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What has happened today? Memory visualisation of a robot companion to assist user's memory

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Abstract

Purpose – *Memory deterioration is one of the most common cognitive issues associated with ageing. Not being able to remember daily routines (e.g. taking medicine) poses a serious threat to personal independence. Smart homes combined with assistive robots have been suggested as an acceptable solution to support the independent living of the older people. The purpose of this paper is to develop a memory visualisation tool in robots and smart houses following the hypothesis that the use of memory aids will have a positive effect on the cognitive capabilities of older people.*

Design/methodology/approach – *This paper describes the iterative development process and evaluation of a novel interface to visualise the episodic memory of a socially assistive robotic system which could help to improve the memory capabilities of older users. Two experimental studies were carried out to assess usability, usefulness and envisaged use of such a system.*

Findings – *Results show that users find a memory tool for the robot useful to help them remember daily routines and when trying to recall previous events. Usability results emphasise the need to tailor the memory tool to specific age ranges.*

Originality/value – *The research to date provides support that for assistive robots to be a truly useful tool, they must be able to deliver episodic memory visualisation tools that enhance day-to-day living (i.e. environmental information, data on the robot's actions and human-robot interaction episodes). Equipping a robotic companion with a novel memory visualisation tool for episodic memory is an excellent opportunity to have a robot provide such a functionality (cognitive prosthetics).*

Keywords *Dementia, Cognitive assistance, Human-robot interaction, Memory visualization, Robot companion, Social robots*

Paper type *Case study*

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The experiment presented in this paper is part of the EU FP7 Project ACCOMPANY-Acceptable robotiCs COMPanions for AgeiNg Years (Accompany, 2012). This project aims at generating an integrated system in which a robot companion is combined with a smart-home environment in order to facilitate independent living for the elderly. The authors would like to thank Nathan Burke, Kheng Lee Koay and Joe Saunders for their technical assistance and helpful collaboration.

1. Introduction

Today, 800,000 people in the UK have a form of dementia, something which costs the British economy £23 billion a year (The Alzheimer's Society, 2014). By 2040, the number of people affected is expected to double (The Alzheimer's Society, 2013) – and costs are expected to triple. The main symptom of dementia is memory impairment causing a decline in cognitive and executive functioning. Normal everyday activities (e.g. keeping appointments, remembering recent events, preparing meals, etc.) are affected because of this condition, with a deterioration of the individual's condition over time. In addition to finding a cure, the need has been recognised to provide a better quality of care for people with memory impairment with facilities that enhance day-to-day living. Assistive technologies could be useful to maintain the independent living of persons in early stages of dementia (The Alzheimer's Society, 2011). The use of socially assistive robots in patient care could assist people with memory impairment to maintain their highest possible level of independence, reduce the burden of family caregivers and improve their quality of life (Luengo-Fernandez *et al.*, 2010). Since 2004, through the participation in different EU research projects (Cogniron, 2004; Lirec, 2009; Accompany, 2012) our research group has been developing tools and enabling technologies for robots and smart houses (Dautenhahn, 2007, 2013) that can provide assistance for autonomous living for older people, providing physical, cognitive and social support (e.g. remind the user to take medicine or to send a birthday card).

This paper proposes the integration of a memory visualisation tool into an existing assistive smart-home system in order to retrieve and visualise information about the smart house, the robot's actions and the interactions between the user and the robot. This episodic memory visualisation tool shows a daily review of events relevant to the user.

The paper is structured as follows. First, we present the relevant background information and literature review and how they relate to our work. Second, we introduce our memory visualisation interface for robotic companions. Next, we present results from two formative studies. A final conclusion and discussion concludes the paper.

2. Background

Dementia is one of the main causes of disability in later life (Department of Health, 2009). In 2010 there were in the UK over 800,000 people to be suffering from late onset dementia (Luengo-Fernandez *et al.*, 2010) and it is estimated that a further 62,000 people are developing Alzheimer's each year (The Alzheimer's Society, 2011). By 2021, the number is expected to rise to one million and by 2051, projected to exceed 1.7 million (The Alzheimer's Society, 2013). Estimates say that one in three people over 65 will die with a form of dementia (The Alzheimer's Society, 2014). Dementia costs the UK approximately £23 billion per year, about twice as much as cancer, yet UK spends nearly 12 times as much on cancer research than it does on researching dementia (Luengo-Fernandez *et al.*, 2010). Delaying the onset of dementia by five years would halve the number of deaths from the condition, saving 30,000 lives a year (The Alzheimer's Society, 2014).

Often long waiting lists exist for sheltered housing projects, homes for the older, nursing homes and other care facilities. The majority of people with dementia will have to cope in their own homes. Most older people wish to stay at home in their familiar environment as long as possible, in line with policy makers' aims to release the pressure on the social system. However, this generates great pressure on informal carers, alongside the increasing shortage of professional carers. In fact, dementia will cost English businesses $3 billion per year by 2030 (already the disease cost English businesses £1.6 billion a year) driving people out of work to care for their relatives and cutting the size of the over 65+ workforce (The Alzheimer's Society, 2014).

Although finding a cure for dementia is important, researchers also recognise the need to provide a better quality of life with facilities and tools that enhance day-to-day living. Assistive technologies can help maintain the independent living of persons with mild cognitive impairment or early stages of dementia (Luengo-Fernandez *et al.*, 2010; The Alzheimer's Society, 2011), for example, by reminding them of what to do next, improving their memory capabilities. The use of smart houses in combination with socially assistive robots in patient care is a reality and can assist people with memory impairment to maintain their highest possible level of independence, reduce the burden of family caregivers and improve their quality of life (Luengo-Fernandez *et al.*, 2010).

Equipping a robotic companion with a visualisation tool for episodic memory is an excellent opportunity to have a robot providing cognitive prosthetics[1]. Such memory visualisation can support the user in remembering past events from the human-robot interaction history. Potentially, this ability to explore interaction histories could enable older persons as well as third parties (e.g. technicians, carers, family and friends) to monitor, maintain and improve the robot's abilities and services. There is evidence in human-human communication that people remember more information more efficiently together (sharing memories or remembering together) than they do alone (Barnier *et al.*, 2008; Harris *et al.*, 2008) and a repeated conversation might facilitate proper activities (Kindell *et al.*, 2013). Memory rehearsal is useful for the retention of memories and involves repeating information in order to get the information processed and stored in memory (Goldstein, 2011). Therefore, this paper describes the development of an interface to visualise the episodic memory of the system which could help to improve the memory capabilities of older users.

Memory visualisation has been studied previously as a means to help understanding computational agents' memory contents (Ho, 2005). Subsequently this has been used in an educational game for teaching children how to cope with bullying (Ho and Dautenhahn, 2008). This interface was later enhanced to be used by children with autism (Ho *et al.*, 2009a), whereby a software interface allowed a user to "travel back in time" to re-experience a particular situation in the story to recognise the characters' emotional states – aiming to assist and thus improve their skills of mind reading. The design of an interface for visualising personal memory is presented in Kremecek *et al.* (2009). Different from our work, it allows only browsing for past events based on a combination of audio and video recordings, and the interface is only a visual prototype that is not linked to a backend data system. In our previous research we started to investigate the visualisation of episodic memory or interaction histories between a human user and a robot (Ho *et al.*, 2013), which led to the work presented in this paper.

In order to develop a memory visualisation tool for older users that provides cognitive assistance, our first goal is to design, implement and test an appropriate memory visualisation tool. Two user studies were conducted in order to allow for iterative system development and involvement of participants with different ages.

Both experiments aim to answer three general research questions:

RQ1. How usable do participants find the memory visualisation tool?

RQ2. How useful do participants find the development and use of such a tool?

RQ3. What type of modifications to the visualisation tool do participants suggest?

Concerning *RQ1*, we expected that the users would find the memory visualisation tool easy and clear to use. In case of *RQ2*, we expected that users would find the tool useful for remembering and reviewing daily routines. This expectation is based on the hypothesis that memory rehearsal is useful for the retention of memories (Goldstein, 2011). For *RQ3* we expected the users to comment on the interface and suggest modifications to the memory visualisation tool which we did not foresee in the design and development of the interface.

Due to the novelty of the memory visualisation tool, our empirical studies focused on system evaluation with healthy participants in order to gain baseline feedback data on the use and usefulness of the design.

3. Experiment 1 – initial episodic memory visualisation interface

The aim of the tool is to show a daily review of events relevant to the user. Since its design and contents reflects on the effectiveness and usability of the memory aid, very high importance is given to the way the information is presented and visualised and what information is relevant for people with memory impairment. In this section we present an early implementation of the visualisation tool and its evaluation with a formative study. We present here the questionnaires and results which will be later on used as feedback to improve our initial implementation.

The system consists of a robot companion, a smart home and a user. We utilise a commercially available robot, the Care-O-bot3®, manufactured by Fraunhofer IPA (Reiser *et al.*, 2013) sited in a fully sensorised house. The visualisation interface is fully integrated in a computational memory architecture planned to support episodic, procedural and semantic aspects of memory. For a full description of the technical implementation of the episodic part of the architecture (see Saunders *et al.*, 2013).

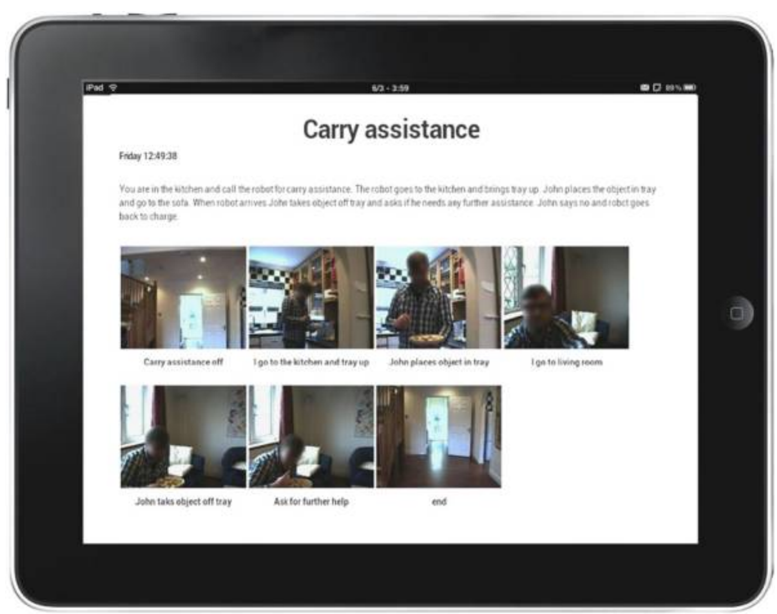
Through a touch interface the robot's interaction history can be retrieved for visualisation. The way the information is presented and visualised to the user is in a "Twitter-like" structure (Figure 1). Each event shows the name of the event in bold, a short description and a representative thumbnail. The events can be sorted by the user in ascendant and descendant chronological order. The user also can search by name through the event name. When the user

Figure 1 Episodic memory visualisation interface presented in a Twitter-like structure

taps an event from the Twitter-like list a more detailed description of the event is provided through the interface (Figure 2) which contains the name of the event, a time stamp, a full narrative description of the event and a whole sequence of pictures from the robot's view describing the sequence in a chronological order with the caption of each picture.

The participants were shown the interface which visualised a daily review of activities of a previous user called John. Participants were then given a short questionnaire which could only be answered

Figure 2 Details of the "carry assistance" event



reviewing the interface. The questions were of the type "What was John doing when the robot reminded him to drink" or "What was John eating when the robot asked if he needed any assistance?" or "What colour is the cup John drinks with?". The experimental session for each participant included an introduction, completion of consent and demographics questionnaires, the actual study with participants using the interface and final questionnaires. The sessions lasted about one hour per participant, including 15-30 minutes on the actual interaction.

3.1 Demographics

There were 20 participants in the sample, four males and 16 females. The age ranged from 20 to 67. The mean age was 43.95 and the median age was 49. The computer usage of the participants suggests that the majority of participants used computers for work/studies as well as for social reasons. There was a split in the sample, however, in that about half of the participants used computers for recreational reasons, such as games. None of the participants programmed computers. The mean number of hours spent on computers in the sample was 35 hours ($SE = 2.98$) with a median number of hours of 33. Only one of the participants had had any experience with robots. The sample was an opportunity sample recruited either directly from adverts on the university intranet or who had been made aware of this research through friends/relatives. In this study there were no specific inclusion criteria in order to involve a broad range of participants.

3.2 Measurements

There were three different measures in the questionnaire:

- The system usability scale (SUS) (Brooke, 2010) measures the usability of a system as a unidimensional construct. Scores can range from 0 to 100 (results from using this scale suggests that 70 suggests overall high usability Bangor *et al.*, 2008).
- The ad-hoc Likert scales questions addressed the general usability of the interface, as well as some issues related to accessing a robot's memory in general (see Table I).
- Open-ended responses.

Table I Ad-hoc Likert scales

Type	*Question*	*Ad-hoc Likert scales*
Usability questions	How clear was it to view the information?	Very clear-very unclear
	How easy was it to use?	Very easy-very difficult
	Would you like to see the events as a video rather than static pictures?	Definitely yes-not at all
General questions	Do you think it is useful to review interactions with a robot?	Very useful-not useful at all
	Do you think that a history of interactions would be useful when trying to recall previous interactions?	Very useful-not useful at all
	Do you think the memory visualisation is useful to find out about erratic behaviours of the robot?	Very useful-not useful at all
	How would you feel about the robot storing all your daily interactions?	Very comfortable-very uncomfortable
	Do you think a feature like this would help you to get a better overview of your daily routines?	Definitely yes-not at all
	Do you think a feature like this would help you remember routines?	Definitely yes-not at all
	How would you feel about having a robot reminding you about events?	Very comfortable-very uncomfortable
	Would you use a memory system like this to help monitor an older family member?	Definitely yes-not at all
	Would you find the past events shown by the robot useful to create conversation topics when you talk to friends?	Very useful-not useful at all
	Would you like the robot to store conversations?	Definitely yes-not at all

3.3 Results

SUS. The mean SUS score in the sample was 77 (SD = 14.41, 95 per cent; CI = 70.68-83.32) and the median was 75. This was significantly different from the expected mean of 68 ($t(19) = 2.79$, $p = 0.01$). This suggests that participants found the system overall acceptable in terms of usability.

Ad-hoc Likert scales. The results from the ad-hoc Likert scales in Figure 3 show that the 95 per cent confidence intervals of the questions regarding the usability and clearness of the memory interface are below the neutral score of 3. However, the participants were more divided as to whether or not they wanted to use video instead of static pictures.

General Likert responses. Figure 4 presents the results from the general Likert responses and shows that the 95 per cent confidence intervals of the participant responses to these questions are below the neutral score of 3, meaning that the participants were overall positive towards all aspects of the utility of the memory visualisation interface. With regards to security and comfort the responses are as well below the neutral score with the exception as to whether or not they would want conversations stored.

Open-ended responses. Responses to the open-ended questions "Is there anything you would change?" and "What other information would you add to the events, if any" suggest the most common type of comments concerned the size of the images. Participants wanted larger photos and/or being able to zoom in parts of the images.

Participants also suggested other types of information that could be recorded, including chronological overviews of activities, visitors to the house and technical information about the robot. In addition they suggested that the facility to check the robot's memory could be used by carers remotely to alert them to potential problems that the user might have.

4. Experiment 2-improved episodic memory visualisation interface

The results and feedback from experiment 1 informed the improvement of the interface and the re-evaluation through an iterative process. The most common type of comments concerned the size and quality of the images. Participants wanted the photos to be larger and/or being able to zoom in on parts of the images to answer better the questions. Moreover, timestamps were suggested. According to the results and the open-ended responses from the initial study, those are the features that the improved memory tool will focus on.

Figure 3 Usability Likert scale responses

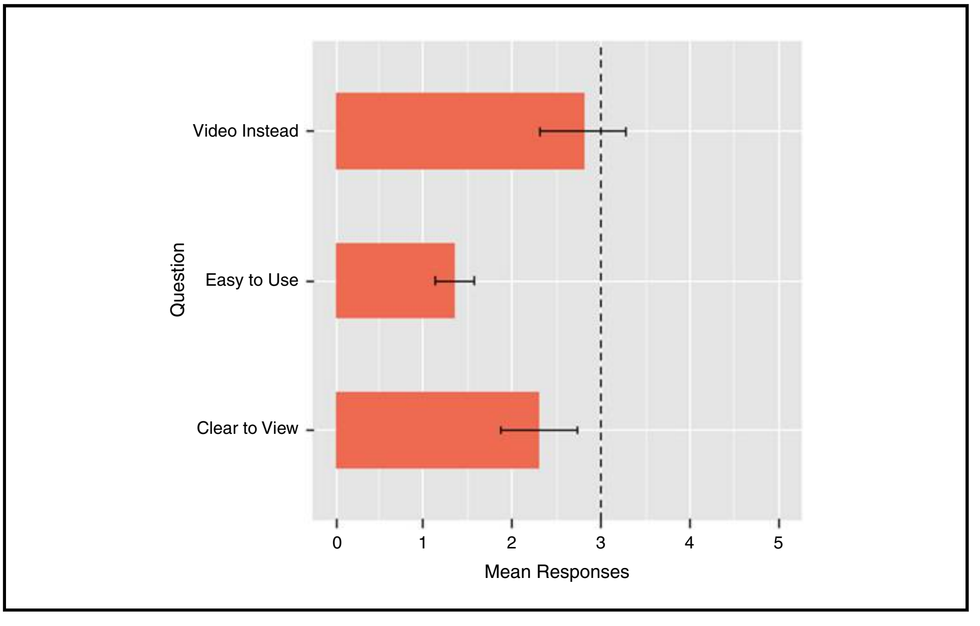
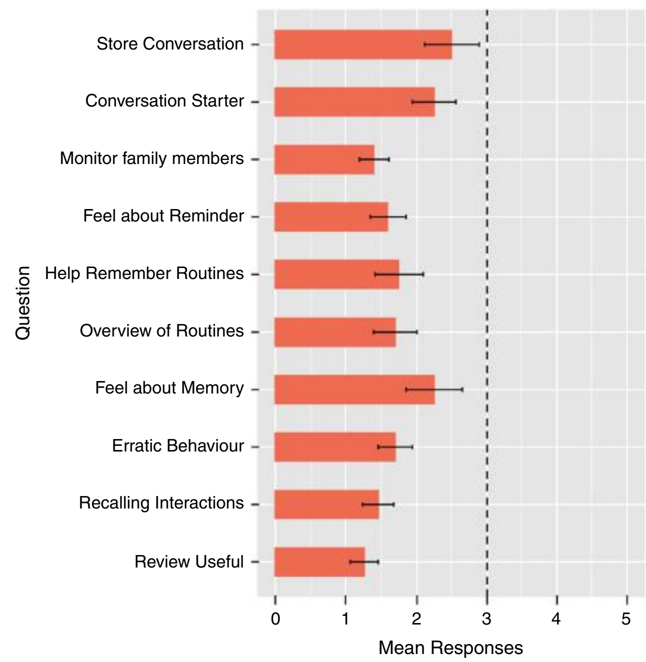


Figure 4 General Likert scale responses



To address the feedback from the initial study, the interface now includes a new screen that comes up every time a picture gets tapped on. This new screen contains a full size image, a short description of what the user is doing and a time stamp indicating when the photograph has been taken. Moreover, since the addition of a new screen increases the navigation hierarchy, in order to ease the navigation between screens a big and clear back button was added, which takes the interface to the previous screen. The improved episodic memory visualisation interface can be seen in Figures 5 and 6.

As in experiment 1, in experiment 2 participants were given the interface with an interaction history that they used to answer questions.

4.1 Demographics

There were eight participants in sample 2, three males and five females. The sample was an opportunity sample recruited either directly from adverts on the university intranet or who had been made aware of this research through friends/relatives. The sample consisted either of people above the age of 70 living independently or people who looked after older relatives/friends. The age of the participants ranged from 58 to 85 with a mean age of 72.3. The distribution of age suggests an even distribution in the sample, which is smaller than the initial experiment.

4.2 Measurements

The measures in the questionnaire are the same three as used in the initial memory interface questionnaire, SUS, ad-hoc Likert scales (Table I) and open-ended responses.

4.3 Results

SUS. The SUS scores for the improved memory visualisation interface ranged from 37.5 to 85. The mean score was 64.38 and the median score was 70. This was not significantly different from the expected average of 68 ($t(8) = -0.64$, $p = 0.54$).

Figure 5 Improved memory visualisation interface for the "carry assistance" event

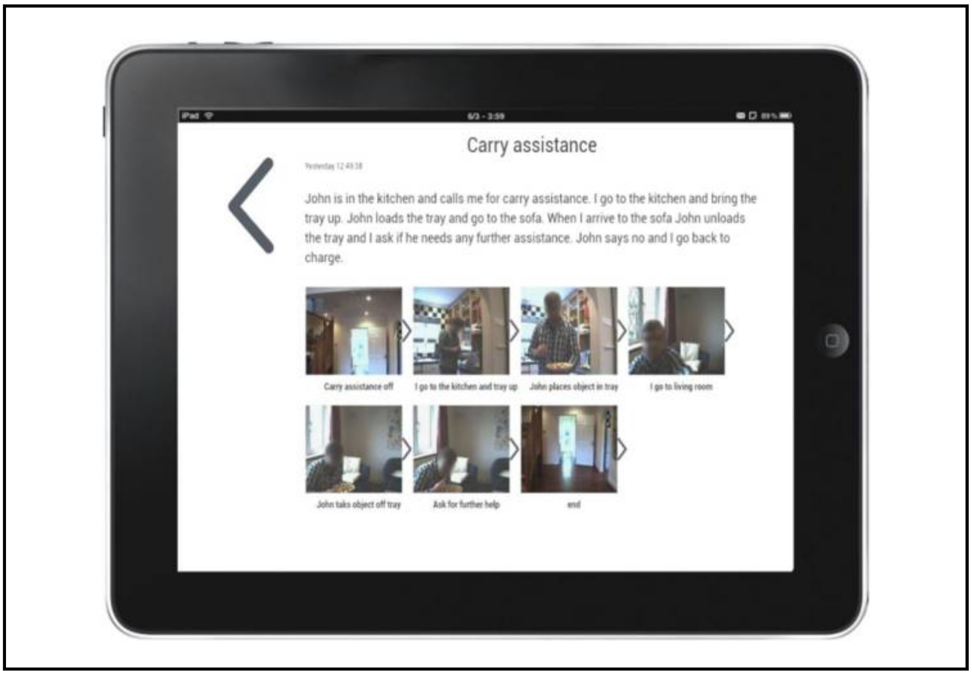
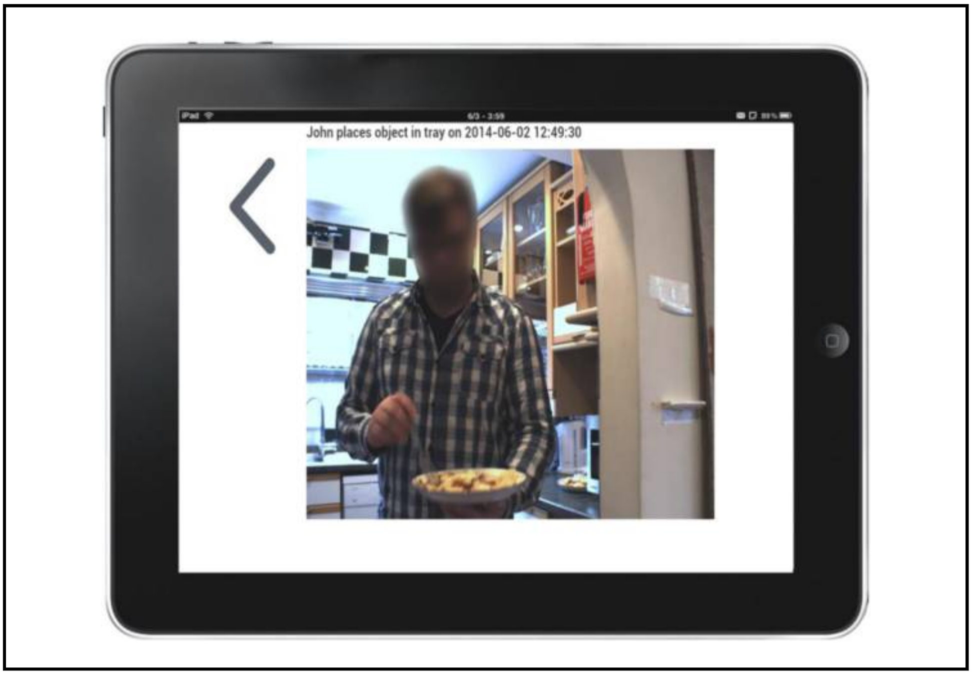


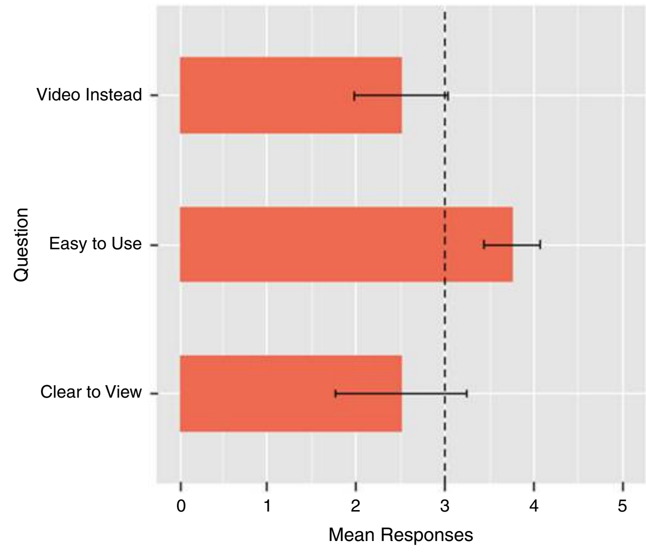
Figure 6 New screen of the full size photographs added to the memory interface



Ad-hoc Likert scales. The results from the ad-hoc Likert scales are presented in Figure 7.

Participants scored the usability of the interface around the neutral value of 3. While five participants stated that it was "Very Easy" or "Easy" to use, two participants rated it as "Difficult". A majority of participants rated the clarity of the interface as "Unclear". Some of the participants suggested to add video recordings.

Figure 7 Improved interface, usability Likert scale responses

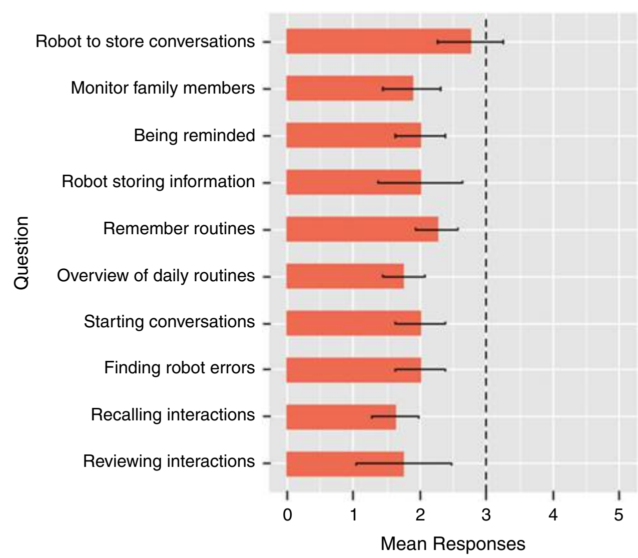


General Likert responses. Figure 8 presents the results from the general Likert responses.

The responses to these questions are overall below the neutral score of 3 to all aspects of the utility, security and comfort of the visualisation memory interface. The only response with a score around 3 is with regards to the storage of conversations by the system.

Open-ended responses. The responses to the open-ended questions "Is there anything you would change?" and "What other information would you add to the events, if any?" suggest that the majority of comments concerned the quality of the pictures. The participants voiced concerns with the brightness of the images used to illustrate the events. There were also some concerns about data protection for the visitors/care workers of owners of such robots.

Figure 8 Improved interface, general Likert scale questions responses



5. Discussion

This paper described the development process and empirical evaluation of a novel memory visualisation tool as part of a socially assistive robotic system. The results and responses from both studies highlight several points. First, let us consider the characteristics of the sample in both cases. In the initial study there is an uneven distribution of ages in the sample while in the second study the age range is more even with a smaller sample.

With regards to the SUS the score of 77 in the initial study, above the 70 score, suggests of an overall high-usability score (Bangor *et al.*, 2008) while in the second study is 64.38, slightly lower but also suggestive of an overall good usability score. This result is well backed up by the responses to the usability ad-hoc questions, which in the initial study the participants found the memory interface clearer to view and easier to use than the neutral score of 3, while in the second study the participants were divided in how easy the interface was to use. These results confirm our assumptions and expectations from *RQ1*.

The responses to the general questions suggests that overall, participants in the initial study felt that the robot memory feature was quite useful and could be used for helping with recalling interactions, routines and error tracking on the robot, which confirms our expectations from *RQ2*. In the initial study participants were also overall quite comfortable with the robot reminding them of activities, and would use such a system to monitor vulnerable family members. The responses in the second study were very similar; participants were overall positive to all aspects of the utility of the memory visualisation system. Moreover, these results suggest that participants, with one exception, felt comfortable with the robot storing information about them. There was no such discomfort for being reminded of events. Seven of the eight participants would use a system like this to look after an older family member. It is interesting to note that in both studies the participants were divided as to whether or not they felt comfortable with the system storing conversations.

As expected, the open-ended responses provide a wider range of comments and suggestions of the interface, which confirms our expectations from *RQ3*. In the first study the most common type of comments was regarding the size and quality of the images. The participants wanted the photos to be larger and/or being able to zoom in on parts of the images. There was a variety of suggestions for what else the robot could store and report back to the user, timestamps, the internal states of the robot, specific problems encountered during the day as well as registering visitors to the property. One participant wanted the footage to be available remotely, so that family members could review it off-site, but one comment questioned whether or not the primary user might be able to trick the system so that it would seem that they performed certain tasks, and another.

In the second study the majority of comments were regarding the quality of the pictures. The participants voiced concerns with the brightness of the images used to illustrate the events and the need of the robot to have a full built-in flash. One participant pointed out that such a facility required the buy-in of all visitors and carers in the home of the person using the robot, while another participant wanted to have records of sleep periods.

6. Conclusion

Many studies support that socially assistive robots could physically, socially and cognitively benefit older people with memory impairment. Our research to date provides support that for assistive robots to be a truly useful tool, they must be able to deliver episodic memory visualisation tools that enhance day-to-day living (i.e. environmental information, data on the robot's actions and human-robot interaction episodes). Present robot companions systems lack such episodic memory visualisation which could aid people with memory deterioration, helping them to remember normal daily routines or keeping their memory active by reviewing past events. Equipping a robotic companion with a novel memory visualisation tool for episodic memory is an excellent opportunity to have a robot provide such a functionality (cognitive prosthetics).

The design and implementation of an episodic memory interface for robots companions for older users is a long and iterative process which undergoes different stages. Initially, the memory tool was submitted to an overall evaluation with users of a wide age range and backgrounds.

Very useful findings were used to improve this initial implementation which was then submitted to an iterative evaluation with older users. Therefore the difference in the results is not unexpected. The concerns raised in the second study did not show up in the initial experiment. Designing for older users requires custom tailored implementations and we need to design them better. Naturally, the development of our memory visualisation interface is an undergoing process and this paper reports the findings along the way.

Future work will aim at testing and evaluating the positive effects of using the memory visualisation tool on participants' cognitive capabilities. The effects of the memory visualisation tool acting as a memory aid would be helping the users to remember daily events or keeping their memory visualisation tool active. For this purpose, a long-term study would be necessary in order to test and evaluate the cognitive impact on the target users. While in the present paper each participant only interacted with the system in one session, it is likely that long-term use will change people's views on use and usefulness. In order to reach a wider audience and increase the sample sizes of our studies, future work may use the outcomes from the field trials and translate them into an online video survey with older people from sheltered housing, homes for older people, nursing homes and other care facilities.

Note

1. Defined as an electronic/computational/robotic device that extends the capability of human cognition or perception (Oxford Dictionary).

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