Systems for Studying the Behavior of
Institutionalized Mentally Retarded Adolescents

Category: (check one)   Device Development /_/   Research Study /x/

Brief Description: Environmental interaction in a dayhall housing 31 severely and profoundly retarded adolescents at the Mansfield Training School, a State of Connecticut institution, was evaluated within the existing facility, and the same facility redesigned to provide an enriched environment. Three methods of systematic behavioral observation were employed to evaluate these environments.

Intended User Group: Severely and profoundly retarded adolescents

Stage of Development: (Check all that are applicable)

A. Device

    Prototype Development   /_/

    Feasibility Testing   /_/

    Clinical Testing   /_/

    Available for Sale (check one)   Yes /_/   No /_/

        Price per unit $ _____

    Availability of constructional details:

B. Research Study

    Intended Utilization: Design of environments for the retarded, including gross-motor and fine-motor activity devices and systems.

    Intended Device Application: _____

    Availability of Intended Device: _____

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OBSERVATIONAL SYSTEMS FOR STUDYING THE BEHAVIOR OF
INSTITUTIONALIZED MENTALLY RETARDED ADOLESCENTS

by

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Environmental interaction in a dayhall housing 31 severely and profoundly retarded adolescents at the Mansfield Training School, a State of Connecticut institution, was evaluated within the initial existing facility, and the same facility redesigned to provide an enriched environment. Three methods of systematic behavioral observation were employed: (1) a photographic monitoring system, (2) an electro-mechanical recording system, and (3) a time-sampling observation system. The enriched environment increased the percent of appropriate, non-self-stimulatory play activities, and decreased the percent of stereotypic behavior, as well as established new patterns of space utilization and an increase in purposeful movement.

Introduction

There is growing recognition that various components of the physical environment can play a significant part in the learning-living cycle. The present study investigated the hypothesis that a well-designed, enriched environment can act as a catalytic agent in eliciting more appropriate and productive behaviors from institutionalized children.

The purpose of this project was twofold. The primary purpose was to provide environmental stimulation for severely and profoundly retarded adolescents with an aim towards reducing stereotypic behaviors, bringing about more purposeful movement and fostering new interaction patterns. The secondary purpose was to develop and test the reliability of observational systems for an on-ward environmental evaluation.

Acknowledgement

Objectives

The concern of this project centered on the following:

1. To provide a greater freedom of choice in the dayhall environment with the expectation that such options would increase the number of appropriate (non-self-stimulatory) activities engaged in by the residents.

2. To determine the effects of the enriched environment on new patterns of space utilization by the residents; for example: (i) a change from sitting in chairs placed along the walls to more diverse patterns of space utilization, (ii) a change from clustering in one corner of the room to more frequent circulation around the room, (iii) a change from inactivity at the tables to an increase in constructive, purposive activities.

3. To determine if the enriched environment would bring about a reduction in the following areas: (i) solitary activities (isolate play; destructive behavior; neutral or stereotyped activity or; self-directed aggression) and (ii) resident-resident aggression and resident-aide aggression.

Method

Subjects. Thirty-one severely and profoundly retarded teen-age and young adult females residing in a ward at

Mansfield Training School served as the subjects. The subjects ranged in chronological age from 11 to 21 (M=15 years). The subject's IQ's ranged from 6 to 48 with a mean of 26. According to institutional records, the instruments used for determining participant's IQ's were (1) Stanford-Binet (and/or Kuhlman); (2) Merrill-Palmer; (3) Vineland, and (4) Peabody Picture.

Staff. The day shift consisted of one or two attendants, responsible for housekeeping, laundry, paperwork, administering medications, escorting the residents to clinic appointments, and generally providing total daily care. Six volunteers each spent about one hour per week, on an irregular schedule, with the residents in the dayhall.

Initial Existing Facility. The existing facility, hereafter referred to as baseline, was a large open room, 32' x 45' with a 16' ceiling. Equipment consisted of 25 plastic chairs routinely set against the walls, and three sets of randomly placed tables and chairs. Balls and toys were occasionally brought into the room by an aide.

Enriched Environment. The existing facility was enriched by dividing the room into two areas -- see Floor Plan. This allowed the subjects the freedom of choosing to be alone, part of a small group, or part of a large group.

The large group area was designed for gross-motor activities. This space included a 10' x 10' carpet-covered pyramid. The central portion of the pyramid was cut out to provide a tunnel. A slide, constructed on one side of the pyramid, led into a large vinyl-covered foam pit.

The small group or privacy area was composed of eleven 3' x 2' x 8' learning booths, each housing a special contingency activity.[1,2] These activities were:

1. Manipulable light switches - six colored toggle switches activated six colored light bulbs in order to familiarize the subjects with color and assist in improving fine-motor coordination.

2. Buzzer reinforced shape matching - eight color-coded geometric shapes were arranged on two levels. The object was to match two red squares or two yellow circles, etc.

3. Airflow booth - behind a plexiglass case were three button activated objects. These buttons activated separate fans which set into motion either a pinwheel, styrofoam balls, or a plastic cup with crepe paper strips. The device was designed to increase visual stimulation.

4. Music booth - by using a pressure sensitive pad, a tape player was activated by the participants stepping onto the floor of the booth. When they stepped off, the music stopped. This was designed to teach them that their actions can affect their environment.

5. Stainless steel mirrors - three walls of the booth were covered with reflective steel to increase body orientation and self-image.

6. Pulley system - a conventional pulley system was placed behind a wall of clear unbreakable plastic. The residents could use the system safely, thereby increasing musculature.

7. Counting frame - an ordinary counting frame was placed in a booth for color stimulation and discrimination.

8. Lock box - a box was built with four manipulable locks to increase fine-motor coordination.

9. Xylophone - for self-imposed auditory stimulation.

10. Punching bag - this activity was designed to be used by the subjects when they were acting in an aggressive manner.

11. Sound activated light-box - the lights were activated when the participants verbalized or emitted other sounds.

Next to the learning booths was a talking tactile board. When one of six different textures was pressed, a taped auditory response named the texture.

Observational Measurement. Three methods of behavioral observational measurement were employed for the purpose of providing systematic descriptions of the social and environmental interaction patterns of residents and staff. Measurement and observational procedures were conducted in the baseline facility for five days and in the redesigned enriched environment for 15 days.

The photographic monitoring system consisted of two 8mm wall-mounted cameras with intervalometers set at four seconds. The electro-mechanical recording system was switched on with pressure sensitive mats located under the carpeting in the learning booths. Entrance into the booths by the residents activated the timers and counters which provided daily information as to the frequency and duration of the residents' use of the contingency activity booths.[2] The behavioral observation system consisted of a time-sampling procedure in which ten categories of behavior were coded at intervals of 15 second duration. See reference 1 for further information about these systems.

Data was gathered on booth utilization during 13 of the 15 days of the enrichment phase. Timer and counter readings were taken at the beginning and end of each four-hour daily observation period. The number of minutes each of ten booths was in use on each of the 13 days was entered into the analysis. There was a significant Booths effect (p < .01). The effect of Days was not significant.

To investigate the differences between booths further, a Tukey multiple comparison test was done to compare differences between the means of each of the ten booths. Music was used significantly more (p < .05) than all but the mirror and shape booths -- see Figure 2. The mirror booth was also used significantly more (p < .05) than all but music and light switch booths -- see Figure 1.

In terms of typical usage by the residents, the music and mirror booths were utilized an average of .73 and .69 minutes per hour by each resident entering the booth. Other booths ranged from .30 minutes per hour per subject (sound-activated-light-box) to .05 minutes per hour per subject (lock-box). Overall, residents were involved in booth activity for a mean of 2.7 minutes per hour.

While the booths were always available to the residents in the room, each booth was analyzed for 13 days, 4 hours per day. Overall, the booths were utilized 13.6% of the observed time. Of this 13.6%, in-booth use distribution showed a high of 36% (music) to a low of 3% (lock-box).

The number of times the pressure sensitive counter on the floor of each booth (8 booths only) recorded counts (referred to as onsets) was analyzed and showed a significant effect by Booths (p < .01). The Tukey analysis of all possible differences between the mean scores of the booths' use indicated that the mirror booth was activated significantly more (p < .05) than sound-light, airflow and lock-box. Also, the music booth was activated significantly more than the lock-box (p < .05) -- see Figure 2.

The number of onsets per hour per resident (computed by dividing the number of onsets by the number of residents) ranged from a high of 4.2 (mirror) to a low of 1.1 (lock-box) and totaled 19.7 onsets per resident per hour per booth -- see Figure 1.

For three of the booths (airflow, light switch and shapes), a second counter recorded the actual number of times the apparatus was manipulated. (These will be referred to as manipulations.) The overall effect by Booths was significant (p < .05). The effect by Days was not significant. The Tukey tests revealed that airflow was manipulated more than either light switch or shapes (p < .05), which did not differ significantly from each other -- see Figure 3.

The average duration of time a resident remained in a booth (seconds/onset) ranged from a high of 12.6 seconds per onset (music) to a low of 3.0 seconds per onset (lock-box). Data pertaining to whether or not the resident actually engaged in booth activity while in the booth was available for only three booths: airflow, light switch and shape matching. For one booth (airflow), the activity was initiated 2.3 times for every entrance into the booth. For the other two (light switch and shapes), the activity was utilized only .33 times for each entry into the booth, or once every third onset (Figure 3).

Discussion

The results of this study indicate that an on-ward enriched environment for severely and profoundly retarded adolescents can reduce neutral or stereotyped activity and increase appropriate activity, thereby creating an environment that can support and reinforce learning activities.

The enriched environment was designed as a sociopietal arrangement with separate zones of sociability. Several new patterns of space utilization emerged as a result. Rather than the constant rocking in chairs around the perimeter and clustering of residents in the corners of the dayhall, they made use of the learning booths for activity or privacy, or played on the pyramid, in the tunnel, on the slide, or in the foam pit. During the enrichment phase, rather than sleeping on the quarry tile floor as they had during baseline, the residents chose to rest in the more comfortable foam pit. While it was concluded that this form of behavior was still neutral, their resting place was more appropriate.
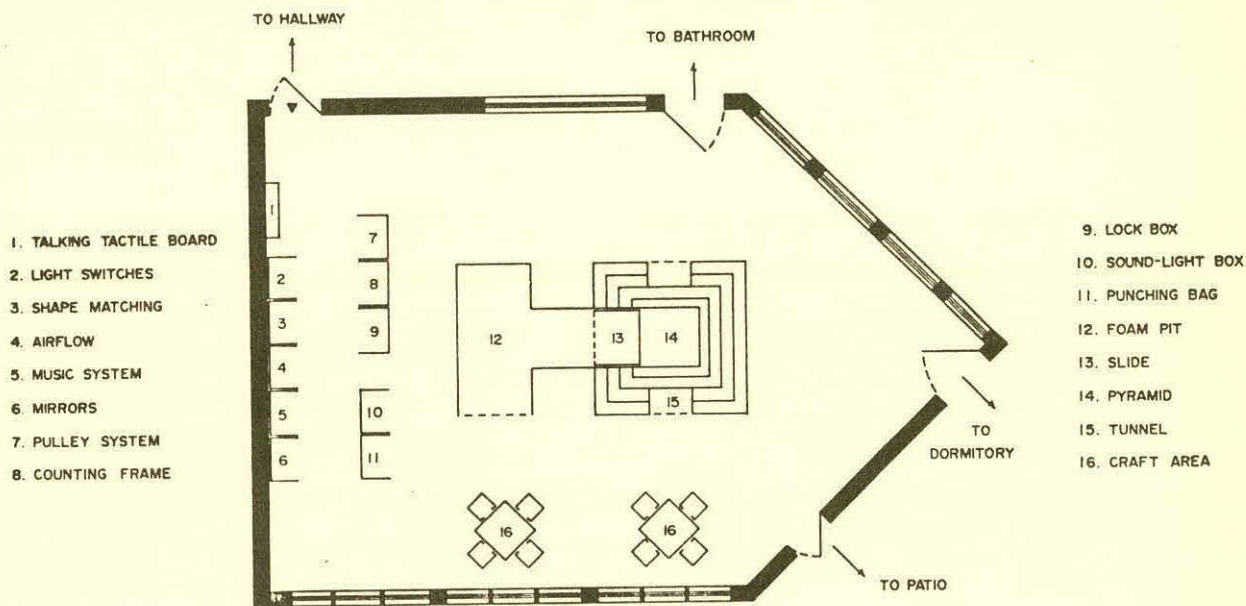
The study provided important information about activities of interest to severely and profoundly retarded adolescents. The mirrored booth, music booth, manipulable light switches and shape matching were entered more frequently than the others. Once inside the booths, the duration of stay was greater in the music and mirrored booths than in the others. While the residents frequented the light switch and shape booths more than the airflow booth, data showing that the airflow booth (button activated pinwheel,

styrofoam balls and crepe paper), was manipulated seven times more than the other two, which suggests strongly that it captured their interest. These data suggest several implications: First, the mirror and music booths were passive activities in that the apparatus did not require any response by the resident other than entry into the booth in order for reinforcement to be received. Secondly, of the manipulable booths, interest was sustained by the device that offered the most varied visual stimulation. Thirdly, and most important, data implied that all of these activities captured the interest of severely and profoundly retarded adolescents to some degree. Therefore, either these activities or variations of them, would be valuable instruments which could serve in their own right or in coordination with a variety of programs as a learning environment in other wards.

References

1. Levy, Ellen. Effects of environmental enrichment on the behavior of institutionalized mentally retarded adolescents. Final Report. Mansfield Training School, Mansfield Depot, Connecticut, 1974.

2. Marshek, Kurt M., and Boly, Louis. Application of university engineering resources toward the solution of problems encountered in the rehabilitation of the retarded. Proc. Boston Conference on Engineering Devices in Rehabilitation, 1974.

TO HALLWAY

TO BATHROOM

1. TALKING TACTILE BOARD
2. LIGHT SWITCHES
3. SHAPE MATCHING
4. AIRFLOW
5. MUSIC SYSTEM
6. MIRRORS
7. PULLEY SYSTEM
8. COUNTING FRAME

9. LOCK BOX
10. SOUND-LIGHT BOX
11. PUNCHING BAG
12. FOAM PIT
13. SLIDE
14. PYRAMID
15. TUNNEL
16. CRAFT AREA

TO DORMITORY

TO PATIO

| MANSFIELD TRAINING SCHOOL | MERRITT HALL | FLOOR PLAN | DESIGNER-ELLEN LEVY | SCALE- 1/4"= I'-0" |

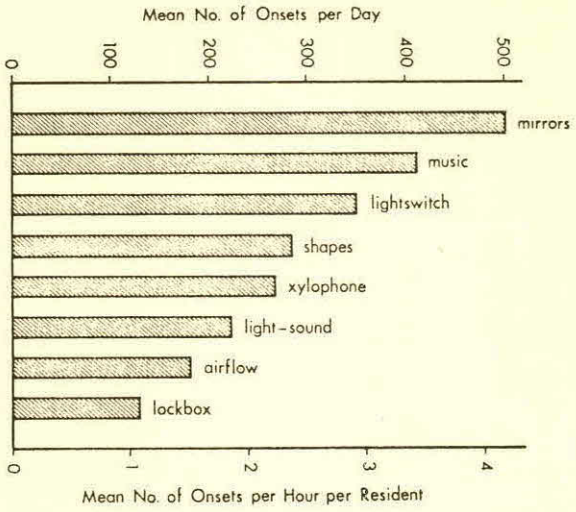**Figure 1**

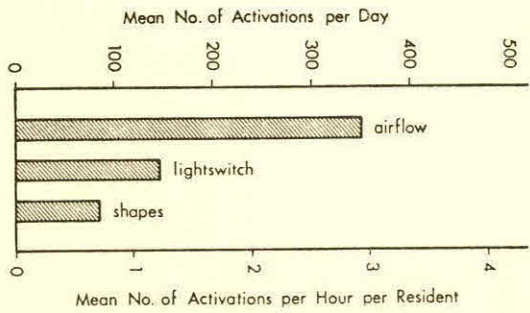Mean frequency of onsets in learning booths by all residents per day and by individual residents per hour.

Mean No. of Onsets per Day

mirrors
music
lightswitch
shapes
xylophone
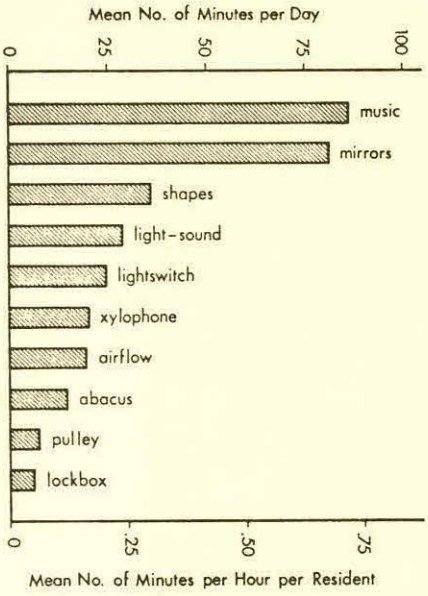light-sound
airflow
lockbox

Mean No. of Onsets per Hour per Resident

Figure 2

Mean duration of time spent in learning booths by all residents per day and by individual residents per hour.

Mean No. of Minutes per Day

music
mirrors
shapes
light-sound
lightswitch
xylophone
airflow
abacus
pulley
lockbox

Mean No. of Minutes per Hour per Resident

Figure 3

Mean frequency of activities in learning booths with manipulable tasks for all residents per day and for individual residents per hour.

Mean No. of Activations per Day

airflow
lightswitch
shapes

Mean No. of Activations per Hour per Resident

Title of Paper: ARTS - A MULTIFUNCTIONAL VOCATIONAL EDUCATIONAL AID

Category: (check one)   Device Development /X/   Research Study /‾/

Brief Description: The Audio Response Time-Sharing Service Bureau (ARTS) for the blind and physically handicapped is described with an emphasis on its word processing and Braille translation functions. A brief outline is given of the ARTS command syntax and some of the user interface problems which arose and their resulting solutions. ARTS is shown to be a multifunctional computer tool designed to focus on specific vocational and educational task situations.

Intended User Group: Blind and physically handicapped

Stage of Development: (Check all that are applicable)

A. Device

   Prototype Development   /‾/

   Feasibility Testing   /‾/

   Clinical Testing   /X/

   Available for Sale (check one)   Yes /X/   No /‾/

      Price per unit $ custom

   Availability of constructional details:

B. Research Study

   Intended Utilization:

   Intended Device Application:

   Availability of Intended Device:

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                                            Watertown, Mass.   02172

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ARTS - A MULTIFUNCTIONAL VOCATIONAL EDUCATIONAL AID

by

Kenneth R. Ingham, Ph.D.
President
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Watertown, Massachusetts

Summary - The Audio Response Time-Sharing Service Bureau (ARTS) for the blind and physically handicapped is described with an emphasis on its word processing and Braille translation functions. A brief outline is given of the ARTS command syntax and some of the user interface problems which arose and their resulting solutions. ARTS is shown to be a multifunctional computer tool designed to focus on specific vocational and educational task situations.

Introduction

The ARTS system consists of two interconnected mini-computer systems and operating programs designed to serve the blind and other physically handicapped. One of these machines is an audio response system (AR) which is capable of receiving input from remotely located handicapped users who type on a standard keyboard terminal attached to their telephone. The signals received by the AR are transmitted to the second machine and turned into spoken letters, punctuation, or number sounds so that the typist can hear what he is typing. The second machine is a full time-sharing system (TS) which can be operated by many users simultaneously. This machine, which has standard storage units such as fixed-head and moving-head discs attached to it, operates the various service programs. However, the input/output which normally would go to groups of teletypes or CRT stations goes instead through the audio response system where it is converted into spoken English. With such a configuration it is possible to program services designed to do job and school tasks and to "run" these on the time-sharing system. The output converted into sounds permits blind and other handicapped persons located at the other end of a phone line to operate the services with as much efficiency as sighted, nonhandicapped persons. In what follows, two of the principal services used by the blind and currently available on the ARTS system located at The Protestant Guild for the Blind, Inc., Watertown, Massachusetts, will be described along with some of the consumer-oriented features built into these services.

Word Processing

Perhaps the most useful functions available to the handicapped ARTS user are those available through the Ideal Editor and Justifier services. These two programs serve the purpose of input/editing text, and formatting of text, respectively.

Editing

One may visualize the action of the Ideal Editor (IED) by considering the following analogy: a user is sitting at his or her desk before an ARTS typewriter keyboard and surrounded by many file cabinets. When the user requests the Ideal Editor service by typing on the keyboard "ied" the program is started and is ready to fetch a file. Here, following the analogy, a file is any folder full of information stored in the file cabinets or is a file as yet empty. Thus, the user may type the command, "fo homework" and IED will, at computer speeds, search through the file cabinets until it has located the folder called "homework". The folder is automatically opened and the typist has before him the first page. He or she may now utilize a simple to learn, but powerful set of instructions which permit him to read, change, add to or delete any part of the text contained in the file "homework". For example, a prose file may be "read" sentence by sentence by typing "rs" wherein the "r" denotes "read" and "s" denotes "sentence". Similarly, a file containing line-oriented expressions such as a recipe list or poetry, may be "read" by commanding "rl" for "read line".

The editor syntax is based on three argument commands terminated by a carriage return. The first, which denotes the function to be carried out could be "a" for "append", "c" for "change", "d" for "delete", "i" for "insert", "r" for "read" and "x" for "exchange". The second argument which denotes the size of text to be effected could be either "k" for "single character", "w" for "word", "l" for "line", "s" for "sentence", or "p" for "page". The third argument specifies the specific unit of text to be operated on. Thus, in our previous example where the third argument was omitted the current or first sentence was understood. On the other hand, the third argument could be a word or expression in the text which enables IED to identify it as the segment to be operated on. Thus, if the word
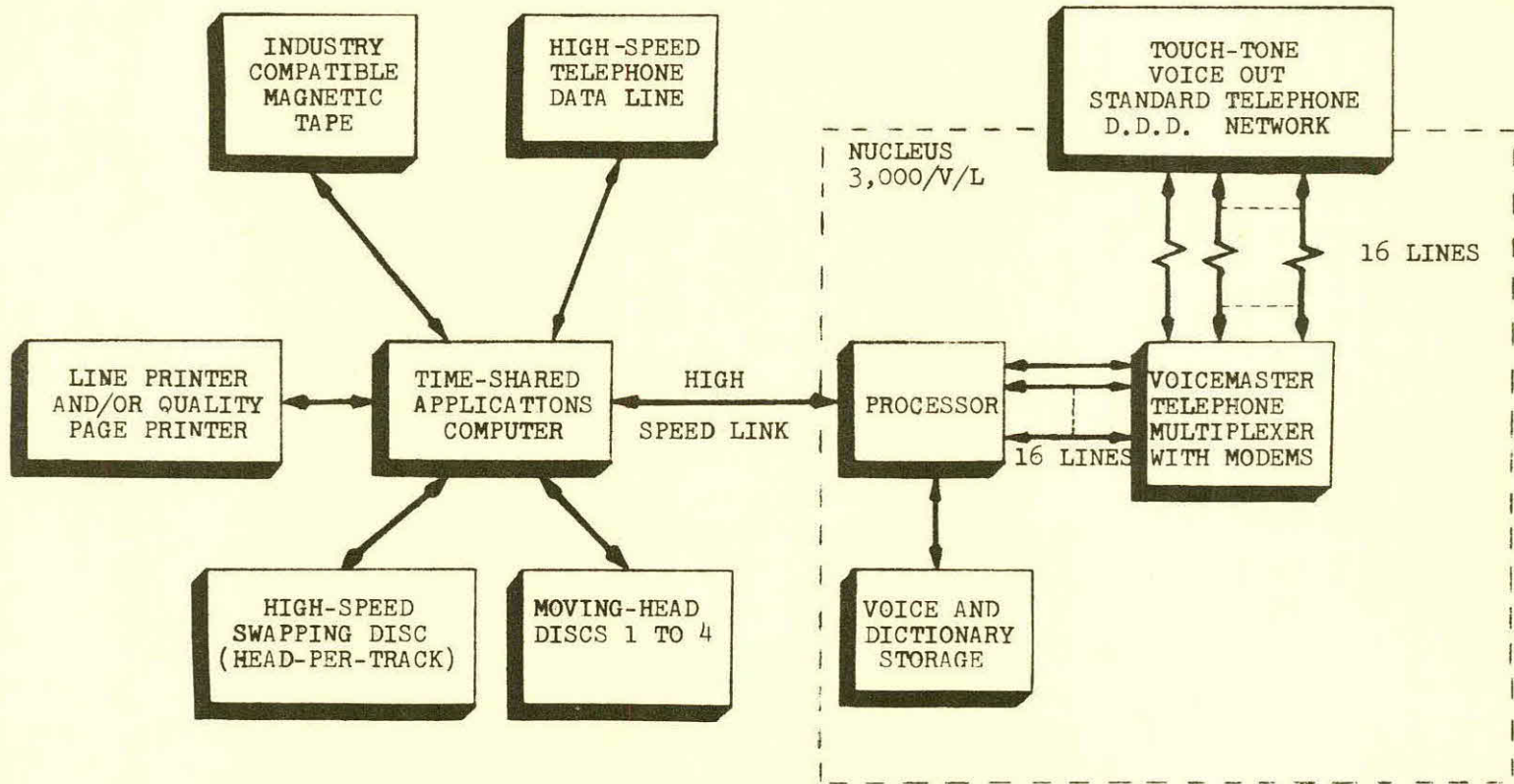
Figure 1

The ARTS Service Bureau Configuration with Typical Time-Sharing Peripherals
and American Systems, Inc. Nucleus 4000/V/L Speech System

"mariner" were located in the text, a search and subsequent operation on the text containing "mariner" could be initiated by typing "!mariner(escape key)(carriage return)", where the "!" and the (escape key) delimit the expression to be searched for. Among the additional single key commands are those which permit the user to search for the next occurrence of the expression by typing "n", or to read the next or preceding segment of text by hitting the "greater than" or "less than" keys, respectively. With this admittedly brief outline we can now illustrate by a few examples how "homework" can be modified.

Our hypothetical user, Susan, wishes to insert a paragraph somewhere in her homework which happens to be a book report. She also wishes to correct the spelling of the author's name which she has used liberally throughout "homework". Susan knows that the insertion should take place just after the paragraph in which she described the author's tendency to indulge in drugs. Therefore, using the command "rs!opium(escape key)(carriage return)" she finds the first occurrence of a sentence containing the word opium. This is spoken out to her from beginning to end irrespective of its position relative to the print line. Unfortunately, this reference did not occur in the desired paragraph. Susan then types the command "n" which causes IED instantly to search and find the next occurrence of a sentence containing "opium". This is the correct paragraph and just to make sure Susan "reads" the next couple of sentences. She listens to the beginning sentence of the following paragraph simply to recall the content. The command "i", where "s" (sentence) and the position are understood, is now given, causing IED to enter a mode wherein characters typed will be stored and inserted into the text between the two paragraphs. After typing the insertion Susan types the escape key which returns her to command mode. Now typing "rs" she listens to what she has typed to guarantee the correctness of typing and content. Using the "c" for "change", or "x" for "exchange" she can correct any mistakes.

The second task is to replace the misspelled author's name throughout the file "homework" by its correct spelling. Susan accomplishes this by typing a global command. These commands consist in enclosing the normal functions noted above within brackets. Once the sequence of instructions, enclosed by brackets, and the carriage return are given, IED will perform as many times indicated the operation enclosed within the brackets. In Susan's instance, the command is to exchange the misspelled name by the correct one. This is accomplished by typing "[x!Colleridge(escape key)(carriage return)Coleridge(escape key)n (carriage return)](carriage return)". The "x" denotes the function "exchange", and the author's name enclosed by the "!" and (escape key) define the word to be searched for, and the first (carriage return) instructs IED to carry out the operation thus far. The second

expression, the correctly spelled name, terminated by the (escape key), instructs IED as to what the substitution is. The letter "n" followed by a (carriage return) tells IED to go after the next occurrence. Enclosing this sequence of commands, which can be executed in their own right, within brackets immediately followed by a carriage return, causes IED to repeat the sequence throughout the entire file "homework". The operations are carried out and Susan's two tasks are completed.

Text Justifying

An essential part of homework preparation, or indeed the composition of any text intended for printing, is type justification or formatting. The Justifier, "Just", service available on the ARTS system operates in two basic modes. The first assumes that the user has typed his text with only the usual control characters such as spaces, carriage returns, tabs, etc. The Justifier takes such text and allocates the characters according to default values such that the appropriate number are placed on each line and the "standard" number of lines placed on each page. Thus, carriage returns are inserted where necessary, blank spaces left between pages, and paragraphing done where carriage returns are immediately followed by tabs.

The second mode of operation for the Justifier includes the use of commands which are inserted along with the text. Each command, typically consisting of two letters and a numerical argument, is initiated by a carot symbol and terminated by a carriage return. The first letter of a command indicates the class while the second the specific operation. The command classes are "a" for "alphabetic", "d" for "diagramatic", "h" for "heading", "l" for "line", "o" for "overstriking", "p" for "page" and "t" for "typefont". The operations allowable with the alphabetic, overstriking and typefont commands generally permit a change in print or Braille output characters; for example, the alphabet may be changed from Roman to Greek, the typefont from pica to boldface and overstriking by user selected characters such as underline permitted. A diagramatic class permits the indication of "here", "there" and "next" diagrams where these descriptive titles signify how they are to be inserted in the text. A "here" diagram is to be inserted immediately, a "there" diagram anywhere convenient and a "next" diagram always at the top of the next page.

The line and page classes have as operations the setting of right, left, top and bottom margins, the indication of right and left indenting, the centering of text and the initiation of automatic page numbering. In addition, line spacing may be changed and new lines or pages conditionally or unconditionally forced. Any of these commands may be given at any time permitting the user to "shape" the organization of the text on the print or Braille page: e.g., tabs may be set for normal

text lines or may be arranged to permit easy columnating of tables. Thus, Susan, in preparing her book report, may use the "lc" command to center lines on the title page, type in a heading with the "h" command that will be printed at the top of each page, and may have each page after the foreword automatically numbered. She may force new pages at the end of each section and may even leave the appropriate room for a picture of the author.

Returning to our analogy, the folder containing the various sheets of paper on which "homework" is printed is now ready for refiling in its appropriate cabinet. This is accomplished by typing "fc" for "file close". The file containing all of the updated information is stored on the ARTS storage unit where it is available for future rework or for printing or Brailling.

Braille Output

The fact that the ARTS services are file-oriented permits the implementing of services such as the IED which "access" the file by name. Some services, when finished, may return the file to storage or may be used to produce output copies. Two such "copying" services are the Justifier, "Just", mentioned above, and Braille, "Brl". Text prepared by the user with the aid of IED is "accessed" by either Just or Brl by typing, for example, "just homework" or "brl homework". The Justifier service will take the text stored in the file "homework" and arrange it for printing. Commands, when encountered, will be executed and a properly finished version of "homework" sent to the output printer/handler. The total operation, taking seconds, permits the user to continue other work while the relatively slow printers and embossers carry out the production tasks.

The Brl service consists of two logically separable functions. The first is that of text justification. All of the commands noted above in the description of the Justifier are available to the user for the purpose of justifying the Braille output. However, the commands for changing typefonts, such as pica to elite, are ignored. On the other hand, Braille does provide the Greek letters and the reproduction of boldface letters. These are output when the required commands are given.

Braille Translation

The second function of Brl is to translate the text from a character by character representation of the typed symbols to a compressed notation known as Grade II Braille. Here the standard Braille abbreviations and contractions are substituted according to the rules of English Braille for the corresponding print combinations. The word "receiving" is translated into "rcvg" while the letter "k" is substituted as the single-cell contraction for

the word "knowledge". Unfortunately, while a computer can do many things, it cannot account for the alogical growth of language. Spelling combinations which correspond to Braille contractions that would, if used, cross syllable boundaries, must be stored in dictionaries. There are very many such spelling combinations and in order to avoid excessive storage requirements, the rule in Braille which forbids the use of contractions crossing syllable boundaries is violated. However, these violations are relatively rare and offer no obstacles to reading.

Translator Modes

An example of a two-letter command class available for text formatting, which is ignored in the Justifier but utilized in Brl, is the "b" class. Here, "bi" instructs the translator to produce Grade I Braille (in essentially one-to-one character-to-symbol translation) while "bl" and "bn" indicate literary Braille and mathematical Braille translation, respectively. The normal default mode is literary Braille. The scientific or mathematical Braille permits the generation of Braille technical symbols, equations and computer programming. It should be pointed out that Braille reading is effectively a one-dimensional process while print reading is two-dimensional. Thus, equations in print may be written spacially with subscripts, superscripts, fractions and certain symbols occupying more than the base line of writing. Braille symbols, on the other hand, are typically embossed on the base line of writing. Two-dimensional print structures must be translated unambiguously into one-dimensional ones. Fortunately, codes such as the Nemeth Code do exist with prescribed rules which, to some extent at least, can be implemented in a computer program. However, the user, while using IED, must indicate the beginning and end points of fractions, superscripts and/or subscripts.

The Braille service, like the Justifier, produces a formatted and translated copy which is then sent to the line embosser attached to the main computer. The Braille or print copies are then mailed to the user.

The Human Interface

The delivery of computerized services to the blind and physically handicapped involves rather special human interface situations. First, programs or services must be written so that they are essentially "idiot-proof" while retaining enough flexibility to cover a wide range of requirements. Second, voice output, both of text and of command input/response messages, must be such that the user may easily follow "what is going on" and can recover from errors. In what follows, some of the features found helpful by the handicapped user will be described.

Programs

Since the user "calls" the services from the ARTS Monitor, and since some of these services operate with both an input and command mode, it is relatively easy to forget where one is and to attempt commands which do not apply. For example, typing text at IED while in command mode will result in that program trying to interpret the text as a sequence of commands. Similarly, commands inserted into the text for type or Braille justification can result in impossible format situations such as would arise when a user attempts line margins wider than the physical page.

When a user has lost his reference he or she may attempt executing harmless commands which will first reestablish the command mode for a given program or at the worst, return the user to the ARTS Monitor. Since the system is file-oriented, both the original text file and the temporary file created for editing will be preserved and restored without loss of information. Therefore, the user simply re-starts as though he were just beginning. In the event of illegal or impossible command sequences, each program has been equipped to reject the sequence as soon as the error is detectable. This is done in a harmless way wherein again, the text is preserved and the user is queried in voice "question mark" or please carry out an appropriate action before attempting this or that command. Services such as the Justifier or Braille translator attempt carrying out the justification process without creating the output file. This is done in order to detect illegal command sequences before wasting storage space or paper. A detected error is analyzed and an appropriate spoken message given to the user along with page and line numbers for the command or text position where the error occurred. Needless to say, such referencing and error detection can only go so far and much common sense is expected of the user. Unfortunately, this common sense is an admixture of normal common sense and learned ARTS common sense. The latter assumes that the rather sophisticated ideas concerned with interactive time-sharing have been acquired. Whether this learning can be done easily for the "average" handicapped person remains to be seen. All indications from our small pilot group suggest that 10 to 20 hours of training is sufficient.

Voice Output

The ASI Nucleus series of speech and tele-processing systems permit the easy modification of the speech output. At any time while operating services, the ARTS user may signal the speech-format control in order to change the speech rate, turn off echo and/or substitute spoken control and punctuation sounds with silence. Thus, sentences which spread over several lines of print may be output with carriage return sounds turned off and with the punctuation replaced by varying intervals of pause. Such output can be made to sound very much like it were being read by a carful reader.

Two factors related to speech output showed up early in the testing. They are 1) speech output with typing input eliminates the carriage mechanism of printing typewriters. A user is instructed to type a continuous line starting at the beginning of a paragraph and ending at the end of the final sentence prior to the next paragraph. The insertion of the intervening carriage returns, when printing is required, is accomplished by "Just". 2) Owing to the fact that the ARTS vocabulary ranges from 2,000 - 8,000 words, not all spelling combinations can be spoken as words. In order to compensate for this, the speech system was programmed to spell such combinations with pausing before and after the combination and with slightly shorter pauses between each letter. It is then possible to easily follow such spelled combinations although in no case is continuous spelling or a significant ratio of spelling to spoken words acceptable.

Conclusion

The preceding services may be used separately by sighted or blind persons for the efficient preparation of text. This text may be read auditorially or may be produced in print or Braille form. Taken together, the two services provide an excellent means by which volume Braille translation and production may be carried out. Sighted typists not required to have a knowledge of Braille may quickly produce Braille text for the employed blind or for students.

These basic services may be used in a variety of vocational and educational situations by secretaries, transcribers, medical secretaries, business people and those occupied in technical vocations. In addition, they may be augmented by a virtually open-ended series of programs written on the ARTS system. The programs available or in preparation include "Talking Basic", "Type-Teaching", and "Form". "Talking Basic" is a compiler which can double as a desk calculator while "Form" permits the generation and reproduction of standard form-oriented text.

ARTS then is a multifunctional, vocational and education aid which permits the development of services which focus on specific task areas.

Title of Paper: A UNIFIED APPROACH TO COMMUNICATIONS AND CONTROL
FOR SEVERELY DISABLED PERSONS

Category: (check one)   Device Development X̄X̄   Research Study /̄ /

Brief Description:

_____ Communications and control systems for severely disabled _____

_____ persons have been developed. _____

Intended User Group: Severely disabled persons.

Stage of Development: (Check all that are applicable)

A.   Device [SEE INFORMATION TO
                    RIGHT] ⟶

    Prototype Development   /̄ /

    Feasibility Testing   /̄ /

    Clinical Testing   /̄ /

    Available for Sale (check one)   Yes /̄ /   No /̄ /

-A "call" device is commercially available, around $100.
-A small communication and control system is also commercially available, around $890, for hospital or home.
-A telephone control system for multi-line business phones is in clinical use.
-A computer-based system is in prototype development.

      Price per unit $ _____

    Availability of constructional details:

B.   Research Study

    Intended Utilization: _____

    Intended Device Application: _____

    Availability of Intended Device: _____

For further information, contact: Name Dudley S. Childress, Ph.D., Co-Director
                                   Address N. U. Rehabilitation Engineering Pgm.
                                     345 East Superior Street, Room 1441
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A UNIFIED APPROACH TO COMMUNICATIONS AND CONTROL
FOR SEVERELY DISABLED PERSONS

by

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Summary - The design of small-scale, medium-scale, and large-scale communication and control systems for severely disabled persons is discussed. A "call" system (small-scale) and an environmental control system (medium-scale), both commercially available, are presented. Also presented is a medium-scale system for control of a business telephone. A large-scale system, computer-based, is described. These various systems are related by a unified design which permits great flexibility in their application.

Introduction

The development work reported in this paper is concerned with assistive systems for very severely disabled people. Primarily these are persons with quadriplegia who have little or no motor ability below the shoulders. Communication and control systems for these people may range from elementary "call" systems to complex "vocational" systems.

A unified approach to the design of systems for severely disabled persons is one which ties together the design concepts of simple and complex systems. It is an approach permitting complex systems to be constructed from simple ones. It is also an approach strongly modulated by clinical experience so that technical design is well united with the life of the disabled person and with the lives of those associated with him.

Concepts Developed from Clinical Experience

Our experience indicates that communication and control systems for severely disabled persons may be divided into three levels of complexity. These are:

(1) Small, simple signalling systems which permit the persons to request assistance. This may result in activating a light at a nursing station, actuating an audio or visual alarm for an attendant, or turning on an "intercom" to talk with a member of the household who is at a distant point.

(2) Medium-scale communication and control systems which are frequently called environmental control systems. They permit control and operation of call systems, telephone, radio, TV, lights, bed, typewriter, etc.

Acknowledgement

(3) Large-scale interactive systems which permit substantially greater control than the medium-scale systems. The concept behind these systems is to perform the duties of communication and control systems, but to go beyond them by providing interactive activities such as message-building, editing, storage, recall of information, communication with outside systems, etc. These are information-handling systems to improve a person's quality of life by permitting vocational, avocational, and recreational activities. Minicomputers or microprocessors form the core of such systems. In such an arrangement the functions become software-changeable, and the systems become extremely adaptable to specific needs of the disabled.

Our experience suggests that the systems under consideration should have the following characteristics:

(1) The systems should be small in size for use in hospital rooms, nursing homes, and homes. It is preferable for the systems to be as inconspicuous as possible.

(2) The devices should be of solid-state construction for reliability and longevity.

(3) Construction of the systems should be simple, permitting easy installation and use.

(4) The input transducers by which the system is controlled should be easily moved aside for patient care by nurses or attendants and easily repositioned. These input components should remain in proper orientation to the disabled person without requiring frequent positioning. They should be unobstrusive, if possible. We have found the parallelogram-type lamp arm well suited as a transducer holder.

(5) Input transducers should match the disabled person's functional abilities. Several input options should be available. Telemetry of input-control data is desirable to permit freedom of movement in the environment without loss of control over it.

We have used sensitive pressure switches (Fairchild) for "puff and sip" input control. This is a control that can be rather generally applied and that is somewhat of a common-denominator-type of input. Nevertheless, a system should permit a variety of biomechanical or bioelectric inputs even though a specific input may be provided as part of the original equipment.

(6) Peripheral interface equipment should allow flexibility. A combination of electrical power outlets and switch closures is required. Momentary and latching closures are both frequently needed, and it is advantageous if interface equipment may be easily modified to match available peripherals.

In the unified design approach the small-scale "call" system becomes the input for the medium-scale communication and control system which we call the comfort-and-communication system (CCS). CCS components are likewise compatible with the large-scale system.

A Call System

Fig. 1 shows a simple "call" system with the "puff-and-sip" transducer mounted on the adjustable arm. This is available in a momentary switching mode for modern hospital call systems and in a latching mode for older hospital systems and for remote signalling or intercom operation.

Fig. 1. Picture of simple "call" system mounted on bed.

Comfort-and-Communication Systems (CCS)

Fig. 2 shows the CCS developed by our laboratory. It is an 8-function device consisting of two main parts. These are the control head and the power-and-peripheral-interface unit.
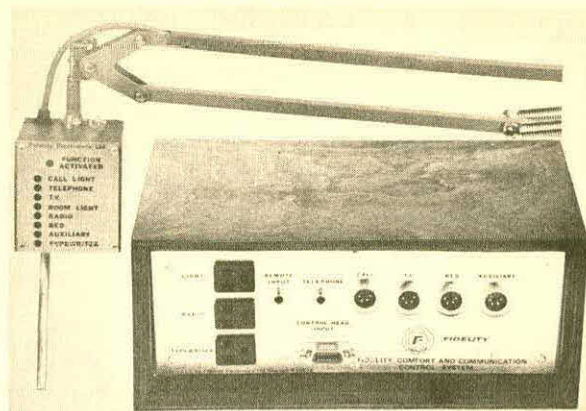
Fig. 2. Picture of comfort-and-communication control system. The control head is shown to left of the power and peripheral interface.

The control head, similar in mounting and activation to the "call system", contains two pressure-sensitive switches which control mode selection and activation. The interface unit also has a "remote input" jack which permits any other two electrical closures to control mode selection and activation. An FM receiver may be plugged in at this location providing wireless control from wheelchair, chair, or bed. For purposes of discussion let it be assumed that the pressure switches are activated by puffing or sipping on the straw which communicates directly with the switches in the control head. A "puff" was arranged to change the selection category and a "sip" to activate the selection. The "puff" switch activates a 1-shot multivibrator, and this signal is counted to 8 by a counter. Its Binary Coded Decimal (BCD) output controls the Light Emitting Diode (LED) display on the face panel of the control head. This indicates the channel selected. The BCD code also goes to the interface unit where it is decoded and enables the appropriate interface unit. This is shown in fig. 3.
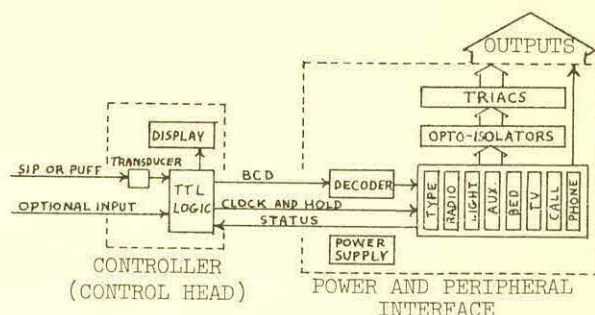

Fig. 3. Diagram showing signal flow in comfort-and-communication control system.

The "sip" switch activates a 1-shot multivibrator and sends a "clock" pulse signal and a "hold" line signal to the interface unit which activates the desired control function. The interface unit contains 8 printed circuit

(PC) control cards, 1 for each output. These are transistor transistor logic (TTL) units which are enabled by the decoder and which respond to "clock" and "hold" lines. The PC boards available are: (1) Momentary, which provide an output switch closure as long as the control switch is activated, (2) Latching, providing "on-off" switching at the output, and (3) Dual momentary, providing alternate momentary control of two output closures.

A telephone card turns the phone "on" and "off" and dials "operator". The PC boards may be interchanged (except for the telephone) to select the type of output desired.

The outputs of the control cards activate LED-coupled photoresistors. This optically isolates all the peripherals from the CCS. The resistor side of these opto-isolators provides either direct control of low-current DC peripherals or control of the gate current of triacs which provide output to AC loads or AC switch closures. Three outputs supply 110v AC. Any 110v AC appliance which has a power rating of less than about 1,000 watts (e.g., room light, radio, typewriter, fan, electric blanket, etc.) may be operated from these outlets. Four outlets provide electrical closures where the power is derived from other sources. One outlet is reserved for telephone switching.

The digital control property of the interface portion of the CCS makes this unit potentially controllable by many digital devices. In particular, it is rather easy to control it with a minicomputer or microprocessor.

A disabled person puffs lightly on the straw to select the desired function. Each puff moves the indicator light one position. A sip on the straw activates the selected function. A status light ("function activated") indicates whether the function selected has been activated. Manually operated switches on control head permit the system to be controlled by attendant or nurse.

The "call" mode may be used to activate: (1) a nurse call system, (2) a wired or wireless buzzer in the home, and (3) a wired or wireless intercom system.

The "telephone" mode will answer incoming calls with a single "sip" signal. When placing a call, the first "sip" gives the dial tone, and the second "sip" automatically causes the system to dial the operator. The unit is used with a modified General Telephone Speakerphone.

The "television" mode turns the TV "on" and changes channels with each new "sip". One channel of the powered channel selector is the "off" position.

The "bed" mode can be used for operating one up-and-down position on an electric bed.

The system only operates while being activated. For example, a "sip" may cause the bed to elevate only as long as the "sip" is held. The next "sip" will lower the bed as long as it is held. The action alternates and for safety purposes only operates while activated (dual momentary). The CCS is usually connected to head elevation on the bed. The output triac will drive electric beds directly or through a control relay on the bed.

A Business Telephone Controller

The power and peripheral interface unit of the CCS already described may be converted into a business phone interface. The PC control boards are replaced with eight identical logic units which operate LED photoresistors. These photoresistors provide the switch-like closures for the phone, and they assure complete electrical isolation from the telephone equipment.

The system, when connected to the necessary relay applique to operate the KTS equipment (developed by Illinois Bell Telephone company), allows the user to select any of four outside lines or an internal communication (COM) line. Dialing is permitted on each of these lines. Calls may be held (HOLD) or released, and messages may be recorded on a tape recorder. Therefore, the eight channels of the CCS are conveniently used. This system is shown in fig. 4.
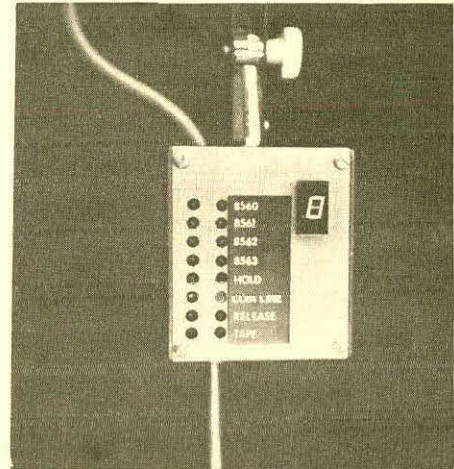

Fig. 4. Picture of control head for business telephone system. Note digital display unit in upper right corner.

Two parallel rows of LED's form the display on the control head. The row of green LED's display the status of each phone line in the same way in which the lighted buttons on a six-button multi-line telephone display the status of its lines (light "off" when line is not in use, light "on" when line is in use, light flashing for incoming calls, and light pulsating for calls on hold). A lighted LED in the row of red LED's immediately adjacent to the green row indicates the position of the

activating system. The operator moves this selection light by "puffing" on the control straw. When the desired selection is reached, a "sip" or series of "sips" will perform the desired operations. For example, an incoming call will cause a green LED to flash at the line location. The operator must now light the red selection light corresponding to this location. This is accomplished by a series of "puffs". A "sip" opens the line and permits conversation with the caller. Moving the red light to the HOLD position and sipping places the call on HOLD. The red selection light is now moved to the COM line location. A "sip" opens the communication line. A second "sip" activates a counter which automatically counts at about 1.5 digits per second. When the desired number appears on the numerical display, the operator "sips" again and the counter counts down while the system dials the desired number. If the party on the COM line accepts the call, the operator moves the red selection light to the RELEASE position and releases the call to the party called. If the call is not accepted, the operator moves the selection light back to the incoming position and opens the line again. If a message is to be left, the operator moves the selection light to the TAPE position. (The line remains open.) A "sip" at this location activates a tape recorder which records the message as repeated by the operator. Outgoing calls may be dialed on the outside lines as they were on the COM line. This is slow, but effective.

The operator may use a Starlite headset, a standard handset mounted on a gooseneck, or a standard speaker phone. The headset is best in a public situation.

Two of the systems described are presently being used within the Rehabilitation Institute of Chicago. The cooperation of Illinois Bell Telephone Company was indispensable for the success of these systems.

An Interactive System

The power of a small computer can be harnessed for use by a severely disabled person. Through its control program, "software", the computer could: (1) control devices in the home or office, (2) allow enhanced use of the telephone as well as store telephone numbers for reference or future dialing, (3) allow the creation of text messages for printout or storage, (4) send messages over the telephone lines to other computers, and (5) provide vocational and recreational possibilities.

A small computer system has been constructed to generate the above functions. It is based around a Data General Nova 2/4 minicomputer with 8,000 words of memory. The operator controls the system by means of "sip" and "puff" switches, and the system communicates with the subject by messages on a TV screen. The name "interactive system" results from interaction between operator and computer.

The major components of the system are: (1) minicomputer, (2) alphanumeric display terminal and associated TV monitor, (3) modem, (4) teletypewriter, (5) interface circuit, (6) CCS, (7) "sip" and "puff" switches. This system, except for items (4), (5), and (6), is shown in fig. 5.
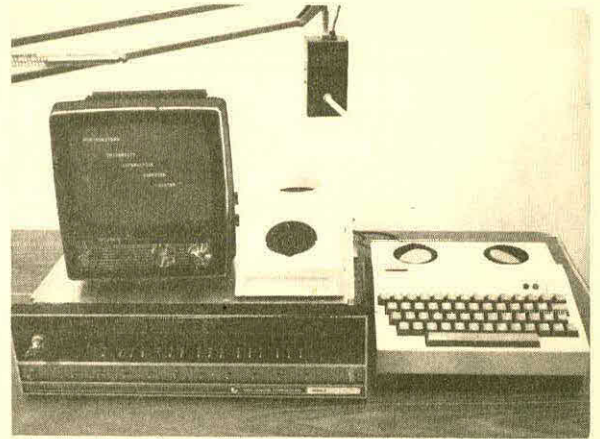

Fig. 5. Picture of interactive system shows minicomputer, TV, modem, display terminal.

Operation

The computer displays a list of initial selections on the TV screen. A marker on the screen, called the "cursor", moves in response to "puffs" on the pressure switches. A "puff" sends the ASCII code for "B" to the computer and a "sip" sends the code for "S". On the list are categories of devices to be activated as well as special control routines for telephone operation and text building. "Puffing" moves the cursor to the correct category, and a "sip" selects the category.

If the selection is device-operation, a new list of choices will be displayed. (Display speed is 2,400 baud.) The choices are the control modes for the selected group of devices. They may be activated by using the same "puff-to-select", "sip-to-operate" scheme as used in the initial selections. (This scheme is used in all control aspects of the system.) When a control mode is chosen for operation, a serial code is sent from the computer to the computer interface circuit. The computer interface circuit presents BCD codes to the CCS interface device. The CCS devices are identical to those already discussed; however, no control heads are used. The computer interface now supplies the BCD instead of the heads. Multiple CCS may be used if many devices are to be controlled. This is shown in fig. 6. Complex control schemes can be accomplished in the control program rather than by designing complex hardware.

If the selection is "message-builder", the computer displays the alphabet on the first two lines of the TV as well as special control characters. Alphabet is presented in order of frequency of letter usage (ETAON...). The
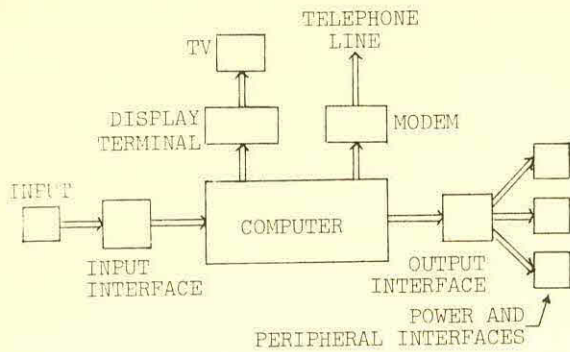
Fig. 6. Diagram shows signal flow in interactive system. The multiple systems at right are power and peripheral interface units of comfort-and-communication control system.

first "puff" causes the cursor to scan the alphabet continuously. (The rate may be changed in the software.) The second "puff" stops the scan in the chosen letter group. Further "puffing" moves the cursor to the correct letter. Then a "sip" records the letter and prints it on another section of the TV and readies the cursor for the next selection. Text messages can be built at approximately four words per minute with this mode of message-building. Control characters are used to edit the message or send the message to (1) the teletype for printing, (2) the "modem" for transmission over the telephone lines, (3) storage for later reference, (4) storage for the telephone program, and (5) storage for the alarm clock program.

If the selection is "telephone operation", the telephone-operating selections are displayed. Telephone numbers previously created by the message-builder may be dialed or stored in a directory with **fifteen** numbers. Stored numbers may also be dialed. Dialing is accomplished by again sending serial codes to the interface. The PC control cards contained in the comfort and communication devices may be simpler than those required for noncomputer-controlled operation. The software handles the complexities.

If the selection chosen is "alarm clock", the clock- and calendar-operating selections are displayed. A time or date previously built by the message-builder can be used to set a clock and calendar contained in the computer. The clock may be set to alert the user at a preset time.

Vocational Possibilities

Messages may be transmitted over the telephone lines, and it has been demonstrated that sip-and-puff-created messages can be used to gain access to a data file in another computer. The subject can use the telephone program to make connection to the other computer. The other computer's messages are transferred to the subject's TV monitor. This process could allow a person to work for companies that keep computer files for their data. The computer-based system has the advantage of being "software" adaptable to a specific vocational need.

Enhanced Message-Building

Scanning methods for message-building are simple, but usually result in low rates of message construction. Crochetiere et al[1] have introduced a scanning approach in which a knowledge of the probability of letter occurrence in the English language may be used to improve message-building rates. This approach has been incorporated into the interactive system, and preliminary results indicate that it may be possible to increase message-building rates by a factor of almost two compared with non-enhanced approaches.

Cost

The possibility of using a small computer for applications of the type described has been made possible by rapidly advancing developments in the semiconductor field. Costs continue to go down and are already approaching the level where individuals may consider private purchase of computers. Also, newer "microcomputers" may further reduce costs. A time may come when the cost of adapting the devices to be controlled may exceed the cost of the computer unit.

Reference

[1] Crochetiere, J. W., Foulds, R. A., and Sterne, R. G., "Computer-Aided Motor Communication", *Proceedings of 1974 Conference on Engineering Devices in Rehabilitation*, pp. 1-5, Boston, Massachusetts, May 1974.

Title of Paper: <u>Vocational Aids and Enhanced Productivity for the Severely Disabled</u>

Category: (check one)   Device Development /‾/   Research Study /X/

Brief Description: The Job Development Laboratory at The George Washington
University has initiated a service through which the severely disabled (cerebral
palsy, muscular dystrophy, spinal cord injury, etc.) may achieve gainful employ-
ment in a variety of occupations (i.e., computer programming, microfilming, statis-
tical analysis, and others. This service utilizes specialized job-client matching
to achieve competitive, long-term employment and cost-effective modification of the job
environment to enhance the client's functional ability.
Intended User Group: Rehab. professionals, vocational counselors, severely
 disabled clients

Stage of Development: (Check all that are applicable)

   A. <u>Device</u>

               Prototype Development   /‾/

               Feasibility Testing   /‾/

               Clinical Testing   · /‾/

               Available for Sale (check one)   Yes /‾/   No /X/

                    Price per unit $ _____

               Availability of constructional details:

   B. <u>Research Study</u>

            Intended Utilization: Job development process may be employed
         by state and local DVR's to achieve more rewarding, long-term employ-
         ment of clients.

            Intended Device Application: Job environment modifications and
         adaptive devices are used to enable client to work successfully and
         competitively.

            Availability of Intended Device: Devices are available as an
         integral part of the job development service.

For further information, contact: Name   Kalisankar Mallik & James Mueller
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                                             420 Ross Hall, 2300 Eye St., N.W.
                                             Washington, D.C. 20037
                                             (202 - 331-6847)

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VOCATIONAL AIDS AND ENHANCED PRODUCTIVITY OF THE SEVERELY DISABLED

by

Kalisankar Mallik, M.S.
Jim Mueller, B.I.D.
The George Washington University
Rehabilitation Research and Training Center
Washington, D.C.

Summary - The Rehabilitation Research and Training Center of The George Washington University in Washington, D.C. has demonstrated that a group of severely disabled persons are competitively productive in a variety of occupations. These include computer programming, microfilming insurance claims adjustment, abstracting, statistical analysis, and editing and proof reading. The disabilities include cerebral palsy, muscular dystrophy, rheumatoid arthritis, multiple sclerosis, and spinal cord injury. Functionally, the majority of the clients are classified as quadriplegics. Despite severe disabilities, 36 clients, working 40 hours per week and earning an average of $8,125 annually, have been placed in the aforementioned fields. The client/job matching process reveals environmental and physical deficiencies necessary for job performance. Cost-effective modification of the environment is employed to enhance the client's functional ability.

Introduction

The National Health Survey statistics [1] indicate that the number of people limited in major activities is increasing each year. A compilation of this data for the last seven years is diagrammed in Figure 1. A breakdown according to disability is shown in Table 1. The nation has responded to rehabilitation needs of the disabled by spending millions of dollars to restore, preserve, and develop functional ability. In 1972, $882 million (Federal - $548 million; State - $149 million, Other - $185 million) [2] was expended to rehabilitate only 326,138 persons by medical restoration, training, guidance, and job placement. However, services for the severely disabled homebound population have been lacking, particularly in overcoming their severe physical limitations as a barrier to employment.
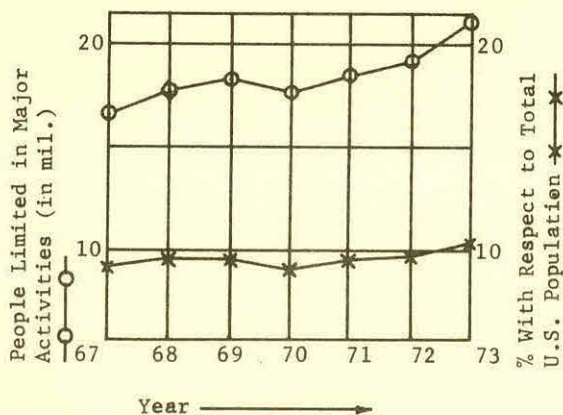

Figure 1. People Limited in Major Activities Vs. Year

Table 1
Persons (in thousands) limited with various conditions in *Major Activities

Year Disability	1970	1972
-Arthritis & Rheumatism	2,101	2,329
-Musculoskeletal Disorders	551	949
-Visual Impairments	358	394
-Hearing Impairments	114	152
-Paralysis (complete or partial)	428	393
-Upper Extremities Impairments (except paralysis)	215	242
-Lower Extremities Impairments (except paralysis)	784	930
-Other (heart disease, cancer, mental conditions, asthma, kidney disease, emphysema, etc.)	13,436	14,199
Totals	17,987	19,588

The U.S. has become information oriented and the techniques, equipment, and materials involved in information handling are in a rapid state of development. These jobs inherently require less manual dexterity and less physical strength than industrial and craft work. Some of these jobs, which are conventional at first look (mail clerk, telephone clerk, computer programmer, insurance claim adjustor, microfilm image inspector) are being done in "new ways". Various adaptations resulting in enhanced productivity of severely handicapped persons are analyzed in the following section.
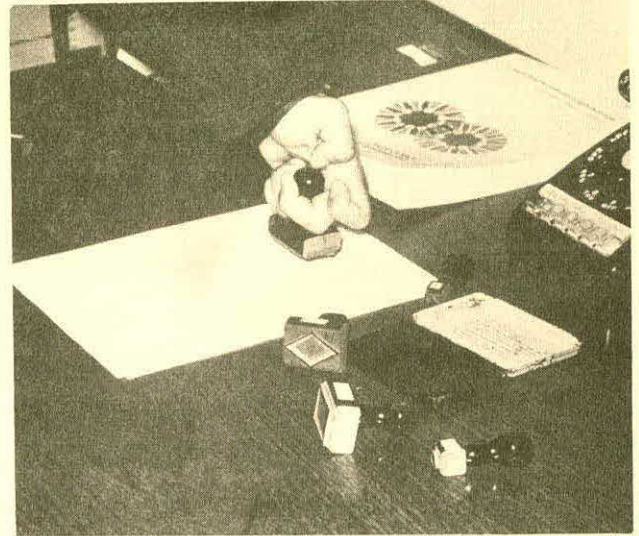
*work, housekeeping and attending school
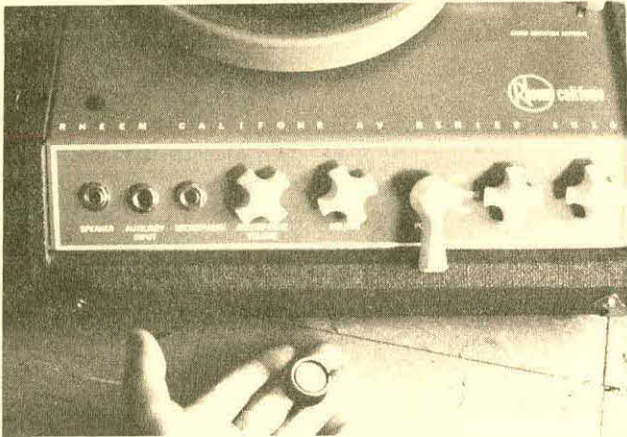
1. CONTROL KNOBS
Problem: Easily distinguished and operated knobs which eliminate difficult twist operation of standard knobs
Solution: Faucet-type molded polyester knobs for added touch and motion feedback
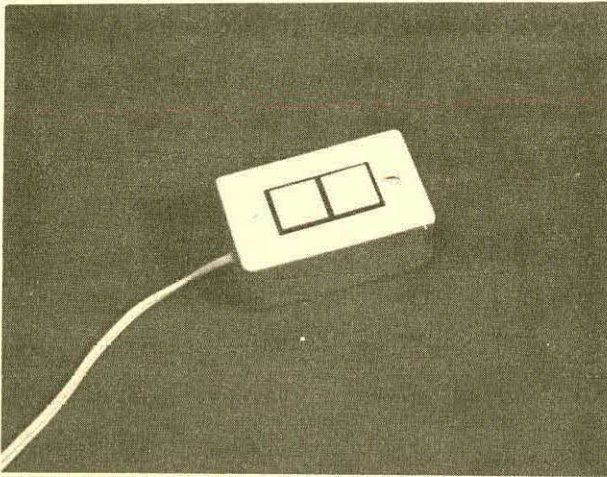Costs: Polyester resin and silicone for molds: $6.00
Assembly time: 5 hours

2. RUBBER STAMPS
Problem: Easy method of drawing complex flow charts for computer programmers
Solution: All charting symbols reproduced in rubber stamps for quick, accurate diagramming
Costs: $5.00 per stamp
Assembly time: None (after original design)

3. REMOTE ON-OFF SWITCH
Problem: Durable light-pressure switch for remote operation of household and/or business appliances
Solution: 15-Amp household wall switch wired to "piggyback" plug, mounted in case
Costs: Single-pole AC touchbutton switch, wiring, plug, and case: $7.25
Assembly time: 4 hours

4. TELEPHONE HOLDER AND CIRCUIT BREAKER
Problem: One-hand operation of a regular desk office telephone
Solution: Spring-loaded extension arm phone holder; stainless steel spring lever to depress phone cradle buttons.
Costs: Custom Luxo Phone Holder: $32.00
Stainless steel cradle lever: $.75
Assembly time: 4 hours

5. DESK FILING SYSTEM
Problem: Easily-accessed desk filing system for insurance office files
Solution: Stacked metal desk drawer dividers along rear of desk surface
Costs: Steel case desk drawer dividers: $15.72 (set of four)
Assembly time: None
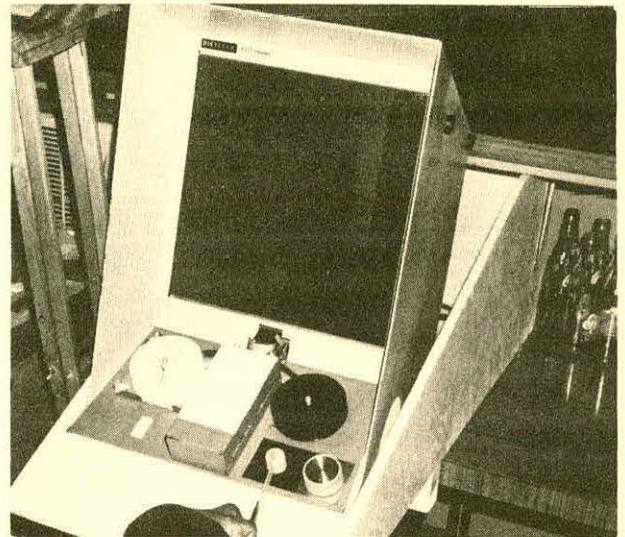
6. MICROFILM VIEWER
Problem: Quick access to office documents and reference materials without need for page turning or book manipulation
Solution: Documents microfilmed and viewer knob adapted for use with simple hand motions
Costs: Dietzgen Model 4317 Reader: $435.00; Microfilm fee: $10-15.00 per book; Knob lever: $10.00
Assembly time: 1/2 hour
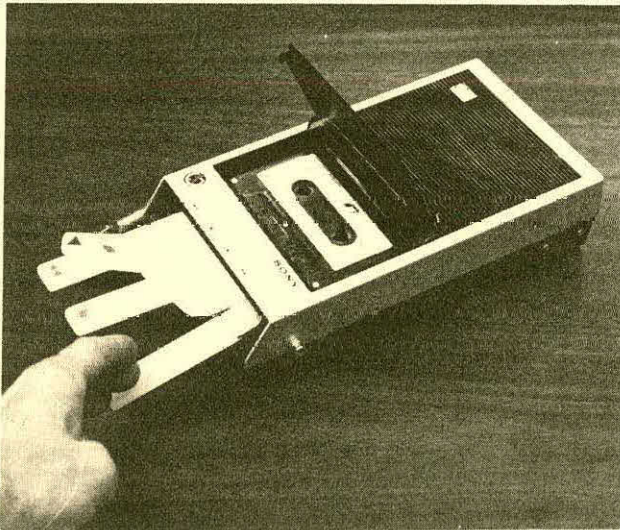
7. TAPE RECORDER
Problem: Substitute for handwriting of office correspondence, editor's notes, etc.
Solution: Tape recorder with snap-on switch levers for operation with light hand pressure
Costs: Sony Model TC 110 Recorder: $120.00; Polypropylene levers: $1.50
Assembly time: 6 hours

8. DICTATING MACHINE
Problem: Dictating machine which may be remotely operated with extremely low force by hand, chin, elbow, etc.
Solution: Lanier Dictating Machine with remote microphone and control box to replace standard hand-held unit
Costs: Lanier Edisette Model 1977 Dictating Machine: $535.00 (including special factory built control box and microphone)
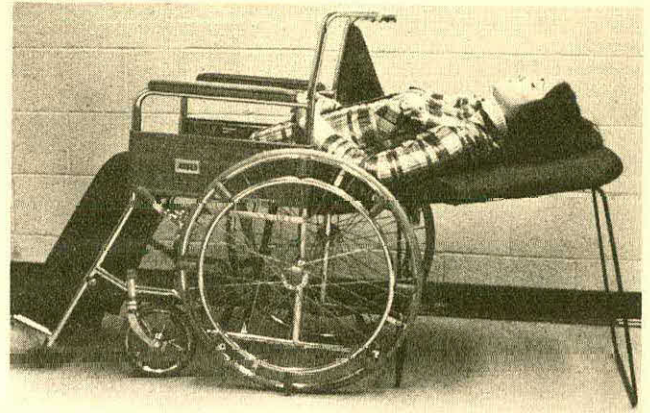Assembly time: None
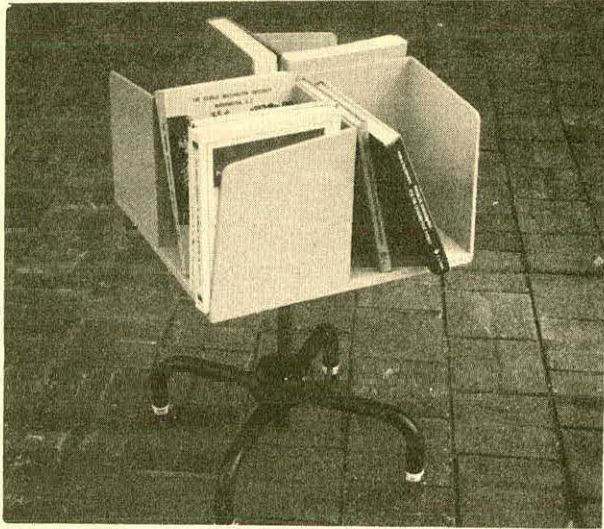
9. ROTATING BOOKSHELF
Problem: Moveable bookshelf allowing easy access of many heavy books with minimum lifting and reaching
Solution: Castered, rotating table sectioned to hold four sets of books; height adjustable
Costs: Surplus typist chair and other materials: $23.50
Assembly time: 10 hours

10. WHEELCHAIR RECLINER
Problem: Relief from pressure sores created by prolonged work in wheelchair without shift of position
Solution: Free-standing upholstered platform and detachable wheelchair back to allow reclining with aid of one attendant
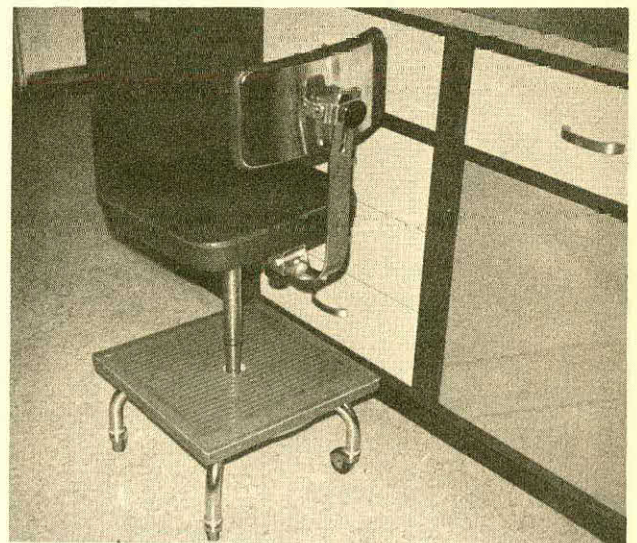Costs: Wood, steel, foam, and vinyl: $20.00
Assembly time: 12 hours
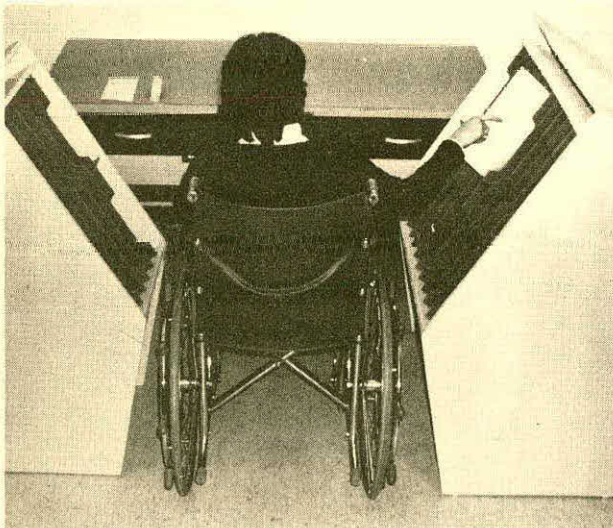
11. MAIL SORTER
Problem: Services of open vertical files for mail sorting from wheelchair
Solution: File cabinets built to proper height and angle for wheelchair-bound employee
Costs: Wood and other materials: $30.00
Assembly time: 30 hours

12. FOOT-SUPPORT CHAIR
Problem: Chair seating at standing level with support for feet to allow machinery operation while seated
Solution: Elevated typist chair with metal platform on base
Costs: Typist chair: $40.00; metal for platform: $5.00
Assembly time: 4 hours

The preceding examples of vocational aids illustrate simple solutions to common job tasks, designed according to individual functional abilities (pinch, grasp, elbow extension and flexion). The combined use of some of these aids has enabled physically impaired clients to be gainfully employed by enhancing their productivity in a variety of tasks. Examples of the utilization of these modified job tools in a wide range of employment are indicated below:

Occupations	Aids
Insurance claims adjustor	= 4 + 5 + 8
Mail clerk	= 11 + electric (letter opener + stapler)* + adjustable table*
Computer programmer	= 1 + 2 + 7 + adjustable table*
Receptionist	= 4 + 6
Magazine editor	= 8 + 9
Microfilm inspector	= 6 + 7 + adjustable table*

* Commercially available

Measurement of Productivity

Environmental adaptations designed for individual clients' capabilities and job requirements increase both quality and volume of output. The following example of a technique for measuring output of a microfilm image inspector illustrates the relationship between job tools, environmental adaptations, and competitive output by physically handicapped persons.
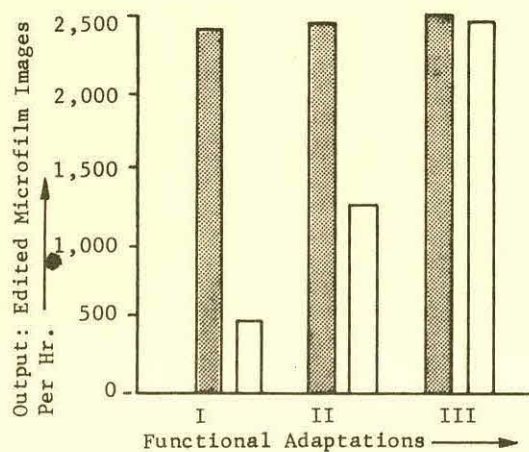
LEGEND
I. Before Functional Adaptations
II. Custom Knobs to Facilitate Grasp
III. Tape Recorder Adaptation Coded Sheets to Minimize Writing
▨ Av. Productivity - Able-bodied
☐ Av. Prod. - Physically Disabled

Figure 2. Measurement of Productivity

In Figure 2, the output for able bodied microfilm image inspectors is traced at approximately 2,500 images/hour for average-size documents on 16 mm film at 20 x the reduction ratio. The worker is rquired to inspect every image for loss of information in the microfilming process and to record this information for subsequent correction. Usually the worker is paid on an hourly basis. One 23 year old severely disabled, high school graduate, who had the basic skills of observation and judgment required for such tasks was limited by his functional capacity for competing on an hourly basis with the able-bodied worker. His initial output was only 500 images/hour. Initial adaptations to the environment made it possible to improve his rate to 1,250 images/hour (far short of competitive output); subsequent adaptations enabled the worker to close the gap between his original output and the current competitive rate. At the rate of $2.50/hour, this homebound person has edited more than 5 1/2 million images in the last 4 years, contracting his services to a wide array of corporate and public organizations.

Conclusion

The decade of the 70's has been described as "the era of accountability". The rehabilitation profession is analyzing the actual impact of dollars spent in terms of a cost-benefit analysis. 3,4 Many ingenious adaptations for one disabled individual have never been utilized for another person because the individual cost factor has been too high. Generally, therefore, the most cost-effective adaptations are simple, low-cost modifications with implications for use by many disabled people in a variety of occupations.

References

1. U.S. Dept. of Health, Education, and Welfare, Current Estimates from the Health Interview Survey, 1967-73.

2. U.S. Department of Commerce, Bureau of the Census, Statistical Abstract U.S., 1974

3. Mallik, K., Cost-Benefit Analysis in the Vocational Rehabilitation of Physically Disabled, Homebound Persons, Proceedings of the 25th Annual Conference on Engineering in Medicine and Biology, Oct. 1972.

4. Pacinelli, R.N., ed., Research Utilization Rehabilitation Facilities: Proceedings of an International Conference, Oct. 1971, 235-285.

The material contained within this publication

has been edited for typographical, and gram-

matical errors by the individual authors, only.