Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol. 32 No. 3, October 1995
Pages 280–284

CLINICAL REPORT

Ultrasonic Head Controller for Powered Wheelchairs

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Abstract—This report describes an evaluation by the Department of Veterans Affairs, Rehabilitation Research and Development Service, Technology Transfer Section (TTS). The Ultrasonic Head Controller Unit (UHCU) is the result of research and development conducted by the Palo Alto VA Rehabilitation Research and Development Center, under sponsorship of the Paralyzed Veterans of America and the VA Rehabilitation Research and Development Service. The UHCU provides an alternative to currently available human/machine interfaces for severely disabled individuals. Unlike switches or proportional joysticks, the UHCU operates without physical contact between the unit and the user. The UHCU produces analog signals in direct response to changes in the head position of the user. These signals can be used to control a variety of communication, robotic, mobility, and recreational devices. This clinical evaluation explored the use of the UHCU for powered wheelchair control by quadriplegic individuals.

Key words: *evaluation/trials, quadriplegic, Rehabilitation Evaluation Unit (REU), sensor, VA Technology Transfer Section (TTS), UHCU, UHCW, ultrasonic head controller unit, ultrasonic head controller wheelchair.*

The research, development, and evaluation of the UHCU was supported by the Department of Veterans Affairs, Rehabilitation Research and Development Service, Washington, DC.

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INTRODUCTION

The results of years of research and development have lead to a product that promotes functional wheelchair mobility and independence in activities of daily living for veterans with high level spinal cord injury and similar neurological disabilities. The Ultrasonic Head Controller for Powered Wheelchairs was developed to provide an alternative to currently available human/machine interfaces for severely disabled individuals. The dissimilarity of the Ultrasonic Head Controller Unit (UHCU) to other currently available control systems makes the UHCU unique; it operates without physical contact between the system and the user.

Earlier models of the UHCU have successfully demonstrated its use as an interface for powered wheelchairs used by persons with quadriplegia. Subsequently, a successful pilot study (1991) of one precommercial model led to further refinements and a resolution to questionable wet weather performance, indicating that the Ultrasonic Head Controller Wheelchair (UHCW) was ready for a multicenter clinical evaluation. A geographically diverse multicenter evaluation was conducted between June 1993 and September 1994. The primary motives of the evaluation were to assess the acceptance of the UHCW by veterans; identify prescriptive (performance) criteria; and to determine what further modifications, if any, were needed to improve the product for optimal use by the targeted population.

Product Description and Function

The UHCW is an electrically powered wheelchair controlled by an attached head position sensing electronic interface unit (**Figure 1a** and **1b**). The unit consists of two ultrasound transducers, an on-off switch, and an associated electronics package housed in derin plastic and mounted on a main support beam constructed of heavyweight painted aluminum (**Figure 1b**). The UHCU attaches to the wheelchair, functionally replacing the joystick. The user's head position becomes a joystick equivalent, controlling the speed and direction of the wheelchair.

During operation, the transducers emit inaudible ultrasonic pulses which propagate through the air until reflected by the user's head. The transducers provide raw data that are used to calculate the user's head position in a two-dimensional plane (**Figure 2**). The user tilts his/her head off the neutral vertical axis (same action as tilting a proportional joystick) in the forward/backward or left/right direction to accomplish the driving tasks desired.

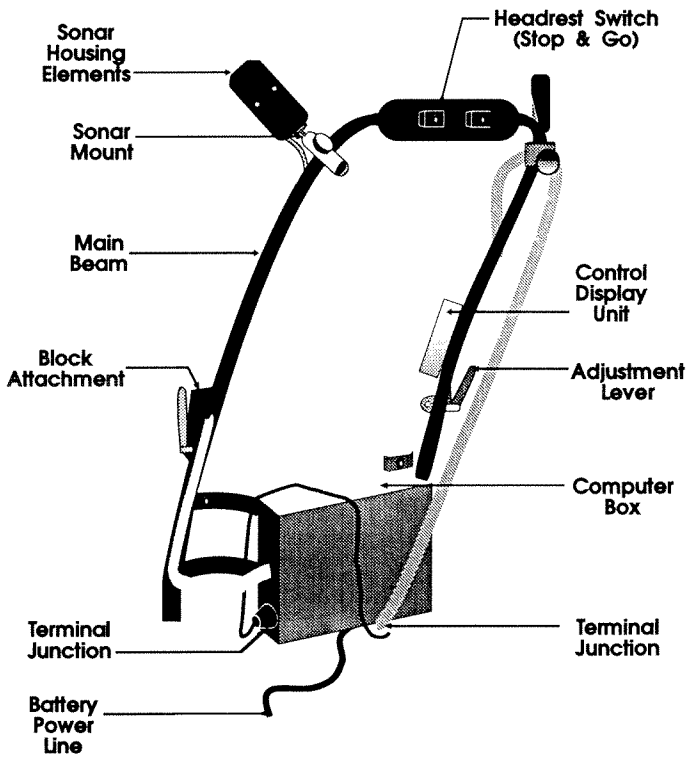

Figure 1b.
Head position sensing electronic interface unit.

Figure 1a.
Ultrasonic head controlled wheelchair.

BACKGROUND

The initial research and development of the first generation prototypes was accomplished by the Palo Alto VA Rehabilitation Research and Development (Rehab R&D) Center, which is supported by VA Rehabilitation Research and Development Service with additional support from the Paralyzed Veterans of America (PVA). These VA prototype UHC units were installed on E&J model 3P and Invacare Rolls electric wheelchairs. A series of design iterations driven by clinical requirements have, over the years, resulted in a model that demonstrated a need to continue efforts toward development for commercial marketing. The second generation models (4 E&J Marathons) were purchased by the VA Rehabilitation Evaluation Unit (REU, currently TTS) from Eureka Laboratories, delivered to the Rehab R&D Center, Palo Alto, CA, in October, 1988 and immediately submitted to acceptance testing. This

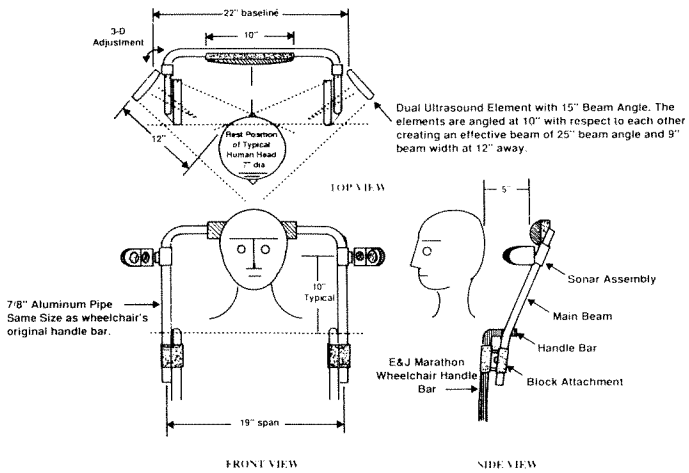

Figure 2.
Orthogonal drawings showing the overall dimensions of the new design in proportion to a typical human head.

acceptance testing raised concerns that required changes to the new models and verified the need for a pilot evaluation. Incorporation of recommended modifications and good results of the pilot evaluation primed the way for TTS to initiate a multicenter clinical evaluation. The initial phase of the multicenter evaluation, halted by poor performance in inclement weather, required resolution by the manufacturer. The manufacturer, Eureka Laboratories Inc., responded with a system which included: 1) environmentally sealed Polaroid sensors (able to withstand water immersion for 24 hours with no effects when housed in a Polaroid enclosure; 2) covers enclosed the top, sides, and back of the sensors (which eventually narrowed the sonar beams to a smaller range); and 3) a software design for rain filtration (that canceled any effects of raindrop reflection); thus enabling the trials to continue.

EVALUATION PROCEDURE AND METHODOLOGY

The clinical trials were conducted at the Spinal Cord Injury Service of six VA Medical Centers. Twenty male subjects (inpatient/outpatients) from among active and first-time users of varied types of wheelchair controllers were recruited with similar levels of spinal cord injury (Quadriplegia C_3, C_4, C_5, and C_6) dysfunction. To operate or facilitate training on the UHCW, whether rated as difficult or easy, subjects reported the need for modifications or required added appliances (i.e., seat belts, chest straps, Roho cushions, and so forth). Training time for this group of subjects was not distinctive when compared to the pilot study group wherein no subjects were experienced in other control systems. Subjects and Principal Investigators (PIs) for this evaluation were asked to scrutinize specific areas; such as, usage requirements for target population, operation, sonar orientation, adjustments (sensor and driving parameters), environment (attendant) effects, driving safety, adequacy of instructions and controllability (speed/acceleration), straight-line driving, turns, and stopping. Most subjects completed training in one day and had unrestricted use of the UHCW for the remainder of the trial period. Seventeen subjects completed the evaluation over a cumulative period of 14 months.

CLINICAL FINDINGS

After spending sufficient time to become familiar with operating the UHCW, PIs and subjects reported on the operating parameters of the UHCW during clinical trials.

In spite of the many incidents of malfunctions/repairs, subjects rated the UHCW's usefulness favorably during and after their trials. Application of selected parameters with reference to the UHCW's operation, control, and overall performance when correct adjustment was possible were rated as "good." Using the scale in **Table 1**, subjects indicated their assessment of the functions listed in the table.

The comments/opinions of subjects were reviewed at the completion of the trials to aid in the determination of overall acceptance or rejection of the UHCW for the targeted population. The following opinions surfaced:

- Advantages: Better all around visibility, noncontact components and hands-free operation with less fatigue
- Disadvantages: Assistance of caregiver always required, set-up and adjustments difficult, and position of on/off switch impossible for kyphotic subjects
- Recommendation for desired changes: On/off switch positioned within reach of subject's head, reclining back chair and positive locking mechanism

Table 1.
Subjects rating of operation/control/performance parameters.

Parameter	Very Good	Good	Poor	Very Poor	N/A
Stability of design to function	6%	65%	18%	12%	0%
Placement of sonar units	0%	65%	18%	18%	0%
Forward speeds	12%	47%	18%	24%	0%
Reverse speeds	6%	35%	12%	24%	6%
Brake response to head position	6%	53%	18%	18%	6%
Negotiating ramps/inclines	12%	12%	12%	0%	59%
Negotiating turns	6%	47%	29%	12%	0%
Straight-line driving	12%	59%	12%	18%	0%
Uneven terrain	6%	24%	12%	0%	59%
Use in inclement weather	0%	0%	0%	0%	100%
Use in hot weather	0%	6%	12%	0%	82%
Safety	12%	18%	29%	24%	18%
Ease of operation	12%	41%	24%	24%	0%
Design appearance	6%	59%	12%	18%	0%
Ease of transport	0%	0%	0%	6%	88%

%Subjects N = 17

to prevent sensor movement, and location of sensor and design of main support beam to decrease range of motion (ROM) required to operate system.

Daily use of the UHCW during clinical trials was not without problems. The clinical trials at various sites produced more than average reports of technical and/or control malfunctions by subject users. A detailed analysis of subjects' and participating investigators' responses (data) indicated the UHCW's high rate of malfunction (adjustments), unsatisfactory design, and sometimes unpredictable performance parameters identified, and focused these problems in four areas (these problems can be attributed to the changes recommended by the pilot study):

1. The wet weather system covers distorted the sonar beams and blocked the holes that are critical to effective alignment of the sensors with the orifice of the user's ear.
2. The ball joint tightening knob (sensor locking mechanism) was not a positive lock and required continuous adjustments.
3. The distance of the sensors from the user's head often proved too great. The 8° bend on the wheelchair back coupled with an additional 8° of recline on the sensor mount support bracket far exceeded the sensor's effective operating limits and makes it impossible for subjects to reach the on/off switch mounted on the support bracket.
4. The seating system E&J standard low back chair proved to be an obstacle during transfers and offered no upper torso support as would be commonplace on a high back recliner.

DISCUSSION

The UHCW, in retrospect (pilot evaluation 1991), is fully operational and functioning as designed. The deficiencies of the pilot are believed to have been satisfactorily addressed by the manufacturer incorporating recommended changes for improvement of future models. TTS found that the UHWC had met its technologic objective of being an acceptable concept for the target population.

A consensus of evaluating participants all agree that the UHCW has at times proved to be troublesome, not only in function but in sitting position as well. These problems were encountered by all sites throughout the trials and proved to be primary factors in concluding that the UHCW at this juncture requires a review of the recommended changes made after the pilot study, including the wet weather system. It is clearly indicated by the less

than optimal performance and expressed comments of subjects and PIs on the UHCW (when compared to the pilot study) that these changes have negatively influenced the performance of the models used in the multicenter evaluation.

The reported data are mixed and offer both positive and negative viewpoints on performance. The consistency of recurring operating/performance malfunctions are pointed out in each of the data instruments throughout the final report. At the conclusion of the pilot study, the UHCW worked nearly perfectly (a few exceptions noted) as designed. Subjects and PIs of the multicenter evaluation were not apprised of the modifications made after the pilot study and, therefore, did not have the opportunity to compare the "before-and-after" performance of the UHCW. However, if they had been, the conclusions of the data would have been totally different. At this point, it is believed that there are other systems readily available on the market which are immediately superior in reliability and ease of use. Moreover, it is believed by therapists and subjects alike that the benefits that were supposed to have been achieved by the UHCW were not realistic for this model. Furthermore, the refinements recommended by the pilot study and the subsequent changes (wet weather system) can readily be revisited by the manufacturer. The problems identified by this evaluation can be overcome and addressed in a timely manner by the manufacturer. The recommendations on the multicenter evaluation should prove useful toward guiding this effort. Finally, the manufacturer, with these recommendations, should seek continuous involvement and feedback from the targeted population and clinicians to ensure that the UHCW commercial product development is competitive with existing technology and products designed for similar application in order to be successfully marketed.

CONCLUSION

The precommercial prototypes used in the multicenter evaluation must revisit and recoup the functionality and reliability of the pilot unit that proved to be successful and acceptable to the targeted population. Moreover, if the recommendations of the multicenter evaluation are considered, the problems that surfaced in this evaluation can be readily addressed and implemented by the manufacturer into a commercially viable product.

ACKNOWLEDGMENTS

The comprehensive research, design, planning, organization, and implementation for a complex evaluation, such as this being reported on, requires the knowledgeable and willing cooperation of many individuals from various professional and organizational prospectives. A special thanks to the many veterans who gave their time and efforts to give this evaluation the real basis for being conducted.