Making Assistive Technology and Rehabilitation Engineering a Sure Bet

Usability of a joystick-controlled six degree-of-freedom robotic manipulator

François Routhier1, PEng, PhD, and Philippe S. Archambault2,3, OT (C), PhD
[1]Center for Interdisciplinary Research in Rehabilitation and Social Integration (CIRRIS), Institut de réadaptation en déficience physique de Québec, Québec, Canada; [2]School of Physical & Occupational Therapy, McGill University, Montreal, Canada; [3]Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), Jewish Rehabilitation Hospital, Laval, Canada.

ABSTRACT
Control and usage of the upper extremities is fundamental to the accomplishment of many activities of daily living. There exists a significant amount of assistive devices that can compensate for upper extremity disabilities. Robotics may provide a better approach for the development of assistive devices, by allowing more functionality. In this paper, we present preliminary results on the usability of a new joystick-controlled six-degree of freedom robotic manipulator, in terms of accomplishing specific motor tasks performed with the upper limb. Our findings show that the participants were generally able to successfully accomplish the six testing tasks on their first attempt. Moreover, they globally identified these tasks as easy to perform and of a relative importance for their daily lives.

KEYWORDS
Robotic device, upper limb, physical disability, grasping, assistive device

BACKGROUND
Proper control and usage of the upper extremities is fundamental to the natural accomplishment of many activities of daily living (ADL), such as feeding, self-care and leisure. Mobility of the hand and arms, and the ability to manipulate and move objects, are important components of activity and participation. Impairments in upper extremity movements may often have a detrimental effect on ADL (1-3). In addition, the same individuals may often be wheelchair bound, which may cause additional difficulties in terms of upper extremity activities due to environmental barriers (1,4,5). Because of the presence of obstacles such as furniture, and of the restricted position in the wheelchair, reaching for objects can become increasingly difficult.

There exists a significant amount of assistive devices that can compensate for a loss of mobility in the upper extremities. However, these existing assistive devices may be limited in terms of functionality. Most assistive devices are only designed to accomplish specific tasks. Simple tools

include “reachers” (6) and mobile arm support systems (3,7) but their the efficacy for upper extremity function has not been demonstrated (1,3).

Robotics may provide a better approach for the development of assistive devices, by allowing more functionality. These include robotic manipulators that can be controlled through a joystick and that are fixed to the user’s wheelchair. A survey of 200 potential users identified the perceived requirements of such robotic devices. These included ease of use, reliability, cost and ability to perform various ADL functions such as reaching for objects, eating, self-care and leisure (8). Because scientific literature is very limited regarding their impact, new investigations need to be conducted. A Canadian company, Kinova, had recently commercialized a new robotic manipulator. This robotic device, named JACO (see www.kinovarehab.com), has not been evaluated yet.

OBJECTIVES

The long-term objective of the project is to demonstrate that JACO is a relevant and efficient alternative for increasing the autonomy of individuals with upper extremity disabilities. In this paper, we present preliminary results on the usability of JACO in terms of accomplishing specific motor tasks performed with the upper limb.

DESCRIPTION OF THE ROBOTIC ARM

The JACO manipulator is a light-weight (3kg) wheelchair-mounted robotic device which was designed to compensate for upper limb impairments. JACO fits entirely under the armrest and does not extend the width of the wheelchair. It is composed of six inter-linked segments, the last of which is a three-fingered hand (see Figure 1). Through the joystick controller, the user can move the robot’s hand in three-dimensional space (first mode of control), while the robot maintains the orientation of the hand. In a second mode of control, the user can modify the orientation of the hand, while keeping the hand centered at the same point in space. Finally, the user can control opening and closing of the hand, with two or three fingers (third mode of control). A button on the joystick is used to switch between modes of control. JACO can reach approximately 1 m in all directions and can lift objects of up to 2.5kg.

Figure 1: JACO joystick-controlled six degree-of-freedom robotic manipulator

METHODS

A convenience sample of 27 participants was recruited at the Institut de réadaptation en déficience physique de Québec (Québec, Canada) and the Centre de réadaptation Constance-Lethbridge (Montréal, Canada) between July 2009 and January 2010. Clinicians of those two rehabilitations centres were asked to identify potential participants in their clients who met the following inclusion and exclusion criteria: 1) being between 18 and 64 years old; 2) being able to understand verbal instructions in French or English; 3) using a powered wheelchair with standard joystick; 3) being capable of pressing the command buttons of the robotic arm JACO; and 4) having no cognitive or memory impairment.

The JACO arm was fixed on a table in front of the participant, approximately in line with the wheelchair's armrest on the non-dominant side (e.g., opposite to the wheelchair's joystick). The joystick to control the JACO manipulator was positioned on the wheelchair's armrest on the participant's dominant side (e.g., in front of the wheelchair's joystick). Participants had to accomplish a series of 6 tasks with the JACO manipulator: 1) Grasping a bottle, located on the left side, on the table; 2) Grasping a bottle located on the right, on a surface near the ground and bringing it on the table; 3) Pushing the buttons of a calculator; 4) Taking a tissue from a box on the table; 5) Taking a straw in a glass on the table; and 6) Pouring water from a bottle in a glass. Participants had to succeed at each task twice. The number of trials necessary for them to succeed was recorded. Participants were also assessed for perceived easiness ("how easy did you find the task?") and importance of performing ("how important is it to perform this task?") each of the tasks, using a 4-point scale (Absolutely, A lot, Not very much and None). A socio-demographic questionnaire was also administered.

Prior to the testing procedure, the participants had a short time (~10-15 minutes) to practice basic operation of the JACO arm and to explore each possible movement of the robotic device: 1) touching targets located left, right, up and down; 2) rotating the hand; 3) pushing objects; 4) activating the grasp function; and 5) placing the arm in its retracted position.

Descriptive statistics have been used to display averages and standard deviation of the success rate, perceived ease of use and importance of performing each of the tasks. Average success rate was expected to be very high (e.g. >95%) for the easier tasks and relatively high (>80%) for the more difficult tasks.

RESULTS

Of the 27 participants, 24 completed the experiment (4 women and 18 men). Two did not finish the tests due to technical problems with JACO. A third participant, an individual with C4-C5 quadriplegia, did not complete the experiment because of too much pain at the elbow when moving the joystick or trying to press the buttons. Socio-demographic data from two participants are missing and data from one of them at the second assessment are also missing. There were no serious adverse incident and the tests and questionnaire were well tolerated.

The participants' characteristics are summarized in Table 1. All lived in an interior environment that had been adapted according to their needs. All but one also had adaptations outside of

Characteristics		**Value**
Age (years)		
	Mean±SD	40.8±16.4
Gender		
	Male	18
	Female	4
Living arrangement		
	Alone	13
	Spouse/family/friend	7
	Divorced/separated	2
Diagnostic group		
	Spinal cord injury	11
	Dystrophy	5
	Other neurologic disorders	7
Wheelchair experience (years)		
	Mean±SD	16.5±13.5

Table 1: Participant Characteristics (n=22).

their home. All but two received no regular help from professional caregivers, but these two both lived with their spouse. Three participants described themselves as working either part-time or full-time, four were engaged in regular volunteer work, three were retired, one was a parent at home and 13 were unemployed. The results of the trials with the JACO manipulator are shown in Tables 2-3.

		Number of trial	
		1	*2, 3 or 4*
Grasp a bottle, located on your left on the table	Test 1	21 (87.5%)	3 (12.5%)
	Test 2	21 (91.3%)	2 (8.7%)
Grasp a bottle located on your right, on a surface near the ground and bring it on the table	Test 1	21 (87.5%)	3 (12.5%)
	Test 2	21 (91.3%)	2 (8.7%)
Push the buttons of a calculator	Test 1	19 (79.1%)	5 (20.9%)
	Test 2	21 (91.3%)	2 (8.7%)
Take a tissue from a box on the table	Test 1	21 (87.5%)	3 (12.5%)
	Test 2	21 (91.3%)	2 (8.7%)
Take a straw in the glass on the table	Test 1	21 (87.5%)	3 (12.5%)
	Test 2	21 (91.3%)	2 (8.7%)
Pour water from the bottle in the glass	Test 1	21 (87.5%)	3 (12.5%)
	Test 2	21 (91.3%)	2 (8.7%)

Figure 2: Frequency and success rate for the two testing attempts (n=24 for test 1 and n=23 for test 2).

DISCUSSION

We attained our objective of evaluating the usability of the JACO robotic arm, at least in a preliminary fashion. All tasks were accomplished with a high success rate of 87.5% and 91.3% on the first and second trial, respectively, except for one task where the success rate was 79.1% for the first attempt. The participants who needed more than one trial to succeed were always the same three. Although our sample size is small at this stage of the project, our findings indicate that potential users, even those with serious upper limb disabilities, may quickly learn the basic operation of a robotic device such as JACO. The JACO manipulator seemed easy to use for simple and common tasks requiring grasping. The task seen as the most difficult was « Grasp a bottle located on your right, on a surface near the ground and bring it on the table ». 16.7% of the participants (4/24) indicated that this task was not very easy to accomplish. By comparison, that rating was given by at most one participant when judging all the other tasks. Moreover, the tasks in this study were rated as important (score of 3 or 4) by a majority of participants (75.0% to 87.5%). Participants had positive comments about their experience with the robotic manipulator and rated it as a potentially helpful device, to assist them in their daily activities. Data collection is ongoing to ensure a larger sample size for analysis. We are also planning to study the effective impact of using a robotic manipulator for longer periods of time (e.g. after 1 month and after 1 year) on outcomes such as quality of life, activities of daily living as well as economic impact (e.g., costs of health services).

Table 3: Easiness and importance of performing each task (n=24).

		1	2	3	4
Grasp a bottle, located on your left on the table	Easiness	0	0	5	19
	Importance	0	4	6	14
Grasp a bottle located on your right, on a surface near the ground and bring it on the table	Easiness	0	4	3	17
	Importance	0	5	2	17
Push the buttons of a calculator	Easiness	0	1	7	16
	Importance	2	4	5	13
Take a tissue from a box on the table	Easiness	0	0	4	20
	Importance	1	5	2	16
Take a straw in the glass on the table	Easiness	0	0	5	19
	Importance	0	5	4	15
Pour water from the bottle in the glass	Easiness	0	1	7	16
	Importance	0	3	3	18

Scoring details: 1-None; 2- Not very much; 3- A lot; 4- Absolutely.

CONCLUSION

Use of a joystick-controlled six degree-of-freedom robotic manipulator such JACO seems to be an effective way to improve autonomy of individuals with upper limb disabilities. Additional research must be conducted to document the long-term impact of such costly assistive devices. Those results can have implications for service providers and also for public or private payer agencies.

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Contact Information:

François Routhier, PEng, PhD, CIRRIS-IRDPQ, 525 boul Hamel est, Québec, Canada, G1M 2S8. Phone: 418-529-9141 x6256. Email: Francois.Routhier@rea.ulaval.ca.