Assessing design features of a graphical user interface for a social assistive robot for older adults with cognitive impairment

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Purpose Over the past several years, a variety of assistive technologies have been conceived and developed to support independent living and quality of life of older adults with mild cognitive impairment (MCI) or Alzheimer's disease (AD). Within this area socially-assistive robotics is a growing field. However, although robotics has the potential to support the elderly with cognitive impairment in daily tasks, the development of usable interfaces remains a challenge. For instance, changes in perceptual and cognitive abilities should be addressed in robotics design because they affect technology use. The aim of the QuoVADis project was to develop a socially-assistive robot for elderly people with cognitive impairment. The semi-autonomous remotely controlled robot consists of a mobile platform guided by a computer and electronic system. The robot input devices include speech control and a touch-screen. The system, capable of social interaction, was specifically conceived to provide cognitive and social support to the user through a suite of applications (task reminder, cognitive training, navigation support, and communication). The purpose of this work was to develop the graphical user interface (GUI) through which these services are provided. In a previous study we defined a set of requirements that were used to design the robot's GUI. In this paper we present results from usability testing of the functional prototype of the GUI with target end-users and the modifications made to produce the final version of the applications. **Method** We used a user-centred design approach for the GUI design. Eleven elderly persons with MCI and 11 elderly with normal cognition were recruited for this study. First, the moderator described the purpose of the research, introduced the robot and explained the evaluation procedure. Then participants were asked to complete a series of tasks using the main menu of the GUI and navigate through its different applications. Performance and satisfaction measures were collected (e.g., time to complete each task, number of errors due to manipulation, number of help requests). Tests were conducted individually. **Results & Discussion** Findings confirmed that most of the features of the GUI were adapted to the needs and capacities of older adults with cognitive impairment. However, individual factors (age, education level, and computer experience) were found to affect task performances. Moreover, some particular aspects of the interfaces (icons, navigation system) had to be modified to make the application usable by the largest number of patients suffering from cognitive deficits. These results were used to develop the final version of the GUI. We confirmed that designing and developing assistive technologies to support elderly with cognitive impairment requires end-user involvement throughout all the development and evaluation phases. This study is an example of a successful design process for assistive technologies to support MCI-patients and their caregivers, involving them throughout all the development phases and applying the concept of iterative evaluations.

Keywords: *socially assistive robotics, elderly, cognitive impairment, graphical user interface*

INTRODUCTION

Mild Cognitive Impairment (MCI) is a condition that affects approximately 10% to 20% of people aged over 65 years[1]. MCI is usually characterized by memory loss but other cognitive deficits can be involved. Although individuals with MCI maintain functional independence in daily life they can exhibit some difficulties when performing complex tasks (e.g., managing bills, preparing meals, medication intake). Besides, studies indicate that these persons are at higher risk than their healthy peers of developing Alzheimer's disease or any other form of dementia. Accordingly, individuals with MCI that progress and convert to dementia have an increasing need of formal and informal care.

Information and Communication Technology (ICT) has been used to develop solutions to support frail older adults and caregivers in their home[2]. These solutions include sensor technology, telecommunications, safety alarms, monitoring devices, cognitive prosthesis, mobility aids, and robotic systems, among others[3,4].

Responding to the needs of these populations has become a major aim of Socially Assistive Robotics

(SAR)[5]. SAR concerns robotic systems capable of providing assistance to the user by means of social interaction[6]. Their scope covers a wide range of tasks for which assistance can be provided without physical interaction. In general, SAR have the potential to contribute to user's daily life at different levels[7,8]:

(i) By supporting and/or compensating functional abilities of the person through different technology-based services (e.g., task reminder, task monitoring, schedule-management systems, navigation aids).

(ii) By contributing to social and psychological well-being of end-users (e.g., communication and social networking services, companionship aspects, recognition and expression of emotional states, collaboration and engagement capacities).

(iii) By providing monitoring that contributes to healthcare and safety. With regard to this issue, SAR can be associated with other devices capable of collecting data on the physiological activity of the person (e.g. fall detector).

(iv) By making a continual assessment of the user's cognitive functioning through the analysis of daily behavior. This aspect concerns applications that collect performance measures during task execution and facilitate the follow-up of cognitive deficits.

User-system interactions

Different modalities can be employed to ensure the interaction between social robots and users[6]. Individual interaction modalities include speech (voice user interfaces), gestural interfaces, and direct input (e.g., touch-screen interface). Furthermore, multimodality constitutes an alternative interaction solution in which individual modalities are combined.

The QuoVADis project

The aim of the French project QuoVADis[9] (2008-2011) was to design and develop a social robot for frail elderly people with age-related cognitive impairment or with a diagnosis of MCI. End-users could also present one or more of the following conditions:

(i) Chronic illness requiring medical follow-up.

(ii) Risk of falling.

(iii) Risk of social isolation or exclusion.

The project was structured into a number of working tasks in which we defined, developed and evaluated a set of services that a robot could provide to support care recipients, as well as family caregivers, in daily activities. Working tasks included: user needs assessment, requirements gathering, prototype development and iterative usability evaluations with functional prototypes of the robot and its applications.

The Kompaï robot

Kompaï (Fig. 1) is a mobile platform guided by a computer system developed by Robosoft[10]. A Web browser or a joystick can be used to remotely control the robot. The robot embeds a group of sensors and cameras that ensure robot's autonomous navigation, target user localization and obstacle detection. Input devices include speech control and a touch-screen from a Tablet PC running Windows 7.

Within the QuoVADis project, the system was specifically programmed to provide cognitive and social support through a suite of applications (e.g., task reminder, cognitive training, navigation support, communication tools). In the present study we focused on the design of some graphical navigation elements of the Graphical User Interface (GUI) since the direct input device (touch-screen) was one of the interaction modalities defined for the robot.

Fig.1. Kompaï Robot (Robosoft)

Robot GUI

GUI based-systems generally consist of a visual display that uses graphical elements (icons, buttons, menus), rather that only text, to convey information and allow navigation in a computer application.

Robot GUI was developed using a User-Centred Design (UCD) approach. An incremental development process was followed to investigate each design feature and to implement it progressively in the general prototype[11]. With this aim, formative usability tests with end-users were conducted throughout all the design and development phases.

The GUI comprises a main menu displaying a set of button icons that give access to robot services (Fig. 2). Once the user selects an application different controls are available for data entry and navigation. Robot services were selected based on the results of two previous needs assessment studies[12, 13].

For the design of the main menu interface we conducted a preliminary study with a group of end-users to explore their preferences with regard to icon characteristics[14]. Nine images were then selected to create the button icons representing robot applications (Fig. 2). According to users' preferences it was decided to use images depicting real objects or actions and to present the buttons unlabeled.

Fig.2. Main Menu icons representing robot services. From upper left to lower right: Email, Video Calls, Cognitive Stimulation, Shopping List, Weather Forecast, Agenda, Web Games, Medication Reminder, Robot Control

GUI design, usability, acceptability

When designing GUIs for elderly users, it must be considered that cognitive and perceptual deficits may hinder the use of these applications[14–16]. Having a limited computer experience constitutes an additional barrier for the adoption of such interactive systems[15,16].

Several studies have confirmed that older users face various difficulties when using some specific features of GUIs. Among the elements that have been associated to accessibility and usability problems in this population are[17–21]:

- Cascading and other navigation menus
- Scrolling
- Images used as titles
- Insufficient visual contrast
- Links/button too small or too close to each other
- Icon comprehension
- Including too many links
- Moving content
- Pop-up windows
- Text that cannot be resized

Therefore, usability testing with representative end-users is a necessary procedure to identify usability barriers and to gain understanding on how users interact with technological applications. Guaranteeing GUI usability was fundamental in the QuoVADis project since robot services had to be accessed through the GUI when using the tactile interaction.

OBJECTIVES

The aim of this study was to assess usability and user's satisfaction of graphical navigation elements of the robot's GUI. Graphical elements included:

(i) Button icons

(ii) Navigation and menu controls

METHODS

Subjects

Eleven elderly persons with MCI and eleven healthy controls (HC) took part in this study. Participants in the MCI group were recruited through the Memory Clinic of Broca Hospital, those in the HC group were recruited through senior centers. All the participants volunteered for this study. French ethical committees CCTIRS and CNIL endorsed this project. Socio-demographic characteristics of the sample are presented in Table 1.

Table 1. Socio-demographic characteristics by group

Group	MCI	HC
N	11	11
Gender	M=5; F=6	M=0; F=11
Age mean (SD)	76,63 (7,92)	76,36 (7,85)
Range	73-86	66-88
EL* (years)	<7=5 ; ≥7=6	<7=6 ; ≥7=5
PC experience	none=0; regular=5	none=4; regular=7

*EL= Educational Level

Material

Tasks were performed on the Tablet PC of the Kompaï robot (12" HD display WXGA, 1280 x 800). A stylus pen was used to input commands to the touch-screen. Sessions were recorded with two video cameras. A grid was used to score user's performances. Data were analyzed with The Observer® XT software.

Procedure

Tests were conducted in individual sessions. First, the test moderator described the purpose of the research. All participants read and signed an informed consent form prior to enrollment.

Afterwards, the moderator introduced the robot and the GUI. Participants were also instructed on the use of the touch-screen. Then, they were asked to complete a set of tasks that required the use of graphical navigation elements:

(i) Main Menu: icon comprehension test.

(ii) Shopping List: icon comprehension test and to enter two products in the list.

(iii) Agenda: enter an event (month, day, details, and confirmation).

Usability measures of graphical elements

Button Icons

(i) For each icon of the Main Menu (Fig. 2) the following aspects were considered:

- Interpretation of the function represented by each icon (1=accurate, 0= incorrect). Button icons were presented without text labels.

- Icon size (3 x 3 cm), use of unlabeled icons, and use of a homogenous palette color were rated using a binary score (1= satisfied, 0= not satisfied).

(ii) In the Shopping List application user's interpretation of product category button icons was rated (1=accurate, 0=incorrect). Button icons were also presented without text labels (Fig. 3).

Fig. 3. Product category button icons. From left to right: Fruits, Vegetables, Meats, Beverages, Cleaning products.

Navigation and control menus

Usability of the following graphical navigation elements was assessed by measuring task duration and number of errors.

(i) Use of the NumericUpDown control to select the number of items by clicking on an up or down arrow in the Shopping List (Fig. 4). Task was repeated twice.

Fig. 4. NumericUpDown control

(ii) Use of graphical navigation elements in the Agenda:

(a) Back and forward arrows to select the month (Fig. 5).

(b) "PLUS" button to open the window to enter event details (Fig. 6).

(c) "ADD" button to confirm the appointment once event details were entered (Fig. 7).

Fig. 5. Month back and forward arrows

Fig. 6. PLUS sign button to open the window to enter details

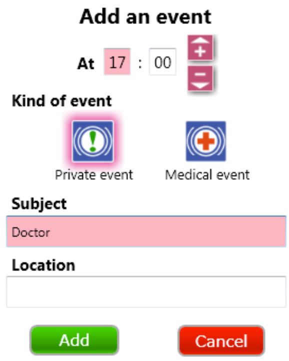

Fig. 7. ADD button to confirm the event after entering event details

Results

Button Icons

Main Menu Icons

Results showed that approximately two-thirds (66%) of the participants gave an accurate interpretation of button icons (Fig. 8). However, there was a single exception concerning the Robot Control icon, which obtained a very low score (9%). Indeed, average score of accurate interpretation for all icons, excluding the Robot Control, was of 73,12%.

Among the icons that were accurately interpreted by the majority of participants were the Weather Forecast (81%), the Medication Reminder (81%) and Web Games (90%). Moreover, both groups (MCI and HC) were very similar in their percentage of accurate interpretation.

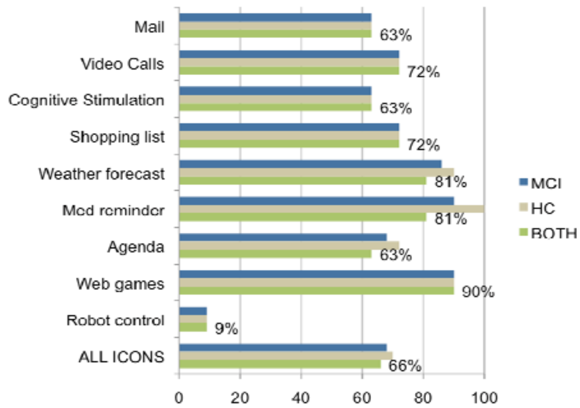

Fig. 8. Percentage of accurate interpretation of Main Menu button icons. Mean values are presented for both groups.

With respect to icons' features, most participants found the actual icon size acceptable (72,7%). In contrast few of them (18%) were satisfied with the use of unlabeled icons. Actually, the majority of respondents considered that the use of text labels could improve icon interpretation. Also, over half of the participants (54,54%) were satisfied with the use of a homogenous color palette.

Shopping list icons

Interpretation results of product category icons from the Shopping List were rather heterogeneous. Some icons obtained high scores: Fruits (100%), Vegetables (77,27%), and Meats (86,36%). In contrast, Beverages (54,54%) and Cleaning Products (36,36%) obtained middle-to-low scores.

Control menus

NumericUpDown control

Some difficulties were observed in both groups with regard to the first and the second use of the NumericUpDown control represented by the mean number of errors (Table 2). Still, participants in the MCI group were slower and made more errors than HC when using this element (Fig. 9, Fig. 10).

An interesting result was the reduction of number of errors when using the NumericUpDown for the second time, particularly for participants in the MCI group, (Fig. 9). There was also a reduction in task duration for both groups between the first and the second use of the control (Fig. 10).

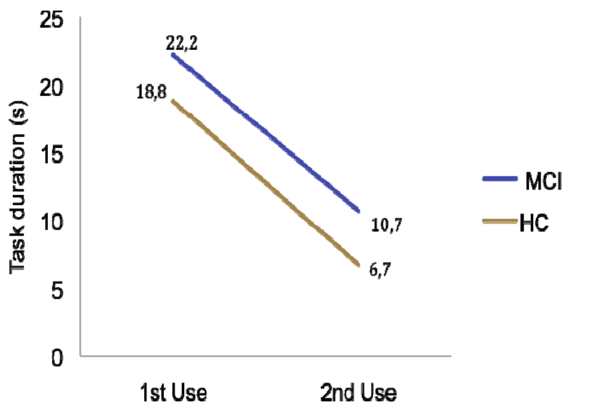

Fig. 9. Mean number of errors by group when using the NumericUpDown control for the 1st and 2nd time

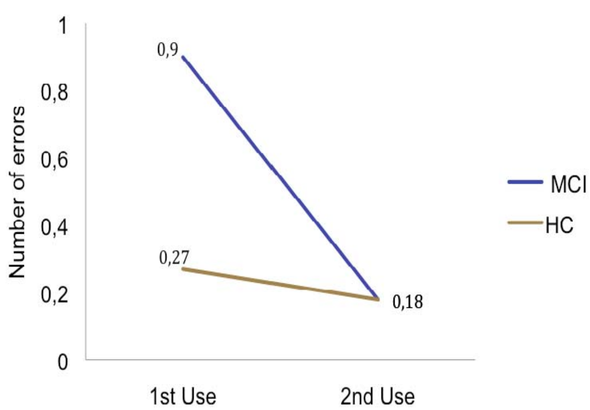

Fig. 10. Mean task duration by group when using the NumericUpDown control for the 1st and 2nd time

Table 2. Mean values of task duration and number of errors (E) when using the NumericUpDown control for the 1st and 2nd time

Group	Duration 1st use (s)	Duration 2nd use (s)	Duration 1st + 2nd (s)	Errors 1st use (Mean)	Errors 2nd use (Mean)	Errors 1st + 2nd (Mean)
MCI	22,2	10,7	16,4	0,9	0,18	0,54
HC	18,8	6,7	12,7	0,27	0,18	0,22
BOTH	20,5	8,7	14,6	0,58	0,18	0,38

Graphical navigation elements in the Agenda

Results related to the use of navigation elements in the Agenda task, such as the Back and Forward arrows (B&F), the PLUS sign, and the ADD button revealed the difficulties that users experienced (Table 3). Older adults in both groups had some problems understanding the function of these navigation controls, in particular the B&F arrows to select the month and the PLUS sign to open the window for entering event details in the Agenda. However, comparing task duration for the use of the three navigation controls results showed that participants in both groups (MCI and HC) were faster when using the ADD button than the other two navigation controls.

Table 3. Mean values of task duration and number of errors (E) in the use of navigation menus by group

Group	B&F (s)	B&F (E)	+ Sign (s)	+ Sign (E)	Add (s)	Add (E)
HC	24,7	0,39	19,4	0,54	15,6	0,36
MCI	22,7	0,36	27,7	0,54	9	0,36
BOTH	23,7	0,37	23,53	0,54	12,32	0,36

DISCUSSION

In this study we assessed initial usability of some graphical elements of the interface of a social assistive robot. Taken as a whole results highlighted that older adults experienced particular difficulties when using some of these graphical elements for the first time but that they were capable to use the system after receiving some guidance. Furthermore, this study has provided us empirical evidence of GUI usability barriers that affect users performance and that require some design modifications.

Button Icons

Correctly interpreting icons is particularly important to perform tasks with a GUI that uses these graphic elements to convey information. In our study results suggest that accurate icon interpretation was associated to the familiarity users had with the function or image depicted. The concreteness of the images, this means the representation of real world objects, seemed to contribute as well to icon interpretation. These observations are in complete agreement with

previous studies showing that familiarity and concreteness influence icon comprehension[21,22].
For instance, in the Main Menu task, icons that obtained the highest interpretation scores represented familiar images for the participants (a sun for Weather Forecast, a syringe for Medication Reminder, and a chessboard for Web Games). On the contrary, older adults showed more difficulties understanding icons representing novel functions, such as Email, Cognitive Stimulation, and the electronic Agenda. In fact, the images used for these icons were more abstract and the link between image and function was in these cases less direct (e.g. a person finding the solution for a crossword puzzle for Cognitive Stimulation, an envelop with an @ sign for Email). Besides, interpretation difficulties observed with the Robot Control icon confirmed the importance of context when inferring the meaning of a symbol. In fact, in our study participants had never seen the robot in movement before the task.
Since older adults can exhibit difficulties in understanding the meaning of unfamiliar icons it seems important to find alternative solutions to represent these novel functionalities. One solution could be the use of efficient metaphors involving familiar physical objects[23]. In fact, since SAR constitutes a recent research field it is very likely that older users lack knowledge about the functions a robot can provide. An interesting experiment could be to explore with representative end-users the semantic fields related to novel functions in order to decide the best pictographic representation. Another solution could be to study the retention of icons' meaning over time, by conducting repeated assessments.
Concerning product category icons in the Shopping List interface, low interpretation scores for Beverages and Cleaning Products icons could be explained by the similarity between the two images used for these icons, which may have lead to misinterpretation. Besides, these icons had a small size (1,5 x 1,5 cm), factor that could have made difficult visual discrimination.
Related to icon's feature (size, use of labels, colors) one limitation of our study was that participants were not confronted to alternative versions of the GUI (labeled icons, icons with differentiating colors). Users' preferences were based exclusively on their opinion of how an alternative design would look like. When conducting usability assessments comparing alternative designs, GUIs that offer similar functionalities but different navigation layouts, could contribute to better assess users preferences[24].
Using text labels have proven to improve icon comprehension in elderly users[21]. A similar effect should be expected for elderly with MCI. Besides, text labels could compensate memory deficits that can hinder usability. In this sense, a compelling research question is whether the use of labels would help to reduce the time a user requires to search for a particular icon on a display. Repeated observations could also help to understand if icon usability over time is more dependent on the use of text labels, images, or even on its position on the interface[25].

Control menus

Results suggest that difficulties faced by older adults concerning the use of the NumericUpDown Control, and the other navigation menus, were related to their lack of knowledge concerning GUI navigation. This is highly plausible since many elderly individuals have had very limited opportunities of learning to use computer-based systems[26]. However, our results confirmed that learning to perform GUI basic actions is possible for elderly, either cognitively healthy or impaired. Some strategies could help to improve the understanding of navigation controls, for example in the Agenda task participants spent less time when using the ADD button than the other two, probably because the button was labeled.
As for previous GUI elements, we corroborated how important it is to study usability over time and not only in a first-use test, to explore the role of learning processes. Older adults benefit from repeated practice with guidance messages when learning to perform basic and complex operations with a computer-based system[27]. In our tests the moderator provided guidance when the user made repeated errors. Automatic solutions should be conceived to offer a direct learning support through the GUI. One of the advantages of SAR is that Artificial Intelligence can be used to provide multimodal guidance for task execution in a robot-user collaborative relation (e.g., voice messages, speech-to-text recognition, engagement and emotional tracking) [7,8].

CONCLUSIONS

Incremental design constitutes a useful method to develop technological applications for older adults since it permits to take into account users characteristics for the design of each GUI element.

This study is an example of a successful UCD process that helped us to identify key design features that will influence use of SAR and, specifically GUIs, by older adults.

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