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EVALUATION OF AN EYE-MOVEMENT CONTROLLED WHEELCHAIR—A PRELIMINARY REPORT[1]

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AN impressive body of knowledge of considerable scientific and technological usefulness has been created by the aerospace programmes of the National Aeronautics and Space Administration (NASA). In several instances, this knowledge has been applied to meeting the needs of the physically handicapped. Notable examples include a reduced gravity simulator to assist in the gait training of paretic patients (Partridge *et al.*, 1970), an electro-optical call system for the extensively paralysed patient,[2] and a waste-management system to assist in the care of incontinent patients.[2]

A guidance system controlled by eye movements is another NASA development with considerable potential for aiding the severely paralysed individual. The system was designed to provide astronauts with a method of spacecraft control should their extremities become immobilised by high G forces encountered during blast off or in specific emergency conditions. Though never utilised in space flight, this guidance system was adapted for use with a motorised wheelchair. While the eye-movement controlled wheelchair has been widely publicised in the popular press[3], information concerning the suitability of this system for extensively paralysed individuals has not been available. Consequently, the present study was undertaken to evaluate:

1. the manoeuverability of the wheelchair, *i.e.* the precision of control possible;
2. the reliability of the system under conditions of extended use;
3. the degree of assistance patients require to use the chair;
4. the time required by patients to become proficient in controlling the wheelchair in a hospital environment.

DESCRIPTION OF THE SYSTEM AND ITS OPERATIONS

Shown in Figure 1 is the eye-movement controlled wheelchair. The Power Handling Unit labelled 'A' is located under the battery tray and contains the electronic components required to drive the motors. The Control Unit labelled 'B' contains the solid state logic circuits, power stage drivers and amplifiers. Several manually controlled switches are located on this unit, including one for

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[2] Medical Benefits From Space Research: NASA Contributions in the Field of Rehabilitation. National Aeronautics and Space Administration Technology Utilization Division, 1971, 1-28.

[3] E.g. *Popular Science* (1971), 98, 62-64; *Time* (1971), 98, 40.

arming the system and turning it off and others for adjusting the sensitivity of the two Sight Switches secured by spring clips to standard eyeglass frames. (The Sight Switch for the right eye is labelled 'C' in Figure 1.)

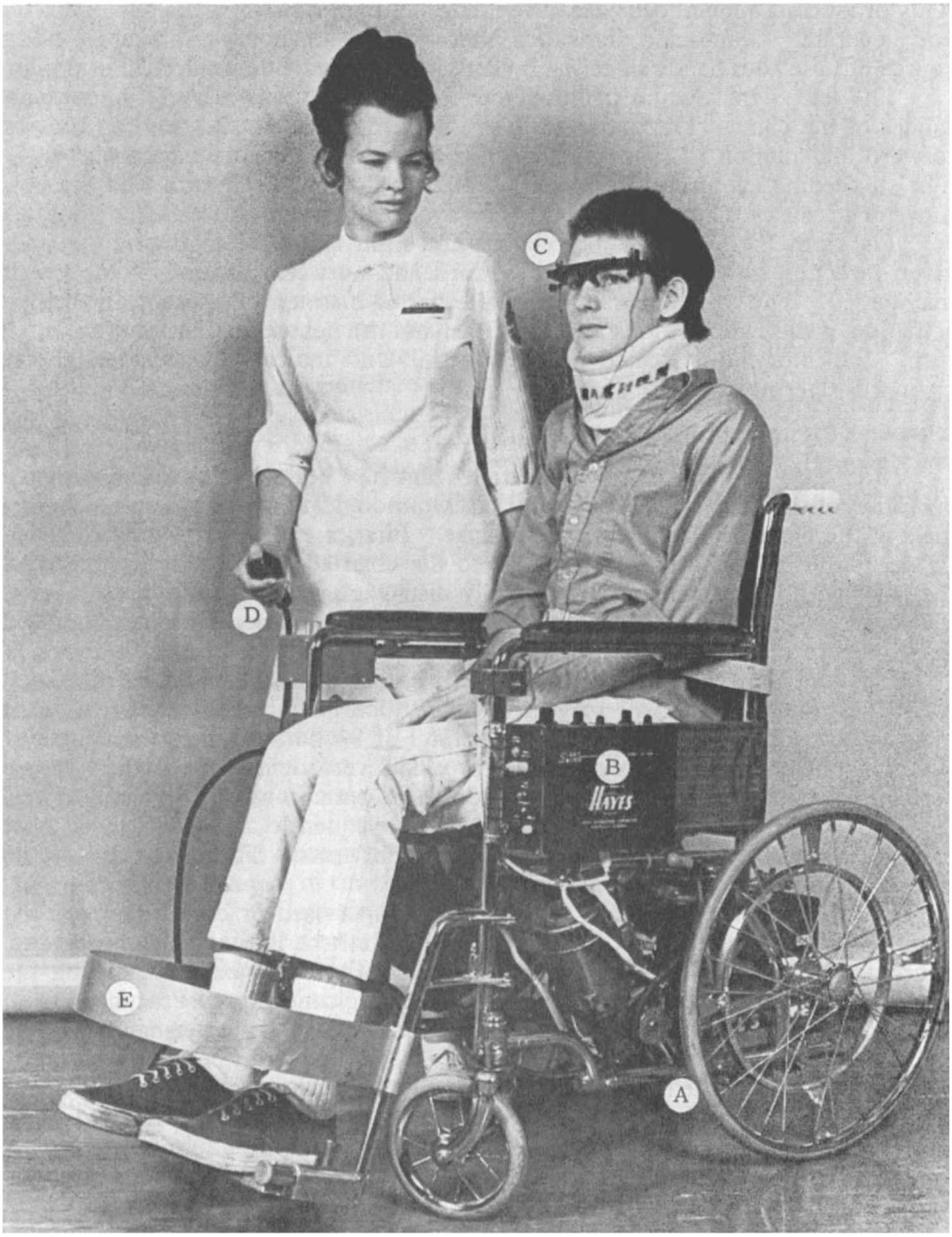

FIG. 1

The eye-movement controlled wheelchair. *A*.—the Power Handling Unit; *B*.—the Control Unit; *C*.—the Sight Switch for the right eye; *D*.—Emergency Stop Switch; *E*.—Bumper Guard.

Each Sight Switch contains two elements—a light source directed to the sclera of the eye and an adjacent photodetector which senses the intensity of light reflected from the eye. The Sight Switches are positioned so that an exaggerated upward and outward diagonal glance will cause the darker iris to intersect the beam. This produces a sudden decrease in the reflected light sensed by the photodetector and generates a command signal for operating the chair. Eyeblinks are not a source of false commands since the reflectivity of the eyelid and eyeball is similar.

The left Sight Switch controls the forward, stop and reverse operational modes of the chair. The appropriate eye movement results in the chair moving forward and motion is maintained until the next eye movement halts the chair. The succeeding eye movement causes the chair to move backwards and the next movement causes the chair to stop. The cycle can then be repeated.

The right Sight Switch controls left and right turns. The chair turns in a given direction only as long as the upward and outward position of the eye is maintained. The switch operates in an alternating manner. For example, the first actuation of the switch results in a right turn and the next actuation results in a left turn. Indicator lights located on the Control Unit indicate which direction the chair will steer next.

RESULTS

After each member of the evaluation team had become acquainted with the operation of the chair, it was decided that two modifications were required before making the chair available for patients' use. First, a hand-held switch (labelled 'D' in Figure 1) was attached by cable to the chair to provide the occupational therapist with a means of instantaneously disengaging the drive motors in case the patient lost effective control of the system. Secondly, a bumper guard (labelled 'E' in Figure 1) was attached to protect the patient's feet from being bumped.

A patient was then selected for whom this mode of wheelchair control seemed particularly appropriate. A 17-year-old C4 quadriplegic, approximately three months post-injury, used the chair for a total of $8\frac{1}{2}$ hours during the course of eight separate sessions. The experience revealed several deficiencies in the system's performance making it potentially hazardous for patients who could not control the chair manually in certain situations. Consequently, it was decided that paraplegic patients should be used in subsequent tests. The last phase of the evaluation included four such patients.

It was found that less than 30 minutes of supervised practice were required by the subject to be able to control the chair within the limits of its capabilities. Learning was facilitated initially by disengaging the drive belts permitting the requisite eye movements to be practised under static conditions. Practice beyond the introductory session contributed largely to smoothness of performance and the ability to react appropriately in novel situations.

So that some patients could be oriented to the techniques of eye-movement control while others were using the chair itself, a training unit was designed and fabricated. The unit consisted of a pair of Sight Switches mounted on eyeglass frames and a panel containing different coloured lights to indicate the operational state of each switch, *e.g.* right or left as well as forward, stop or reverse. Skill developed from using the training unit appeared to be readily transferable to controlling the chair itself.

There were no complaints by subjects that the low intensity light directed toward the eye interfered with normal vision. Patients and the professional staff also agreed that the arrangement of mounting the Sight Switches on the eyeglass frames was cosmetically acceptable. There were complaints about the discomfort caused by the nose piece of the frames which was secured by a tight elastic band encircling the back of the head. Without this band, however, the frames would occasionally shift due to sudden head movements or jarring motions transmitted by the chair. As a result, the orientation of the Sight Switches was altered, affecting their sensitivity to eye movements. The Sight Switches would also occasionally shift in position with respect to the eye because they could not be clamped securely enough to the frames. To overcome this problem a new means of mounting the switches was devised, consisting of a clamp tightened by a knurled screw. In addition, a more flexible wire was used to connect the Sight Switches to the clamp since the original wire was so resilient that it would not maintain a given bend.

Two other relatively innocuous problems in the system's performance were encountered. First, the chair failed to maintain straightline tracking in either the forward or reverse direction because the swivel-type front wheels could not be satisfactorily aligned. The tendency of the chair to deviate to the side could be readily corrected by the experienced user, but was a troublesome complication to the neophyte. Secondly, the system could be used effectively only at its two fastest speeds. It was totally inoperable at the 'low-low' speed and the front casters failed to become aligned at the 'low' speed as the chair initially accelerated. The necessity of using the faster speeds, 'high' and 'high-high', proved stressful for some novice users.

A more serious problem was that the chair would occasionally start, stop or change directions without an eye-movement command or at other times be unresponsive to the requisite eye movements. In the first of several tests to determine the basis of these difficulties, the electrical parameters of the Sight Switches were monitored over a 3-hour period during which the ambient illumination was maintained at a fixed level and the motor-drive mechanism was engaged to simulate normal operating conditions. It was found that for the first 45 minutes after having turned on the power, reliable operation could be maintained only if the sensitivity of the Sight Switches was frequently readjusted—a procedure for which a quadriplegic would require assistance. This warm-up time, considerably longer than the five minute period specified by the manufacturer, was suspected to be partly due to changes in the battery terminal voltage supplying the logic circuits. By installing a regulating circuit to maintain a constant voltage level this was confirmed. With the regulator installed, stable operation was reached in 30 minutes. It was concluded that during this time the photodetector is being gradually heated by the light source. Until the photodetector reaches a stable temperature, its output changes. This can be remedied by improving the thermal insulation between the light source and the photodetector within each Sight Switch.

Even after a 1-hour period when thermal, illumination and voltage factors were well stabilised, internally generated, spontaneous changes in the state of the logic circuits were occasionally observed which in normal operation would result in the chair changing directions or stopping. It was not established whether this erratic performance is due to the design of the electronic circuitry or to the unreliability of some of its components.

Another basis for the system's unreliable performance was its susceptibility to changes in the level of ambient illumination. This deficiency was dramatically illustrated one sunny day when the chair passed within approximately 10 feet of the brightly illuminated, electronically operated glass doors of the building. The chair failed to respond to the patient's eye-movement command to stop, and as the doors automatically parted, the cable of the emergency stop switch became entangled in the spokes of one wheel and was pulled loose from its connection on the chair. The chair passed through the doors, down a ramp and into the street. Everyone except the quadriplegic occupant of the chair was thoroughly shaken by the incident. Following this and related incidents, tests were conducted to document the system's vulnerability to variations in the intensity of the ambient illumination. Two 150-watt incandescent bulbs were suspended approximately four feet above the subject's head. To simulate the actual operation of the chair, it was supported on blocks to allow the wheels to turn freely. Using an illuminometer and a variable voltage autotransformer a given level of brightness was selected and the sensitivity controls for each Sight Switch were appropriately adjusted. The brightness was then gradually increased or decreased until one of two kinds of malfunction occurred —a change in the operating mode of the system unaccompanied by an eye-movement command or a failure of the system to respond to an eye-movement command. When the sensitivity settings were initially established in a brightness condition equivalent to that measured in a well illuminated office, a decrease in brightness equivalent to the level recorded in an ordinary hallway resulted in spurious commands either to turn or to stop. When the brightness was increased to a level measured directly under a fluorescent light fixture, the system failed to respond to commands to either turn or to stop.

DISCUSSION

The current prototype of the eye-position operated wheelchair demonstrates the feasibility of the Sight Switch mode of control. A number of improvements are required, however, before the system can be considered a practical means of mobility for the quadriplegic patient. Effort must be directed toward:

(*a*) overcoming the sensitivity of the control system to changes in the level of ambient illumination;
(*b*) eliminating spontaneous changes in the state of the logic circuits;
(*c*) improving the thermal insulation of the photodetectors to shorten the stabilisation time and
(*d*) providing an unfailingly reliable control mode, operable by the patient, to stop the chair in case the normal controls malfunction.

Even after the eye-movement actuated guidance system is improved, its practical value cannot be fully assessed until it is compared with alternative systems of wheelchair control developed for the extensively paralysed individual. A chin-activated control unit devised by Engen (1970) is now in daily use by more than 15 patients and a version of this unit is commercially available.[4] In a wheelchair developed at the Ranchos Los Amigos Hospital, the guidance system is actuated by the patient's tongue (Lipskin, 1970). A sonic control system has been developed by Newell and Barr (1971) which responds to differences in the frequency of a humming noise produced by the patient. A pneumatically controlled system also has been described in which control is achieved by the operator puffing and sucking through an air tube (Lipskin, 1970). Yet another approach involved the

[4] Everst and Jennings, Incorporated.

sensing of head movement in order to steer a motorised chair (Selwyn, 1967). A comparative evaluation of several of these systems is reportedly under way at the Veterans Administration Prosthetic Centre (Lipskin, 1970).

Summary

A motorised wheelchair controlled by the user's eye movements was evaluated regarding its practicability for extensively paralysed individuals. The observed merits of the wheelchair included the unobtrusiveness of the Sight Switches and the rapidity with which individuals learned to control it with reasonable facility. Liabilities included the sensitivity of the control system to changes in the level of ambient illumination, occasional spontaneous changes in the state of the logic circuits and lack of a control capability that would enable the occupant to stop the chair in case the normal controls malfunction. It was concluded that until these deficiencies are overcome, this wheelchair guidance system cannot be recommended for patients' use.

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Résumé

Une chaise roulante motorisée, qui est contrôlée par les mouvements des yeux, a été étudiée en ce qui concerne l'utilisation pratique par de grands malades paralysés. Les mérites de cette chaise roulante sont, en particulier, la discrétion des commandes visuelles et la rapidité avec laquelle les individus ont appris à la contrôler avec facilité. Par contre, certains defauts one été relevés concernant la sensibilité du système de côntrole aux changements dans le niveau de la luminosité ambiante, des changements occasionnels spontanés dans les circuits et le manque d'une possibilité de contrôle donnant à l'occupant de la chaise la possibilité de l'arrêter au cas où les contrôles normaux ne fonctionneraient plus. Il a été conclu que jusqu'à ce que ces défauts puissent être résoulus, cette chaise ne sera pas recommandée.

Zusammenfassung

Ein motorisierter Rollstuhl, der durch Augenbewegungen kontrolliert wird, wurde auf seinen en praktischen Wert untersucht. Die Autoren kamen aber auf Grund ihrer Untersuchungen zu dem Ergebnis, dass dieser Rollstuhl mit seinem gengenwärtigen Kontrollsystem für gelähmte Patienten ungeeignet ist.

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