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Functional Evaluation of ASIBOT: a New Approach on Portable Robotic System for Disabled People

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In this work, an innovative robotic solution for human care and assistance is presented. Our main objective is to develop a new concept of portable robot able to support the elderly and those people with different levels of disability during the execution of daily tasks, such as washing their face or hands, brushing their teeth, combing their hair, eating, drinking, and bringing objects closer, among others. Our prototype, ASIBOT, is a five degrees of freedom (DOF) self-contained manipulator that includes the control system and electronic equipment on board. The main advantages of the robot are its light weight, about 11 kg for a 1.3m reach, its autonomy, and its ability to move between different points (docking stations) of the room or from the environment to a wheelchair and vice versa, which facilitates its supportive functions. The functional evaluation of ASIBOT is addressed in this paper. For this purpose the robotic arm is tested in different experiments with disabled people, gathering and discussing the results according to a methodology that allows us to assess users' satisfaction.

Keywords: Assistive robotics, portable robot, functional evaluation, rehabilitation engineering

1. Introduction

In the disability sector, there is a steady stream of new products that interact with the users in higher or lower degree in order to meet their everyday needs. During the last 15 years the rehabilitation technology has been evolving towards more flexible and adaptable robotic systems. These robots aim to assist the elderly and people with special needs in their homes. Nowadays, the rehabilitation robotics technology focuses on three main concepts:

- Static systems that operate in a structured environment.
- Wheelchair-mounted robotic systems for personal and care applications.
- Portable manipulators able to move to achieve their supportive functions.

The first type of robotic systems is very useful when the user needs help in the same living environment and for the same application, such as eating, drinking, washing, shaving, etc. These robots have very good mechanical stability and adaptability to the environment. The robotic arm HANDY 1 (Topping (2002)) is a good example of static robot system. It is a low cost solution for personal care and assistance. However, this kind of system has some important limitations:

- It cannot perform different tasks in different environments since it is not portable. For instance, to shave in the bathroom would be difficult if the robot must be carried upstairs each time and then back downstairs for eating.

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- It occupies considerable floor space.
- It has limited manoeuvrability and dexterity due the robot's static base positioning.

Other types of rehabilitation robots are those mounted on a wheelchair. The current market leader of this type is the MANUS system (Kwee (1997)). This robot is used by the disabled in some structured environments to maintain independence in some tasks such as pouring a drink, drinking, meal preparation, and washing. However, its stability on the wheelchair should be carefully studied and controlled. Moreover, the arm is permanently fixed on either the left- or right-hand side of the wheelchair.

A competitor of MANUS is the robot RAPTOR (Mahoney (2001)), developed by the Rehabilitation Technologies Division of Applied Resources Corporation (Phybotics (2010)) and aproved by the American Agency for Health. RAPTOR is simpler than MANUS, with only 4 DOF plus the gripper and with a simpler interface, which makes it cheaper.

The third concept in rehabilitation robotics is a portable robot able to move independently of the wheelchair or the user, with the possibility to switch between the environment and the wheelchair. KARES II robot (Song et al. (1998)) is an example of this type. Its main tasks are serving a meal and beverage, picking up an object from the floor, shaving, wiping a face with a wet towel, and turning a switch on and off, among others.

A further step in this line is ASIBOT, a portable light weight robotic arm totally developed by the research team Robotics Lab in the University Carlos III of Madrid. Thanks to its ability to autonomously switch between the wheelchair and the walls of the rooms where the tasks take place, it can extend the human abilities in a wide range of domestic tasks: housekeeping, assistance, entertainment, etc.

In this paper, we focus on the performance of ASIBOT when dealing with people with different levels of disabilities, mainly disabled people with spinal cord injuries. The assessment of the robot (Balaguer et al. (2006); Jardón et al. (2006)) is carried out for the following tasks: drinking, brushing one's teeth, and washing one's face.

The rest of the paper is organized as follows. Section 3 introduces the robotic arm ASIBOT. Section 3 describes the characteristics of the users and their degree of disability. Section 4 presents the experimental procedures followed to assess the robot during operation. In Section 5 the experimental results obtained are discussed. And finally, Section 7 concludes with some conclusions and future works.

2. Description of ASIBOT

The robotic system ASIBOT (Figure 1), described in Balaguer et al. (2006), Jardón et al. (2006), Balaguer et al. (2007), Jardón et al. (2008a), is a prototype totally developed by the research team RoboticsLab in the University Carlos III of Madrid. It is a significant advance in service robots (Balaguer et al. (2005), Giménez et al. (2005), Jardón (2006)), with 5 DOF and divided into two parts: the tips, that have a docking mechanism to connect the robot to the wall or a wheelchair, and the gripper. The body has two links that contain the electronic equipment and the control unit of the arm. It is important to note that the robot is symmetric, being possible to fix the arm by any of its ends. It is made by aluminium and carbon fiber and it has DC motors as actuators, with Harmonic-Drive gears. The range and position of the different joints are shown in Figure 2.

The power supply is taken from the connector that is placed in the center of the docking station in the wall or the wheelchair. All the electromechanical and

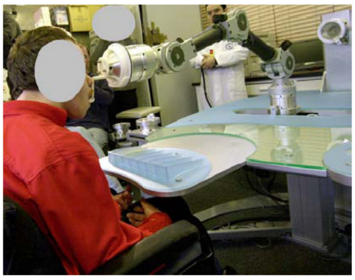

Figure 1. Robot image in feeding operation

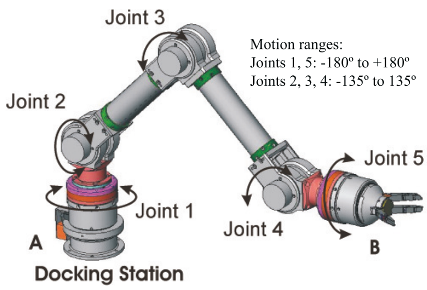

Figure 2. ASIBOT kinematics

electronic equipments are on board: amplifiers, encoders, the axis control board, and the main CPU in order to communicate with the user of the arm.

ASIBOT has a modular design able to work in a wide variety of settings with a high range of autonomy and mobility, since it can move along the walls, the furniture, or other surfaces with accuracy and reliability via connectors located along the route the robotic arm moves along (Figure 3). Once one of its ends connects one connector, the other end disconnects and gets free to support the

Figure 3. ASIBOT connected in both tips' connectors

patient. This modular design allows us to readapt the system to the resulting functional demands and to variations in the patient's conditions (Balaguer et al. (2006), Jardón et al. (2006)).

In addition to its mobility, the fact that it is anchored to a single point allows it to manipulate tools attached to its free end, which has actuators controlled by the system and/or the user (Cabas et al. (2005), Cabas et al. (2006)). This is of great interest for people with motor disabilities in their upper extremities, since it allows them to bring objects closer and pick up and move utensils for everyday activities to a nearer working area (Jardón et al. (2008b)). It is important to remark that all the operations are carried out in safety conditions, since the final contact with the robot or the utensils is performed at the user's command.

ASIBOT's end must achieve mechanical fixing in the docking station and electrical contact for power supply. Besides, it must allow connecting a wide variety of end-effectors or tools to accomplish different tasks. A preliminary design consisting of a retractile three-finger gripper (Cabas et al. (2006)) has been successfully developed (see Figure 2), though it is expensive and complex. This is the reason why we are currently working on the design of a multifunctional end-effector that allows the user to perform different tasks limitating the number of tools involved, reducing this way the space requirements and the cost of the system. Meanwhile, a huge set of low-cost tools (spoons, brushes, etc) has been developed by rapid prototyping techniques to be able to proceed with verification tests with severely motion impaired people who could be aided using the robot and its adapted tools (manually adapted so far). The location of the tool holders must be studied for each robot application environment (kitchen, bathroom, etc.) and this is another study being currently addressed by the RoboticsLab team.

ASIBOT needs to operate close, and also in contact, with humans - more than any other kind of robot. Its design must follow different requirements than those for conventional industrial applications: safety is first and foremost. ASIBOT has been conceived as a fail-safe system, one that intrinsically cannot cause harm on failure. A change to brushless motors eases automatic breaking on electrical failure. Besides, as a light-weight manipulator, motor inertia causes much less damage than those heavy ones with strong reductions.

Besides, we are working on a new concept called Cognitive Safety, for which a cognitive system is integrated in ASIBOT so that the arm can safely adapt to specific users through learning techniques (user modeling is involved). Apart from these learning procedures, sensor integration is a fundamental issue when it comes to cognitive safety. A sensorial network will be defined and set, including on-board and environment sensors of different types. Thanks to this sensorial integration, the robot perception can be flexibly integrated with its own actions and the understanding of planned actions of users in a shared workspace. Therefore, the cognitive safety will be supported by the sensorial network at low level and the user model and task execution awareness at a higher level.

In sum, ASIBOT has an innovative design with all the functionalities to assist the disabled people described next, who participate in the experiments for the robot assessment.

3. Description of the users

The case study presented in this work considers six patients from the Spinal Cord Injury National Hospital of Toledo, Spain, who meet the following characteristics:

- They are disabled patients with spinal cord injuries.
- They had suffered spinal cord injuries for a period of time longer that one year before the tests were carried out.
- They are affected at neurological levels from C3 (more serious injury) to C8 (less serious injury), which implies that they have mobility limitations in their upper extremities in the ranges specifies in Figure 4, where frontal, back and lateral parts of the body affected by each lesion are remarked.
- They had spent regular periods of time in their homes before the tests, which gave them a perception of the main difficulties found in their daily activities. Based on their experience in facing numerous dependency problems, they are able to evaluate the functionality of technical aids from a more objective point of view.

No cases with acute injuries are considered. Other exclusion criteria are: epilepsy, mental retardation, uncorrected visual deficiency, or psychiatric problems. We cannot forget that ASIBOT is a prototype to assist patients in specific tasks (not to replace them), but it is the patient who governs the performance of the robot during operation. For this reason, the user must have all the faculties to do so (control and react). That is why these exclusion criteria have been considered.

4. Experimental procedures

The methodology followed to assess ASIBOT is based on gathering information in a structured format from the interactions of selected users with the robot. A testing procedure has been created specifying different settings and tasks to be carried out. The information is gathered from each of the users who interact with the technical aid. That information is then analysed. Finally, the results are discussed in order to use them as the base for the design of a new prototype that fulfils the needs and expectations of the users.

4.1. Information gathering methodology

In order to develop a methodology to assess the user's perception and satisfaction when using ASIBOT as an assistance technical aid, a strong revision of the most

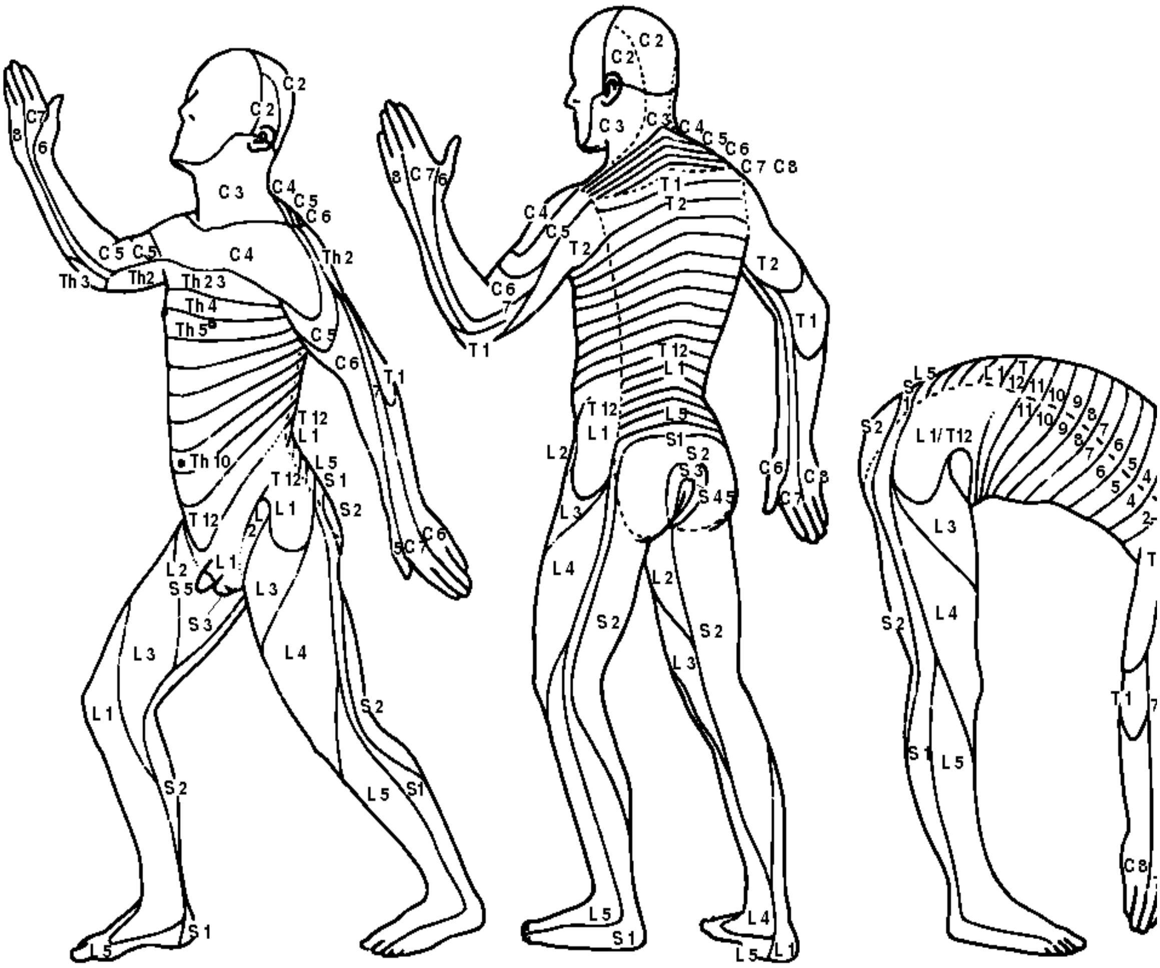

Figure 4. Levels of spinal cord injury. In our case, patients with spinal cord injuries from C3 (more serious) to C8 (less serious) are considered.

relevant bibliography related to this subject has been carried out (Jutai et al. (2005), Demers et al. (1996)).

Our design approach in this line aims the introduction of the usability concept for specific situations, that is, according to the specific user's characteristics and needs. This way, the methodology to evaluate the product must provide information about each individual user by means of consecutive interactions with them, allowing the patients to benefit directly from the assistance and information gathered in their presence (Demers et al. (1999), Demers et al. (2000)).

For this reason, and taking into account the lack of procedures for the assessment of user's perception and satisfaction, our design is based on the following techniques: "Usability tests" (Page et al. (2001), Nielsen (2000)) and the application of evaluation criteria as defined in what is known as "The KIU Test" (Rubin (1994)).

The main goals of these techniques refer to identifying the most frequent problems; detecting errors, needs, or requirements; generating design criteria and final user requirements; as well as a global usability assessment of the product, which allows us to identify which aspects need to be modified in the new design. However, the main deficiencies in usability deal with the following criteria: ease of learning how to use it, utility, functionality, ease of use, and user's satisfaction (Smith (1996), Batavia et al. (1990), Lenkert et al. (2003)).

These deficiencies have been considered in the design of our own questionnaire. The validity of the data and understanding of the questions are verified previously. The questions are analysed to make sure that they fulfil our objectives. Besides, the total time to complete the questionnaire is not more than 30 minutes, in order to prevent fatigue or distraction. Questions that evoke negative stimuli to the user are eliminated and explanations on how to fill in the questionnaire are included.

The questionnaire for the experiments has four parts:

- A first part with seven closed questions, with answers given on a Likert summative five point satisfaction scale (from +2 to -2) and focused on an assessment of the functions or activities suggested for the robot to perform during the tests.
- The second part consists of questions in the former format focused on the assessment of eight general characteristics of the robot: appearance, dimensions, usability, speed of response, safety, robustness, multi-use functionality, prior training.
- In the third part, three open questions are proposed about the use of the prototype, its utility, and assistance needs of each patient.
- Finally, a general assessment of the technical aid is done through two specific questions with answers in an ordinal scale format from 0 to 10 points.

The tests have been held in a hospital context, carried out in a suitable scenario to accomplish the studied activities. The facilities at the hospital's Occupational Therapy Unit have been used to partially simulate a daily home environment.

4.2. Experiment procedure

Prior to the experiments in real settings with ASIBOT, a pilot test is done to assess the different ways of interacting with the Human-Machine Interface (HMI), implemented in a PDA in our case. In the shape of large visual-tactile buttons, the different functions to be performed by the robot can be activated through the following modes, ranked from the greatest to the smallest mobility requirements (Figure 5):

- Tactile, via user's touch or a pencil.
- Joystick, to choose the functions with a button to validate them.
- Voice recognition, with different options for selection and activation by voice.
- Single switch and scanning interface: a sequence of options is lighted and different choices for the options can selected.

In this pilot test, a questionnaire similar to the one proposed to assess the use of the robot has to be completed. The users are asked about each of the interfaces and their ease of use, practicality, how appropriate each interface is given their capabilities, and the ability to handle them without any help. Finally, two open questions encourage users to give any suggestions or ideas for making control simpler.

After this pilot test, experiments with the robot in real scenarios have to be performed. In order to do so, the users are previously asked their a priori opinion about the situations, activities, or tasks where they think robot assistance would be helpful. In order of importance, they rank those situations where they need personal assistance. According to that information, the environment is set to assess the functionality of the robot in those adverse conditions described by the users.

5. Experimental Results

The experiment procedure has three main parts:

Figure 5. PDA screen details and access-granted devices

- First stage: Assessment of interfaces and first contact with the robot.
- Second stage: Handling the robot in a scenario.
- Third stage: Gathered data analysis.

The complete procedure and the experimental results are discussed next.

5.1. First stage: Assessment of interfaces and first contact with the robot

As commented previously, our case study considers six users who meet the inclusion criteria described in the Description of users section in this paper.

In this first stage, the HMI assessment of the robot is done, as described in the Experiment procedure section. After evaluating the different interfaces offered, the following conclusions are drawn from the users' answers:

- Except for one person, they all are capable of HANDLING ON THEIR OWN the different interfaces offered: voice recognition (with different options), joystick, tactile, and lighted sequence with a selection button.
- Regarding EASE OF USE, their selection in order of preference is: tactile, voice recognition, joystick, and lighted sequence.
- The most PRACTICAL interface turns out to be the tactile one, followed by voice and joystick with the same score and finally, the lighted sequence.
- The interfaces based on VOICE recognition and JOYSTICK are preferred by the users regarding APPROPRIATENESS of the interface given their MOVEMENT ABILITIES.

After this first face-to-face session with the users, information is obtained via a questionnaire in order to focus the subsequent real experiments with the robot on the most frequently demanded activities.

In one of the first questions about their main demands for independence, the users state which activities they find more unpleasant and they would like to be able to do without depending on another person, independently of the capability of the robot to accomplish these tasks. Getting dressed and washing themselves, in that order, were mentioned by the great majority of the users.

They are also asked to rate (in order of importance) four settings or situations proposed where using the robot would be more helpful. The results in order of importance are the following ones:

(1) Daily hygiene: washing their face and hands, brushing their teeth, combing their hair, shaving, or using make-up.
(2) Lying in bed.
(3) In the wheelchair: eating, drinking, bringing objects closer, etc.
(4) In the kitchen: opening cupboard doors, moving utensils, etc.

The results show that personal hygiene functions are the most appropriate to test the robot's performance and assess the user's perception more reliably. For this reason, the final assessment is going to be carried out in a bathroom scenario (Figure 6(a) and Figure 6(b). The assessment of available resources for the experiments also leads to our decision to use the bathroom facing the mirror, given the chances it offers to assess a larger number of basic functions in everyday life. We propose three functions to test in this setting: drinking a glass of water, brushing one's teeth, and washing one's face.

5.2. Second stage: Handling the robot in a bathroom scenario

For the final experiment, the group selected is composed by four of the six users from the previous stage plus one new user who meets all the inclusion criteria although he was absent during the pilot test. Therefore, the total number of users for this step is five. They are all male and represent each cervical level of injury from C3 to C8. The functions of drinking a glass of water, brushing their teeth, and washing their faces with a sponge are assessed.

Prior to handle these three situations with the real robot, the users have a first contact with it and have time to learn how it works and how their interaction with the robot will be performed. It is important to remark that the human factor is trivial in all this procedure and we must ensure that the users are receptive to the experiment from the very beginning.

After the experiments, and for each of the functions, the patients are first asked seven questions regarding the robot's performance during the activities. They are instructed (Figure 7) to assign a response scored on a Likert satisfaction scale from -2 to +2, where +2 is "completely satisfied", +1 is "satisfied", 0 is "not sure", -1 is "dissatisfied", and -2 is "completely dissatisfied". This satisfaction scale has been considered for this evaluation according to the detailed study presented in the Handbook of Usability Testing (Rubin (1994)), which shows that the Likert satisfaction scale is one of the most common scaled-response format questions in survey design and improve the levels of measurement in social research through the use of standardized response categories in survey questionnaires.

The global results of each function are shown in Tables 1, 2, and 3, respectively. The most relevant data of each of the three functions are discussed next:

- For the DRINKING function, the average score is 0.91. A score of 1 would mean "satisfied" and 0 would mean "not sure". Therefore, the use of the robot for this

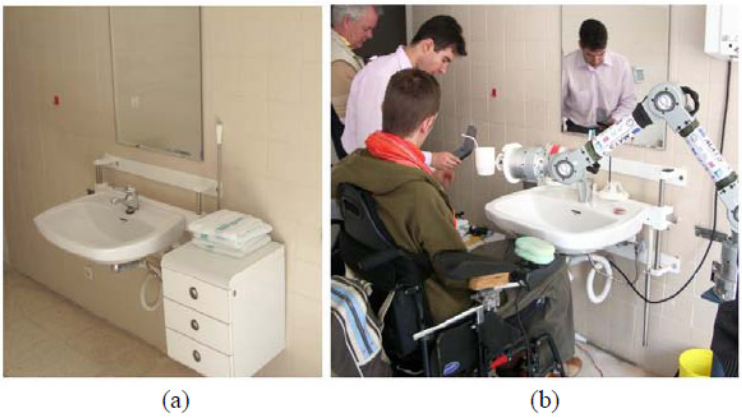

Figure 6. Bathroom scenario: before adaptation (a) and after adaptation (b)

Table 1. Drinking function assessment.

Level of Injury	$C3-C4$	$C4$	$C5-C6$	$C6$	$C7-C8$	$Totalscore$	$Average$
Helpful for user's autonomy	1	1	2	1	-1	4	0.8
Practical and useful	1	1	2	2	0	6	1.2
Additional need of support while using the robot	-1	0	1	1	-1	0	0
Independency	1	1	2	2	1	7	1.4
Physical effort	2	1	2	2	0	7	1.4
Success	1	0	2	2	-1	4	0.8
Motivation	1	1	2	1	-1	4	0.8
Total score	6	5	13	11	-3	32	
Average	0.86	0.71	1.86	1.57	-0.43	0.91	0.91

function can be defined as CORRECT (Table 1).

- For the BRUSHING ONE'S TEETH function, the average score is 0.49. According to the above criteria, the use of the robot for this function can be also defined as CORRECT (Table 2).
- For the WASHING ONE'S FACE function, only two users give a response. The average score is -0.86. A score of -1 would mean "dissatisfied" and 0 would mean "not sure". Therefore, the use of the robot for this function CAN BE IMPROVED (Table 3). However, the reliability of this result is conditional on the fact that only a small sample of the group participates in the test.

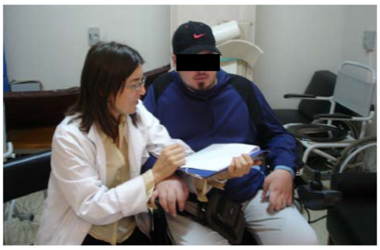

Figure 7. Occupational therapist gathering user's perception

Table 2. Brushing one's teeth function assessment.

Level of Injury	$C3-C4$	$C4$	$C5-C6$	$C6$	$C7-C8$	$Totalscore$	$Average$
Helpful for user's autonomy	1	1	1	1	-1	3	0.6
Practical and useful	1	1	0	1	-1	2	0.4
Additional need of support while using the robot	-1	0	-1	1	1	0	0
Independency	1	0	0	2	0	3	0.6
Physical effort	2	1	0	2	0	5	1
Success	0	-1	-1	1	1	0	0
Motivation	1	1	-1	1	2	4	0.8
Total score	5	3	-2	9	2	17	
Average	0.71	0.43	-0.29	1.29	0.29	0.49	0.49

Table 3. Washing one's face function assessment.

Level of Injury	$C5-C6$	$C7-C8$	$Totalscore$	$Average$
Helpful for user's autonomy	-1	0	-1	-0.5
Practical and useful	-1	0	-1	-0.5
Additional need of support while using the robot	-2	1	-1	-0.5
Independency	-2	0	-2	-1
Physical effort	0	0	0	0
Success	-2	-1	-3	-1.5
Motivation	-2	-2	-4	-2
Total score	-10	-2	-12	
Average	-1.43	-0.29	-0.86	-0.86

From these results, we can conclude that the users' perception is that the robot performs the functions of drinking and brushing their teeth properly. However, its performance when washing their face should be improved.

In a second step, the robot characteristics are evaluated by the users, expressing their opinion with the same range of satisfaction scores, from -2 to +2. The best results are for its robustness (averaged 1), its multi-use functionality (averaged 1), and its speed of response (averaged 0.8). Lower scores are given to its dimensions and appearance, averaged -0.8 and -0.2, respectively (Table 4).

In a third step, three open questions are made:

Table 4. ASIBOT's characteristics assessment.

Level of Injury	$C3-C4$	$C4$	$C5-C6$	$C6$	$C7-C8$	$Totalscore$	$Average$
Appearance	-1	-1	0	1	0	-1	-0.2
Dimensions	-1	-1	-2	1	-1	-4	-0.8
Usability	1	-1	2	1	-2	1	0.2
Speed of response	1	1	-1	2	1	4	0.8
Safety	0	0	1	2	-1	2	0.4
Robustness	2	1	1	2	-1	5	1
Multi-use functionality	1	2	1	2	-1	5	1
Training	2	2	0	0	-1	3	0.6
Total score	5	3	2	11	-6	15	3
Average	0.63	0.38	0.25	1.38	-0.75	0.38	0.38

Table 5. Overall assessment.

Level of Injury	$C3-C4$	$C4$	$C5-C6$	$C6$	$C7-C8$	$Totalscore$	$Averageoffirstfourusers$
Independence provided by the robot in everyday life	8	6	5	6	0	5	6.25
Replacing their carer with the robot	9	6	8	6	0	5.8	7.25

- First of all, users are asked what changes they suggest in order to make the robot more useful. The most common suggestions are: a smaller size, voice recognition, the possibility of including additional tasks adding other terminal devices, and more safety conditions as far as the stopping function of the robot is concerned.
- Additional tasks for this robot that might be useful for the users are: cleaning the house, cooking, making or unmaking the bed, folding sheets, dressing, shaving, tasks requiring accuracy, combing their hair, cutting their nails, picking up glasses, opening windows, and opening doors.
- Finally, they are asked again to rank the most unpleasant tasks they would like to be able to do on their own and not depending on someone else, regardless of the capability of the robot to perform such tasks. The personal hygiene tasks stand out against moving around, dressing, and picking up or reaching objects.

Finally, regarding the overall assessment of the robot after its use, they are asked two questions: one concerning the independence the robot could provide and the other one about replacing their carer with the robot, freeing that person from doing the work. The average scores in response to these matters are commented next (Table 5):

- They would attain greater independence in their everyday lives: an average of 5 out of 10.
- They would be interested in freeing their carer or relative from having to perform these tasks to help them: 5.8 out of 10.

One patient has scored both items with 0 because his injury level, C7-C8, is less serious and he has an acceptable amount of mobility in his upper extremities. It is more efficient for him to do those functions by himself than with the robot's support. This fact has brought the average scores down quite a bit. Considering only the other four users, the averages would be 6.25 and 7.25 out of 10, respectively. Anyway, the score is above 5, which can be considered to be a positive result in the overall assessment.

5.3. Third stage: Gathered data analysis

Once the first and second stages are completed and all the data regarding users' perception through the experiment are gathered, the researchers are ready to discuss the results and do the final assessment of the whole procedure, establishing the relations between the level of injury and the final score for each function. The gathered data analysis will be used for the improvement of the prototype and to establish new research lines to achieve the user's requirements.

Our current research work is focusing on the improvement of ASIBOT in aspects such as its portability, its functionality to be used for new ways of human-robot collaboration, and the development of an embodied cognitive intelligent system with learning capabilities, among others.

6. Discussion of Results

The evaluation of outcomes in assistive technology is perhaps one of the greatest challenges for rehabilitation practitioners, researchers, engineers, and suppliers of technical aids (Batavia et al. (1990), Lenkert et al. (2003)). Like any product used regularly, technical aids must satisfy users' expectations regarding the functions they hope to perform. In the case of products designed for the field of disabled people, this requirement becomes even more important, considering the fact that the functions to be performed are generally essential for personal autonomy (Simon et al. (1997), Carr-Hill (1992), Demers et al. (2002), Parker et al. (1991)).

Due to a lack of theoretical knowledge, the satisfaction determiners are vague in the field of assistive technology. The relations between the variables involved in the experience of satisfaction and the assistive technology are generally represented within a linear general framework, inspired by Simon and Patrick (Simon et al. (1997)). The Quebec User Evaluation of Satisfaction with assistive Technology (QUEST) (Demers et al. (1996)) is also a pioneer scale for satisfaction measurement. It is considered as the most relevant tool in functional assessment for assistive technology. It covers both the device and the service components of assistive technology (Demers et al. (2000), Demers et al. (2002)).

Although we agree that this instrument is quite useful, we have decided to develop our own questionnaire because QUEST considers many aspects that cannot be taken into account when prototypes which are not in the market are considered. Another problem is the fact that a proposal of modifications is required to improve the functional aspects of the current prototype to develop a new improved one. Therefore, the device must be assessed in specific scenarios and regarding some functional characteristics.

Our assessment methodology is based on the QUEST test with some specific and local changes to adapt the questionnaire to our population and product. The designed questionnaire is similar to QUEST regarding device aspects such as usefulness, training, robustness, safety, dimensions, simplicity of use, appearance, and effort of installation. However, we could not be asked about service components for the prototype considered. Besides, we must have in mind that we are required to assess and to facilitate the robot improvement.

Another difference from QUEST is that a previous study is performed to obtain information to develop the final experiment according to users' needs expressed previously. In this pilot test information about each robot's interface is received, its ease of use, and which the best scenario is to carry out the experience. Following the users' priority, the scenario selected in our case is the bathroom.

In this line, the originality of our methodology lies in the interactivity and user-directed approach to assess satisfaction with assistive technology. With this approach, it is the user who determines the degree of importance of the variables that represent those factors more likely to influence the usability and the aspects to take into account to modify an existent prototype (Demers et al. (1996)).

Three different functions have been tested in the bathroom scenario set in the hospital context: drinking a glass of water, brushing one's teeth, and washing one's face. From the experimental results obtained, we can conclude that the use of the prototype is correct for the functions of drinking a glass of water and brushing ones teeth. Its use for washing ones face with a sponge should be improved. Only two users agreed to test this last function, which may justify the low score obtained.

In relation to the device characteristics, the best results are for its robustness, its multi-use functionality, and its speed of response. Lower scores are obtained for its dimensions and appearance. Although these results are good in average, some suggestions of the users to make the robot more useful focus on a smaller size of the prototype, the improvement of its mobility, voice recognition, the possibility of including additional tasks adding other terminal devices, and more safety conditions as far as the stopping function of the robot is concerned.

In relation to the overall assessment of the robot after its use, the patients have been asked two questions: one concerning the independence the robot could provide and the other one about replacing their career with the robot, freeing that person from doing the work. For the first question the average is 5 out of 10 and for the second one is 5.8.

One patient has scored both items with 0 because his injury level, C7-C8, is less serious and he has an acceptable amount of mobility in his upper extremities. It is more efficient for him to do those functions by himself than with the robot's support. This fact has brought the average scores down quite a bit. Considering only the other four users, the averages would be 6.25 and 7.25 out of 10, respectively. Anyway, the score is above 5, which can be considered to be a positive result in the overall assessment.

We have also found a relation between the level of injury and the final score. For users with lower levels of injury, C7-C8, the results are worse. It is due to the fact that their upper limb functional situation is better and they do not need such a sophisticated device to assist them. However, for users with greater mobility problems, the scores are higher, since they really take advantage of the robot assistance to support their daily activities.

There are other tests and results in literature in relation to specific population such as geriatric patients (Parker et al. (1991)) or those with rheumatic disease (Rogers et al. (1992)). Our case study is specifically directed to spinal cord injury population.

Considering devices themselves, it is possible to find some research about functional assessment for wheelchair users. Different tools to assess wheelchair functional behaviours have been described (Stanley et al. (2003), Kirby et al. (2002)). In the same line, our experience reported here takes into account a specific device for a specific population with different spinal cord injury levels.

Although a similar experience is reported by Rumau et al. (Rumeau et al. (2006)) regarding a priori evaluation of the acceptance of an activity monitoring device for disabled elderly, only professional carer are asked instead of users.

It is necessary to state that our experience aims to give response to a specific problem involving disabled people and researchers who are far from the users and their environments. That can justify some limitations in the scientific methodology, in spite of the efforts to take all the practical aspects into account. However, we consider this experience very interesting and of great utility for all the parts involved in this research: the users, the ASIBOT team, and the clinical team.

7. Conclusions

According to the results presented in this paper, in general terms we can say that the users' degree of satisfaction when using ASIBOT as a technical aid is quite high. The robot overall assessment shows good results and the users conclude that it provides independence in their daily tasks to an extent that they would replace their carer with the prototype.

However, from the discussion of the results it is also clear that ASIBOT must be improved in specific key aspects according to users' expectations: the size of the prototype must be reduced, its mobility must be improved, voice recognition should be integrated as well as more end-effectors to allow the users to perform a wide variety of tasks, and safety requirements are also to be extended.

Our efforts are currently running in these directions. An study on ASIBOT's kinematics improvements is being done to achieve the mobility requirements necessary for the specific tasks to be performed with the disabled users with the minimum size requirement. The design of multifunctional end-effectors is being also addressed in order to allow the user to perform different tasks limitating the number of tools involved, reducing this way the space requirements and the cost of the system. And regarding safety, we are working on a new concept called Cognitive Safety, for which a cognitive system is integrated in ASIBOT so that the arm can safely adapt to specific users through learning techniques (user modeling is involved). Apart from these learning procedures, sensor integration is a fundamental issue when it comes to cognitive safety. A sensorial network will be defined and set, including on-board and environment sensors of different types. Thanks to this sensorial integration, the robot perception can be flexibly integrated with its own actions and the understanding of planned actions of users in a shared workspace. Therefore, the cognitive safety will be supported by the sensorial network at low level and the user model and task execution awareness at a higher level.

All these issues will be presented in detail in a future paper the authors are working on.

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