JRRD
Journal of Rehabilitation Research & Development
Vol. 36 No. 3 July 1999

The robotized workstation "MASTER" for users with tetraplegia: Description and evaluation

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Abstract--The rehabilitation robotics MASTER program was developed by the French Atomic Energy Commission (CEA) and evaluated by the APPROCHE Rehabilitation centers. The aim of this program is to increase the autonomy and quality of life of persons with tetraplegia in domestic and vocational environments. Taking advantage of its experience in nuclear robotics, the CEA has supported studies dealing with the use of such technical aids in the medical area since 1975 with the SPARTACUS project, followed by MASTER 10 years later, and its European extension in the framework of the TIDE/RAID program. The present system is composed of a fixed robotized workstation that includes a six-axis SCARA robot mounted on a rail to allow horizontal movement and is equipped with tools for various tasks. The Operator Interface (OI) has been carefully adapted to the most severe tetraplegia. Results are given following a 2-year evaluation in real-life situations.

Key words: *clinical evaluation, rehabilitation, robotics, tetraplegia, workstation.*

INTRODUCTION

The number of persons with tetraplegia increases every day. This is due to improvements in medical treatment (we now save people with severe injuries who, 10 years ago, would have died) and to increases in the causes of tetraplegia (e.g., accidents involving cars and sports, genetic diseases, problems at birth).

Doctors in charge of rehabilitation have become increasingly preoccupied with the quality of life they are able to offer to persons who are totally dependent due to a disability. During the international congress of CARDIOSTIM in Nice, France in 1990, the necessity of substituting high technology for human assistance, particularly on financial grounds, was recognized.

Among modern solutions, a robot used for the replacement of manipulation function constitutes a credible alternative and is why major research laboratories have studied this field for more than 20 years. However, because of a lack of funding, many studies have not gone beyond a demonstration model.

In 1975, the French Atomic Energy Commission (CEA) studied the transfer of its experience in the field of nuclear robotics to the specific problem of assisting persons with disabilities. At the same time, similar studies were undertaken in the United States Department of Veterans Affairs and the concept of a robotized workstation was developed. Many papers have been published on the design of such technical aids, and on their evaluation in real situations, under the names DeVAR in the U.S. (1-3), SPARTACUS (4,5) and MASTER in France (6,7), HANDY1 (8) in the UK, Neil Squire MOM (9) in Canada, and so forth.

In 1992, taking advantage of the MASTER control command and the results of the French evaluations, MASTER was redesigned by

OXIM (UK) for a European Community TIDE (Technology for the socio-economic Integration of Disabled and Elderly people) initiative called RAID (Robot for Assisting the Integration of the Disabled [10,11]) and evaluated for a short period in the UK, Sweden, and France, in the frame of EPIRAID (12).

The first part of this paper describes the version of MASTER manufactured by OXIM (UK) for the APPROCHE organization. APPROCHE is the French acronym for "Association pour la Promotion de Plateformes RObotiques Concernant les personnes HandicapEes," an organization for promoting robotic systems relating to people with a disability. This organization coordinates studies of 10 French rehabilitation centers dealing with functional tetraplegia (e.g., spinal injury, muscular dystrophy, cerebral palsy). The second part describes the evaluation grid defined by the therapists and users themselves (and the objectives assigned to them) at the APPROCHE centers. These are KERPAPE, PEN-BRON, GARCHES, COUBERT, DIJON, LAY-SAINT-CHRISTOPHE, BERCK, SAINT-HILAIRE-DU-TOUVET, CERBERE, and L'ARCHE. Finally, the third part describes the results obtained during 2 years of evaluation at these centers.

METHOD

Concept

Our first thought in beginning this study was to undertake a precise ergonomic and technical analysis of the daily assistance needs of the functional person with tretraplegia, at what time during the day a robot could replace human assistance, and when such a technical aid would satisfy the needs and thus be effectively used. The conclusions reached by this analysis were that to meet the needs, such a technical aid should be able to perform repetitive tasks (e.g., give a drink, load a floppy disk into a computer, grasp a phone receiver). However, it must be integrated within the overall control of the user's environment; the robot is in charge of tasks involving the manipulation of objects, but there is supervision of the Environmental Control System (ECS) when other tasks are being performed.

A robot can be operated in two ways, by either manual or remote control, or by executing automatic routines that have been pre-programmed. The manual mode allows the user to control the robot directly via a configurable user interface. The automatic mode allows fast execution of tasks without tiring the operator, but requires that the objects that are going to be manipulated remain in the same position, while the manual mode allows objects to be moved in an unstructured environment. To meet the needs of the users, the equipment should be able to perform both automatic and manual tasks, activate the ECS, and offer the possibility of loading office software, so that essential tasks can be carried out independently by the operator without having to call for the help of an attendant.

Design

The evolution of the MASTER project included construction of a prototype (MASTER 1), manufacture of four units, and evaluation in real-life situations over a 1-year period. Based on experience and the advice and criticism received (13), MASTER 2 was designed and evolved into the present MASTER/RAID workstation that is illustrated in **Figure 1**. The latter includes:

1. A robot RT 200, manufactured by OXIM in the UK, with a vertical axis and a horizontal rail giving a significant working volume. The robot moves in front of a metallic structure incorporating shelves to hold objects to be manipulated.
2. The robot is equipped with a standard gripper and a specialized pneumatic tool for manipulating books and sheets of paper; the terminal tool is automatically changed depending on the task to be performed. The pneumatic tool was designed and tested by LUND University in Sweden (14), evaluated for a short period, then modified and adapted by OXIM.
3. The pneumatic tool works in conjunction with a reader board that includes some pneumatic functions (suction cup to maintain the book on the reader board, brackets holding the pages). Also, it is equipped with a sensor that allows it to measure the dimensions of the book and its thickness.

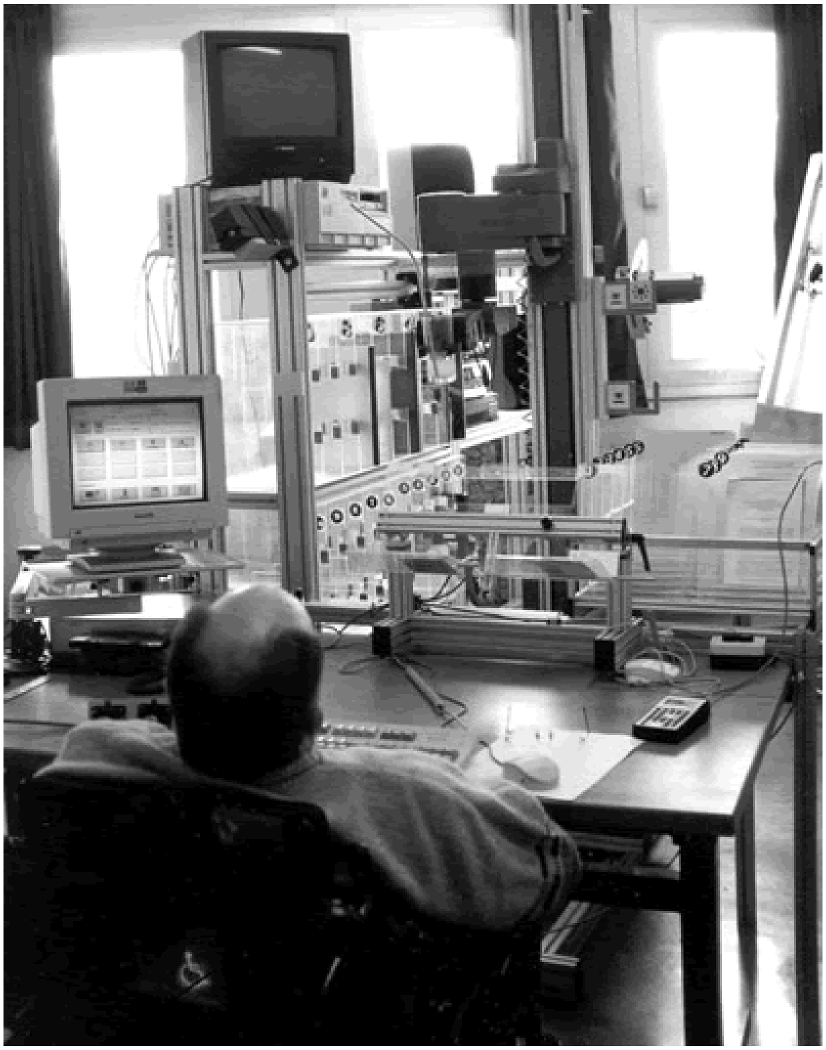

Figure 1.
General view of the MASTER/RAID workstation.

MASTER Operating Modes

The user controls four functional modes in real time: manual, automatic, and environmental control (ECS), and office mode.

The *manual mode* allows the user to control the robot directly via a configurable user interface. Driving in joint space is very difficult, even for persons without disabilities. Therefore, different coordinated movements have been implemented in MASTER to make the control easier.

The *automatic mode* allows specifically programmed tasks involving handling and grasping objects in known positions. The user selects the actions, the nature of the liquid, the cassette number, and so forth, and can take control in manual mode if the task is difficult to program completely (e.g., pouring liquid into a glass and drinking), or, if it is necessary, to take into account unforeseen changes in an object's location. In addition, the user can, at any time, cancel a program and enter the ECS mode (e.g., for dialing, switching on equipment).

The *ECS mode* allows electrical appliances to be controlled via infrared transmission. A phone interface is provided for calling a number already entered into a directory, or for dialing in manual mode by selecting the number digit by digit. All these actions can be controlled directly by the user, or can be initiated by a safety routine.

The *office mode* gives access to the classic office routines available under the WINDOWS graphical environment; this is necessary for vocational purposes.

The ability to access the different modes at any time is a fundamental requirement for a robotized system dedicated for persons with disabilities because it ensures good performance in real situations (i.e., in a locally structured, evolving environment). This is essential to productive and adaptive human-machine cooperation.

Man-Machine Communication

Modularity

The interface keeps the user informed of the state of the system and allows selection of its running mode, initiation or cancellation of automatic routines, change to manual mode if necessary, and access to the ECS and office modes. All these actions have to be performed in real time and depend on the residual motricity of the individual user, who is informed about the state of the system via a PC display, where graphical windows appear (**Figure 2.**) Different methods of communication are available to select an action: mouse pointing and clicking, joystick pointing and validation by a switch (in this case, the joystick and switch are used as a mouse in the office tasks), speech recognition, a scrolling menu, or the keyboard keys. The control of the system requires, at a minimum, the ability to move a switch, although the nature of the switch (mechanical contact, pneumatic sip and puff, electronic touch control, etc.) and its position with respect to the user with disability are not critical.

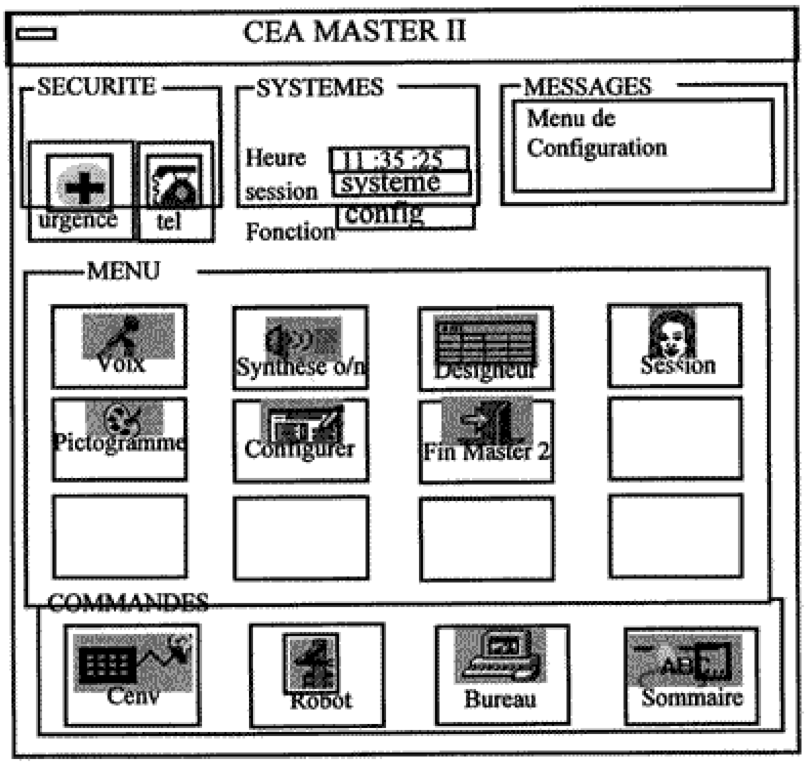

Figure 2.
A MASTER graphical display.

Movement of the robot in manual mode is brought about by using switches or proportional sensors (joysticks). Each movement involves three primary motions and a maximum of three sensors is employed (e.g., a joystick with two degrees of freedom and a roller to provide a third degree of freedom). However, the system can be operated with only one or two degrees of motricity if this has been allowed when configuring the system. In this case, a sequencing procedure is automatically executed. For example, if movement is needed, the system first suggests motion along the x-axis, then along the y-axis, and finally along the z-axis, in a repeating sequence.

Configuring Process

Identification of the needs of persons with disabilities showed that a configuration process is required in order to adapt the user interface to the nature of each individual's ability. This is accomplished by a software program that interrogates the operator via various graphical pages in order to establish the required parameters.

The following parameters are taken into consideration:

- motricity number of the user (from 1 to 3)
- scrolling speed of the menu
- whether a speech recognition unit is used. If one is used, the system will automatically offer the user an opportunity to work on the vocabulary. Selection using voice commands is faster than scrolling the menu.
- whether a voice synthesizer is used to recall the operating instructions (useful for people with low vision).
- the dead time between two pulses coming from the user interface switch (particularly useful for people with uncoordinated motion).
- the dead zone for each proportional sensor. Calibration of the "zero" and the maximum exploratory areas are performed by training, in cooperation with the user.

- assignments for each function employed in the manual mode. This allows consistent parameters to be defined for each command with respect to the sensor position and the maximum velocity for each movement.

Modularity and the ability to easily configure the man-machine dialogue remain essential elements of the design of a robotized system.

Task Programming

Task programming is generally the responsibility of an occupational therapist with the necessary special training, and is often carried out in collaboration with the user. The MASTER system computer uses a custom graphics-based language for task programming.

Safety Aspects Related to Mixing the Different Running Modes

Persons with disabilities can interrupt an automatic task at any time to stop it and transfer control to the manual, ECS, or office mode. Sometimes such a change can present some risk. For example, having opened a tap, stopping the program improperly can lead to an overflow. For this reason, chained safety routines have been included that, in this particular instance, will immediately close the tap before going on. Furthermore, it is possible to restart the program where it has been interrupted, or simply cancel it, if so ordered by the user. If some elements belonging to the workstation have been moved, or if an object is held by the gripper, going ahead with another automatic task might introduce the risk of collision or of dropping the object. For this reason, the programmer has the ability to add suitable programs to consider these difficulties.

Modifying the Coordinates of a Point During Task Execution

A program written in the MASTER programming language consists of a list of orders for arm displacement (go to, circle, straight line,etc.), control orders (automatic changes to the manual mode, to the ECS, etc.), assessment of the trajectory points, and management of the programs. A block of characteristic trajectory points is associated with this list during the training phase. Sometimes, in real situations, it is necessary to change some points during task execution. For example, positioning a wheelchair precisely in front of the workstation is rather difficult, while adjusting the position of the user's mouth in order to drink is time-dependent. The manual mode gives the user an opportunity to make the necessary adjustments. Moreover, the system is able to memorize the gripping points of objects, making it possible to retrieve them automatically once they have been manipulated.

Task Analysis

Task programming calls for a precise analysis of the task to be performed, taking into consideration external interventions or interactions with other tasks. A methodology including the following steps was developed to achieve effective programming:

- functional analysis of the task, specifying its elementary sequences
- definition of the various states in which the arm can be found, and for possible objects to be manipulated
- assignment for sequences and states
- creation of links between the different sequences
- creation of an operations flowchart, and the programming itself.

Safety Grounds

To ensure safe operation of the robot by the user with disabilities, the following solutions have been adopted:

- The speed and acceleration of the motors of the robot have been limited, and can be configured in recognition of the nature of the user's abilities.
- The switch functioning as an emergency stop when the arm is moving can be situated anywhere in the user's range (feet, chin, elbow, shoulder); the occupational therapist determines the type of sensor to be employed and the most suitable location for it.
- As noted above, the permanent interaction of the different modes should contribute to the safety of the user.
- The speech recognition unit and the scrolling menu can be used simultaneously upon validation.
- The initiation procedure is automatically loaded when the robot is switched on so that it can be restarted easily whether or not a problem occurred during its previous operation.
- Voice synthesis can be used to remind the user of the different instructions.
- The working zone close to the user is situated at the extreme reach of the arm in order to minimize the consequences of an accidental collision. When the arm enters this zone, the speed of the robot is automatically reduced.
- Safety routines are automatically loaded and chained when an emergency stop is detected.

EVALUATION PROTOCOL

Three evaluation processes were conducted concurrently: a technical evaluation by the CEA, a functional evaluation by

APPROCHE, and a psycho-sociological study by specialists at the PARIS University René DESCARTES. They occurred from October 1995 to October 1997. A total of 91 persons (65 men and 26 women), with an average age of 32.7 years (from 15 to 66 years), have contributed to the MASTER evaluation.

Technical Evaluation

Ten occupational therapists were trained by CEA during the 2 weeks prior to setting up the robot in the evaluating sites. They learned to drive the robot and configure and program the tasks. Most of the centers had a competent engineer or technician to help the therapists. Frequent fax exchanges between CEA and the centers helped solve the majority of the problems that arose during the evaluation period.

A questionnaire was given to the occupational therapists aimed at validating the functionality of the system. The questions dealt with the following:

- difficulties in accessing the PC and WINDOWS environment
- evaluation of the training period employed to teach the use of the system
- the operating mode
- the kinds of operator interfaces and the adaptations introduced by the occupational therapists
- use of the automatic mode to perform tasks
- use of the manual mode
- using the environmental control system
- using the office routines
- putting the safety programs in action
- configuring the mode to characterize the ability of the user, and task programming by the occupational therapist
- the number and types of failures observed.

Functional Evaluation

All subjects participated voluntarily. A common evaluation grid was established following discussion with the therapists and users who took the following into consideration:

User's Information

- sex
- age
- level of education
- professional activity: previous or current, probability of eventual return to the work force
- life-style (home or institution)
- living conditions (single, married, with family)
- nature and time period of disability
- self-reliance (toilet, meals, movement, communications)
- frequently used technical aids (computer, environmental control system, voice recognition unit, etc.)
- financial situation (income, subsidies, etc.).

Subject Selection Criteria

- people with functional tetraplegia who need permanent assistance in their daily lives
- teenager or adult
- study level not considered
- no intellectual deficiency.

Definition of the Tasks

Different themes were assigned to each site, though the evaluation grid was set up beforehand and was the same for each. One site was assigned to study the interest in robotics as an aid to university students, another for robotic assistance in the home, and another for use in a hospital setting. The robots were set up in occupational therapy departments or in personal bedrooms.

Tasks were defined and grouped into three domains: daily life, leisure, and vocational applications.

Three indexes, quoted from zero to four, were defined to evaluate the tasks: a priority index (PI), the priority assigned to performing the task using a robot; an index of ease of use (IEU); and a satisfaction index (SI).

The following items were assessed by the occupational therapist at the end of the evaluation because they were purely subjective: comparison of the duration of the task by persons with and without disabilities; the gain in autonomy; and the usefulness in daily life, leisure, and for vocational purposes. The evaluation phase included two steps for the user: proper training and experimentation.

Psychosociological Evaluation

In parallel with the technical evaluation conducted by the CEA, a psychosociological study was carried out by the specialists of the PARIS V University (Pr MORVAN Department). Users were interviewed at the start, after the training period, and at the end of the trial period. The results were collected and computerized. This evaluation provided information on the reasons for interest in, or rejection of, the system and will be published later.

RESULTS

User Information

Figure 3 illustrates the number of users who were already familiar with computers. The time required for instruction in the use of the system was generally short and is shown in **Figure 4.**

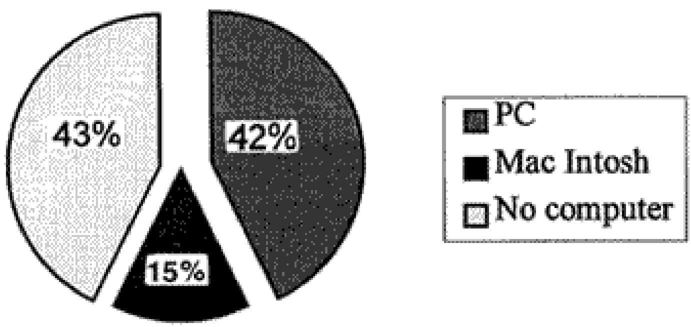

Figure 3.
Percentage of the users familiar with computers.

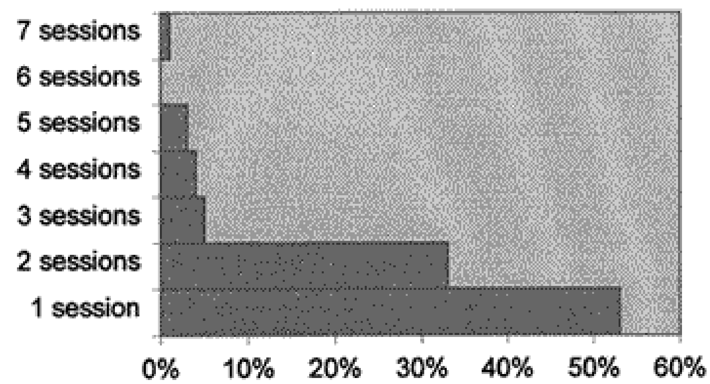

Figure 4.
Teaching duration (1 session = about 4 hours; percentages are of subjects completing sessions).

Robot

1. The SCARA architecture leads to intuitive movements.
2. Six degrees of freedom appear absolutely necessary for certain tasks that require complex movements, such as turning a page.
3. Mechanical constraints are sometimes penalizing.[es]
4. Tools:
    a. The specialized pneumatic tool was considered to be well-adapted to handling books and sheets of paper, but not sufficiently reliable when tasks involved page-turning.
    b. The gripper was considered to be well-adapted to the assigned tasks.
    c. Users have asked that frequent changes of tools be avoided because this slows execution and makes the task more complex.
5. The lifting ability of the arm did not reach the 2 kg reported by the manufacturer.
6. The speed of the robot in large displacements (0.15 m/s) was felt to be too low, but for safety reasons must be limited.

Operator Interface

1. The graphical presentation of the Operator Interface (OI) was considered to be good and easy to understand.
2. Interfaces employed are generally commercially available products, as shown in **Figure 5.**
3. The speech recognition unit was considered to lack reliability and to require painstaking training, but it remains a very desirable OI and was a high priority with users.

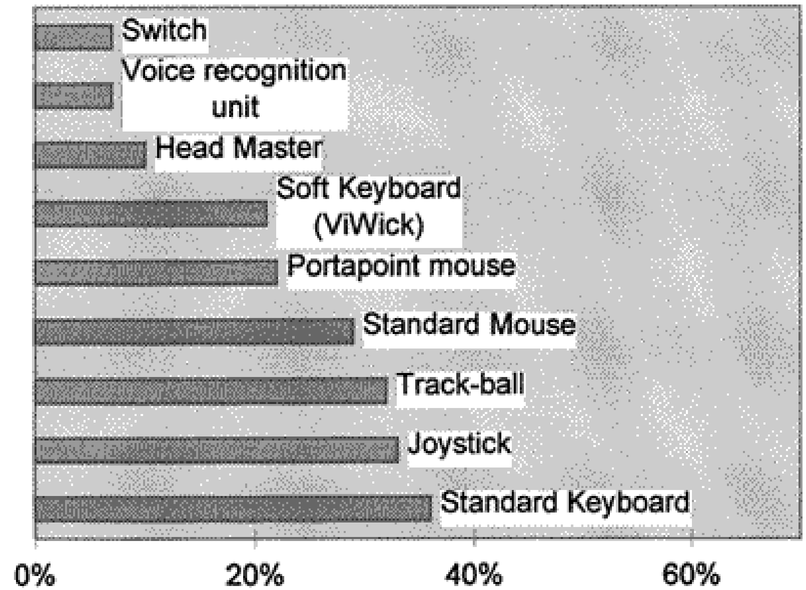

Figure 5.
Percentages of subjects using the various operator interfaces.

Applications

Table 1 shows the interest of users in the different operating modes.

Table 1.

User response on the reason for interest (or noninterest) in robotic applications.

	Automatic Mode		Manual Mode		ECS
	Reason	**No.**	**Reason**	**No.**	**No.**
Interest					
	Easy	24	Security	37	
	Fast	8	Autonomy	12	
	Autonomy	3	Accurate	10	
	Accurate	11	NA	14	
	NA	30			
Total		76		73	66
No Interest					14
	No viability	3	Complicated	10	
	Inaccurate	2	Too slow	2	
	Too slow	1	Dangerous	1	
	NA	9	NA	4	NA 11
Total		15		17	25

No. = Number; NA = No Answer.

Configuring and Programming

The configuration and programming phases rely upon the judgment of the occupational therapists. The configuration process was considered useful and very important with respect to the versatility of the system. The therapists asked that configuration of the safety zone be based upon the user's ability rather than having it be the same for every user. The therapists did not have a problem in configuring the ECS, and the programming language allowed them to write the necessary programs. However, while the task of establishing the trajectory points was readily mastered, the programming process was felt to be time consuming; therefore, improvements in that area are needed.

Failures

Figure 6 shows the failures observed during the evaluation period. It is noticeable that:

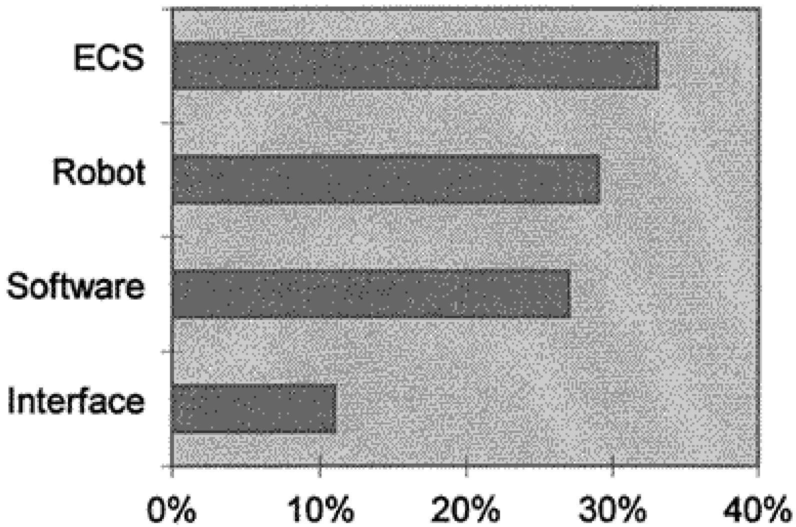

Figure 6.
Percentage of failures per subsystem.

1. the main failures occurred during the first year of evaluation in the programming phase, where the robot was seldom in operation.
2. the majority of the failures involved the ECS, reducing interest of the system, though without stopping the evaluation.
3. bugs in the MASTER software were encountered in the early phases and were corrected by implementing a new version after 6 months of operation.
4. several problems were due to the limitations imposed by using WINDOWS 3.1.
5. failures involving the robot itself (e.g., shifts in trajectories, motor failure, cable breakdown, circuit board failure, air compressor failures) often forced a halt to the evaluation.[es]

Conclusions

In conclusion, an increasing number of command interfaces are on the market for the user with disability. Therefore, it is essential that such a robotized system be integrated within the whole environment of the user. In other words, the range of command options must make the system available in all contexts. For example, the speech recognition unit should not be limited to MASTER software but should be compatible with other WINDOWS software. Similarly, the MASTER mouse software should be compatible with commercial office products. Moreover, the software has to be "open" with respect to other multimedia applications, so that it does not introduce computer incompatibilities. Finally, to be accepted, it is essential that such technical aids exhibit great reliability.

Clinical Results

User Features

The main characteristics of the users with disabilities are reported in **Table 2.** Automobile and sport accidents remained the main causes of the disabilities reported. The level of motor spinal injuries of the 91 users having participated in this study was C2 (4%), C3 (6%), C4 (18%), C5 (28%), C6 (24%), and C7-C8 (20%). The average time that the subjects have been disabled is 8.5 years, with values ranging from 0.5 years to 45.5 years. As for technical aids, 72 persons had an ECS, 66 a free-hand telephone, 43 a personal computer, and 8 a fax machine. Human assistance was required by every subject (48 percent were hospitalized) with individuals requiring an average of 8 hours assistance per day (the requirement ranged from 1 to 24 hours per day). Incomes of the subjects were chiefly from government subsidies, though only 14 persons were willing to give precise amounts. In general, the monthly income is about US$1460; nevertheless, large variations in income were observed.

Table 2.
Subject sample. **N = 91**

	No.

Age Groups	< 20	13
(Average = 32.7)	20-29	30
(NA = 1)	30-39	20
	40-49	16
	> 50	11
Sex	Male	65
	Female	26
Educational Level	Primary school	13
	Secondary school	53
	University	25
Activity	Employed	4
NA = 7	Students	21
	Unemployed	59
Living Situations	Married	23
NA = 4	Alone	33
	In the family	31
Location	Home	39
NA = 1	Specialized institution	7
	Hospital	44
Disabilities	Spinal injuries	50
	Muscular dystrophy	17
	Cerebral diseases*	11
	Brain trauma	7
	Spinal or cerebral trunk degeneration	6
Dependency	Dressing	90
	Toilet	90
	Taking meals	79
	Drinking	78
Mobility	Electric wheelchair	75
	Manual wheelchair	14
	Difficult walking	2
	Driving car	7
Communication	Normal speaking	86
	Voice synthesis	5
	Assistance with writing	72
Technical aids	ECS	72
	Hands-free telephone	66
	PC	43

No. = Number; NA = No answer; < = less than; > = greater than; * cerebral palsy, SEP, etc.

Evaluation Duration

Each workstation has been evaluated during one year and then removed to another site for one year. Each evaluation included a time for training and adapting the OI, the durations of which are reported in **Figure 4**; the evaluation time is reported in **Table 3.**

Table 3.

Evaluation duration.

Evaluation Duration	# of users	% of users
1 to 5 days	28	31
6 to 10 days	42	46
11 to 15 days	12	13
16 to 20 days	4	4
21 to 25 days	0	0
26 to 30 days	1	1
31 to 35 days	1	1
> 35 days	1	1
No answer	2	2

= Number; % = percentage; the average duration was 8.3 days, ignoring one evaluation center, which has evaluated the system with only one user during 180 days. SEP, etc.

Summary of the Results

There were no instances wherein the user with disability could not use the system.

Results of tasks evaluated by the 10 APPROCHE sites are reported in **Tables 4,5,** and **6.** Eighty-six percent of the subjects considered the training "easy." Seventy-five percent of the subjects considered access to the control station "well-designed," although 64 percent of the users felt that a second control station was necessary in order to separate the different functions (leisure, office, domestic), in order to have better visibility of each part of the station or to use the station in a recumbent position.

Table 4.

Evaluation of office tasks.

Office Task	No.[1]	PIR[2]	IEU[3]	SI[4]
Diskette insertion in the PC drive	88	2.85	3.63	3.56
Grasping a book	71	3.04	3.49	3.35
Grasping paper sheets	68	3.00	3.75	3.43
Setting a book on the reader board	65	3.25	3.60	3.55
CD ROM insertion in the driver	59	2.66	3.51	3.36
Turning paper sheet on the reader board	59	2.27	3.32	2.22
Throwing paper in a waste bin	57	2.84	3.65	3.51
Turning book pages	49	1.90	2.84	1.69
Setting and removing paper sheets in/from the printer	48	3.21	3.77	3.73
Grasping card from a box	32	2.90	3.50	3.25
Grasping a big sheet sorter	27	2.85	3.52	3.07
Stapling paper sheets	27	2.67	3.33	2.85
Setting paper sheets on a table	24	2.88	3.67	3.67
Grasping a pencil	17	2.24	3.59	3.41
Making photocopies	10	3.10	3.90	3.90
Filling the printer with paper sheets	10	2.50	3.50	3.30

Grasping an eraser	5	1.80	3.40	3.00
Grasping a paper clip	3	1.00	3.67	2.67

[1]Number of users that evaluated the task; [2]PIR = **P**riority **I**ndex to perform the task by **R**obot (quoted between 0 and 4); [3]IEU = Index of ease of use (quoted between 0 and 4); [4]SI = Satisfaction index (quoted between 0 and 4).

Table 5.

Evaluation of leisure tasks.

Leisure Task	**No.[1]**	**PIR[2]**	**IEU[3]**	**SI[4]**
Video tape insertion	64	3.03	3.67	3.56
Setting up a videotape recorder	54	3.89	3.61	3.67
Audio tape insertion	53	2.96	3.72	3.23
Grasping a book	50	3.26	3.52	3.32
Setting a book on the reader board	46	3.37	3.57	3.48
CD audio insertion	45	2.87	3.64	3.51
Grasping a magazine	38	3.24	3.63	3.47
Setting a magazine on the reader board	38	3.11	3.55	3.34
Setting up a tape recorder	36	2.89	3.61	3.58
Turning book pages	35	2.09	2.57	1.74
Setting up a radio by pressing buttons	26	3.07	3.78	3.81
Setting a remote control in action	21	2.38	3.62	3.52
Grasping a remote control	16	2.81	3.38	3.50
Nintendo tape insertion	13	1.85	3.54	3.38
Showing a CD	4	3.75	3.25	3.50
Showing a CD to somebody else	4	2.75	3.25	2.50
Setting up a television set	1	4.00	4.00	4.00
Turning magazine pages	1	4.00	4.00	4.00

[1]Number of users that evaluated the task; [2]PIR = **P**riority **I**ndex to perform the task by **R**obot (quoted between 0 and 4); [3]IEU = Index of ease of use (quoted between 0 and 4); [4]SI = Satisfaction index (quoted between 0 and 4).

Table 6.

Evaluation of domestic tasks.

Domestic Task	**No.[1]**	**PIR[2]**	**IEU[3]**	**SI[4]**
Using a glass	57	2.95	3.51	3.32
Pouring water from a thermos with a pump	45	2.71	3.11	3.16
Putting things in a waste bin	24	3.17	3.58	3.33
Pouring a drink from a standard bottle	22	3.32	3.82	3.14
Using a microwave oven	22	2.18	3.00	3.09
Taking a cookie	14	2.64	3.21	2.93
Lifting telephone receiver	11	3.00	3.09	3.45
Filling coffee, straw, sugar or milk	11	1.18	2.55	2.18
Taking drugs (pills)	9	2.33	3.00	3.11

Shaving	9	1.11	2.89	1.67
Brushing teeth	9	0.78	2.50	1.75
Serving a guest	5	3.80	3.80	3.80
Starting an electric coffee pot	5	3.60	3.40	3.60
Grasping a straw	5	3.20	3.40	3.60
Grasping a piece of chewing gum	5	3.00	3.40	3.20
Starting an electric fan	4	3.00	3.20	3.00
Using the phone	2	3.50	4.00	4.00
Using a refrigerator	1	4.00	4.00	4.00
Drinking with a straw/standard bottle	1	3.00	4.00	4.00
Turning on a lamp	1	0.00	4.00	0.00

[1]Number of users that evaluated the task; [2]PIR = **P**riority **I**ndex to perform the task by **R**obot (quoted between 0 and 4); [3]IEU = Index of ease of use (quoted between 0 and 4); [4]SI = Satisfaction index (quoted between 0 and 4).

With respect to the operating modes, 84 percent considered the automatic mode interesting, while 80 percent judged the manual mode necessary on security and autonomy grounds, but felt that in practice it was too slow and too complex. The environmental control system was much appreciated (73 percent). Other options gathered are: "aesthetic judgment is varied" (44 percent were appreciative, 16 percent did not like the system, and 40 percent had no opinion); 61 percent considered the system insufficiently reliable; 66 percent thought the organization of the station to be functional, but in general the visibility was considered poor. Estimations of the autonomy and time gain are reported in **Table 7,** and the usefulness is illustrated in **Figure 7.**

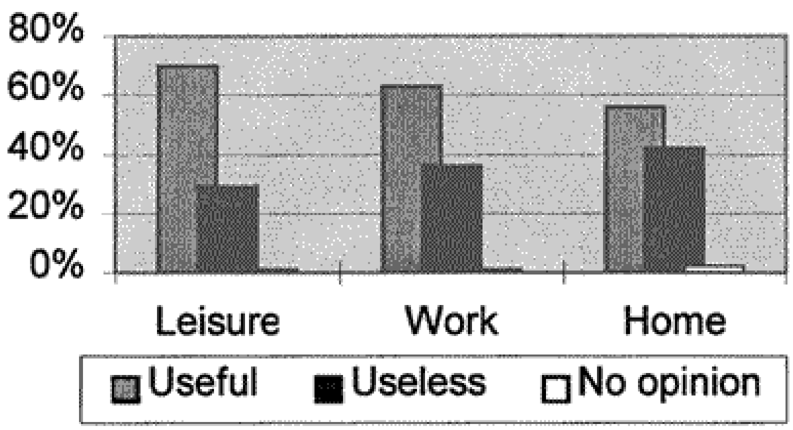

Figure 7.
Usefulness as rated by percentages of subjects.

DISCUSSION

Our experience has shown the system to be usable with every kind of functional tetraplegia, whatever its origin, and the objectives of the study have been shown to be realistic and achievable. The teaching and configuration processes are considered to be fast and easy and, though the execution speed remains lower than for an unimpaired person, this does not seem to be a major problem for the users with disabilities.

The robotized workstation requires a dedicated facility and future models should be made more compact and more reliable. Automatic tasks that can be selected by the user are the real benefit of such "tools." For example, turning pages is an essential requirement, but the present prototype needs to be improved with regard to its reliability. The safety aspects have been well-studied and employing the system for vocational purposes can be envisaged. From the therapist's point of view, robotics has become an established and necessary technical aid in compensating for deficiencies in the upper limbs. Nevertheless, human assistance remains essential, notably for dressing and nursing tasks. A commercial prototype is being developed by a French manufacturer in close collaboration with the CEA and APPROCHE.

CONCLUSION

The objective of robotics is not to take the place of attendants but to provide better autonomy. At the present time, the French Government only provides subsidies to guarantee employment of an attendant for 4 or 5 hours a day. Thus, a person with a disability stays alone for long periods of time; therefore, suitable technical aids can be justified on safety grounds. Furthermore, such aids can improve the mental and physical well-being of persons with tetraplegia without making them completely dependent upon nondisabled people. At the present time, there are no other ways to solve this fundamental problem of loneliness and freedom of decision. Robotics allow persons with disabilities to control their lives, and encourages their efforts to reenter society.

ACKNOWLEDGMENTS

The authors wish to thank the following APPROCHE partners for their indispensable contributions: André J.M (Pr), André P.F (OT), Bussel B. (Pr), Chopin I. (OT), De Barmont H.(OT), Desert J.F. (MD), Didier JP. (Pr), Galtier F. (MD), Joly H. (OT), Konopnicki S. (OT), Lee D. (OT), Mériadec F. (OT), Nadeau G. (MD), Olivier S. (OT), Prince A. (MD), Rémy-Néris O. (MD), Reynaud L. (OT), Tanguy E. (MD), Virey K. (OT).

For the production and evaluation of the four MASTER 1 prototypes, the CEA was aided by grants from Caisse Nationale d'Assurance Maladie des Travailleurs Salariés and Mutualité Française. APPROCHE has purchased and evaluated five units MASTER with the aid of grants from Association Française contre les Myopathies and Association pour la Gestion du Fonds d'Insertion Professionnelle des Personnes Handicapées. A station was purchased by CEA for its discussion with the rehabilitation centers.

REFERENCES

1. Van der Loos FM. VA/Stanford Rehabilitation Research and Development Program: lessons learned in the application of robotics technology to the field of rehabilitation. IEEE Trans Rehabil Eng 1995;3(1):46-55.
2. Hammel J. The role of assessment and evaluation in rehabilitation robotics : moving from concept to clinic to context. IEEE Trans Rehabil Eng 1995;3(1):56-61.
3. Van der Loos FM, Hammel J. Engineering reasonable accommodation: the delivery and use of assistive technology in a vocational training program. Technol Disabil 1996;5(3/4):371-82.
4. Guittet J, Kwee HH, Quetin N, Yclon J. The SPARTACUS telethesis: manipulator control studies. Bull Prosthet Res 1979;10-32(Fall):69-105.
5. Kwee HH, Tramblay M, Barbier R, et al. First experimentation of the SPARTACUS telethesis in a clinical environment. Paraplegia 1983;21:275-86.
6. Détriché JM, Lesigne B. The robotized system MASTER. Proceedings of the Third Japanese-French Biomedical Technology Symposium, Himeji Dokkyo University, Japan; 1989.
7. Busnel M, Morvan JB. Evaluations d'un système robotisé: le Robot Master1. Paris, CTNERHI; 1996.
8. Topping M, Smith J. The development of Handy1, a rehabilitation robotic system to assist the severely disabled. Industr Robot 1998;25(5):316-20.
9. Birch G. Cameron. User acceptability in robotic assistive devices. Proceedings of the ICORR'90 Conference; 1990. p. 83-94.
10. Dallaway JL, Jackson RD. Raid--a vocational robotic workstation. Proceedings of the 1992 International Conference on Rehabilitation Robotics. Keele University (England); 1992.
11. Cammoun R, Détriché JM; Lauture F; Lesigne B. RAID: une station de travail orientée bureautique pour les personnes handicapées. Proceedings of Les technologies de l'information dans le domaine de la santé: quels produits et services pour demain? Institut National des Télécommunications, Evry, France; 1994. p. 17-9.
12. Danielsson C, Holmberg L. Evaluation of the RAID workstation. Proceedings of the 17th annual RESNA conference, Nashville (USA); 1994. p. 451-3.
13. Cammoun R, Détriché JM, Lauture F, Lesigne B. Clinical evaluation of the MASTER robotized system. Definition of the new version. Robotica 1993;11:535-9.
14. Bolmsjo G; Eftring H. Raid robotic end-effector developments. 1st TIDE congress, Bruxelles, Belgique; 1993.

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