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ORIGINAL RESEARCH

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ABSTRACT

Purpose: Past research with JACO has principally focused on the short-term impacts on new users. Therefore, this study aims to document the long-term impacts of this assistive device on users and their family caregivers following prolonged use.

Methods: Users' characteristics, caregivers' characteristics and expenses related to JACO were documented with questionnaires designed for this study. Upper extremity performance was measured with an adaptation of an upper extremity performance test, the TEMPA, and accomplishment of life habits was documented in an interview based on the LIFE-H questionnaire. Satisfaction with JACO and psychosocial impacts of its use were measured with validated questionnaires, namely the QUEST and the PIADS-10. Impacts of JACO on family caregivers were documented with a validated questionnaire, the CATOM. Descriptive statistics were used to report the results.

Results: Seven users and five caregivers were recruited. One user had expenses related to JACO in the past two months. Users had a better upper extremity performance with JACO than without it and they used their robotic arm to accomplish certain life habits. Most users were satisfied with JACO and the psychosocial impacts were positive. Impacts on family caregivers were slight.

Conclusions: JACO increased performance in manipulation and facilitated the accomplishment of certain life habits. Users' increased participation in their life habits may slightly decrease the amount of caregiver assistance required. Future studies are needed to clarify its economic potential, its impact on caregivers' burden, including paid caregivers, and the variability in the tasks performed using JACO.

➤ **IMPLICATIONS FOR REHABILITATION**

- The use of JACO may have positive impacts on its users in terms of upper extremity performance, accomplishment of life habits, satisfaction with the device and psychosocial impacts.
- More research is needed to quantify more accurately the economic potential of the long-term use of JACO, to explore the factors related to the variability in the tasks performed using JACO, and to clarify the impact of JACO on caregivers' burden, including paid caregivers.

Introduction

People with upper extremity disabilities have motor limitations restricting their social participation [1,2]. To alleviate this situation, the support of a family caregiver is often required. In Canada in 2012, eight million persons were caregiving for a relative, either a family member or a friend, with a chronic health condition [3]. Being a family caregiver implies many responsibilities that can have psychological, health, professional and financial consequences for the person who provides assistance [3]. The use of an assistive device can allow the person being cared for to become more independent and improve his or her participation in activities [4]. Thus, the use of an assistive device can have a positive impact on both the user and the family caregiver.

Robotic arms, such as the iARM (Exact Dynamics, Didam, The Netherlands; exactdynamics.nl) and the JACO robotic arm (JACO hereafter; Kinova Robotics, Boisbriand, Canada; kinovarobotics.com), are assistive technologies specifically designed to increase the independence of people with upper extremity disabilities by allowing access to manipulation activities [5]. Robotic arms are mounted on the motorized wheelchair of the user and can be controlled through a variety of interfaces [5]. People living with disabilities such as muscular dystrophy, spinal cord injury, spinal muscular atrophy and other neuromotor impairments may benefit from using a robotic arm [6].

JACO has been studied in controlled conditions in a rehabilitation research laboratory. It has been shown that physically impaired adults who have never used JACO are able to execute

both basic movements (e.g., reach up) and specific activities (e.g., take a tissue from a box) with a success rate between 79% and 93% on the first attempt [7]. JACO can also reduce the amount of required caregiver assistance by a projected 1.31 h per day [7]. This result is consistent with that obtained by Romer et al. [8], who measured a potential reduction in caregiver assistance of 0.7–1.8 h per day with the assistive robotic manipulator (ARM). In similar controlled conditions, Clark [9] examined the improvements in the accomplishment of life habits (e.g., preparing a meal) with the Assessment of Life Habits (LIFE-H) as well as progress in the ability to control JACO through seven training sessions, over eight weeks, in users aged between 7 and 21 years. An improvement in the global score of the LIFE-H was obtained for five participants out of seven, while all participants improved their ability to control JACO to reach, move, release, slide, turn over and press on objects. The use of JACO at home by new users receiving the arm for a month has also been studied [10]. It indicates that improvements were achieved in some life habits for some participants [10]. Users also positively rated their quality of life and were globally satisfied with this assistive device [10].

These past studies with JACO have principally focused on the short-term impacts on new users in controlled environments: all participants were provided with JACO and were asked to learn to use it during one session or over a few weeks. It is therefore not known whether the short-term impacts of using a robotic arm can be sustained over a longer period in the user's environment. It is critical to determine the long-term impacts of the robotic arm to better understand its acceptability and its impacts on the life of the users and their caregivers over a longer period of time. Therefore, the aim of our study is to document the motor, psychosocial and financial impacts of using JACO as well as the impacts on a user's life habits and satisfaction with the device over a period of more than six months. We also aim to document impacts of the long-term use of JACO on the family caregivers. We chose to study JACO over other robotic arms considering the evidence available on the short-term impacts of its use. Since the evidence is limited to a period of two months or less, we chose a time frame of more than six months, which we thought was long enough to detect permanent change in the life of a user.

Methods

Design and experimental procedure

This study is a case series where multiple individuals receiving the same intervention (i.e., the use of JACO) were evaluated. This design is relevant for clinicians and users since it provides the opportunity to identify potential impacts in different environmental conditions [11].

JACO users and their family caregivers participated together in a single session of approximately four hours held at the user's home. During this session, informed consent was obtained from both the user and the family caregiver. This was followed by the administration of the French-language versions of the assessment questionnaires and evaluations by a trained research assistant. The study was approved by the research ethics board of the *Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale*, site *Institut de réadaptation en déficience physique de Québec* (Quebec City, Canada).

Recruitment of participants

Users were recruited from Kinova Robotics clients living no more than 350 km from the study location. Users had to be 14 years old or over, speak French, and have used JACO for at least six months.

Family caregivers were included in the study if they were over 18 years of age and were the main family caregiver of the JACO user.

The company contacted all potential participants in their client's list to validate if they met the inclusion criteria and if they were interested in participating in a research project. The company's role in this study consisted solely of putting the research team in contact with the users corresponding to the criteria and agreeing to be contacted for a research project. No prior screening of participants was conducted by the company.

Measures

Participants' characteristics

The following demographic and personal information were collected to describe JACO users: age, gender, medical diagnosis, years/months of use of JACO, years using assistive technologies, and hours per day spent in a wheelchair. Family caregivers' demographic and personal information were also documented: age, gender, relationship to the user, if they lived with the user, and hours and frequency of assistance given to the user.

Users' upper extremity performance

Upper extremity performance was evaluated with a measure developed for this study based on an upper extremity performance test for the elderly (TEMPA), version 2.0 [12]. The reliability of the original version of the TEMPA has been demonstrated with older adults having upper extremity disabilities [12]. The TEMPA can also be used with younger adults [13]. Its validity has been demonstrated with adults having upper extremity dysfunction due to multiple sclerosis [14].

Three tasks were taken directly from the TEMPA: *Pick up and move a jar*, *Handle coins* and *Pick up and move small objects*. Six tasks were excluded because they could not be realized with JACO, mostly since they required the use of both hands. The research team developed six other tasks that they thought more appropriate for JACO. Two were inspired by the tasks of the TEMPA (*Take a spoonful of coffee* and *Pick up a bottle and pour water*) and four were developed specifically for the study (*Pick up a straw and put it in a glass, Push buttons on a calculator, Turn a glass jar upside down* and *Push checkers on a game board*). These nine tasks were pre-tested by the research team to establish if they could be realized with the robotic arm within a reasonable time. A time limit was added to each task to limit the burden of the evaluation in terms of time and effort required from the participant. The original four-point scale from 0 to –3 of the TEMPA was used, where 0 indicates that the task was completed successfully without difficulty and –3 that the task could not be completed [15]. For each task, the participant received a functional score and a score for each dimension of the main upper extremity neuro-sensorimotor skills, namely active range of movements, strength, gross movements, prehension and fine movements [15]. Due to the changes made to the original version, minor modifications of the scoring were required: (1) users completing less than 25% of a task within the time allocated or abandoning the task before completion were given –3 for the functional score, but the neuro-sensorimotor skills were scored independently and (2) users who could not complete the tasks without JACO because their upper extremity disabilities were too severe were given –3 for the functional score and for each of the neuro-sensorimotor skills.

Users' life habits

An interview based on the Assessment of Life Habits (LIFE-H) versions 3.0 [16] and 4.0 [17] was developed specifically for this study

to document the accomplishment of life habits by JACO users. The validity and reliability of the LIFE-H have been demonstrated with adults having functional limitations [18,19]. Twelve life habits involving prehension and upper extremity movement were selected from the LIFE-H (see Table 3). JACO users had to rate their level of difficulty (*none or a little*, *some*, *a lot*) and briefly describe the type of difficulty they encountered for each of these life habits. They could respond *cannot accomplish the life habit*, for life habits in which they would have participated if they had not had upper extremity impairment, or *not applicable*, if they would not have participated even in the absence of impairment. Users also had to list the assistive devices they used (JACO or others) and describe the human assistance and specific activity adaptations they required. Finally, they were asked to rate their level of satisfaction with the accomplishment of these life habits on a five-point scale ranging from *very satisfied* to *very dissatisfied*. The level of satisfaction was not rated if users had responded *not applicable*.

Users' satisfaction

The technology subscale of the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) version 2 was used to explore users' satisfaction [20]. The reliability and validity of the technology and services subscales have been demonstrated in different languages and with different populations using varied assistive technologies [20]. Eight aspects of JACO were evaluated with this scale, namely dimensions, weight, ease of adjusting, safety, durability, ease of use, comfort and effectiveness. Each aspect was scored on a five-point scale from 1, *not satisfied at all*, to 5, *very satisfied*. Users were then asked to identify which three of these eight aspects were most important to them.

Psychosocial impacts on users

The 10-item version of the Psychosocial Impact of Assistive Devices Scale (PIADS-10) [21] was used to document psychosocial impacts of the use of JACO. The reliability and validity of the original version of the PIADS have been demonstrated in different languages and with different populations using varied assistive technologies [22]. JACO users' views regarding their happiness, independence, self-esteem, productivity, quality of life, sense of control, and eagerness to try new things as well as their ability to participate, adapt to activities of daily living and take advantage of opportunities since using JACO were evaluated. Users were asked to note the increase or decrease that had occurred since they began to use JACO for each item on a scale ranging from –3 (*big deterioration*) through 0 (*no change*), to 3 (*big improvement*).

Impacts on family caregivers

Using the Caregiver Assistive Technology Outcome Measure (CATOM) [23], main family caregivers of JACO users were asked for their opinion regarding JACO's impact on their lives and the changes that had occurred since users received the robotic arm. Preliminary evaluation of the psychometric properties of the CATOM has shown promising results with family caregivers [23]. Part 1 of this questionnaire asks caregivers to indicate all of the activities for which they provide help to the assistive technology user. Part 2 consists of two series of questions. The first refers to specific activities that are physically or emotionally demanding for the caregiver (14 questions). The second contains four questions on activities that help the assistive technology user. Each question contains two dimensions. Caregivers rate each question on frequency (burden dimension), using a scale ranging from 5 (*never*) to 1 (*nearly always*). They also have to indicate the changes that

had occurred in this frequency since the user received the assistive technology (change dimension), on a scale ranging from 1 (*a lot more*) to 5 (*a lot less*).

Economic impacts on users and caregivers

An in-house economic questionnaire was developed for this study. The first part of this questionnaire documented the expenses assumed by users or family members related to JACO (e.g., repairs on the robotic arm) over the preceding two months and the care provided by a paid caregiver. The second part complements the life habits assessment. It documents the different tasks accomplished in the previous week, the increased independence provided by JACO in these tasks, and the reduction in paid and unpaid caregiver assistance resulting from using JACO. The increased independence refers to the tasks for which JACO was used. In the third part, using a scale from 0 (*completely disagree*) to 10 (*completely agree*), users were asked to share their opinion regarding the following three statements: (1) "JACO is the main assistive technology that allows me to stay at home. Without JACO, I probably wouldn't be able to stay at home", (2) "JACO is an assistive technology that allows me or would allow me to study and/or work" and (3) "With JACO, my family caregivers (unpaid caregivers) feel more comfortable leaving me alone".

Data analysis

Since statistical analysis of difference is not appropriated with this type of design [24], a descriptive analysis was realized for all measures used.

Findings

Participants' characteristics

Seven JACO users (average age 34 ± 10 years) and five family caregivers (average age 52 ± 14 years) were recruited. The main characteristics of JACO users and family caregivers are presented in Tables 1 and 2, respectively.

Users' upper extremity performance

Users 1, 2, 3 and 6 were not able to complete any of the nine tasks in the modified version of the TEMPA without JACO. User 4 pushed buttons on a calculator and checkers on a game board with his left hand. User 5 pushed checkers on a game board with his right hand. User 7 picked up a straw and put it in a glass, handled coins, picked up and move small objects using both hands, and pushed checkers on a game board once with his left hand and another time with his right hand. Table 3 presents the total functional score and neuro-sensorimotor skills scores of each participant for each task without and with JACO.

Users' life habits

Table 4 shows users' participation in each life habit and whether JACO is used or not. The table also shows the level of difficulty encountered, the amount of human assistance required and the level of satisfaction.

Users 4 and 6 used JACO for meal preparation and had difficulties in opening the refrigerator door and to plan how to grasp food. Users 4 and 6 used other assistive devices or adaptations to prepare meals such as an opener, a straw and a lowered counter. All users drank with JACO, either directly from a glass or with a straw. Only User 6 had difficulty directing the glass to his mouth

with JACO. Users 1, 3, 4 and 5 used JACO to eat, but User 4 used it only for snacks. The other three users ate complete meals with JACO, but only occasionally. Users 1 and 5 indicated that it was due to the time required and the large amount of manipulation needed. In terms of assistive devices used, Users 1 and 3 ate with the feeding tool developed for JACO and Users 5 and 7 employed adapted utensils for the majority of their meals.

As for users participating in their personal care with JACO, Users 1, 3 and 4 reported difficulties with the amount of manipulation required and with precision. Also, Users 1, 3, 4 and 7 reported using other assistive devices and adaptations such as a lift. Only User 4 took some of his medications with JACO. He adapted a cup to be able to grasp it with JACO but had difficulty taking the medication from the cup with his mouth. For written

Table 1. Characteristics of users.

User	Diagnosis	JACO used for (years)	AT use[a] (years)	Motorized wheelchair use (h/day)
U1	CP	3.5	>10	>11
U2	DMD	2.5	>10	>11
U3	AMC	1.5	>10	>11
U4	SMA	4.0	>10	>11
U5	Tetraplegia	0.5	8	>11
U6	CP	2.0	>10	>11
U7	Tetraplegia	1.5	>10	>11

CP: cerebral palsy; DMD: Duchenne muscular dystrophy; AMC: arthrogryposis multiplex congenital; SMA: spinal muscular atrophy; AT: assistive technology.
[a]Includes motorized wheelchair use.

Table 2. Characteristics of caregivers.

Caregiver	Relationship to user	Living with user	Amount of help provided
C1	Spouse	Yes	Daily (1 h)
C2	Mother	Yes	Daily (6 h)
C3	Mother	Yes	Daily (24 h)
C5	Mother	Yes	Daily (7–8 h)
C7	Mother	No	Daily (n/a)

n/a: information not available.

communication, User 1 read using JACO to turn pages, but thought this took a long time. For writing, Users 3, 5 and 7 were able to write without JACO; Users 5 and 7 used a device attached to their wrist to do so. User 3 could use his hands but also used JACO to pick sheets and pen for writing. However, he found that JACO lacked sufficient precision. For telecommunications, no user reported difficulties with JACO. However, all of them used other technologies than JACO, a virtual keyboard for example, or adaptations to be able to use telecommunications such as an adjustable shelf.

The use of JACO to handle furniture and household equipment depended on the availability of other assistive technologies or on accommodations and the particular upper extremity impairments. User 1 found that using JACO in these tasks was time-consuming. Users 3 and 4 reported limitations related to the robot's reach and to the number and precision of the manipulations required. User 1, who employed JACO for shopping, encountered a lot of difficulties handling his credit cards and money. For their leisure activities, Users 1 and 3 found JACO to be time-consuming in these activities. Users 1, 4, 5, 6 and 7 used other assistive technologies such as a card holder, an adapted computer access system or a stylus.

Users' satisfaction

Table 5 shows the total score on the QUEST for each user as well as the mean and standard deviation. Six users out of seven have a mean score of 4.5/5. For the three most important aspects related to user satisfaction, six indicated ease of use, four durability, four effectiveness, three dimensions, two ease of adjusting, one safety, and one comfort.

Psychosocial impact on users

Table 5 also shows the total score on the PIADS-10 for each user as well as the mean and standard deviation. Four users have a mean score higher than 2/3, two users have a mean score between 1/3 and 2/3 and one has a mean score lower than 1/3.

Table 3. Scores obtained by each user on the TEMPA without and with JACO.

	Functional rating[a]		Range of movements[a]		Strength[b]		Gross movements[a]		Prehension[c]		Fine movements[d]	
User	L	R	L	R	L	R	L	R	L	R	L	R
Scores without JACO												
U1	−27	−27	−27	−27	−12	−12	−27	−27	−27	−27	−24	−24
U2	−27	−27	−27	−27	−12	−12	−27	−27	−27	−27	−24	−24
U3	−27	−27	−27	−27	−12	−12	−27	−27	−27	−27	−24	−24
U4	−23	−27	−27	−27	−12	−12	−25	−27	−21	−27	−20	−24
U5	−27	−24	−27	−24	−12	−12	−27	−24	−27	−27	−24	−24
U6	−27	−27	−27	−27	−12	−12	−27	−27	−27	−27	−24	−24
U7	−21	−21	−18	−18	−12	−12	−19	−19	−27	−27	−24	−24
Scores with JACO												
U1		−4		−1				−6		−1		
U2		−7		−7				−9		−5		
U3		−4		−1				−4		−4		
U4		−3		0				−4		−4		
U5		−5		0				−9		−6		
U6		−18		−3				−16		−11		
U7		−13		0				−11		−7		

Columns in grey represent items that cannot be evaluated with the JACO robotic arm.
L: left hand; R: right hand.
[a]Maximum score = 0, minimum score=−27.
[b]Maximum score = 0, minimum score=−12.
[c]Maximum score = 0, minimum score=−27 without JACO and −24 with JACO.
[d]Maximum score = 0, minimum score=−24.

Table 4. Life habits accomplished by users.

Life habit	Accomplishment of the life habit		Level of difficulty[a]			Human assistance[b]			Level of satisfaction		
	Yes	Yes with JACO	None/little	Some	A lot	Light	Significant	Complete	Satisfied	±Satisfied	Dissatisfied
Meal preparation[c]	U4–6	U4–6	U5	U4, 6				U4–6	U4–6	U7	U1–2
Taking a meal	U1–7	U1–7	U2, 5, 7	U1, 3, 4, 6		U5, 7		U1–4, 6	U1–7		
Personal care[d]	U1–4, 7	U1, 3–4		U1, 2, 3, 7	U4	U1		U2–4, 7	U1–5	U6–7	
Dressing[e]	U5	U5	U5					U5	U2–6	U7	U1
Taking medicine	U4, 7	U4	U4, 7					U4	U2–7		
Written communication[f]	U1, 3, 5, 7	U1, 3		U1, 3, 5, 7		U1, 7	U3, 5		U1, 3	U5, 7	
Using telecommunication[g]	U1–7	U1, 4–6	U1, 3–7	U2		U2–5, 7	U6		U1–7		
Light household maintenance[h]	U4			U4				U4	U4		
Using furniture[i]	U1–7	U1–7	U1, 5–7	U2, 4	U3		U1	U1, 2, 3, 4, 6	U1–7		
Using goods and services[j]	U1, 7	U1		U7	U1	U7	U1	U1	U2, 3, 5	U1, 4, 7	
Education	U3	U3			U3		U3		U3		
Leisure	U1–7	U1, 4, 5, 6	U2, 4–7	U1, 3		U3, 5, 7	U1, U4, 6	U1	U1–7		
Other[k]	U2–4, 6–7	U2–4, 6–7	U2, 7						U2, 7		

[a]It can include or not equipment or human help.
[b]It excludes users who reported not needing human help. Help is considered complete when the majority of life habit tasks have to be done by the caregiver even when the user participates.
[c]Tasks done with JACO: open refrigerator, take out food, turn on a coffeemaker, and turn on a microwave oven.
[d]Tasks done: blow nose ($n = 3$ with JACO; $n = 1$ without JACO), brush teeth ($n = 1$ with JACO; $n = 2$ without JACO), put on make-up ($n = 1$ with JACO), wash face ($n = 1$ with JACO), wash upper body and hair ($n = 1$ without JACO).
[e]Tasks done with JACO: take clothes out of the cupboard and put a hat on.
[f]Tasks done: turn pages of a book ($n = 1$ with JACO), bring material closer ($n = 1$ with JACO), write ($n = 3$ without JACO).
[g]Tasks done with JACO: push buttons and hold a telephone.
[h]Tasks done without JACO: control a vacuum with a smart phone.
[i]Tasks done with and/or without JACO: open and close doors, cupboards, drawers, turn lights off and on, use the washbasin, adjust heating/air conditioning, and control security system.
[j]Tasks done: handle bank cards and bank notes ($n = 1$ with JACO; $n = 1$ without JACO).
[k]Tasks done with JACO: adjust glasses, scratch an itch, shade eyes from the sun, fix one's hair, push elevator buttons, open doors with push-button, water plants, put laundry in washer, pick up objects from the floor, hold an umbrella.

Table 5. QUEST and PIADS-10 scores for each user.

	QUEST			PIADS-10		
User	Total[a]	Mean[b]	SD	Total[c]	Mean[d]	SD
U1	37	4.6	0.5	28	2.8	0.4
U2	36	4.5	0.5	8	0.8	0.9
U3	38	4.8	0.5	23	2.3	1.1
U4	37	4.6	0.7	29	2.9	0.3
U5	40	5.0	0.0	28	2.8	0.4
U6	28	3.5	1.3	13	1.3	0.9
U7	37	4.6	0.5	18	1.8	1.1

SD: standard deviation.
[a]Maximum score = 40, minimum score = 8.
[b]Maximum score = 5, minimum score = 1.
[c]Maximum score = 30, minimum score = −30.
[d]Maximum score = 3, minimum score = −3.

Impacts on family caregivers

Table 6 presents the answers to each question for the caregivers. The burden dimension of the CATOM was computed for the five caregivers recruited while the change dimension was calculated for only four since one had not been with the user prior to receipt of JACO.

Economic impacts on users and caregivers

During the two months preceding the evaluation, only one user had expenses related to his JACO since he required a counter to be lowered, to facilitate the use of his assistive device. The hours covered by public insurance were not affected by the use of JACO. The tasks performed with JACO during the week preceding the assessment are detailed in Table 7. Two tasks were not realized by any participants during that period: prepare a meal or a snack, and do household shopping, household chores, dishes, clear the table or tidy up the house. For Users 1, 4 and 7, the

results reported did not represent a typical week: Users 1 and 7 were not attending school or work as usual, while User 4 was going through a period of reorganization of the schedules of his paid caregivers. The score given by each user to the three statements is presented in Table 8.

Discussion

This study documents JACO's impacts for seven users and their family caregivers following use of more than six months. Participants reported positive impacts from using JACO, even though some difficulties were encountered.

Results on the TEMPA demonstrate that users had a better performance with JACO than without, when asked to perform specific upper-extremity tasks. Even though some tasks were difficult with JACO for some users, it allowed them to complete tasks they could not have done without JACO (or only with great difficulty). The mean and individual scores on the QUEST indicate that most JACO users were satisfied with this technology; this result was also obtained by Routhier et al. [10] when evaluating JACO after one month of use at home. Only User 6 reported less satisfaction by indicating he was *not satisfied at all* for the adjustability aspect. The scores on the PIADS-10 indicate that JACO had positive psychosocial impacts on all users but that these impacts were small for some users: User 2 had a score of less than 10 and User 6 had a score of less than 15. These users are also the ones who gave the lowest score to all three statements on the third part of the economic questionnaire and who had some of the lowest functional rating scores on the TEMPA. These results support the possibility that not all users benefit of JACO to the same extent. For example, the lower upper extremity performance with JACO of User 6 and the problems he encountered in the adjustment of JACO to its wheelchair could explain, at least partially, his lower satisfaction with JACO and the fewer psychosocial impacts.

Table 6. Results on the burden and the change dimensions of the CATOM for each caregiver.

	Burden dimension				
CATOM items	Nearly always	Frequently	Sometimes	Rarely	Never
Part 1 (a)					
1. How often does your relative require your help with this activity?	A2, 3, 7		A1, 5		
2. Do you physically help your relative when he/she is performing this activity?[a]	A1, 2, 3			A5	
3. Do you ever feel that you must be nearby when your relative is performing this activity?[a]	A2, 5	A1			A3
4. Do you ever provide verbal hints or directions to help your relative perform this activity?[a]	A2				A1, 3, 5
5. Do you ever feel that helping your relative in this activity requires too much of your time?		A1	A2, 5		A3, 7
6. Do you ever feel that your relative may be harmed when he/she is performing this activity?[a]	A2		A1		A3, 5
7. Do you ever feel you may be harmed when you are helping your relative to perform this activity?					A1, 2, 3, 5, 7
8. Do you ever feel physically tired after helping your relative in this activity?		A3	A2, 7		A1, 5
9. Does the help you are providing to your relative in this activity ever result in pain or physical strain?			A7		A1, 2, 3, 5
10. Do you ever miss having free time because of the help you provide in this activity?		A1	A2		A3, 5, 7
11. Do you ever feel anxious while your relative is performing this activity?[b]			A1		A3, 5
12. Do you ever feel annoyed about having to help your relative with this activity?			A2	A1	A3, 5, 7
13. Do you ever feel overwhelmed by the help your relative needs in this activity?			A2	A1	A3, 5, 7
14. Do you ever feel that the equipment used in this activity limits the use of space within your home?[a]					A1, 3, 5, 7
Part 2 (a)					
15. When you consider all of the help you are providing to your relative, do you ever feel that the amount of work is too high?			A2, 3	A5	A1, 7
16. Do you ever feel that all the help you are providing to your relative limits your recreational and leisure activities?			A1, 2, 5		A3, 7
17. Do you ever feel that all the help that you are providing to your relative limits your work or volunteer activities?		A2			A1, 3, 5, 7
18. Do you ever feel that all the help you are providing to your relative strains your social and family relationships?		A2	A3, 5		A1, 7

	Change dimension				
CATOM items	Much more	A little more	No more no less	A little less	Much less
Part 1 (b)					
1. Does your relative require more help, less help, or is it the same as before?[a]			A2, 7	A5	A3
2. Do you need to provide more physical help to your relative, less physical help, or is it the same as before?[a]			A2, 7	A3	A5
3. Do you feel that you must be nearby more often when your relative is performing this activity, less often, or is it the same as before?[a]			A2, 7	A5	A3
4. Do you provide more verbal hints or directions, fewer verbal hints or directions, or is it the same as before?[a]			A2, 3, 5, 7		
5. Do you feel that helping your relative in this activity requires more of your time, less of your time, or is it the same as before?[a]			A2, 7	A3	A5
6. Do you feel that your relative may be harmed more often, less often, or is it the same as before?[a]			A2, 3, 5, 7		
7. Do you feel you may be harmed more often, less often, or is it the same as before?[a]			A2, 3, 5, 7		
8. Do you feel more physically tired after helping your relative in this activity, less physically tired, or is it the same as before?[a]			A2, 5, 7	A3	
9. Does the help you are providing to your relative in this activity result in more pain or physical strain, less pain or physical strain, or is it the same as before?[a]			A2, 3, 5, 7		
10. Do you have more free time, less free time, or is it the same as before?[a]	A5	A3	A2, 7		
11. Do you feel anxious more often while your relative is performing this activity, less often, or is it the same as before?[b]			A3, 5, 7		
12. Do you feel more annoyed, less annoyed, or is it the same as before?[a]			A2, 3, 5, 7		

(continued)

Table 6. Continued

CATOM items	Burden dimension				
	Nearly always	Frequently	Sometimes	Rarely	Never
13. Do you feel more overwhelmed by the help your relative needs in this activity, less overwhelmed, or is it the same as before?[a]			A2, 3, 7	A5	
14. Do you ever feel that the equipment used in this activity limits more the use of space within your home, less, or is it the same as before?[b]			A3, 5, 7		
Part 2 (b)					
15. When you consider all of the help you are providing to your relative, do you feel that the amount of work is higher, lower, or is it the same as before?[a]			A7	A2, 5	A3
16. Do you feel that all the help you are providing to your relative limits more your recreational and leisure activities, less, or is it the same as before?[a]			A7	A2, 3, 5	
17. Do you feel that all the help that you are providing to your relative limits more your work or volunteer activities, less, or is it the same as before?[a]			A2, 3, 5, 7		
18. Do you feel that all the help you are providing to your relative strains more your social and family relationships, less, or is it the same as before?[a]			A2, 3, 7	A5	

Note. Free translation of the French version of the questionnaire.
[a]Includes four caregivers.
[b]Includes three caregivers.

Table 7. Tasks done by users with the JACO during the week before the evaluation and impact of the use of the robotic arm on caregiver assistance.

Tasks	Done with JACO	Reduction in assistance by[a]	
		Family caregivers	Paid caregivers
Grasp, move, pick up and recover objects	U1, 3–7	U1, 3, 5–7	U1, 3–4, 6–7
Eat a meal or a snack	U1, 3–5	U3, 5	U1, 3–4
Prepare a drink	U1, 3, 5, 7	U1, 3, 5, 7	U1, 3, 7
Drink a drink	U1–5, 7	U1–3, 5	U1, 3–4
Open and close a door/drawer	U1, 3–6	U1, 3, 5–6	U1, 3–4, 6
Take medication	U4		U4
Put on make-up, shave, brush hair or teeth	U1, 3	U3	U1, 3
Use a computer/tablet or telephone	U1, 4–5	U1	U1, 4
Do an activity related to school or a job	U1, 4		U1, 4
Do an activity related to leisure	U1, 3, 5	U1, 3	U1, 3
Other[b]	U2–4, 6	U2	U4

[a]Users could have noticed a reduction in family and/or paid human help or may not have noticed any impact on caregivers.
[b]Includes adjusting his glasses, to scratch oneself and to hold a hat.

Table 8. Score to each statement of the economic questionnaire for each user.

User	"JACO is the main assistive technology that allows me to stay at home. Without JACO, I probably wouldn't be able to stay at home"	"JACO is an assistive technology that allows me or would allow me to study and/or work"	"With JACO, my family caregivers (unpaid caregivers) feel more comfortable leaving me alone"
U1	7.5	8	10
U2	2	0	5
U3	3	6	9
U4	10	10	10
U5	4	5	8
U6	1	4	0
U7	5	7	9

However, for others, even if JACO only had a small impact on their autonomy, it was highly significant for them. For example, User 5 reported in the interview his satisfaction with participating in dressing by using JACO to pick up the clothes he wanted to wear. This, and other elements of his participation, could explain the high scores of this user on the QUEST and the PIADS-10, showing a high satisfaction and high psychosocial impacts.

The results from the LIFE-H-based interview and in-house questionnaire showed that JACO made it easier to accomplish certain life habits. All participants used JACO in some of their life habits, although, JACO was not used in all the life habits that were realized by users. Furthermore, the life habits used for the evaluation of users were selected among the life habits included in the original version of the LIFE-H questionnaire. Therefore, there is a possibility that users engaged without JACO in other life habits that were not documented in this study. This finding is consistent with the results obtained by Routhier et al. [10] and Clark [9], both of whom, through an assessment with the LIFE-H, observed an

improvement in the accomplishment of some life habits with JACO after one month and eight weeks of use, respectively. The present study shows that these results are maintained over a longer period of time. Users' increased participation in some of their life habits could reduce the amount of human assistance required. In this study, JACO helped users to drink completely independently, which had a substantial effect on the human assistance required in this task. However, the results on the CATOM showed that the impact on family caregivers of using JACO was low. Indeed, for all questions, at least one caregiver reported that there was no difference since the acquisition of JACO. However, for some caregivers there was a positive difference (e.g., more free time, less physical help) and no caregivers reported an increase in the strain or the help required by the user. One explanation for these results could be that JACO was used only for some life habits, as mentioned above. That was also the opinion of users, who more or less agreed (five users out of seven scored 5/10 and less) with the following statement on the in-house questionnaire: "JACO is the main assistive technology that allows me to stay at home. Without JACO, I probably wouldn't be able to stay at home." This result is consistent with that obtained by Gelderbloom et al. [25] in their examination of the effectiveness of the MANUS robot manipulator. Those authors reported that the amount of assistance required by a person with an upper extremity disability did not seem to be affected by the presence of the robotic arm. Caregivers had to prepare the activities done with the MANUS robot manipulator, but assistance did not have to be constantly given thereafter. Despite this, users of the MANUS robot manipulator and their caregivers reported increased independence. The same could be observed with JACO: the caregiver is needed to assist in certain tasks and to complete tasks where JACO cannot meet needs, but the sense of independence (measured with the PIADS) generally increased.

The impact on family caregivers, even though slight, could indicate that once JACO is well integrated into a user's life habits, it could reduce the number of hours of assistance required. This is consistent with the results of Romer et al. [8] and Maheu et al. [7], who quantified in hours the economic potential of a robotic arm. They obtained a decrease in assistance of 0.7–1.8 h and 1.31 h per day, respectively. In the present study, the data collected with the in-house questionnaire did not make it possible to quantify the amount of assistance spared by having users integrate JACO in their life habits. However, it must be taken into account that not all tasks performed by paid caregivers may be accomplished instead with JACO. Thus, it is possible that assistance time saved through the use of JACO allowed caregivers to spend more time on other tasks. In future studies, the focus should be on the extent of the impact of using JACO on the number of hours of formal care provided that could potentially be saved since some funding bodies pay for services from paid caregivers but do not pay for the robotic arm.

Limitations

In this case series, change in the user's performance cannot solely be attributed to the intervention [11] or in this case, the use of JACO. For example, the presence or absence of a caregiver could have influenced the use of JACO but this was not documented in the study. Also, generalization is limited considering the small sample size, the different diagnoses included in the same study, and the specific contexts of participants. It is, however, the first study to look at the possible long-term impacts of JACO even though we cannot conclude on the effectiveness of the use of JACO.

To document the economic impact, an in-house questionnaire was used whose psychometric properties have not been demonstrated. In addition, it documented the costs related to JACO only for the two months preceding the assessment: other major expenses could have been incurred outside the assessment period. Also, this questionnaire did not quantify the amount of autonomy provided by JACO. The CATOM was used to measure the impact of this assistive technology on caregivers, but since this questionnaire was developed specifically for family caregivers, it did not allow us to document JACO's impacts on paid caregivers.

The participants recruited for this study could have been biased in favour of JACO since they were referred to us by the company that sells it. However, the company's only role was to contact all the clients in the geographic area chosen for this study and to ask permission to send us their names.

Conclusions

The results of this case series demonstrate that the use of JACO increased performance in manipulation and facilitated the accomplishment of certain life habits. Users' increased participation in their life habits may decrease the amount of caregiver assistance required, if only slightly. Although the impact on caregivers' burden was judged to be slight, this finding supports the potential of JACO in reducing the amount of assistance required demonstrated in other studies. Users reported being generally satisfied with their device and that using JACO had positive psychosocial impacts.

In future research, the economic potential of the long-term use of JACO could be quantified more accurately by measuring its contribution to reducing caregiver assistance and increasing autonomy. Also, factors related to the variability in the tasks performed using JACO could be explored. In addition, to clarify and quantify the impact of JACO on caregiver burden, future studies should be extended to a larger number of caregivers, including paid caregivers.

Disclosure statement

The authors report no conflicts of interest.

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