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CLINICAL REPORT

Adequacy of power wheelchair control interfaces for persons with severe disabilities: A clinical survey

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Abstract—The extreme difficulty with which persons with severe disabilities have been taught to maneuver a power wheelchair has been described in case studies, and anecdotal evidence suggests the existence of a patient population for whom mobility is severely limited if not impossible given currently available power wheelchair control interfaces. Since our review of the literature provided little evidence either in support or refutation of the adequacy of existing power wheelchair control interfaces, we surveyed 200 practicing clinicians, asking them to provide information about their patients and to give their impressions of the potential usefulness of a new power wheelchair navigation technology. Significant survey results were:

- Clinicians indicated that 9 to 10 percent of patients who receive power wheelchair training find it extremely difficult or impossible to use the wheelchair for activities of daily living

- When asked specifically about steering and maneuvering tasks, the percentage of patients reported to find these difficult or impossible jumped to 40

- Eighty-five percent of responding clinicians reported seeing some number of patients each year who cannot use a power wheelchair because they lack the requisite motor skills, strength, or visual acuity. Of these clinicians, 32 percent (27 percent of all respondents) reported seeing at least as many patients who cannot use a power wheelchair as who can

- Nearly half of patients unable to control a power wheelchair by conventional methods would benefit from an automated navigation system, according to the clinicians who treat them.

We believe these results indicate a need, not for more innovation in steering interfaces, but for entirely new technologies for supervised autonomous navigation.

Key words: *activities of daily living, automation, disabled persons, nervous system diseases, robotics, spinal cord injury, wheelchairs.*

INTRODUCTION

With the advent of microprocessors, significant innovation has occurred in power wheelchair control interfaces. In addition to the more common interfaces such as sip-and-puff and chin and head controls, power

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wheelchair users have available to them such complex control schemes as tongue touch pads and eye gaze systems. Nevertheless, we suspect that, in spite of today's sophisticated control interfaces, persons with severe and/or multiple disabilities may yet find it prohibitively difficult to steer a power wheelchair in typical residential, institutional, or office settings in which maneuvering space is limited, the approach to furniture and objects is tightly constrained, and the necessity to negotiate doorways requires precise control. In fact, case studies have been reported, both in the literature and anecdotally, of individuals with high-level spinal cord injury (SCI), multiple sclerosis (MS), or brain injury (BI) who have spent months, even years, learning to steer a power wheelchair—in some cases, with only marginal results (1,2). Further, an extensive review of the literature has produced little insight into the number and characteristics of users of power wheelchair control interfaces or the adequacy of these control technologies.

An alternative strategy to seeking greater innovation in the rider-wheelchair control interface is to employ a combination of microprocessors/computers and sensors that assist or completely assume control of power wheelchair navigation at the discretion of the rider. From the past 10 years of published literature, one finds at least a dozen independent, research initiatives devoted to the development of such navigation aids (3–14). The authors are involved in the development of a Computer-Controlled Power Wheelchair Navigation System (CPWNS), which relies on video detection of environmental cues in combination with wheel rotation information. This system promises to provide the basis for safe, versatile, and robust autonomous wheelchair control for persons with severe disabilities (13). To better document the existence and nature of the target patient population for this emerging technology, we sent a short questionnaire and brief, informative videotape describing the CPWNS to 200 clinicians, asking them to provide information about their patients and to give their impressions of the potential usefulness of this new technology.

METHODS

We surveyed 200 practicing clinicians in a variety of clinics, residential treatment facilities, and rehabilitation hospitals. Efforts were made to survey a variety of geographically dispersed facilities providing inpatient, outpatient, and residential care for a wide range of mobility-limiting conditions among persons of all ages. Surveys were sent to the Spinal Cord Injury Centers, Blind Centers, and Geriatric Rehabilitation and Extended Care Centers (GRECCs) within Veteran's Health Services of the Department of Veteran's Affairs. Survey recipients were also selected from organizations listed by the National Multiple Sclerosis Society, the Muscular Dystrophy Association, the Amyotrophic Lateral Sclerosis Association, and the National Directory of Head Injury Rehabilitation Services (15). Additional surveys were sent to selected institutions listed with the Commission on Accreditation of Rehabilitation Facilities (CARF), based on information found in the Directory of Medical Rehabilitation Programs (16), the Medical and Health Information Directory (17), the Directory of Nursing Homes (18), the Hospital Blue Book (19), and the Healthcare Blue Book (20).

The questionnaire is presented in **Appendix A**. Each of the 200 recipients was sent a packet containing the questionnaire, a postage-paid return envelope for the survey, and a 3-minute videotape describing a computerized system for power wheelchair navigation intended for persons with severe disabilities. Packets were addressed personally to the director of each facility or to the director of rehabilitation services if the name of the incumbent was available. A cover letter requested that the clinician view the videotape and complete and return the questionnaire. The letter asked that the clinician forward the packet to the person most involved with wheelchair seating/training if, in fact, the recipient was not that person. The recipient was also encouraged to duplicate the survey if his/her colleagues were willing to provide additional responses or to return the survey marked "N/A" if none of the questions applied to any segment of the institution's patient population. A telephone number was provided to enable recipients to obtain additional information or additional packets, and recipients were given the option to return the survey by fax. Each survey packet was numbered, and recipients who did not respond within 60 days were sent follow-up requests (letter only).

RESULTS

Survey Respondents

Sixty-five surveys (33 percent) were returned by recipients. Of these, 10 were blank or marked "N/A". The remaining 55 contained information on patients with mobility impairments and are summarized in this report.

Table 1 provides a profile of the types of facilities surveyed. Comprehensive rehabilitation hospitals provide care for a wide range of conditions including SCI, BI, stroke, fractures, pulmonary disease, neurological disorders, and musculoskeletal diseases/injuries. Institutions specializing specifically in BI, SCI, and/or stroke are listed separately. Seven of the surveyed institutions were reported as exclusively pediatric facilities, though potentially many others serve large numbers of children. As indicated, survey respondents were representative of the surveyed population as a whole with respect to type of institution. Response rates for VA SCI centers and facilities for the blind were slightly higher, while responses from institutions providing comprehensive rehabilitation were proportionately fewer.

Table 1.
Profile of health care providers by type.

Type of Facility	Surveys Sent	% of Total Sent	Surveys Completed	% of Total Completed
Comprehensive Rehab Hospitals	50	25	9	16
MS/ALS/MD Clinics	39	20	8	15
BI/SCI/Stroke Care Facilities	28	14	7	13
MR/DD/CP Care Facilities	25	12	7	13
VA SCI Centers	23	11	8	15
Blind Centers/Schools	21	11	9	16
Geriatric Care Facilities	14	7	4	7
Wheelchair Vendors	0	0	3	5
Total	200	100	55	100

MS=multiple sclerosis; ALS=amyotrophic lateral sclerosis; MD=muscular dystrophy; BI=brain injury; SCI=spinal cord injury; MR=mental retardation; DD=developmental disability; CP=cerebral palsy.

Survey respondents appeared to be unbiased with respect to both size and geographic distribution (see **Figure 1**). Completed surveys were received from 29 states, the District of Columbia, and Puerto Rico. Directories used to select survey recipients reported institution size ("number of beds" or "number of beds devoted to rehabilitation") for approximately 60% of the facilities surveyed.

An indication of size of the relevant patient population in each responding institution was provided by the questionnaire itself. Survey questions I.1 and I.2 sought to define, for each facility, the number of patients who are power wheelchair users. These census figures were used in subsequent analyses to weight responses to other questions. For example, if one facility trains 100 patients per year to use a power wheelchair and reports that 2 percent of these patients have difficulty using the chair, while a second institution trains 10 patients, 20 percent of whom have difficulty, the simple average of patients who experience difficulty is 11 percent (2 percent+20 percent)/2) but the weighted average is 3.6 percent ((2 percent×100+20 percent×10)/110).

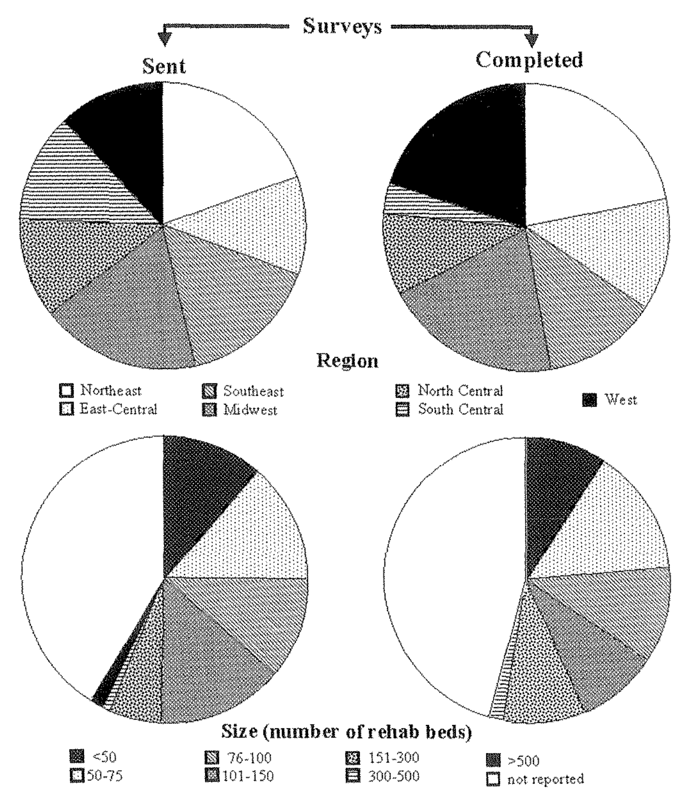

Figure 1
Geographic and size distributions of survey population and respondents.

Nature and Adequacy of Power Wheelchair Control Interfaces

The principal objective of our clinical survey was to gain insight into the types of control interfaces employed by power wheelchair users and the adequacy of these controls. According to the clinicians who responded to our survey, more than 95 percent of power wheelchair users maneuver their chairs with joystick, sip-and-puff, head, or chin controls (**Table 2**). Only eight respondents reported having patients who use any other type of control interface. Potential explanations for this phenomenon include: a) clinicians are unaware of more sophisticated control interfaces and, therefore, do not prescribe them; (b) more sophisticated interfaces are not accepted by users, perhaps because they are ineffective and/or prohibitively difficult to use; or, (c) more sophisticated interfaces are unnecessary because joystick, head control, and sip-and-puff interfaces are adequate.

The survey responses summarized in **Tables 3 and 4** suggest that the power wheelchair control interfaces used may not, in fact, be adequate to provide truly independent mobility for substantial numbers of persons with disabilities. Respondents to our survey reported on average that approximately 10 percent of the patients they train to operate a power wheelchair cannot use the chair upon completion of training for activities of daily living (ADL) or can do so only with extreme difficulty. Clinicians also indicated that even among their patients who are regular power wheelchair users, 40 percent of these persons have difficulty with steering tasks such as maneuvering the chair throughout the confines of a typical home or office environment, including passage of doorways and entering and exiting elevators. Further, clinicians reported that between five and nine percent of regular power wheelchair users find such tasks impossible without assistance.

Table 2.
Power wheelchair control interfaces used (survey question I.1).

Percent of patients using	Simple Average (n=46)	Weighted* Average (n=30)
Joystick	81	81
Head or chin control	9	9
Sip and Puff	6	9
Other (eye gaze; tongue pad; head, hand, foot switch controls)	4	1
Total	100	100

* weighted by total number of power wheelchair users reported in survey question I.1.

Table 3.
Adequacy of existing control interfaces.

Measure	Simple Average	Weighted* Average
Percentage of patients who, after training, have extreme difficulty using a power wheelchair for ADL	6	6*
Percentage of patients who, after training, find it impossible to use a power wheelchair for ADL	4	3*
Total Percentage (survey question I.3)	**10 (n=42)**	**9 (n=38)**
Percent of power wheelchair users who have difficulty with steering tasks	32	35**
Percent of power wheelchair users for whom steering tasks are impossible without assistance	9	5**
Total Percentage (survey question I.4)	**41 (n=49)**	**40 (n=32)**

* weighted by numbers trained, reported in survey question I.2; **weighted by total number of power wheelchair users reported in survey question I.1.

Table 4.
Proportion of patients unable to use a power wheelchair (survey question I.5).

Measure	Simple Average	Weighted Average
Percentage of patients evaluated annually who are not candidates for a power wheelchair because they lack requisite motor skills, strength, or visual acuity	18* (n=15)	26** (n=44)
Percentage of these patients who could benefit from a computer-controlled navigation system	49 (n=49)	44*** (n=45)

* mean of all responses to the first part of question I.5 given as a percentage; ** all responses to question I.5 (percentage or absolute number) weighted by the estimated number of patients seen annually (see text); ***weighted by responses to questions I.2 and/or I.5.

Independent Mobility Options for Persons with Severe Disabilities

In addition to assessing the adequacy of available control interfaces for regular power wheelchair users, our survey results also document the existence of a group of persons for whom no independent mobility options exist at this time. Eighty-five percent of responding clinicians reported seeing some number of patients each year for whom use of a power wheelchair is not an option because these patients lack the motor skills, strength, or visual acuity needed to control the chair. Twenty-seven percent of respondents reported evaluating at least as many patients who cannot use a power wheelchair as who can (i.e., the number reported for question I.5 was greater than or equal to the response to question I.2). It was estimated from survey responses that 18–26 percent of non-ambulatory patients who cannot use a manual wheelchair are also unable to operate a power wheelchair (see **Table 4**). Clinicians indicated that nearly half their patients who are unable to operate a power wheelchair using conventional methods would benefit from a computer-controlled power wheelchair navigation system.

A secondary objective of our survey was to evaluate the perceived usefulness of an emerging technology whereby a computer controls the steering of a power wheelchair on behalf of its rider. As indicated above, clinicians reported that 44–49 percent of their patients who are unable to operate a power wheelchair would benefit from this technology. Persons with spinal cord injury and disorders such as MS, amyotrophic lateral sclerosis (ALS), and Parkinson's disease, alone or in combination with other disabilities, were the patient populations most frequently cited by clinicians as likely to benefit. Further, when asked to consider the possibility of enabling persons with cognitive disabilities to travel unassisted to specified locations within an institution at pre-programmed times (a potential future application of computer-controlled navigation), 91 percent believed such capability would be useful for at least a few patients, and 23 percent believed it would be useful for many.

DISCUSSION

There appeared to be no major misinterpretations of survey questions that warranted excluding significant amounts of data from analysis; however, many respondents elected to leave some questions blank. (Only 17 questionnaires were returned 100 percent complete.) Blank responses were not assumed to represent zero unless circumstances indicated this was the respondent's intent.

Missing responses were taken into consideration in presenting aggregate results. Specifically, since responding institutions varied greatly with respect to size, it was desirable to weight responses accordingly. This, however, resulted in discarding the information provided by numerous clinicians who opted not to answer census questions I.1 and/or I.2. To avoid this loss of data, both simple averages and weighted averages were reported. In all cases but one, simple and weighted averages differed by no more than five percentage points.

The only disparity greater than five percentage points between simple versus weighted averages occurred with the first part of survey question I.5 (patients who are not candidates for a power wheelchair). Fifteen clinicians responded to the question with a percentage, and the remainder with an absolute count. Since five of the respondents who gave a percentage provided no census data (questions I.1 or I.2), the percentages could not be interpreted and were included only in the simple average shown in **Table 4** (18 percent). The average of 26 percent in **Table 4** was obtained by weighting all other responses (both percentages and absolute numbers) by the total number of patients evaluated annually, which was taken to be the sum of all patients trained to use a power wheelchair (question I.2) plus those who were not candidates for a power wheelchair (question I.5). Alternatively, if one omits from this computation all responses given as percentages, the resulting weighted average jumps to 36 percent (n=34).

Regardless of careful construction of the questionnaire, data problems such as the foregoing are inherent in survey methodology. Every effort was made to manage these inconsistencies in a manner that did not compromise the validity of the study findings.

CONCLUSION

According to survey respondents, the vast majority of patients who use a power wheelchair rely on joystick, sip-and-puff, chin, or head control interfaces. Very sophisticated control technologies such as eye gaze or tongue pad interfaces are employed by fewer than 5 percent of power wheelchair users (perhaps as few as 1 percent). This would indicate that individuals with severe disabilities which compromise respiratory drive and/or limit the dexterity of the head and hands have few options for steering a power wheelchair. This notion is further reinforced by the fact that 85 percent of respondents reported evaluating some number of patients annually for whom a power wheelchair is not an option because they cannot control it. Of these clinicians, 32 percent indicated that they evaluate at least as many patients who cannot use a power wheelchair as patients who can. These include persons with high-level SCI, nervous system diseases, cognitive impairment, and blindness, presumably in conjunction with mobility impairment. One must conclude that, for these persons, *no independent mobility options exist at this time*. Further, our clinical survey provides evidence that existing control technologies may not be entirely adequate even for persons who use a power wheelchair on a regular basis. On average, responding clinicians reported that approximately 40 percent of their patients who use power wheelchairs have difficulty with steering tasks and that between five and nine percent find such tasks impossible without assistance.

One potential solution to the shortcomings of power wheelchair control technologies is to enable a computerized navigation system to assume control of steering tasks at the behest of the rider. A computer-controlled power wheelchair navigation system, which functions in a well-defined but minimally modified environment, has been developed at the University of Notre Dame, Automation and Robotics Laboratory. The navigation system has repeatedly demonstrated its ability to guide a power wheelchair along the precise trajectories typically required within a home, office, or institution with reliability approaching 100 percent. In a joint development project between the University and the Rehabilitation Research and Development Service of the Department of Veterans Affairs, investigators are downsizing the original system and incorporating a number of safety and convenience features, producing a device suitable for patient testing. Persons with disabilities who have difficulty operating a power wheelchair will be recruited to test the new guidance system and provide feedback for subsequent stages of development. Because the navigation system is implemented using relatively low-cost components that may be readily retrofitted to an existing power wheelchair, the long-term goal of the project is to produce a commercially viable product at a reasonable price. Such a system would provide persons with severe mobility impairments a degree of autonomy not otherwise attainable.

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APPENDIX A

SURVEY - AUTOMATICALLY GUIDED WHEELCHAIR

Part I. The following questions pertain to patients who cannot use a manual wheelchair:

1. How many patients of your institution are regular users of a power wheelchair? ________

Of these individuals, what percentage use each of the following power wheelchair control mechanisms:

joystick	______%	sip and puff	______%
chin contol	______%	head control	______%
eye gaze control	______%	other	______%

(if other, please describe)________________________________

2. How may patients are trained annually by staff of your facility to use a power wheelchair?

_____ males, age range: _____ average age _____
_____ females, age range: _____ average age _____

3. At the conclusion of training, what percentage of these individuals
have no difficulty using a power wheelchair in activities of daily living (ADL)? ______%
have moderate difficulty using a poweer wheelchair in ADL? ______%
have extreme difficulty using a power wheelchair in ADL? ______%
find it impossible for practical purposes to use a power wheelchair in ADL? ______%

4. What percentage of your power wheelchair users have some difficulty with wheelchair maneuvering tasks, e.g. steering the chair through doorways, on/off elevators, or within the confines of a typical home or office? ______%

What percentage find it impossible to accomplish some or all of these maneuvering tasks without assistance? ______%

5. How many patients do you see annually who cannot use a power wheelchair because they lack the motor skills, strength, or visual acuity needed to control the chair? ______%

What percentage of these patients do you feel could benefit from a computer-controlled wheelchair such as the one described in the accompanying video tape? (Assume the guidance system is "reasonably" priced and can be retrofitted to the power wheelchair of the patient's choice without interfering with necessary seating and positioning aids.) ______%

Part II. The following question pertains to patients with lower limb disabilities and cognitive impairment:

1. Assume that a reasonably priced computer-controlled wheelchair was available for cognitively impaired patients which would transport them unassisted to pre-programmed locations at individually pre-programmed times (for example, to the nurse's station to receive medications, to dining room at meal times, to clinic for therapy appointments, etc.) Do you perceive that such a device would be

(please check one)
- ☐ not at all useful.
- ☐ useful only in a very small number of cases.
- ☐ useful for many wheelchair restricted patients with cognitive disabilities.

Part III. The following question pertain to all patients:

1. In your opinion, patients with what types of disabilities (or combinations of disabilities) would most benefit from a computer-controlled wheelchair navigation system similar to the one described in the accompanying video tape?

____
____
____

How many of these patients does your facility treat annually? ______

2. In order to be optimally beneficial to your patients, what operating characteristics would you consider essential to a computer-controlled wheelchair navigation system similar to the one described in the accompanying video tape?

____
____
____

Please return survey within 10 days of receipt to:
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P.O. Box 20
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or fax survey to 1-708-531-7960

Thank you for your help!