1. Continuous and reliable electrode/skin contact during movement;
2. Accurate placement of electrodes over muscle sites during use and from day to day;
3. Simplicity of unaided donning and doffing;
4. Comfort during prolonged wearing periods;
5. Ease of maintaining cleanliness;
6. Durability (so far, 3 mo of use); and
7. Inexpensiveness (cost is less than $20 for T-shirt and electrode assemblies).

In summary, it was shown that by using a certain readily available material, a simple T-shirt could be made and configured with appropriate electrodes to provide a satisfactory amputee/prosthesis interface for myoelectric arm prostheses. The new harness also shows potential for use in other rehabilitative applications, such as electrotactile displays for amputees, and sensory augmentation devices for the blind and deaf, surface electrical stimulation of muscles for scoliotic and paralyzed patients, electrotactile lumbosacral braces, and so forth. Further experiments on additional applications are suggested.

Low Cost Assistive Device Systems for A High Spinal-Cord-Injured Person in the Home Environment — A Technical Note[a]

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Introduction

Two important needs for the high spinal-cord-injured person are independent mobility and manipulative capability. Advancement in powered wheelchairs over the past several years is now enabling better mobility. Mouthsticks enable an extensive variety of low-force manipulative functions within a limited distance of the operator's head. Robotic arms are being developed to increase the ability of quadriplegics to perform manipulative functions.

[a] This report was prepared as part of NAVSEA Contract N) 24-78-5384, this portion sponsored by the Veterans Administration Rehabilitative Engineering Research and Development Service.

This report presents experience with a new electric wheelchair controller and various simple, low-cost devices, which were provided to a high-level quadriplegic to use in and about his residence for the purpose of maximizing his functional capabilities. By this means it is hoped to improve the quality of life for quadriplegics of this type.

A Volunteer Quadriplegic Subject

M. C., a quadriplegic who volunteered for this evaluation, is 32 and has no functional use of his limbs. He sustained his injury in 1964. He and his wife were married in 1969 and have lived together since then in a one-level small frame house of which they are the owners and sole occupants. His wife is a nurse, and he is alone in the house while his wife is at work. Prior to 1979 he spent his days in a non-powered wheelchair which he was unable to move. Although he was able to use a mouthstick to turn the pages of a book placed in front of him, after finishing the book he was unable to replace it with a new one.

In March 1979, the Johns Hopkins group furnished M. C. an electric wheelchair with the low profile chin controller and a motorized pop-up mouthstick holder. His work area was modified by his wife and relatives to utilize the additional equipment provided and described in this report.

This equipment is intended to address needs of quadriplegics in the C-3, -4, -5 range who lack any significant or useful upper-limb function. They must have sufficient cervical spine and temporomandibular range of motion both for effective use of a mouthstick and for operation of a wheelchair chin controller. The specific functions addressed include: basic mobility of the wheelchair; ingress and egress from the house with opening and closing of the storm door; management of reading materials; use of a typewriter, a speaker telephone, and a standard touch operated telephone; and remote operation of lights and electrical appliances.

In order to provide a low cost solution to some of the needs of the handicapped person, maximum use is made of commercially available devices. The prime element for mobility is an E&J Model 3P electrically powered wheelchair. The chin controller is an add-on unit developed at Johns Hopkins. Manipulation is achieved by a mouthstick. Storage, retrieval and use of the mouthstick are important elements of this integrated systems concept. A description of the quadriplegic volunteer and of the basic elements involved in the evaluation follows.

Chin Controlled Wheelchair with Motorized Mouthstick Holder

The JHU-VA chin controller was developed due to the lack of a commercially available controller operable by a high level quadri-

plegic and compatible both with use of a mouthstick and with remote operation of a robotic arm. The controller is plugged into an existing electrical fitting on the E&J Model 3P wheelchair. No additional modifications are required. Experimental units are currently being evaluated by three quadriplegic volunteers. Construction and testing of the additional units are planned.

Speed is proportionally controlled by depression of the chin lever. Steering is accomplished by moving the lever from side to side. The unit may be adjusted for high sensitivity (small lateral neck motions for steering) or low sensitivity (high lateral neck motions for steering). Figure 1 shows a quadriplegic volunteer positioning the controller to drive straight. When not needed for mobility, the controller may be easily pushed aside (Fig. 2) and retrieved when required. On-off power to the controller is accomplished by lifting the chin lever. The wheelchair motors may be shifted to the high torque mode by a hard push to the left. A second push will return the unit to normal torque. Except for sensitivity adjustments, all of these functions are achieved by chin motion alone.

Another important addition to this wheelchair is the motorized pop-up mouthstick holder which can be easily attached to either of the wheelchair arm rests. This unit allows the mouthstick to be kept in an inconspicuous location during wheelchair movements (Fig. 1) and to be easily retrieved when needed to perform manipulative functions. The motorized unit is activated by moving the chin lever to the extreme right when the chin controller is in its "off" mode. The wood mouthstick utilized in this system has a magnetic coupling in its shaft which allows the quadriplegic to use it at its full length (approximately 50 cm) or to remove the terminal segment himself and use it at its shorter length (approximately 38 cm long).

Lighting/Appliance Control System

One of the commercially available systems in this clinical evaluation is a remote control system manufactured by BSR, Inc., and sold by retail chain stores such as Sears and Lafayette Radio. The complete system consists of an ultrasonic command unit (16 channel capability), ultrasonic receiver/control console, and as many remote control modules as desired. The ultrasonic command unit is mounted on the wheelchair (Fig. 3) and has a line of sight range of approximately 30 feet.

The motorized mouthstick holder moves the mouthstick within easy reach of the user, allowing full access to this keyboard. The receiver/control console is located in the worktable area between the reading stand and the typewriter (Fig. 4). It incorporates a micro-

FIGURE 1.—Quadriplegic with Chin Controller positioned to drive straight ahead.

processor controller and can control up to 16 functions on each carrier channel. The appliances or lamps to be controlled are plugged into remote modules located at the normal wall outlets for the appliances or lamps. A complete set of controllers and four remote modules costs $120.00. This system may be operated remotely, from the unit on the wheelchair and/or from the keyboard on the control unit on the table.

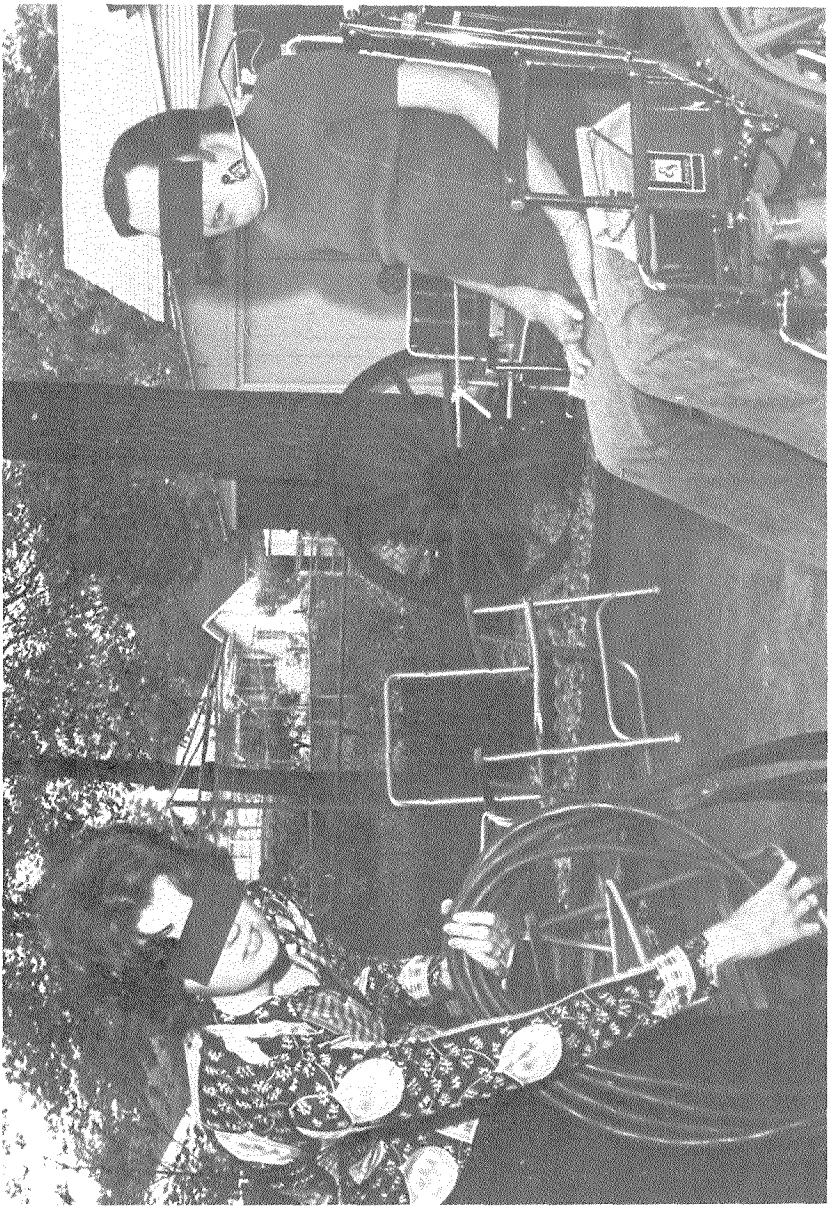

FIGURE 2. — Chin Controller in non-operating position.

Some of the functions being controlled by the quadriplegic in this clinical test program include a speakerphone amplifier, table lamps, electric typewriter, tape recorder, and the television. The remote units may be placed in any wall outlet throughout the home without

FIGURE 3.—Quadriplegic operating ultrasonic command unit mounted on wheelchair arm.

any extension cords. It is also possible to communicate between nearby houses fed by the same 110 volt transformer circuit, to provide an additional means for a handicapped person to summon help.

Multiple Book Reading Stand

One of the important needs for a quadriplegic is the ability to manage various reading materials. The mouthstick is, of course, an excel-

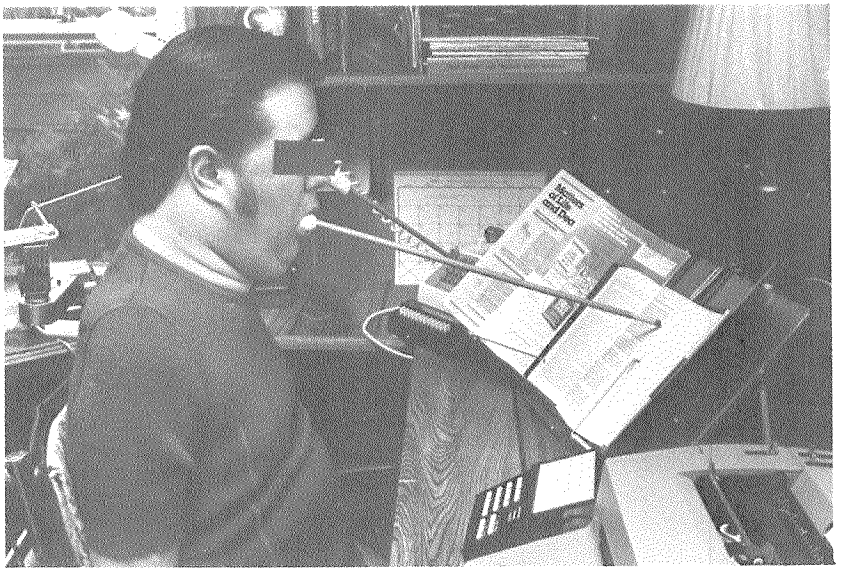

FIGURE 4. — Quadriplegic at work table.

lent tool for turning pages of a book or magazine. Since this new wheelchair chin controller is not in the way of the mouthstick, use of the mouthstick is uninhibited. The problem is then one of finding a suitable book/magazine holder capable of holding a variety of reading materials sufficient for a day of reading. Excessive length is a problem characteristic of traditional reading stands which have been designed to hold a quantity of reading materials. This problem is avoided if the books are attached in a mode which enables them to overlap when either closed or open.

The book holding rack utilized is a commercially available industrial catalogue/magazine rack sold by office supply companies (Fig. 4). Its performance is improved by mounting it on a swivel base. This base is not visible in the illustration. Several magazines, books, and other reading materials may be placed in one book holder and kept securely in place for turning pages with one mouthstick. The only modifications to the available commercial components are the addition of a wider flange at the base to better support pages of thick books to prevent them from sliding down, and moveable fingers to hold pages of smaller books, such as paperbacks. One reading rack has been set up with two full size telephone directories whose pages are easily manipulated by the subject in these tests. The reading stands may be purchased in multiples of 6 inch lengths up to 24 inches wide. Costs start at $15.00.

Use of the Typewriter

The electric typewriter can be an important communication means, once the quadriplegic gains mastery in the use of a mouthstick. Simple tools such as mouthsticks and headsticks have been widely used in rehabilitation centers and in the home for tasks involving keyboard devices such as the typewriter. In addition to the actual typing, the need exists to place paper into the typewriter as well as to remove it when a page is completed. A paper management scheme has now been devised at Johns Hopkins which is mouthstick compatible. The system consists of a special paper tray arrangement and special mouthstick ends (Fig. 5). A ball type electrical typewriter was selected to eliminate carriage motion considerations. The tray holding the supply of typing paper is placed at a 45-deg. angle and has a retainer bar at the bottom of the tray to allow one sheet at a time to be dispensed. For paper management, a two-piece lightweight hollow-tube mouthstick is utilized. The lower (detachable) portion of the mouthstick is fitted with a small suction cup. This allows one sheet of paper to be easily manipulated into the typewriter, with the subsequent typing task accomplished by disconnecting the detachable portion and retaining the fixed-length rod for keyboard manipulation. Upon completion of a page, the sheet may be removed by reattaching the lower portion of the mouthstick and then using the suction feature of the hollow mouthstick to place the sheet in the "out" basket. Thus, the

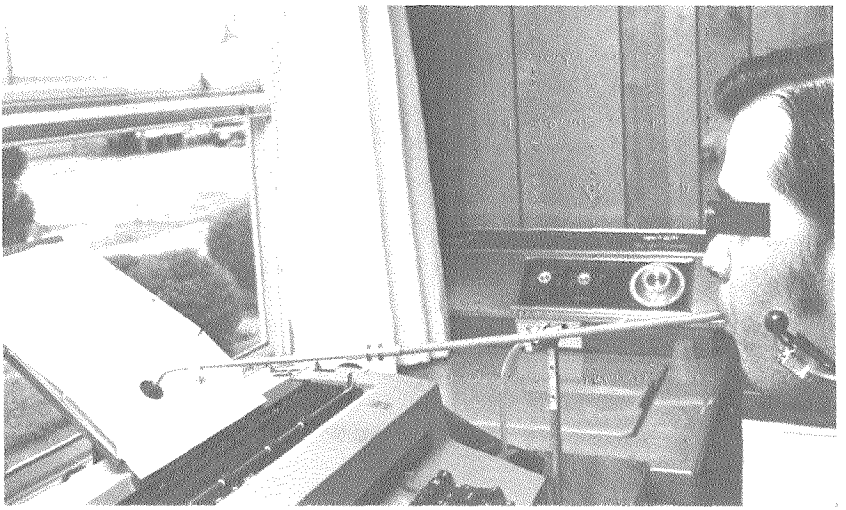

FIGURE. 5 — Quadriplegic using special mouthstick and paper feeder to load typewriter.

total management of the typing task may be accomplished without assistance.

A similar paper tray arrangement has been investigated for the management of loose page reading material such as memoranda or correspondence. In this instance, each sheet is dispensed with the mouthstick into a reading tray suitably located in front of the user to allow him to read daily correspondence. This system, in conjunction with the book reading stand previously described, gives the quadriplegic much flexibility in his choice of reading material.

Another function associated with the hollow mouthstick feature is the ability to drink water in a manner similar to sipping with a straw. The dual mouthstick holder shown in Figure 5 has one side fitted to a plastic tube inserted in a glass of water. By inserting the longer portion of the mouthstick into this side of the holder, the quadriplegic may take a sip of water when he chooses.

Telephone Management

The approach for telephone management considers three main factors: use of speakerphone, handset, or a combination thereof; storage and retrieval of telephone numbers; and dialing out and use of speakerphone to answer the telephone when away from the work area.

The telephone arrangement was set up to include both a speakerphone and telephone handset in the system. This allows utilization and evaluation of both subsystems. The handset may be preferred for privacy and minimum noise. The physical arrangement for the handset is shown in Figure 6. The handset is suspended on a counterweighted arm to allow it to be in the up position where it is out of the way and easily approached in the wheelchair (Fig. 4) or in the normal phone use position (Fig. 6). The phone is pulled down into the normal phone use position by means of a small ball hanging on a short string where the quadriplegic can easily pull on it with his teeth. Touch tone dialing is accomplished with a mouthstick. The dial tone activate button is also mouthstick operated by moving a simple lever clamped to the telephone. A conventional phone number index card system is located under the phone within easy reach of the mouthstick. Two large phone directories are located nearby on the industrial book holding rack previously described.

A speakerphone is handy for answering incoming telephone calls when the individual is not directly in front of the handset phone and when privacy and noise are not important to the user. This speakerphone is plugged into one of the remote control units previously described and may be activated by the ultrasonic controller located on

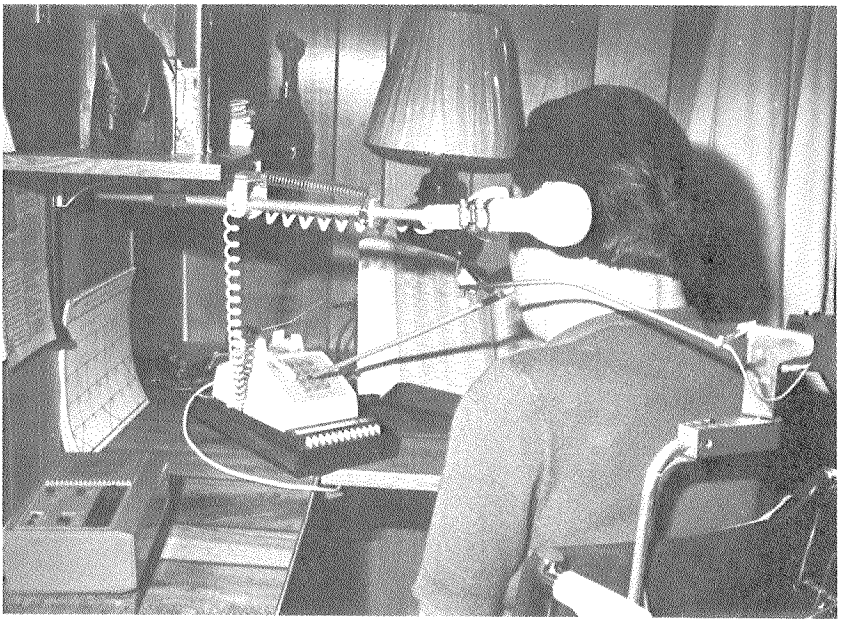

FIGURE 6. — Quadriplegic dialing handset phone.

the wheelchair or the table control unit. This allows the phone to be answered promptly from almost anywhere in the room without driving to the exact location of the phone. This volunteer is also experimenting with the concept of activating a tape recorder by means of a remote control unit to easily record phone conversations related to business matters. The tape recorder unit used by this quadriplegic is a commercially available unit (Sanyo Model M2511) which features one-button control for Record, thus making all of its functions compatible with a mouthstick. (Most other tape recorders require two buttons to be depressed simultaneously for the Record mode.) The ultrasonic controller on the wheelchair opens up many options for remote operation of electrical devices, thereby reducing need to drive precisely into a particular position for each device.

Storm Door Operation

One of the requests by this volunteer was to have a means of managing the storm door, for independent egress and ingress to his house. This has been accomplished without the use of a motorized system as follows:

1. The wheelchair is used to push the door open. This motion also lifts a small weight via a pulley into a latched position, to be used to close the door upon re-entry.

2. A conventional hydraulic screen door closer with the spring removed holds the door open. This prevents the door from suddenly being closed by the wind.

3. The user pushes the door closed with his wheelchair from the patio side of the door.

4. To re-enter the door from the outside, the user drives against a hinged flap fastened to the bottom of the door (Fig. 7). Pressure of the wheelchair against the flap opens the door partially.

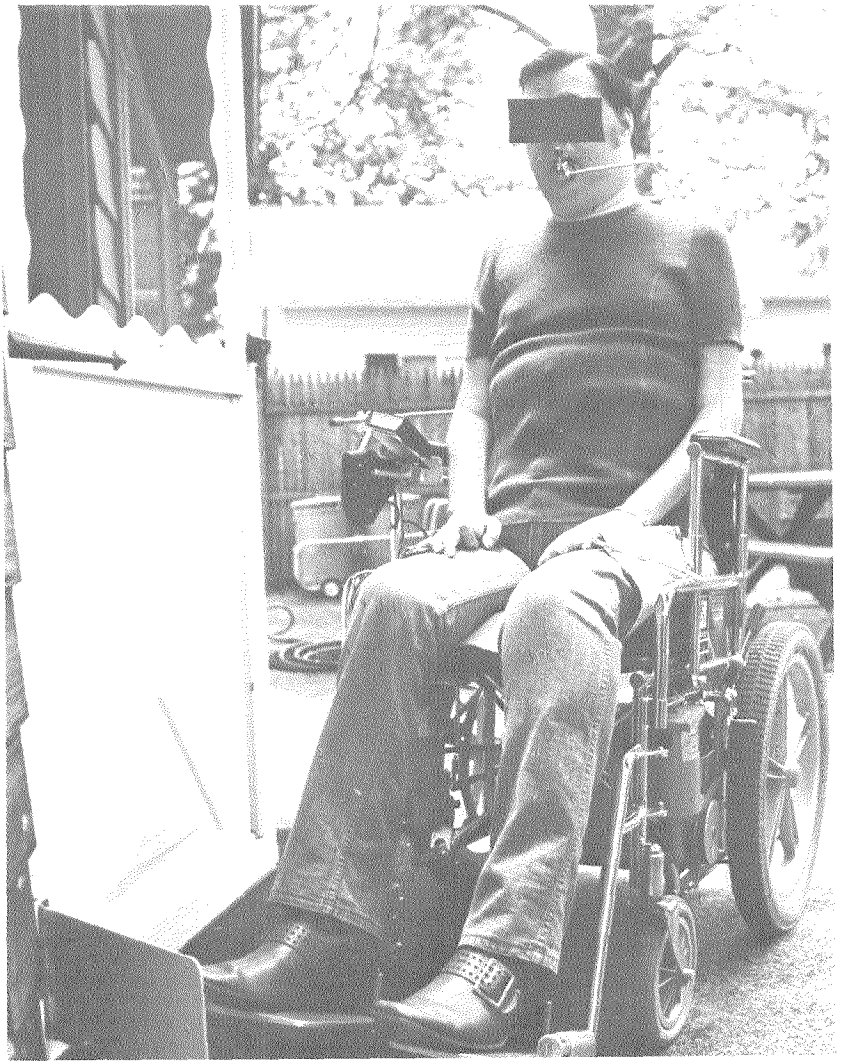

FIGURE 7. — Quadriplegic drives against hinged flap to open storm door.

5. By then driving against the open edge of the door, the user can open it fully and drive through.

6. After re-entering the home, the user activates a latch with wheelchair motion allowing the weight to pull the door closed behind him. This system uses low cost components and works effectively on the storm door without attendant assistance.

Conclusions

This report has described a system utilizing low-cost components to allow a high level quadriplegic to perform certain functions on his own. Results from 4 months of evaluation by one quadriplegic have indicated the concept shows promise. Clinical testing will be continued with this volunteer and others, to better define required system components and to examine alternative arrangements to accomplish some basic tasks to improve the quality of life for these severely handicapped persons.

Acknowledgment

The writers would like to gratefully acknowledge the support of John H. Loveless of the Applied Physics Laboratory/The Johns Hopkins University, who designed and fabricated much of the special hardware described in this report.