Devices for Assisting Manipulation: A Summary of User Task Priorities

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***Abstract*—Currently, none of the commercially available rehabilitation robots are widely distributed among individuals with limited use of their arms and hands. Market success requires design that achieves an acceptable tradeoff between function, appearance, ease of use, reliability, and cost. User defined task priorities are an imperative consideration within the design as devices which fail a user's functionality requirement will never succeed in the market place. Consequently, this article reviews nine different task priority surveys conducted by seven institutions across England and North America which reflect the views of over 200 potential users of such technology. They include predevelopment questionnaires that focus on user task ability and anticipated use of an orthosis or rehabilitation robot, and postdevelopment surveys that investigate task functionality with a specific robot. The survey results indicate that a device must accommodate a wide range of object manipulation tasks in a variety of unstructured environments. Specific tasks which rated highly were picking things up from the floor or off a shelf and tasks associated with eating, personal hygiene, and leisure activities. The range of functional tasks implies that interdisciplinary design teams are required for "successful" rehabilitation robotic and orthotic device design.**

I. Introduction

At the present time, there are less than a dozen assistive manipulators commercially available or near commercialization. Of these devices, some have been designed specifically to assist in the task of eating while others are wheelchair-mounted manipulators, mobile manipulators, or desktop manipulators [37]. In addition, many organizations have conducted rehabilitation robotics and powered orthotics research [19], [26], [27], [33] with the common goal of providing independent manipulation for individuals who are unable to perform manipulation tasks due to injury, neuromuscular disease, or other severely physically disabling conditions. Despite these efforts, however, none of the rehabilitation robots designed for general manipulation tasks have been "successful" in the marketplace, meaning that none are widely distributed among those who have limited use of their arms and hands. Market success for a rehabilitation robot would require designing a device which meets a user's acceptance level of cost, reliability, appearance, ease of use, and function. Cost and reliability factors can be calculated by the design team. However, appropriate appearance, ease of use, and function cannot be adequately defined without the participation of the end user. In the field of human computer interface design, the first step in designing the user interface is understanding the functionality required [35] or understanding how the application will be used [2]. In the field of rehabilitation robotics and powered orthoses, the design of a successful device also requires a clear understanding of what functionality, or what task priorities, the users require of the device. While appearance is also important, it is beyond the scope of this review. Ease of use is addressed in a separate publication [36]. This paper summarizes the results of nine surveys, all of which assist in defining the task priorities of those who may benefit from the use of a rehabilitation robot or powered orthosis. We review four predevelopment surveys which investigate tasks that potential users would like an assistive manipulator to perform [1], [16], [23], [28], [33], and five postdevelopment surveys which investigate the functional use of a specific robotic device [4], [13], [17], [18], [23], [25].

In defining the functionality required of a device, there are many factors which influence a user's task priorities. Some of these are the user's age, living accommodations, disability, and familiarity with technology, assistive devices, and rehabilitation robots or powered orthoses. One's priorities may also be influenced by whether the disability has been present from birth, as with cerebral palsy, or was incurred abruptly, as with most spinal cord injuries. A person's priorities may differ depending on whether he or she lives in an institution, with a family member, or independently with employed attendant care to assist with daily living tasks. The small number of subjects in each survey make it impossible to draw conclusions about subject groups regarding each of these influences. However, demographic information (Tables I and IV), and prior exposure to the technology under question is succinctly outlined for each study to provide the reader with an opportunity to reflect on the source of responses collected from each survey conducted. Despite differences between individuals who took part in answering questionnaires, several common task priority themes emerged from all surveys. These themes focus on providing an ability to manipulate everyday items within a typically unstructured environment. The tasks focus primarily on areas related to eating, conducting some activities of personal hygiene, and taking an active part in the miscellaneous activities of one's day. The task list implies that a robotic device must have the capacity to accommodate

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TABLE I
SUMMARY OF PREDEVELOPMENT SURVEYS

Research Group	Target Device	Year	Total #	Age Range	% Male	Disability							Format
						SCI	MS	MD	CP	Arthritis	Polio	Other	
BIME	Robotic	1986	42	16 - 65	64%	10	25		3	2		2	Interview
Middlesex University	Robotic	1989	50	16 - 75[1]	56%	12	8	4	9	5	2	10	Mail & Interview
Queen Alexandra Centre	Robotic	1991	36	8 - 87[2]	83%	23		9				4	Interview
University of British Columbia	Upper-limb Powered Orthosis	1991	11	27 - 65	64%	1		7			1	2	Telephone
Total / Percentage			139	–	–	33%	24%	14%	8%	5%	2%	14%	

[1] 46 were between 16-75 with 3<16 and 1>75.
[2] 53% were between 20-40.

unstructured environments and a large range of tasks. There is also an implication that the device must fit within the social context of the individual's living environment.

II. PREDEVELOPMENT SURVEYS

A. Introduction

Four separate research groups have conducted extensive predevelopment surveys with potential users, as summarized in Table I. These surveys included interviews with a total of 139 adults, with the number of subjects ranging from 11 to 50 per survey. Disabilities represented were spinal cord injury (SCI), multiple sclerosis (MS), and a variety of other neurological and physiological impairments. The questionnaires determined demographic information, pastimes, employment status, and the use of assistive technology, in addition to tasks that potential users were or were not able to perform and hypothetical suggestions as to how a user might want to use a rehabilitation robotic or orthotic device.

Each of the surveys asked the respondents to rate a list of tasks as those which they could perform independently, could do using an aid, or could not do. The first survey, conducted in 1986, had a task list of 14 items which one would typically conduct around the house, such as cooking, doing housework, and operating a television. The remaining three surveys had a task list of 70–80 items which were listed under the categories of Personal Hygiene, Domestic, Recreation, and Work/School. In all four cases, the last item on the questionnaire was an open-ended question. In the first survey, the question was phrased, "If you were to have a mechanical arm in your home, what types of things would you expect to use it for?" whereas the other three asked, "What five tasks would you like to do, but cannot?" It is important to note that this question makes no mention of a robotic or orthotic device. Consequently, the context of the questionnaire would largely influence whether the five tasks would be those which the user anticipates could be performed with a robot or orthosis, or whether they are tasks which have no context, in the user's mind, of being performed with an assistive device. In addition, several found that people do not have an *a priori* wish list and often cannot conceptualize how they would use a robotic arm [1], [7], [23].

B. Surveys Emphasizing Rehabilitation Robotics

1) The Bath Institute of Medical Engineering: In 1986, researchers at the Bath Institute of Medical Engineering (BIME) and the Royal National Hospital for Rheumatic Diseases, both in Bath, England, conducted a survey of individuals with upper-limb impairment who would potentially make use of a rehabilitation robot [7], [16]. Surveys were conducted by interview with 42 disabled adults who had either limited or no upper limb ability. In response to questions regarding their ability to perform specific tasks, 67% said that they were unable to cook, 64% were unable to do housework, 61% were unable to open a can or bottle, 59% were unable to prepare food, 54% were unable to prepare a hot drink, and 36% were unable to reach things from a shelf. Many more were able to do these things, but "with difficulty." The majority were able to operate the television and telephone, brush their teeth, put a cassette into a player, and turn faucets and switches [7].

The people interviewed were shown a conceptual diagram depicting a robot in use, as presumably few of the individuals interviewed had previous experience with a rehabilitation robot. The interviewer also suggested that the robot could be used to prepare a cup of tea. In response to the open-ended question, "If you were to have a mechanical arm in your home, what types of things would you expect to use it for?" there were a total of 47 responses from the 42 who participated. The most common response, 18 out of the 47, was to "prepare a hot drink," the task previously suggested by the interviewer. The other responses were: feeding, kitchen use, and picking up items from the floor (4/47 each), loading a cassette-tape (3/47), plugging things in and moving hot things (2/47 each), washing, brushing teeth, playing chess, loading a video, opening beer cans, eating fruit, pouring coffee, using the telephone, watering plants, and smoking a cigarette (one response each). Respondents suggested, without prompting, that a mobile device would be of far greater use, but that if it were to be stationary, the kitchen would be the best site [7].

2) Middlesex University: As a follow-up to the 1986 BIME Institute survey, Middlesex University of Middlesex, England (formerly Middlesex Polytechnic), conducted an extensive survey in 1989 as the basis for developing a wheelchair-mounted robotic aid [28]. The 50 individuals with disabilities who took part in answering the 110-question survey primarily had a spinal cord injury at C7 or above, with the majority at C5 or C6 (four each) [28]. Subjects who were interviewed in person were first shown a video tape of a computer-graphic simulated robot performing five different tasks. The simulation of a wheelchair-mounted robotic arm, with kinematics similar to a Unimation PUMA robot, performed the tasks of operating a VCR, answering the telephone, getting a book from a high shelf, and picking up an object from the floor. The same computer-simulated robotic arm was then depicted as a workstation robot and performed a drinking task [29].

3) Queen Alexandra Center: In 1991, the Queen Alexandra Centre of Victoria, B.C., Canada, conducted "Robotic Aid Questionnaires" with 36 individuals who had a spinal cord injury or muscular dystrophy. The Queen Alexandra Centre used the Middlesex survey with minor alterations.

Both the Middlesex and Queen Alexandra Centre surveys demonstrate that, with the exception of personal hygiene, many of the tasks which users cannot do are also those which could be carried out with a robotic arm. For instance, tasks that require stretching, gripping, and reaching to the floor all rated highly on the "not able to do" list for both surveys and can be achieved with some rehabilitation robots. The same tasks were also high on the list of the top five tasks under "most like to do but cannot" [22], [28]. On the other hand, washing hair [28] and changing a leg bag [23], which rated highly on the "not able to do" list, are not necessarily tasks which are easily attended to by an electrical, motor-driven manipulator. There were some differences between the two studies in the responses to the open-ended question. In the Middlesex survey, there were a total of 17 different responses. The top tasks listed were, with frequency of response in parentheses: reaching, stretching and gripping (22), gardening (13), reaching to the floor (12), cooking (10), eating/feeding (9), lifting large objects, and dressing (6 each). In the Queen Alexandra study, there were a total of 49 different responses to the same question. The most prevalent responses were: pick up item from the floor, get item from the refrigerator (4 each), write, answer the telephone, operate a CD, cassette or record player, drive, empty a leg bag (3 each), open/close door, washroom aid, pour a drink, and fishing (2 each). The other tasks were predominantly those related to dressing, personal hygiene, recreation, environmental control, communication, and leisure. Both surveys had responses which included wheelchair transfer, walking, driving, playing sports, and assisting with elimination functions [22], [28].

4) The Neil Squire Foundation: In 1983, the Neil Squire Foundation of Vancouver, Canada, began to develop a robotic device for severely physically disabled individuals. Specifications for the robotic device were established after consultation with leading robotics researchers, rehabilitation professionals, and many individuals with severe disabilities who assisted in developing an extensive wish list of tasks to be performed by the robotic arm [6]. The wish list emphasized vocational, personal hygiene, and eating and drinking tasks [12]. Individuals emphasized the need for simplicity, minimum mass, reliability, and low cost [6]. Although the development of the initial wish list was not formalized, and consequently not included in the tables, the contact with potential users assisted in the development of the robotic device, called the Robotic Assistive Appliance (RAA), which is included in the postdevelopment survey section of this paper.

C. Powered Upper-Limb Orthosis Survey

The University of British Columbia: In 1991, a team at the University of British Columbia in Vancouver, Canada, interviewed 11 potential users of a powered upper-limb orthosis. A powered upper-limb orthosis is an exoskeleton worn by a user who has severe arm muscle weakness but who retains at least some degree of sensation. In contrast to a robotic arm, the orthosis moves the user's arm. Ten of the subjects were interviewed by telephone, one in person. All but two of the subjects had seen a prototype powered orthosis, developed previously by the Toronto-based Hugh MacMillan Rehabilitation Centre, prior to the interview [34]. In answer to the question regarding the top five tasks that each would "most like to do but cannot," the tasks, with the frequency of response given in parentheses, were identified as: reaching/picking up objects (9), personal hygiene, hobbies/crafts (7 each), eating/drinking (6), housework, dressing, and strengthening grip (4 each), cooking, toileting/transferring (2 each), and reading and using the computer (1 each) [1], [32], [33].

D. Discussion of Predevelopment Surveys

Table II: Results of Predevelopment Surveys summarize the task priority listing of the 139 people surveyed in the four studies by recording the most prevalent responses to the open-ended question. Although the first survey specifically asked about robot use and the others asked about tasks that the person "would like to do but cannot," the results indicate that reaching, gripping, and picking up objects from the shelf and floor are all important tasks. Preparing food and drinks plus eating and drinking were also rated highly by those surveyed, although there was some concern over the loss of social interaction. Tasks related to personal hygiene were prevalent in response with a higher percentage response rate from the Queen Alexandra and orthosis surveys. Leisure activities, like gardening, hobbies, and crafts, were generally regarded as important by those surveyed. In the Middlesex study, 13 of the 50 respondents listed gardening as a desirable activity; 7 of the 11 in the orthosis study listed hobbies and crafts under tasks to be performed; and seven different leisure activities were listed in the Queen Alexandra survey [22], [28], [32].

Specific vocational tasks did not appear on the top of the list of tasks requested. However, many manipulation tasks, which were rated highly in all studies, could facilitate employment. Communication tasks like writing, operating a computer, or using a telephone were also prevalent and could

TABLE II
RESULTS OF PREDEVELOPMENT SURVEYS

	BIME[1]	Middlesex[2]	Queen Alexandra[2]	University of British Columbia[2]
Total # of Subjects	42	50	36	11
Reaching, stretching, gripping, picking up objects	–	22	18	9
Reach or pick up from the floor	4	12	4	–
Cooking, fixing food, drinks	18	10	9	2
Eating, drinking	4	9	–	6
Personal Hygiene Dressing	2	3 6	11 3	7 4
Gardening / Hobbies & Crafts / Leisure	1	13	8	7

[1] Survey question: "What would you like to use a manipulator for?"
[2] Survey question: "What five tasks would you like to do, but cannot?"

TABLE III
RESULTS OF PREDEVELOPMENT SURVEYS

Research Group	Employed		Unemployed
	Part-time	Full-time	
BIME	7%	0%	93%
Middlesex University[1]	4%	17%	79%
Queen Alexandra Centre	12%	13%	75%
University of British Columbia[2]	0%	36%	64%

[1] Employment status of working aged population, ages 16-59.
[2] "Unemployed" includes "Retired" and "Homemaker".

be employment-related tasks. The low rate of employment among those surveyed, as tabulated in Table III, would understandably skew answers to an open-ended question against specific vocational tasks.

Three of the studies asked about the potential of purchasing a device. The BIME survey found that 60% felt that the system would be of some practical use to them, but only 43% of those surveyed said that they would seriously consider buying a mechanical arm at the suggested price of about £2,000 [7], a price which is a fraction of any rehabilitation robotic device on the market. Eighty-four percent of those surveyed by the Middlesex study indicated that they would consider buying such a device if the price was "within their means," but no price was associated with this qualification [28]. Finally, those in the University of British Columbia survey indicated that the price they would be willing to pay would be dependent on the independence that the device provided, but again, no amount was suggested [1].

III. POSTDEVELOPMENT SURVEYS

A. Introduction

There are now several commercially available, or near available, rehabilitation robotic devices on the market. Five different research groups have conducted surveys after consumers have used the developed prototypes [4], [13], [17], [18], [23], [25]. Although many other rehabilitation robotic and orthotic device evaluations have taken place, they were not included in this paper, as their focus was different from evaluating task priorities with a population of users. The postdevelopment surveys represented in this paper were conducted in three countries, yielding a total of 65 users surveyed, with a range of 5 to 24 users per survey. Survey participants predominantly had a spinal cord injury, while muscular dystrophy, cerebral palsy, and multiple sclerosis were among other disabilities represented, as noted in Table IV. Three of the research groups conducted studies with tabletop workstation robotic arms, whereas the remaining two were conducted with wheelchair-mounted manipulators. While each study reflects device-specific capabilities, commonalities in the postdevelopment surveys are reflected across task domains, as seen in Table V, and assist in specifying future design requirements for functional rehabilitation robotic and orthotic devices.

B. Desktop Robotic Arms

1) The Bath Institute of Medical Engineering (BIME): Following the initial 1986 BIME survey, this research group developed a desktop system using the Atlas robot in 1986–1987. This robot could be located on any convenient table top. Two additional design iterations were developed based on the desktop system in 1988 and 1990–1991 [17]. The second prototype was an Atlas robot built into a workstation, and the third was a purpose built robot, the Wolfson, integrated into a workstation. The first prototype was evaluated by five disabled individuals predominantly in their homes [16]. Evaluation of the second prototype was conducted by six individuals in a hospital setting within the first year of injury [18]. The third was conducted by five people, including one person who had taken part in the previous study, in the home [17]. In the second study, subjects were asked to rate the robot in the categories of Work, Communication, Hobbies, Entertainment, Feeding, and Personal Hygiene as "important," "not sure," or "unimportant" [18]. In the third study, the same categories were rated as "essential," "useful," or "no use" [17]. Both of these evaluations found that work, communication, hobbies, and entertainment tasks were predominantly "essential" or "useful" when carried out by the robotic system, and that feeding and personal hygiene tasks were predominantly "unimportant" or of "no use" [17], [18]. Hillman interprets these results by saying, "The personal applications of feeding and personal hygiene were rated lowly because the use of a human assistant was preferred" [18, p. 241].

2) The Robotic Assistive Appliance: The Robotic Assistive Appliance (RAA), which was developed by the Neil Squire Foundation as a result of the initial interviews described in the predevelopment section, is a workstation-based manipulator with six degrees of freedom plus end-effector actuation. One of the degrees of freedom is a lateral arm which allows the robot to travel over a worktable [3], [30]. The system is operated through an IBM PC or compatible computer via any interface which an individual uses to interact with the computer, such as voice recognition, Morse code, direct keyboard, expanded keyboard, or scanning [30].

A study was conducted in 1987 with five individuals using a prototype version of the RAA. Interviews were conducted in

TABLE IV
SUMMARY OF POSTDEVELOPMENT SURVEYS

Research Group	Device	Year	Total #	Ages	% Male	Disability							Location
						SCI	MS	MD	CP	Arthritis	Polio	Other	
Bath Institute of Medical Engineering (BIME)	Atlas Table Top	1986-87	5	41 - 65	80%	2	3						Home
	Atlas Workstation	1988	6	23 - 53	83%	6							Hospital
	Wolfson Workstation	1990-91	5	22 - 55	80%	4	1						Home
Neil Squire Foundation	RAA	1987	5	27 - 49	80%	4						1	Lab
Stanford/Palo Alto VA	DeVAR	1989	24	23 - 73	100%	23						1	Hospital Rehab Center
Hugh MacMillan Rehab Centre	MANUS	1992	6	6 - 17	33%				3	1	1	1	School, Centre, & Home
			7	23 - >40	Not Listed	1		2	2			2	
Queen Alexandra Centre	Inventaid Arm	1993	7	13 - 20	100%			7					Centre
Total / Percentage			65	–	–	62%	6%	14%	8%	< 2%	< 2%	8%	

an informal, verbal exchange, both before and after working with the RAA. Prior to working with the robot, the subjects were asked what tasks they wished to have performed, and what tasks they actually expected the robot to be able to perform. At the conclusion of the study, the subjects were asked to list tasks that were desired, expected, and now believed they could perform with the robot. Some of the tasks subjects wished to have performed, without consideration of the robot's capabilities, were: dressing in the morning, washroom attendant, transfer from bed to wheelchair and back, opening doors, security, and food preparation. Before being introduced to the robot, they "expected" it to assist with eating, drinking, turning appliances on and off, opening drawers, conducting personal hygiene tasks like brushing teeth, combing hair, shaving, applying makeup, and manipulating objects like paper, printer paper, books, floppy disks, and a pen or pencil. The final task list contained almost all of the tasks in the "expected" list prior to using the robotic arm, with the addition of page turning and bringing things within reach [4].

DeVAR, the Desktop Vocational Assistant Robotic workstation developed by Stanford University in collaboration with the Palo Alto VA Rehabilitation Research and Development Center, is commercially available from Independence Works, Inc., of Palo Alto, CA. It was evaluated by 24 high-level quadriplegics to determine functionality and user preference. DeVAR III, the version used in this evaluation, was a voice-controlled Unimation PUMA-260 industrial robotic arm with an Otto Bock Greifer prosthetic hand. The robot was mounted in the center of a wheelchair accessible 3′ × 6′ table. The VOTAN VPC-2100 voice unit recognizes voice commands and produces digitized voice messages to confirm the user's intentions. All tasks carried out by the robotic system were preprogrammed functions, with additional manipulation available by using commands like move "forward" or "back." Eighty-three percent of the 24 subjects were more than one year postinjury and none had prior experience with robots [13].

All evaluations took place over an 18-month period at the Palo Alto VA Medical Center at the wheelchair accessible table. The following items were situated near or mounted on the table: a microwave oven, refrigerator, tool holder for an electric shaver, spoon, electric toothbrush, pump toothpaste, adapted wash/dry cloths, and a mouthstick. Subjects used the robot to brush their teeth, prepare meals, wash their faces, and shave (18 and 8 subjects participated in the last two tasks, respectively). The majority of subjects were satisfied with the task completion. Notably, the majority also preferred the robot over an attendant to conduct the tasks of getting a mouthstick, brushing teeth, eating, and preparing a meal. The users enjoyed the independence, convenience, and control provided by the robot. At the completion of the testing, subjects were asked, "What tasks would you most like to have the robot do for you?" in an open-ended format. The top five tasks listed were: hygiene tasks like brushing teeth, shaving, and washing (9/24), meal preparation and eating (6/24), getting a drink of water (6/24), fetching and carrying objects (4/24), and operating environmental appliances like the telephone, television, and stereo (4/24) [13].

C. Wheelchair-Mounted Manipulators

1) The MANUS Manipulator: In September 1992, the Hugh MacMillan Rehabilitation Centre of Toronto, Canada, concluded a study of the MANUS wheelchair-mounted manipulator. As part of this evaluation, 13 severely physically disabled individuals took part in evaluating their capabilities using it within independent living, vocational, and educational environments. Six of the participants were children, three of whom used a powered chair, one was pushed in a manual chair, and two walked (one with lower limb prostheses). Of the seven adults, one adult lived in a hospital environment, two with their parents, and the others lived independently in a special unit with 24-h attendant care available [25].

TABLE V
RESULTS OF POSTDEVELOPMENT SURVEYS

	BIME[1] (Proto II)	BIME[1] (Proto III)	RAA[2]	DeVAR[3]	MANUS[4]	Inventaid[5]
Total # of Subjects	6	5	5	24	13	7
Work/School Fetch & carry objects	4 (5)	3 (4)	4 (4)	4 (24)	moderate high	42%
Communication / phone	2 (5)	3 (4)	–	1 (24)	mod. to low	–
Domestic Opening doors, drawers, etc.	–	–	–	4 (24)	high to mod. high	69%
Hobbies/Leisure	2 (5)	2 (5)	1 (4)	–	–	35%
Entertainment/Recreation	1 (5)	3 (5)		–	mod. to low	–
Feeding or Eat/Drink Prepare meal	– (5)	– (5)	2 (4)	6 (24)	high moderate	15% 68%
Personal Hygiene	– (5)	– (5)	4 (4)	9 (24)	moderate	48%

The total number of responses are listed in parentheses.
Survey questions:
[1] Task category rated as "Important" or "Essential"
[2] Response to open ended, informal discussion about expected and desired robot task performance.
[3] Response to "What tasks would you like the robot to do for you?"
[4] General response under "want to do" of tasks within the category.
[5] Percentage of tasks within this category rated as "very important to perform with a manipulator".

The MANUS manipulator, commercially available from Exact Dynamics, B.V., of The Netherlands, is six inches wide, mounts on the left side of the wheelchair, operates off of the wheelchair battery, and requires an on-board controller to be mounted on the chair, typically behind the seat [20]. The input device that came with the MANUS was a 16-key keypad, which the participants were generally unable to operate. A unique input device was developed for each individual to accommodate his or her physical abilities. Researchers asked participants of the study to respond to a seven-page "Action Checklist." This included about 75 different "Actions" under the headings of: Eating/Drinking, Food Preparation, Grooming/Toileting/Dressing, Opening Door/Drawer/Cabinet, Telephone Calls, Writing/Drawing, Desk Work/School Work, Manufacturing, and Miscellaneous. All tasks either had been achieved by rehabilitation robots in the past, or had previously been identified as desirable capabilities of a robot manipulator [25]. This checklist asked the individuals to respond to the Action with "want to do," "do not want to do," "have done (with the robot)," "not applicable," or "do without manipulator arm." The actions that all of the 13 participants "wanted to do" were to: pick up a book and place a book on a shelf. The other most desirable tasks were to: pour liquid and fetch objects from shelves (12 each), turn knobs (10), drink from a cup or glass, use a standard fork, knife and spoon, and grasping and releasing (9 each). It was possible to perform all of these tasks with the robot, although with widely varying ratings of effectiveness [25].

2) The Inventaid Arm: In 1993, the Queen Alexandra Centre for Children's Health in Victoria, Canada, purchased an Inventaid Arm from the Papworth Group of England, manufacturers of the device. The Inventaid Arm is a joint-controlled, six degree of freedom manipulator plus gripper, which uses Flexator air muscles powered by a tank of compressed air which must also be located on the wheelchair [15]. A questionnaire about the manipulator was distributed to seven young adults with muscular dystrophy, all of whom lived in a group home, except one who lived at home. The individuals used their electric wheelchairs between 10 and 16 h per day (13 h per day average) and needed assistance anywhere from 7 to 24 h per day (16 h per day average).

Subjects were asked to complete the questionnaire after viewing a video of the Inventaid Arm being used by the inventor and experimenting with the arm for about five minutes themselves. The survey listed over 80 tasks under the categories of: Eating/Drinking, Food Preparation, Domestic Tasks, Grooming and Toileting, Leisure/Recreation, and Desk/School Work. Many of the tasks were the same as those listed in the 1991 predevelopment survey conducted by the same institution. Subjects were asked to rate the tasks for both "How well can you do these tasks on your own?" and "How important would it be for you to have a manipulator arm to do these tasks?" on a scale from "1 = not at all" to "5 = very well/very important." At the end of the questionnaire, each was asked to list "What five tasks would you most like a manipulator arm to do?" The top five tasks listed in response to this open-handed question were: picking objects up from the floor (6), opening doors, reaching high, operating light switches, and drinking from a cup or glass (2 each) [23].

Out of the surveys conducted, this is the only one in which both personal skill level and manipulator importance were rated for the same set of tasks. The majority of those surveyed were capable of doing tasks related to eating and drinking, and felt these were not very important for a manipulator arm to be able to do. Many of the food preparation, domestic, and grooming tasks were impossible for the majority of users, and were rated as very important. In general, tasks that subjects rated as "unable to do" correspond with those they most wanted to be able to do. Exceptions to this were "drinking from a cup/glass" and "holding the phone" which were commonly rated as very important even though many were still capable of doing this. This may be because they foresee these tasks being important in the future when they are no longer able to perform them due to the degenerative nature of the disease. A similar conclusion was made in the predevelopment BIME survey [7]. In the personal hygiene/grooming category, there was less of a match between ability and the importance of having the manipulator arm perform the task, possibly because of a preference some users have for human assistance with these tasks. Over all, the task ratings were high, however, considering that the majority of the subjects found the noise level (6/7), speed (5/7), appearance (5/7), and accuracy (4/7) to be unacceptable [23].

D. Discussion of Postdevelopment Surveys

Table V: Results of Postdevelopment Surveys summarize the task ratings for all five studies. As each research group executed a very different survey, categories were generalized for the purpose of cross comparison. The BIME prototype surveys record general ratings for six categories: Work, Communication, Hobbies, Entertainment, Feeding, and Personal Hygiene. As the Neil Squire survey was an open-ended discussion, task requests were listed under categories specified by other surveys. The same process of categorization was used for the task list generated in the DeVAR study in which subjects were asked to respond to the question of "What would you like a robot to do for you?" [13]. With the MANUS Manipulator survey conducted by Hugh MacMillan, the number of responses under "want to do with a manipulator" for the task list of the specific category are generally summarized from the original tables [25]. For the Queen Alexandra survey with the Inventaid arm, the percentage of tasks listed under "very important to perform with a manipulator" were calculated and listed under the appropriate category [23].

Work, school, or tasks associated with these activities were rated highly for all studies. Communication, a category in the BIME studies, was rated moderate to high in that study, but low or moderate to low in other studies, with no rating at all for the RAA and the Inventaid Arm. In the category of Domestic, there was no applicable rating for the BIME prototypes or the RAA, since most of the tasks in this category were opening doors, drawers, cabinets, windows, and operating appliances, for which stationary robots are not well-equipped. Four of the participants in the DeVAR study indicated that they would like to use the robot to operate appliances like a telephone, television, or stereo, even though the system was not set up to do so. In the MANUS survey, the 13 tasks listed under the category of Opening Doors/Drawers/Cabinets were rated highly [25]. In the Inventaid Arm study, the Domestic category which included reaching to the floor, getting an item from the refrigerator, turning faucets, and other similar tasks, was rated highly.

It is difficult to differentiate between Hobbies and Entertainment, both BIME survey terms, Leisure/Recreation, a Queen Alexandra category, and Recreation, a Hugh MacMillan term. The intended tasks which differentiate Hobbies from Entertainment are not specified in the BIME study. The 21 tasks under MacMillan's Recreation list could be classified as hobbies, entertainment, or domestic (operating television, VCR, etc.) and the 24 tasks under the Queen Alexandra study could be classified under all three as well. In addition to the difficulty in classification of categories, Recreation also suffers from ambiguity because a low rating may reflect a lack of interest in the specific activity or hobby listed. Perhaps it is this ambiguity which resulted in only a moderate rating of both categories in the BIME study, or perhaps there was a moderate rating because stationary robots only allow for leisure activities which are conducted at the workstation. There was little or no interest in the category shown for the RAA or DeVAR. However, the DeVAR study focused on activities of daily living. In addition, four of the DeVAR participants did request operating appliances, which we listed under Domestic for the purpose of cross comparison, but using some appliances, like a television, could also be considered an Entertainment task [13]. The MANUS group showed a low to moderate rating for tasks under Recreation, and 35% of the tasks under the category of Leisure were rated as "very important" by the subjects in the Inventaid group [23], [25].

The largest difference between devices is seen under the categories of eating, drinking, preparing a meal, and using the device for personal hygiene. These categories represent tasks which will be performed by a caregiver if a device is unavailable. Consequently, the adequacy of the device is more likely to be compared to the time it takes an attendant to perform the same task. The reason that no one in either of the BIME surveys found these tasks to be "important" or "essential" could be related to the time it took to perform these tasks. While timed performance tests are not available for the second and third prototypes, the Atlas robot was once used in the laboratory to prepare a hot drink and took 30 min to do so [16]. By comparison, it took about 10 min to prepare and eat soup with the DeVAR robot [13]. This is within the range of time that it would take a caregiver to perform the same task. Evaluations have indicated that a task must be accomplished within a "reasonable" amount of time, but that the added control over the task, privacy, independence, and freedom from an attendant's schedule and presence may outweigh the increased time it takes to perform the task with a robot [15]. Other daily living tasks that DeVAR was programmed to perform were accomplished in 5 to 10 min, which may reflect why 6 of the 24 requested Eating/Drinking/Preparing meals, and 9 of the 24 requested conducting Personal Hygiene tasks, when asked to list, in an open-ended format [13], tasks for which to use the robot. The users, of course, were also influenced by the fact that they all had the opportunity to use the robot to perform these exact tasks. Those who were surveyed about the RAA, however, did not have the opportunity to execute preprogrammed tasks, yet two of them requested food-related activities and all four mentioned that they would want to use the device for personal hygiene tasks [4]. With the MANUS group, the response was high for tasks under the category of Eating/Drinking, but moderate for tasks under Food Preparation [25]. In contrast, the seven young men with muscular dystrophy, who responded to questions about the Inventaid Arm, rated only 15% of the 7 tasks under

Eating/Drinking as "very important," but 68% of the 12 tasks under Food Preparation were rated as "very important." The low, 15%, "very important" rating is understandable given that the same set of tasks received a 58% rating as those which they "perform very well" [23]. As for Personal Hygiene tasks, the MANUS group showed a moderate rating for the eight tasks listed under this category, and the Inventaid group had a 48% rating of "very important" for 24 tasks under this category [25].

IV. Discussion of Task Priorities for Pre- and Postdevelopment Surveys

The predevelopment surveys all listed reaching, stretching, gripping, and picking up objects from the shelf or floor as a very high priority. The same kinds of tasks received high ratings by most of the postdevelopment surveys, as can be seen under the categories of Work/School, Fetch and Carry Objects, and Domestic/Opening Doors (Table V). The lower rating under this category for DeVAR, and the absence of the Domestic category for the BIME prototypes, may reflect the stationary nature of the desktop systems.

Tasks of cooking, fixing food and drinks, and eating or drinking are highly rated in the predevelopment surveys. These same tasks also generally rated highly on the postdevelopment surveys, with the exception of the BIME surveys, which may have been due to the fact that the prototypes were not particularly well-equipped to provide this function efficiently.

Tasks related to personal hygiene were present on the predevelopment surveys, but only rated highly for the Queen Alexandra and orthosis studies. The same category received a moderate rating on postdevelopment surveys, with the exception of DeVAR which was rated high. The high rating inevitably reflected the fact that DeVAR was programmed specifically to conduct personal hygiene tasks for this study and the users surveyed had successfully completed such tasks.

The category of Gardening/Hobbies and Crafts/Leisure was highly rated in the predevelopment survey and interest in such tasks was also reflected across the postdevelopment surveys. Although ambiguity in the survey results of the postdevelopment responses prevent an exact comparison between pre- and postdevelopment surveys, users make the point that this category of tasks is valuable.

Specific employment-related tasks are absent in the predevelopment surveys and received a mixed rating in the postdevelopment surveys. As was mentioned in the predevelopment discussion, the high unemployment rate, as shown in Table III, would influence the lack of employment-related responses to an open-ended question. The employment-related rating across the postdevelopment surveys may reflect the devices and the format of the survey, as opposed to the potential for employment-related activities performed with the assistance of a manipulator. For instance, none of the 24 participants of the DeVAR study suggested exact work-related tasks, but the generation of DeVAR used in this study was specifically programmed to perform tasks of daily living. A subsequent generation of DeVAR demonstrated a successful vocational application [14]. The vocational study was not included in this paper, as the focus of the study was not consistent with the objectives of this review. Many other employment-related research activities with rehabilitation robotics have also been performed, but also fall outside of the scope of this review [5], [8]–[10]. It is valuable to note that the Work category rated highest for the BIME prototype and four of those who took part in the RAA evaluation suggested work-related activities. One advantage of vocational tasks is that the cost of the device can be offset by employment income. Also, from a design point of view, vocational tasks can frequently be structured to take place in one setting. As mentioned in the predevelopment discussion, many generic manipulation and communication tasks may also facilitate employment.

The results of both the pre- and postdevelopment studies indicate that potential users would like to perform tasks in unstructured environments, which would provide them with independence in activities associated with miscellaneous object manipulation, eating, and leisure activities. It is important to remember, however, that acquisition of robotic and orthotic devices by the end-user population is very much dependent on the medical, vocational, and support resources available to the user [21]. Consequently, designers of such devices must not only consider the important answers to questions posed to the end-user population, but must also acknowledge the needs and concerns of professionals and others who are an integral part of the lives of people with severe physical disabilities. This includes medical personnel and professional agencies, who will frequently be asked to authorize the purchase of a robotic or orthotic device, attendant caregivers, who will not only be required to perform set-up and auxiliary care but may also be partially replaced by the device, and family members, who are equally impacted by the presence of a robotic or orthotic device.

Nonuser Surveys: The focus of this review article is on the task priorities identified by active and potential users of assistive manipulation devices. Surveys that have been conducted with nonusers, however, have produced insight into design specifications and priorities. Perspectives from the able-bodied population, caregivers, and medical personnel provide useful comparisons to information collected from the user population.

McWilliam [24] conducted the first evaluation of task priorities in 1970 for the purpose of prosthesis design. The results of 17 able-bodied individuals, who recorded and rated 180 tasks of daily living, emphasized eating and drinking tasks, but failed to note the importance of reaching and grasping objects from various locations, as identified by the disabled respondents. Similarly, in the Queen Alexandra Centre's post-development studies, the comparison between the responses of the disabled users and those of their caregivers showed that the caregivers rated the importance of drinking from a straw, pouring liquid, brushing teeth, operating a CD player, playing video games, typing on a keyboard, and turning the computer on and off much higher than the users did. On the other hand, the importance of drinking from a glass, opening doors, washing/drying the face, using a vending machine, gardening, and manipulating printouts were rated much lower than the users' responses [22]. In addition to choosing different

TABLE VI
USER TASK PRIORITIES

Priority	Task
High	Picking up misc. objects, esp. from floor or shelf Carrying Objects
Moderate to High	Eating/Drinking Preparing Food & Drinks Personal Hygiene Leisure & Recreation

priorities, these results suggest that, for the particular robot being considered, users were more ambitious about what they would like to do than the caregivers.

Glass and Hall [11] conducted a 53-item questionnaire in 1987 with 51 experienced occupational therapists to determine their views towards the use of robotic aids for people with disabilities. Activities of daily living were rated highly, with over half of the respondents indicating them as tasks they would most want a robot to perform for their patients. Their expectations were high, with specific tasks reported as cooking and meal preparation, feeding, lifting and carrying heavy objects, dressing, grooming/hygiene, turning, transfers, shifting weight, and elimination functions. While technically impressed with the robots, they were wary of them, finding them mysterious, difficult, and unfriendly.

The nonuser surveys have demonstrated several points. First, disabled individuals, as the potential users, should be contacted directly to determine their priorities, since others identified different task priorities. Second, the attitudes of therapists, caregivers, etc., may affect the acceptance of the device, and third, the required tasks should be examined from a broad perspective to determine what will bring the greatest benefit to the user.

V. CONCLUSION

Surveys were conducted by seven research groups in order to gain feedback directly from potential or active users of assistive manipulation devices. The four predevelopment and five postdevelopment surveys generally agree on task priorities as listed in Table VI. The tasks related to picking things up off of the floor or a shelf and fetching and carrying objects are rated the highest among users. The importance of opening doors or drawers was noted in predevelopment studies and rated highly in the postdevelopment wheelchair-mounted robot studies. With these task priorities, users are implying a desire for a mobile device which can operate in an unstructured environment.

Tasks associated with eating also received a high priority, yet apprehension was voiced about losing social interaction during mealtime. The conclusion of these studies implies that, while performing such tasks independently is important, other factors, like having a device which integrates well with the social aspects of cooking and eating, is also important.

Tasks associated with personal hygiene, while prevalent on the task lists, also received a mixed rating, also possibly because of the loss of social interaction which potentially comes with using a manipulator to perform such tasks. In addition, using a mechanical manipulator may be intimidating or frustrating, especially if it is not designed to perform such tasks or is not able to perform the tasks in a time-efficient manner.

The emphasis that users placed on leisure activities suggests that such devices should address needs across many task domains. The variability of potential users' interests in leisure activities again implies the need for a mobile device and one that can operate in a variety of environments, including such areas as the garden.

Comparing the desired tasks to the capabilities of current and prototype devices shows that the reaching tasks are generally well-performed by the wheelchair-mounted robotic arms, depending on the weight and the size of the objects to be grasped [23], [25]. Eating or drinking appear to be performed satisfactorily by DeVAR and the MANUS, although not for all shapes, sizes, and consistencies of food [13] and not using standard utensils [25]. Devices specific to eating are also available, as discussed earlier [37]. Personal hygiene tasks are performed with varying ability, with the majority of the DeVAR users "satisfied" with the robot's performance in brushing their teeth, washing their face, and shaving [13]. Problems with personal hygiene tasks are related to the complexity of the motions [1], [33] and the desire for them to be performed by a human attendant [18]. Recreational tasks have been explored much less, but should be possible given a device which can be used in unstructured environments. Some specific vocational tasks are now performed reasonably well by several workstation robots [4], [8], [14]. However, high costs and difficulties with implementation prevent widespread distribution of such systems.

Although some of the available devices meet specific task performance criteria, none meet the balance between functionality, appearance, ease of use, reliability, and cost. There are many dimensions which define the acceptable criteria for these parameters. For instance, the "cost" parameter encompasses the price of the device, upkeep and service, training for use, plus an understanding of the funding dynamics for assistance technology [31]. Selecting appropriate design criteria requires an interdisciplinary team, where clinical and rehabilitation professionals who have an expertise in the physiological and sociological aspects of severe physical disability work in collaboration with engineers and those with technical expertise. End users are important members of the team to assist in defining appropriate functionality, appearance, and ease of use. Functionality is a paramount concern as devices which fail functionality criteria will never "succeed" in the market place. The task priorities of the over 200 users and potential users who took part in the nine surveys reviewed here indicate that device adaptability is required in order to accommodate the variety of user's disabilities, environments, daily activities, and preferences. By providing adaptability, the user has the opportunity to assist in defining device potential through independent experience.

REFERENCES

[1] C. Anglin, "A functional task analysis and motion simulation for the development of a powered upper-limb orthosis," M.A.Sc. thesis, Univ. of British Columbia, 1993.

[2] L. J. Bannon and S. Bødker, "Beyond the interface: Encountering artifacts in use," in *Designing Interaction.* London: Cambridge Univ. Press, 1991, ch. 12.

[3] G. Birch and W. Cameron, "User acceptability in robotic assistive appliances," Neil Squire Foundation Newsletter, Winter/Spring 1991.

[4] G. Birch, J. Young, M. Fengler, A. Carpenter, C. McIntire, B. Mayes, S. Hornstein, K. McKay and W. Cameron, "Development of high level supervisory software and ancillary mechanical hardware for an assistive manipulative appliance (robot) interim report," Neil Squire Foundation, Health and Welfare Project No. 6610-1545-5, 1987.

[5] M. Burrow and T. Single, "The Georgia Tech robotic manipulator: A six degree of freedom arm for rehabilitation applications," in *ICORR, '90 Conf. Proc.*, J. Trefsger and M. Gilbert, Eds. Delaware: University of Delaware/Alfred I. duPont Institute, Applied Science and Engineering Laboratories, June 1990, pp. 57–67.

[6] W. Cameron, G. Birch, M. Fengler, J. Young, A. Carpenter, C. McIntyre and K. McKay, "Capitalizing on robot technology—MAD, MOM, DAD and next," in *Proc. RESNA 13th Annu. Conf.*, J. J. Presperin, Ed. June 1990, pp. 331–332, vol. 10.

[7] T. P. Clay, M. R. Hillman, R. D. Orpwood and A. K. Clarke, "A survey of the potential disabled users of a robotic aid system," Bath Inst. of Med. Eng., Royal United Hosp., Bath, Avon, UK, 1985.

[8] J. L. Dallaway and R. D. Jackson, "The RAID workstation for office environments," in *Proc. RESNA '93 Annu. Conf.*, M. Binion, Ed. RESNA Press, June 1993, pp. 504–506, vol. 13.

[9] J. M. Détriché and B. Lesigne, "Man machine interface and programming aspects of the robotized system 'MASTER' for handicapped people," in *Conf. Papers—1991 Int. Conf. Rehab. Robotics*, Georgia Institute of Technology, June 1991, pp. 68–80.

[10] K. G. Engelhardt and R. A. Edwards, *Human-Robot Interaction.* Philadelphia, PA: Taylor and Francis Ltd., 1992.

[11] K. Glass and K. Hall, "Occupational therapists' views about the use of robotic aids for people with disabilities," *Amer. J. Occupation. Therapy*, vol. 41, no. 11, pp. 745–747, Nov. 1987.

[12] R. G. Guilhamoulie, "TRIUMF robotic arm project: Description and documentation for development," Neil Squire Foundation, Vancouver, BC, Tech. Rep., Spring 1984.

[13] J. Hammel, K. Hall, D. Lees, L. Leifer, M. Van der Loos, I. Perkash and R. Crigler, "Clinical evaluation of a desktop robotic assistant," *J. Rehab. R & D*, vol. 26, no. 3, pp. 1–16, Summer 1989.

[14] J. M. Hammel and M. Van der Loos, "Evaluation of a vocational robot with a quadriplegic employee," *Archives Phys. Med. Rehab.*, vol. 73, pp. 683–693, July 1992.

[15] J. Hennequin, "Inventaid: Technology for the disadvantaged," in *Proc. RESNA Int. '92 Conf.* RESNA Press, 1992, p. 588, vol. 12.

[16] M. R. Hillman, "A feasibility study of a robot manipulator for the disabled," *J. Med. Eng. Technol.*, vol. 11, no. 4, pp. 160–165, July/Aug. 1987.

[17] M. R. Hillman and J. Jepson, "Evaluation of a robotic workstation for the disabled," *J. Med. Eng.*, vol. 14, pp. 187–192, May 1992.

[18] M. R. Hillman, G. M. Pullin, A. R. Gammie, C. W. Stammers and R. D. Orpwood, "Clinical experience in rehabilitation robotics," *J. Biomed. Eng.*, vol. 13, pp. 239–243, May 1991.

[19] R. D. Jackson, "Robotics and its role in helping disabled people," *Eng. Sci. Educ. J.*, vol. 2, no. 6, pp. 267–272, Dec. 1993.

[20] H. Kwee and C. Stanger, "The Manus manipulator," Rehab. Robotics Newsletter, Applied Sci. and Eng. Lab., A. I. duPont Inst., Spring 1993.

[21] L. Leifer, "RUI: Factoring the robot user interface," in *Proc. RESNA Int. '92 Conf.* RESNA Press: June 1992, pp. 580–583, vol. 12.

[22] J. Mattie, personal communication, facsimile, Sept. 1994.

[23] J. McKechnie, "Results from the 1991 and 1993 robotic aid/manipulator arm surveys," Queen Alexandra Centre for Children's Health, Tech. Rep., Dec. 1993.

[24] R. McWilliam, "A list of everyday tasks for use in prosthesis design and development," *Bullet. Prosthetics Res.*, pp. 135–164, Spring 1970.

[25] M. Milner, A. King and G. Verburg, "Evaluation of the MANUS manipulator arm in ADL, vocational and school settings," Hugh MacMillan Rehabilitation Centre, Toronto, Final Rep. Nat. Health Res. and Dev. Program No. 6606-4158-59, Sept. 1992.

[26] S. A. Napper and R. L. Seaman, "Applications of robots in rehabilitation," *Robotics and Autonomous Syst.*, vol. 5, no. 3, pp. 227–239, 1989.

[27] S. D. Prior, "A review of world rehabilitation robotics research," Middlesex Polytechnic, London, UK, Int. Rep., Dec. 1989.

[28] ——, "An electric wheelchair mounted robotic arm—A survey of potential users," *J. Med. Eng. & Technol.*, vol. 14, no. 4, pp. 143–154, July/Aug. 1990.

[29] ——, personal communication, electronic mail, Feb. 1994.

[30] "Regenesis Development Corporation," North Vancouver, B.C., Regenesis Development Corp.

[31] B. Romich, "Assistive technology and AAC: An industry perspective," *Assistive Technol.*, vol. 5, no. 2, pp. 74–77, 1993.

[32] D. P. Romilly, C. Anglin, R. G. Gosine, C. Hershler and S. U. Raschke, "Analysis and development of a powered upper-limb orthosis," in *ICORR '94 Conf. Proc.*, 1994.

[33] ——, "A functional task analysis and motion simulation for the development of a powered upper-limb orthosis," *IEEE Trans. Rehab. Eng.*, spec. iss., vol. 2, no. 3, pp. 119–129, Sept. 1994.

[34] W. F. Sauter, G. Bush and J. Somerville, "A single case study: Myoelectrically controlled exoskeletal mobilizer for amyotrophic lateral scalerosis (ALS) patients," *Prosthetics and Orthotics Int.*, vol. 13, pp. 145–148, 1989.

[35] B. Shneiderman, *Designing the User Interface*, 2nd ed. Reading, MA: Addison-Wesley, 1992.

[36] C. A. Stanger, "Designing the user interface for an electro-mechanical assistive manipulator," Applied Sci. and Eng. Labs., A. I. duPont Inst., Tech. Rep. ROB9403, May 1994.

[37] ——, "Rehabilitation robotics: What's gripping?" in *Conf. Proc., Technology and Persons with Disabilities*, California State University, Northridge, CA, Mar. 1994.

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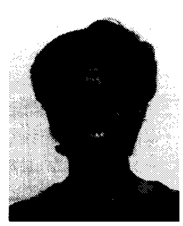

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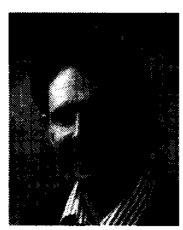

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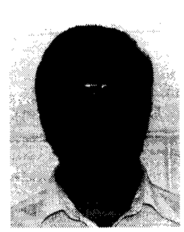

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