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Abstract: As life expectancy increases, the number of people affected by negative consequences of cognitive aging is also expected to rise. With a view to develop preventive and rehabilitative strategies, a cognitive intervention programme has been designed on the humanoid robot Pepper, integrating cognitive games through an easy-to-use interface alongside further interaction opportunities, to increase participant's motivation. The robot's behaviour has been customised to the user in terms of personality (interaction distance, verbal feedback) and personalised activities; crucially, it performs a cognitive assessment and can recommend games tailored for each user and their stage of training. By developing an associated external web-based platform, professionals may easily monitor and analyse users' data. Finally, a part of the prototype has been tested with several experts and users, including older adults, to evaluate the interaction and specify possible improvements. Positive results have been received, highlighting that the more sociable the robot appears to be, the more satisfactory is the overall experience. Further developments on social robots delivering cognitive training appear to constitute a great potential to support healthy aging with adaptations to various environments, such as private homes, community centers and nursing homes, not to mention offering increased flexibility in social distancing situations, such as for the current Covid-19 crisis.

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Abstract

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Highlights

- A social robotics methodology for caregivers to guide a semi-autonomous cognitive training routine for people with MCI or AD.
- Personalised robot behaviour, adapting human-robot distance, encouragement style, interaction activities, and game complexity to the user, by a cognitive assessment system.
- Caregiver-robot interface, to keep track of user progress and dynamically adjust training parameters on the robot setup.
- Preliminary user-study for evaluation of robot acceptability when playing cognitive games, with positive outcome.

Robotic rehabilitation for cognitive impairment

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Abstract

As life expectancy increases, the number of people affected by negative consequences of cognitive aging is also expected to rise. With a view to develop preventive and rehabilitative strategies, a cognitive intervention programme has been designed on the humanoid robot Pepper, integrating cognitive games through an easy-to-use interface alongside further interaction opportunities, to increase participant's motivation. The robot's behaviour has been customised to the user in terms of personality (interaction distance, verbal feedback) and personalised activities; crucially, it performs a cognitive assessment and can recommend games tailored for each user and their stage of training. By developing an associated external web-based platform, professionals may easily monitor and analyse users' data. Finally, a part of the prototype has been tested with several experts and users, including older adults, to evaluate the interaction and specify possible improvements. Positive results have been received, highlighting that the more sociable the robot appears to be, the more satisfactory is the overall experience. Further developments on social robots delivering cognitive training appear to constitute a great potential to support healthy aging with adaptations to various environments, such as private homes, community centers and nursing homes, not to mention offering increased flexibility in social distancing situations, such as for the current

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[1]This work was carried out while Sara Cooper was at Middlesex University, during her BSc in Biomedical Engineering.

Covid-19 crisis.

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1. Introduction

Rehabilitation robotics is most often associated with physical aspects, such as in physiotherapy, or in assistive technologies. A less developed subfield is that of cognitive rehabilitation aided by social robots.

This paper presents a social, assistive robotic system, based on the small humanoid robot Pepper, able to play cognitive games with users in an adaptive way, according to skill profile and previous interaction records. The robot can perform cognitive assessment on new subjects, and subsequent customised cognitive games, while allowing medical professionals or carers to keep track of subjects' progress. The system is particularly targeted at older adults with mild cognitive impairment.

With the constant increase of life expectancy, the number of people suffering from MCI (mild cognitive impairment) is growing quickly [1]. Alzheimer's Disease International reported that 50 million people worldwide are living with neurocognitive disorders, and that this number will almost double every 20 years, to reach 152 million by 2050 [2]. MCI may represent a transitional state towards neurocognitive disorders [3]. It can impact different cognitive areas (attention, memory, executive functions, etc.) without affecting activities of daily living (ADL) and social functions [4]. Early detection and treatment of MCI patients is thus very important, since these individuals are very likely to develop Alzheimer's disease (AD) later on [5].

It is thus advised to perform cognitive rehabilitation earlier on for individuals affected by MCI, since they are typically very responsive to it, and receive positive benefits from multi-centric rehabilitation approaches [3]. Treating them can delay the onset of more debilitating impairments, which can have a big impact on their quality of life, and prevent the high treatment costs of AD and similar disorders [6].

In fact, cognitive rehabilitation programs have been shown to be effective in improving the quality of life of affected people, but they are usually very expensive [7], and need different professionals depending on subjects' needs. Due to the repetitive, long tasks bearing a major burden to medical staff, and the difficulty and costs for users of accessing care centres, it is challenging to offer medical attention to everyone in need.

This is where computer-based cognitive rehabilitation is already playing an important role in extending the coverage of treatment beyond the current limits of people and care centres [8]. This approach has indeed shown positive outcomes against traumatic brain injury, amnesia, Alzheimer's Disease and others, but lacks the important contribution given by the physical presence of a therapist, and the fundamental sensorimotor components of cognition which are much reduced when interacting solely on a screen.

Considering all of the above, socially assistive robots (SAR) can be a cost-effective alternative to help reducing workload for caregivers, improving access to treatment, and providing support beyond the limits of standard computer based rehabilitation [9]. In cognitive stimulation therapy, robots can support and enhance the care, monitor multiple users simultaneously, and perform highly personalised training, increasing motivation for individuals in care, while providing continuous performance assessment [10, 11].

It is worth stressing that the aim of SAR is not to substitute caregivers or reduce their contact time with assisted individuals, but rather to provide additional treatment/support time, while improving the quality of time spent with professionals. For this, it is necessary to take into account the specific needs of the clinicians or carers as well as the target users in order to design proper robotic assistants, through the means of an interdisciplinary collaboration between the fields of psychology and robotics.

This study constitutes a step in such direction, introducing a prototype implementation of an integrated cognitive rehabilitation framework on a popular social humanoid robot. The framework here introduced offers a range of cognitive games aimed at treating different kinds of mild impairments. Game playing is supported by a variety of robot features, such as touchpad, tactile sensors, visual identification of people and moods, voice recognition and generation. The final system is able to perform an initial cognitive assessment of users, and design a customised exercising plan across different cognitive domains. Live and historic tracking and updating of progress allows it to offer a flexible training regime, which changes according to recent results, subject profile, and professionals' recommendations. A continuously updated database of progress for each person is always accessible to professionals, and the intervention is planned and monitored as a collaboration between professionals and the robotic system.

The structure of this paper is as follows. Sec. 2 overviews the related works on socially assistive robots for use in cognitive treatment, Sec. 3 describes the overall project framework, Sec. 4 details the implementation of the proposed cognitive rehabilitation system on Pepper the robot, Sec. 5explains the user-study conducted to validate part of the system and evaluate system acceptability, with a discussion on the achieved results, and Sec. 6 draws the final conclusions.

2. Related research

Encouraging preventive and innovative cognitive programs to enhance older adults' cognitive reserve, reducing hospital stays and encouraging home care could be a possible solution to reduce the social-economic impact of neurocognitive disorders. As an example, the worldwide cost of dementia was estimated in the United States to be of 818 billion dollars in 2015, with an increase of 35% by 2010 [12, 13, 14].

An important aspect to consider is the caregiver burden. Informal caregivers, such as family members, play an important role in caring for people with neurocognitive disorders, and the cost of informal care represents a conspicuous component of social costs [15]. Caregiver burden increases with Alzheimer's Disease severity [16]. Identifying possible interventions that can reduce the risk of neurocognitive disorder and/or alleviating the burden of caring for people with neurocognitive disorders would have great social-economic impact.

The notion that cognitive engagement is protective or supportive of cognition with age is reinforced by evidence that individuals who report high participation in mentally stimulating activities (e.g. reading, chess) show less cognitive decline, and the same happens with social activities. Furthermore, the use of enjoyable training exercises that are user-centred, and that foster participant's intrinsic motivation are considered pivotal to improve rehabilitation effectiveness [9, 17].

Examples of the above include computer-based cognitive training [9] (e.g. FitBrains [2] , CogniFit[3] or software packages such as Neuropsychological Training (NPT) [6]. It was found that older adults attending 15 hr/week of tablet computer interaction for 3 months had improved social cognitive functions and better skills in their activity of daily living (e.g. baking)

[2]https://five.agency/projects/brain-trainer/

[3]https://www.cognifit.com/

compared to two separate control groups (passive and active group) [18]. However, computer-based apps lack the positive aspects of human-human interventions.

Considering all this, socially assistive robots (SAR) can be a cost-effective alternative as they have shown to reduce stress of users in eldercare, improve communication and reduce feeling of loneliness [19]. When used specifically for training, they increase motivation and provide performance assessment [10]. They can offer multimodal interaction, making it easier and more natural for people to interact with [11], deliver higher quality care, monitor multiple users simultaneously. SAR can also facilitate client diagnosis, customise treatment and maintain records of clinical and home-based practice [20], as well as reducing the workload of the caregivers [21].

Different SAR have been developed to assist older adults with physical disabilities and with cognitive impairment, through social interaction. Some examples are: the robot PARO, for improving socialization and reducing psychiatric disorders [22]; Care-O-Bot [23], which helps to assist in home tasks (e.g. kitchen tasks); NAO robot, for upper-limb rehabilitation by giving verbal feedback on exercise execution[24], assisting children with autism [25], as well as foster learning through encouragement during cognitive games [26]. Krebs et al. [27] developed a robot that engage the user in a memory card game using verbal and non-verbal behaviours, while Tangibot [10] was designed as a home-care robot to offer functional support to carers and patients, track physical and psychological well-being and deliver therapeutic help, in particular to participants with memory problems, mild cognitive impairment or early dementia.

The robot Mini [11] can deliver cognitive stimulation to be used at home or in care homes in an autonomous way, using exercises previously set by professionals, ranging from temporal orientation, attention, perception, memory, executive function and language games. Tapus et al. [28] developed a SAR able to motivate an individual during a cognitive task, which helped improve cognitive attention through a music based game, while adapting its behaviour to the individual's disability level and personality. The robot could provide detailed reports of user progress to therapists and professionals. This is a major feature, as the robot can store data in the cloud, and integrate it with other large-scale health data in order to ease its analysis, prediction and personalised use [29].

Many large research projects have focused on the ageing population, such as CompanionAble [4], targeting care of people with MCI by fall detection mechanisms integrated with emergency calls or remote monitoring services, and using social interaction capabilities, as well as reminders and cognitive games, to reduce loneliness and increase autonomy. EnRichMe [30] used PAL Robotics Tiago robot for health monitoring, additional care and social interaction support for older people with MCI in domestic environments. The final design was based on feedback from both carers and users. H2020 GrowMeUp [5] used Pepper with over 60 people living alone, with the goal of learning and adapting to the need of users.

Current EU Projects, such as SHAPES [6], are aiming to create the first European open Ecosystem enabling the large-scale deployment of a broad range of digital solutions for supporting and extending healthy and independent living for older individuals. A major goal is to introduce companion robots to support older individuals staying at home and perform tasks such as physical and cognitive exercises, help moving, and engage with the community.

More specifically on the focus on this paper, there are few works that focus on developing a SAR for cognitive rehabilitation that comprises multiple games targeting a wide range of cognitive functions, instead of focusing on specific areas with one or two activities (e.g. [31]), while constituting a helpful and versatile tool for assisting caregivers and professionals. The present research proposes an engaging robot cognitive stimulation system that can be used to enhance mood and cognitive abilities of older adults, by delivering a diverse set of cognitive games, encourage the users, and at the same time develop a dynamic interface with therapists to monitor and guide participant progress. Some fundamental design aspects that were taken into account are the importance of robot-caregiver loop, asides from the robot-end-user loop [32] and the effect of different kind of robot feedback on user engagement and performance during physical exercise games [33].

More precisely, the 3 main goals of this research are:

1. Design a rehabilitation program with multiple cognitive games that target different cognitive domains based on participant needs.
2. Include components that keep the user motivated by customising the

[4] https://cordis.europa.eu/project/id/216487
[5] https://cordis.europa.eu/project/id/643647
[6] https://cordis.europa.eu/project/id/857159

robot behaviour according to user attitude and preferences.

3. Implement a user-interface for professionals, including patient progress tracking and control.

Findings from this research are expected to help further works in introducing SAR in eldercare and improve both end-users and professionals' perception of them.

3. Cognitive rehabilitation with a humanoid robot

The proposed framework makes use of the robot Pepper from Softbank Robotics (Figure 1), a 4-foot tall humanoid robot with cameras, sensors and an integrated tablet as additional user interface. The robot was chosen for its friendly aspect and advanced skills in terms of human-robot social interactions, since it is endowed with face and expression recognition, voice interaction skills, and with a large range of touch sensors.

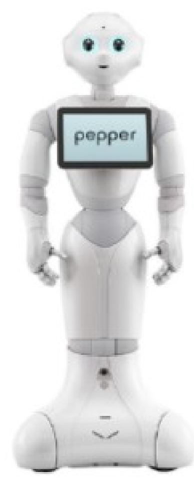


Figure 1: Softbank Robotics Pepper robot.

The final system is made of two main components, the database of subjects and sessions, and the set of cognitive games implemented on the robot.

3.1. Database and webpage design

One of the main goals of this work is for Pepper to customise the treatment for each user, and to allow caregivers to track each user's cognitive rehabilitation progress. By storing the data in a MySQL database instead of

Pepper's internal memory, it will be possible for professionals to retrieve data remotely, even after Pepper is switched off. The scalability of the database offers the option to include more medical data, and high security mechanisms to deal with such data. The database stores the user's personal details, and their recommended games and preferences.

The database needs also be accessible to caregivers or other relevant professionals in order to make it possible for them to insert and view user data, among other things, in order to keep track of their progress. Adding to the above the option to easily adjust the settings of the training, this project offers a user-friendly robot-caregiver interface, aside from the robot-end user interface, that tends to be highlighted in related works as a fundamental feature ([24, 27]), for making the caregiver's work easier and more consistent. The caregiver interface is based on a newly designed webpage (based on Python's Django framework). This includes models - forms, templates and views, while taking care of most of the components required for web development.

3.2. Cognitive game design

In order to create an ad-hoc treatment to support cognition, a set of 9 specific cognitive games were developed based on the six main neurocognitive domains defined by DSM-5 (Diagnostic and Statistical Manual of Mental Disorders) [34]: complex attention, executive function, social cognition, learning and memory, language, perceptual-motor functions. This allowed us to customize the training component based on the participants' needs. The cognitive games (exemplified in Figure 2) are inspired by previous paper and pencil games often used in neuropsychological rehabilitation [35]. Table 1 summarises all the games, showing what main cognitive functions they activate, and which disorders they may be targeted at (even though it is often the case that a game may contribute to multiple cognitive functions, and hence be helpful for various disorders).

All the games have multiple levels of difficulty - usually 3 - so that Pepper can adapt a game based on the user's progress. For example, in language games words get more complex, while in memory games there are more items to remember. Level adjustment makes use of the errorless learning methodology, to increase user motivation [36]: exercises are repeated for perfecting them before making the game more difficult [6]. In our case, the level of difficulty is increased after 4 consecutive correct answers, and decreased again

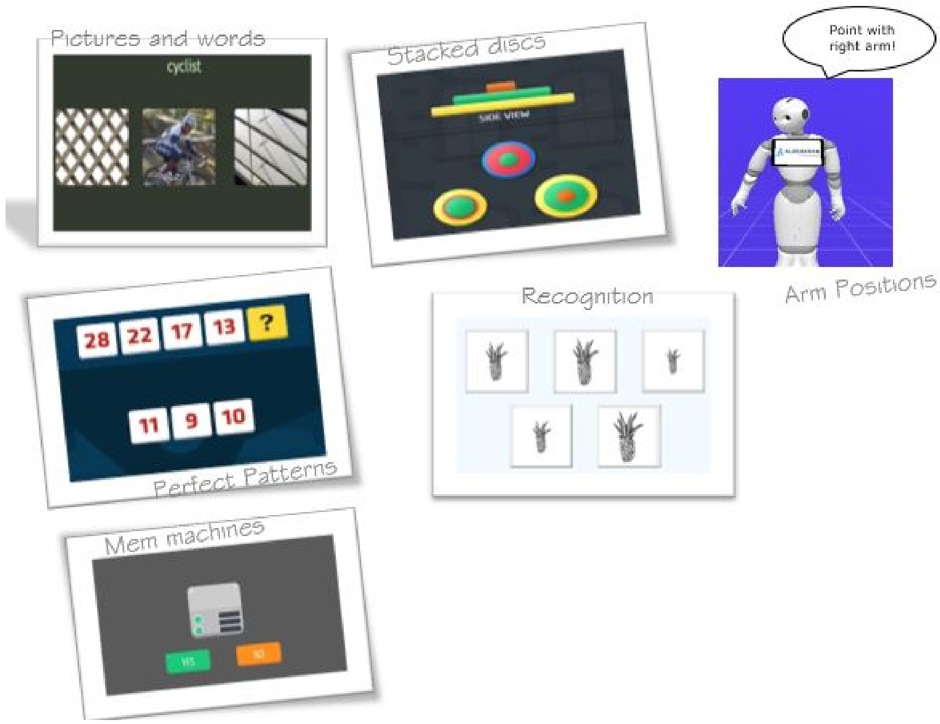


Figure 2: Cognitive game examples.

after 2 consecutive wrong answers. Table 1 indicates the amount of levels each game has, as well as the number of exercises per session.

Aside from these fairly complex games, eleven additional Javascript games were included [37] and implemented on the robot tablet. They include temporal and spatial orientation, recognition, memory, logic, language and attention games and are shorter than the previous games. They should be more suitable for individuals that only require a few sessions of interaction. In addition, in order to improve human-robot interaction, Pepper also provides oral feedback and personalised encouragement to the user.

4. Implementing the rehabilitation system

This section describes the technical implementation of the system more in detail, including the selection and design of the cognitive games, treatment customisation and user progress tracking.

Table 1: Characteristics of the main games implemented using Pepper

Name of exercise	Description	Domain Stimulated	Possible disorder application	Levels	Number of exercises per session
Stacked discs (SD)	Choose the top view that matches the side view	Visual and Spatial Perception	Spatial disorders	3	16
Mem machines (MM)	Select previously seen machines	Short and long term memory; Attention; Visual perception	Memory Impairments Inattention	3	16
Arm positions (AP)	Mimic arm gestures or perform them on command	Motor function; Spatial perception	Motor Disorders Spatial disorders (e.g. neglect)	12	16
Perfect patterns (PP)	Complete the pattern of numbers or shapes	Attention; Problem solving and reasoning	Executive Dysfunction	3	16
Words and pictures (WP)	Select the appropriate word for the picture shown	Language abilities; Visual-perception/recognition	Agnosia (visual); Language disorder	3	16
Questions and answers (QA)	Answer yes/no answers to simple questions	Verbal comprehension and production; Visual perception	Agnosia Language disorder	3	16
Moods (M)	Match what Peppers says to the expression/voice used (word "happy" with "happy" voice)	Attention functions; Executive functions;	Inattention Executive function	2	16
Simon game (SG)	Repeat light sequence	Sustained Attention; Short term Memory; Visual perception	Memory Impairment Inattention	8	Maximum 8
Word memory (WM)	Select the words said by Pepper in the appropriate order	Selective Attention; Short and long term Memory; Executive functions	Memory Impairment Inattention	8	16

4.1. General game design

Most of the games involve the use of Pepper's tablet, where images or the Javascript-based game are shown. To design the Javascript-based apps, we used the Jumpstarter package [7], which allows to use NAOQi modules in Javascript and exchange data through ALMemory. As the user plays a game with Pepper, the result of the game is stored in the MySQL database in the specific user's file, as well as its response times. As a result, in a future session, Pepper will be able to retrieve this data and adjust the initial game level accordingly, as well as enable clinicians to view the progress (Figure 3).

date	time	patient_id_id	exercise_id_id	result	duration	level	state
2018-02-12	15:23:04	1	3	12	60	3	Completed
2018-02-12	15:30:38	1	2	14	30,2091429234	3	Completed
2018-02-12	15:55:16	1	1	15	100,338917017	3	Completed

Figure 3: User progress is saved on the MySQL database for later use

4.2. Gesture recognition system

In games QA, MM and M (please see Tab. 1) the user must respond using yes/no answers. This can be done in three different ways:

[7]https://github.com/pepperhacking/robot-jumpstarter

1. Select yes/no using the tablet's buttons, for people who interact easily with the tablet.
2. Respond yes/no orally: for people who may struggle to interact with the tablet (e.g. Parkinson's disease users).
3. Respond by head gestures: for those with speech or physical impairments, or simply to provide a more natural interaction.

The Intel Euclid Developer Kit (ZR300 RealSense 3D camera) has been used to enable yes/no and arm pointing gestures (Figure 4), taking the SDK code as starting point.

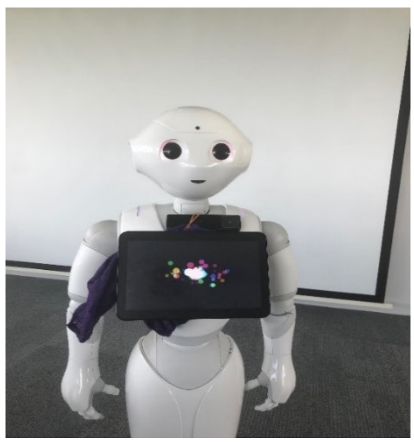


Figure 4: The Intel Euclid Developer Kit mounted on Pepper.

4.2.1. Head gesture detection

For detecting yes/no gestures, the pitch/roll/yaw data given by the camera is processed through four main steps (Figure 5, [38]).

- Averaging: the user's reference pose is computed by averaging across a sequence of samples.
- Filtering: a low-pass filter is used to to remove high frequency noise.
- Possible gesture detection: peaks in the pitch component may result in a "yes" gesture; while consecutive positive and negative peaks in yaw may correspond to a "no". Average of yes/no peak amplitudes have to be recorded for each participant to allow for individual differences.

- Final gesture detection: identification of significant peaks in pitch or yaw, suggesting a “yes” or ”no” gesture, respectively, if the other two rotational components do not show significant peaks during the expected interval.

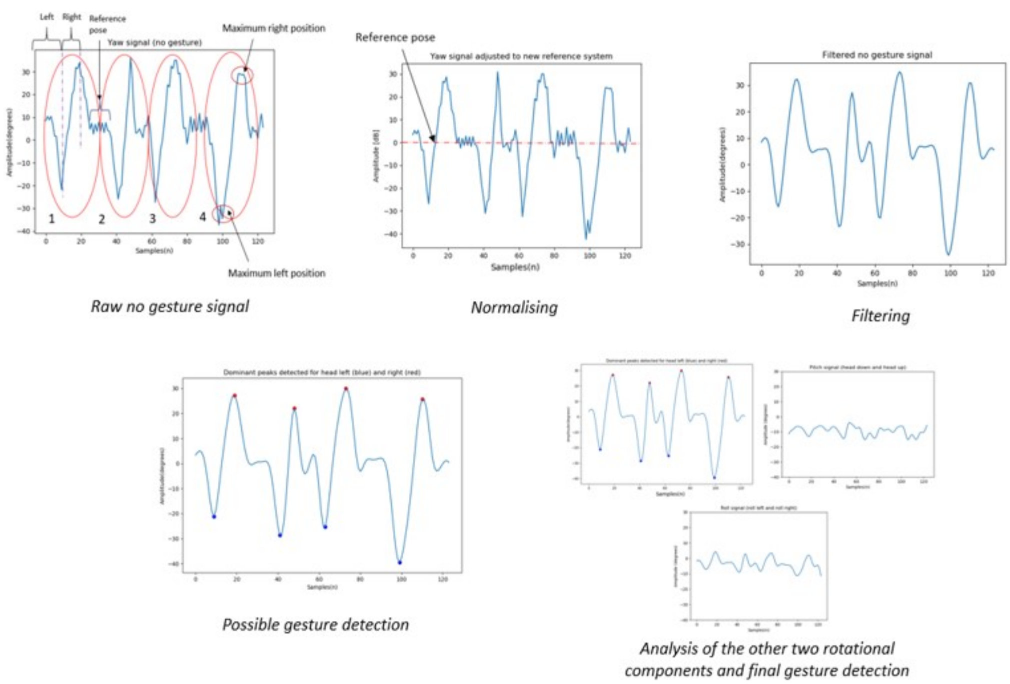


Figure 5: Summary of head gesture processing

4.2.2. Arm gesture detection

The camera gives the world coordinates of the pointing vector (Figure 6), and this information is processed to detect the following:

- Left or right arm.
- Pointing higher or lower.
- Arm raising or lowering.

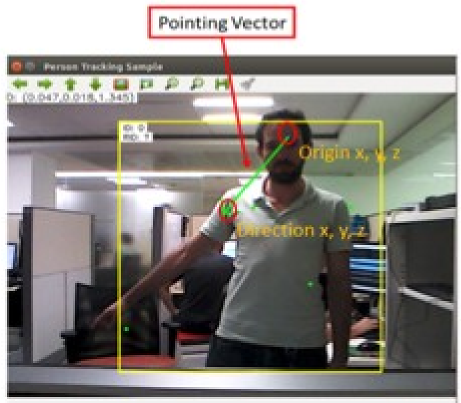


Figure 6: Arm pointing vector

4.3. Improving human-robot interaction

Using an adaptable human-robot interaction model has shown to improve the interaction experience [39, 31]. Adapting the robot's personality to the user's appears to have positive benefits, apart from adjusting the games and their level to the person's needs. Adapted aspects can include:

- Adjustment of proxemics-behaviour or human-robot distance.
- Adjustment of prosodic features for giving feedback and encouragement depending on personality.
- Game selection based on cognitive assessment.
- Game level adjustment based on user progress.

In order to uniquely identify the user, the clinician or caregiver is required to fill in a form accessed from the web page with the user's personal details. The data is thus stored in the database, where each user is given a specific ID (Figure 7).

id	name	surname	age	nationality	hometown	comments
1	Nerea	Ezkurdia	21	Spanish	Donostia	None
2	Sara	Cooper	21	Spanish	Eibar	None

Figure 7: The new user and all their personal data are stored in the database

By using the ALFaceDetection module, Pepper can learn a new face, and assign their ID to the face. After that, whenever Pepper meets the same person, it will recognise the face immediately and be able to access all their data from the database. By way of a back-up, the clinician will also be able to input their ID directly through the tablet interface in the event Pepper should fail in terms of recognition.

4.3.1. Behaviour adaptation based on user personality

We implemented a web form and Pepper's tablet version of the Eysenck's Personality Questionnaire to determine the user's personality [39, 31]. The test represents personality with two main dimensions: introversion/extraversion and neuroticism/stability. For simplicity, only two states are considered per dimension. Pepper adapts its behaviour in two ways based on user personality.

Interaction distance/proxemics

Pepper will establish a longer distance with users classified as introverted (1.7 m) and a shorter one with the extroverted (1.2 m), according to [31]. Distance adjustment will only take place when tablet contact is not needed (e.g. initial introduction, gesture-based games), using Pepper's ultrasonic sensor.

Adjustment of encouragement

Related works highlight that humans tend to have a more positive experience with robots that show prosodic features related to their own personality [31]. As such, introverted subjects tend to prefer more nurturing praise; while the extroverted appreciate challenge-based motivation, see Table 2.

Apart from the verbal content, through Pepper's ALAnimated Speech module the speech velocity, pitch and velocity are also adjusted. Table 3 shows all the adjustments done based on user personality.

Complementary relaxing activities

So that the user does not engage only through games with Pepper, and provide breaks in between, the user has the chance to:

- Engage in different multimedia activities based on user preference. For this, in the first rehabilitation session the user will have the chance to indicate his/her preferences on movies, books, animals, etc; stored in

Table 2: An example of how the vocal content of feedback changes depending on user personality

Nº of correct answers	Duration	Personality	Vocal content of feedback	Animation
5 or 6	<threshold	Introvert	”I'm glad you are progressing so well, I'm here for you, I hope it's not too hard. You don't have to hurry so much though, take more time to think and you will get even better, ”patient name””	Enthusiastic_4
		Extrovert	”If you answer so fast you won't improve, ”patient name””	No_1
	>threshold	Introvert	”I'm glad you are working so well, I'm here for you, please continue just like that, I hope it's not too hard... ”patient name””	Enthusiastic_4
		Extrovert	”Come on, you can do better than that! ”patient name””	No_1

Table 3: Pitch, speed and volume values for each personality type

Personality	Distance	Pitch	Speech rate	Volume
Introvert	1.7	80	100	60
Extrover	1.2	100	120	90

their data file. Depending on it, Pepper will play a different animation in between a set number of game, e.g. if the user likes movies, Pepper will show a Star Wars video on the tablet (Table 4).

Table 4: Multimedia activities designed

Topic	Subject	Activity description
Reading	The Three Musketeers	Pepper tells a short version of the Three Musketeers story, including images in the tablet, animations and sounds when they are needed
Watching TV shows	Game of Thrones (GoT)	Pepper shows its favourite scene of GoT and comments on it
Watching movies	Star Wars	Pepper shows its favorite of Star Wars and comments on it
Sports	Football	Pepper performs the animation “football” as it shows players playing football in the tablet
Music	Elvis Presley	Pepper plays the song Jailhouse Rock as it dances and shows the official video clip on the tablet

- Conversations: improving speech communication and having the robot show interest in the user is expected to improve the interaction. While Pepper's speech understanding is quite limited, for the purpose of designing a framework - extendable in the future - we have set 6 possible topics designed using QIChat, which Pepper selects based on user preference (also collected from a webpage form). Pepper will also store new data obtained through conversation in the database for future reference and usage.

4.3.2. Cognitive assessment

Before beginning a cognitive training program, it is essential to measure the cognitive abilities of the end-user, so that Pepper can determine which kind of exercises are suitable, and most useful, for the user, and have a baseline level to compare future performances. A screening cognitive test was developed (Pepper Cognitive Evaluation, PCE) based on worldwide screening neuropsychological tests as the Mini-Mental State Examination [40], MoCA [41], Severe Impairment Battery [42]. The test presents different questions covering the 6-neurocognitive domains of the DSM-5 mentioned above. Test administration is carried out directly by Pepper.

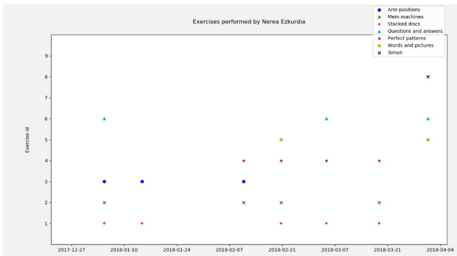
In the case that the participant presents issues interacting with the tablet due to psychological disorder, the caregiver/clinician can conduct the test and input the results of each section into the web form. Based on the performance of the participants' screening tests, Pepper will recommend cognitive games suitable to promote impaired cognitive functions. For example, if a participant performs poorly in the memory task, Pepper would suggest memory and attention games.

4.4. User progress tracking

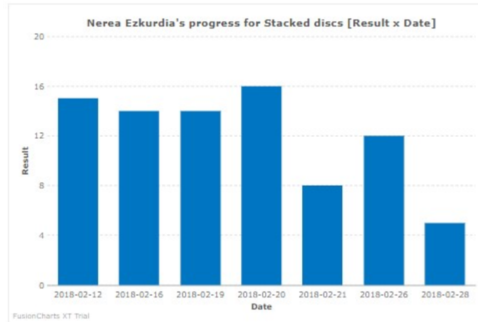
Caregivers or clinicians can follow the progress of each patient, where they can see what games they have played and a progression chart indicating their progress through time (game score and duration). Figure 8a shows sample charts, which uses FusionCharts [8] integrated in the Django webpage. Further charts can be easily added on request.

Charts can be very valuable in ascertaining whether users are improving in the cognitive functions each game is supposed to train and determine what exercises to change, add or remove. As depression symptoms or low mood can be one of the causes of low rehabilitation performance [43], especially among those with neurocognitive disorder, the Geriatric Depression Scale (GDS) short version [44, 45] has also been incorporated, which is used to generally screen depression symptoms in older adults [6]. Much like for the PCE and Eysenck tests, GDS scale can be administered by the clinician (through a web page form) or by Pepper - where Pepper asks and displays the questions and the user must respond using the tablet. Within this project, the test can be used to adapt Pepper's behaviour based on the user depression scale.

[8] https://www.fusioncharts.com/



(a)



(b)

Figure 8: Sample time chart showing the games that a particular person has played since the beginning of the cognitive therapy programme with Pepper (a) and progression chart indicating score and date

Clinicians should consider the score on the GDS run by Pepper only in a qualitative point of view, and not as diagnostic value.

4.5. Final prototype design

The full **cognitive rehabilitation programme**, based on Pepper and on the new database, integrates most of the aforementioned components (Figure 9). It includes an initial training session where user data is registered, including face recognition, surveys of hobbies, personality and a cognitive assessment, to select suitable Pepper mode and games, in order to achieve treatment customisation.

In all subsequent sessions, Pepper will first adjust the distance to the user, based on user personality, and then offer the chance to chat and/or suggest a questionnaire for assessing the participant's mood based on the GDS. The games can be chosen by the caregiver, by the user through the tablet, or by Pepper itself, based on the latest cognitive assessment. During the games, Pepper will adjust difficulty level and give encouragement based on personality, and will entertain the user with an activity at the end of the training. A session is composed by two rounds of 16 exercises, separated by a break, where the user has the chance to chat with Pepper.

In addition to the full rehabilitation routine, a **cognitive training app** was designed with the help of two expert psychologists in neurocognitive rehabilitation. The goal of the app is to develop specific cognitive games that could be used to foster participant cognition. The user first takes the

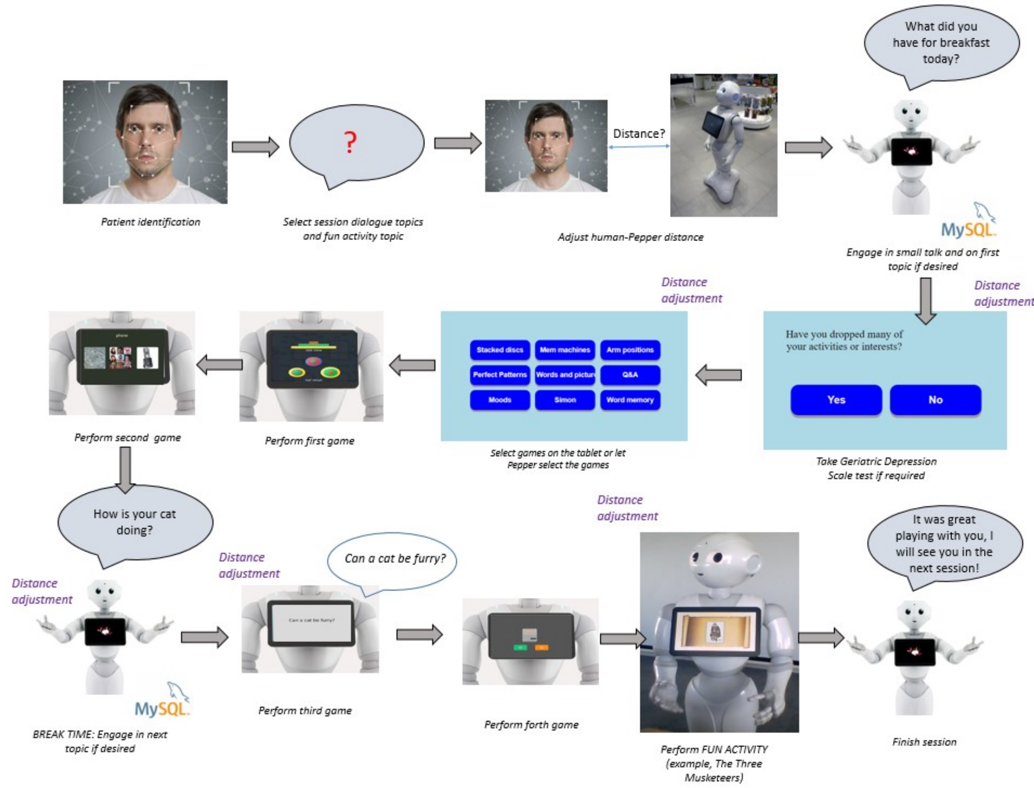


Figure 9: The full cognitive rehabilitation programme

cognitive assessment test with Pepper, and then plays as many cognitive games as they want. A web page offers professionals the option to see:

- User list, ordered by their ID
- Detailed user information, including their personal details, rehabilitation progress charts and survey results (Figure 10).

All the code developed for this project, including the Django webpage, Choregraphe programs as well as the nodeJS interface with the database models, can be assessed through a dedicated GitHub repository[9].

[9] *https://github.com/SaraCooperAmun/cognitive-rehab-pepper*

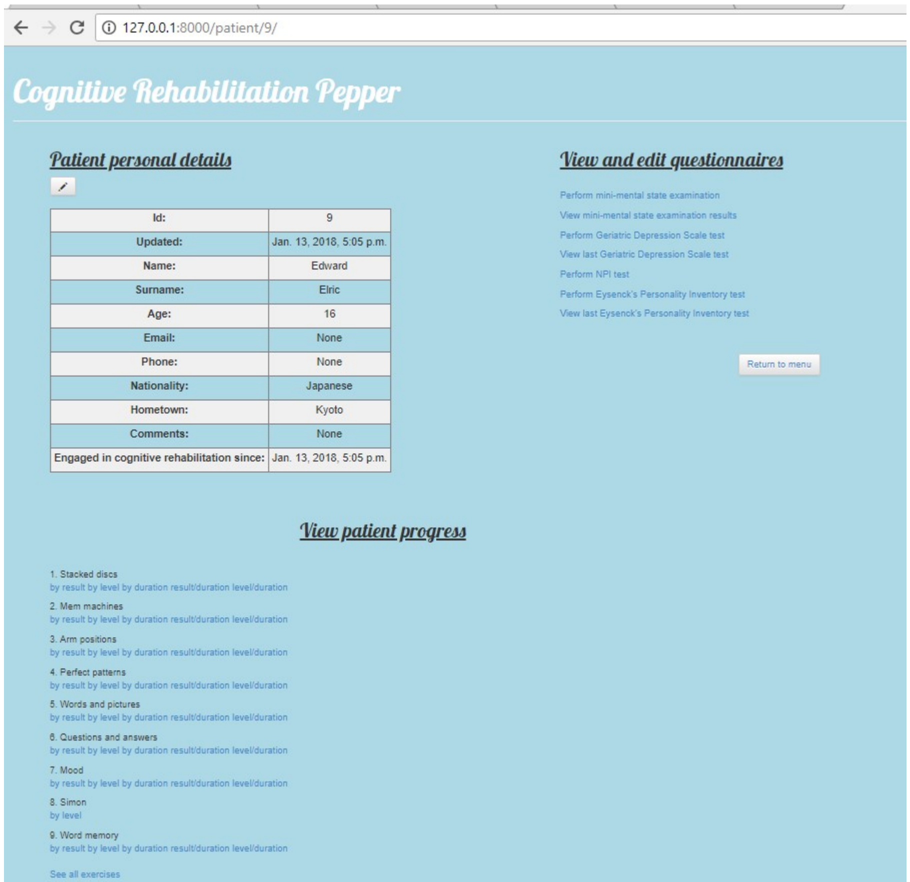


Figure 10: Django webpage interface, patient detail view

5. Validation/Experiments

In the following section we report the results obtained from the user studies conducted at Middlesex University, as a collaboration between the Departments of Deign Engineering and Psychology. The goal was to evaluate the human-robot interaction and overall acceptance of the robot while users were engaged in cognitive games. To do so, we used the cognitive training app described above, consisting of the cognitive assessment test followed by the cognitive games, which users could play as much as they wanted.

The group of participants was composed of 16 healthy older adults (11 females and 5 males, age 60.5 ± 23.1, range: 19-82). Inclusion criteria were the following: (i) MMSE score greater than 25 (normal cognition); (ii) no psychopathology that would interfere with participation in the activities; (iii) fluent in English. Ethical approval was granted by the Middlesex Psychology Department's Ethics Committee. All participants gave written informed consent in accordance with the Declaration of Helsinki. Participants were recruited in collaboration with U3A (University of the third Age of London).

5.1. Experimental procedure

A selection of activities were initially offered to the participants in order for them to familiarise with Pepper. Users could see the robot dance, offering a hug or letting itself get tickled. Once they felt comfortable, participants were shown the cognitive training app and were then given an anonymous semi-structured questionnaire.

The questionnaire was based on 32 questions (fully presented in the Appendix) aimed at assessing a number of aspects related to participants' interaction with the robot. Content validity of the survey was assessed by 5 experts in psychology and robotics that judged whether test items were essential for the aim of the questionnaire. The final questionnaire was modified accordingly to experts' suggestions.

The first 27 of the 32 questions were quantitative, based on a 5-point Likert scale. Participants had to indicate how strongly they agreed or disagreed with several statements, about how the robot looked like to them and how it made them feel, how they found the interaction while playing the cognitive games, the facility of interaction with the tablet, speech understanding and Pepper's feedback. The last 5 questions were semi-structured, asking a YES/NO question followed by a space for writing a short explanation for the choice. These questions were used to assess participants interaction with the robot in general, and addressing the possible benefits of having Pepper in a home environment or care homes, plus any other suggestions that could be used to improve the experience. Each study took about 30 minutes to be completed.

5.2. Results of quantitative questions

For the quantitative part, answers from the Likert scale were analysed through SPSS statistic 25. For the interpretation of the results, a threshold of 3.5/5 (70% of the rating scale score) was chosen as a measure of "agreement". The first 22 questions, related to the robot interaction, were divided in positive (n=9), negative (n=9) and neutral statements (n=4). Results are presented in Figure 11.

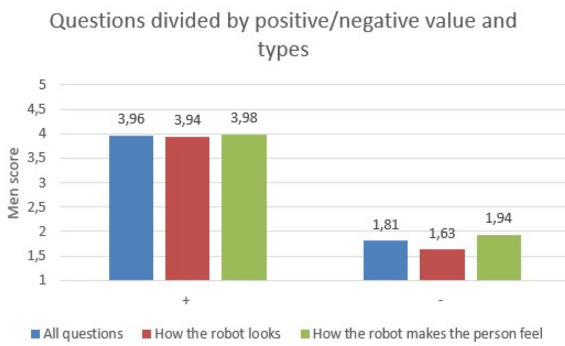
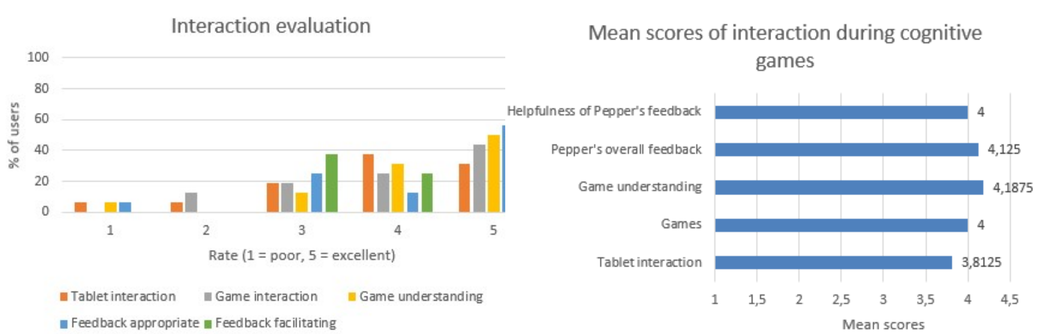


Figure 11: Positive and negative scores about participants impression about Pepper and how it made them feel.

Participants did not consider Pepper aggressive, distant or scary. Instead, they felt most of all engaged, pleased and amused ($M = 4.25 \pm 0.6$). Some did feel confused and uneasy ($M = 2.31$), although not significantly. Regarding user interaction during cognitive games, Figure 12 shows that most participants find the game interaction positive, especially highlighting Pepper's feedback as appropriate (rating of 5/5 for 57% participants). Interestingly, this was not correlated with how helpful they found it. Users found the games easy to understand (average of 4.185).



(a) Rating of overall human-robot interaction during the course of cognitive games

(b) Average score of interaction during cognitive games

Figure 12: user feedback on robot impression of game interaction

Table 5 shows a summary of the findings so far. For instance, Pepper's overall feedback and game understanding were rated particularly high (4.125 and 4.18 out of 5 respectively), with an overall robot impression and game interaction impression of 3.57/5 and 4.025/5, respectively.

Table 5: Summary of survey results

Question types	**Positive statements (5-point Likert scale)**	**Negative statements (5-point Likert scale)**
How the robot looks	3.94	1.63
How the robot makes the person feel	3.98	1.94
Helpfulness of Pepper's feedback	4	
Pepper's overall feedback	4.125	
Game understanding	4.18	
Games	4	
Tablet interaction	3.81	
Overall robot impression	**3.57**	
Overall game interaction impression	**4.025**	

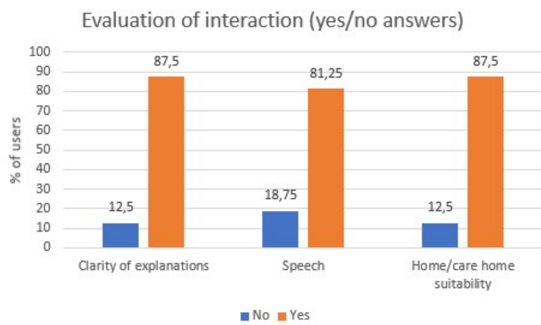
5.3. Results of semi-structured questions

A qualitative approach based on grounded theory [46] was used as a theoretical framework for analysing answers on the open questions of the semi-structured interview. An inductive approach based on the constant comparative method [47] was employed to analyse survey answers, that were grouped in categories **(for more information see [48])** through ATLAS.ti (Scientific Software Development GmbH), a software for qualitative text analysis. Frequencies of the obtained categories were also computed.

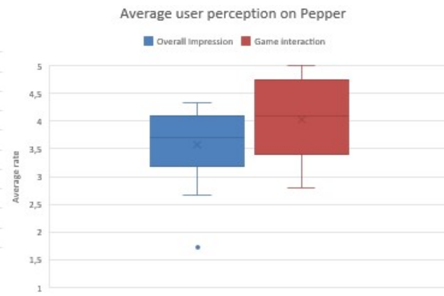
Figure 13a shows the user responses for yes/no answers, indicating that 87.5% of the participants believed that Pepper would be a suitable tool for care homes or private homes; and impressions about Pepper's speech and explanations were also positive. Figure 13b highlights the overall results of the survey, with an average of $M = 3.57$ ($SD = 0.701$) rating regarding overall robot impression and an average of $M = 4.025$ ($SD = 0.7758$) specifically for game interaction.

Correlation between different parameters was checked (e.g. speech understanding with game interaction perception, tablet interaction, overall perception of robot) to see which features may be the most predominant in affecting the overall impression.

Table 6 summarises the most significant correlations found. For instance, significant effects were detected in overall Pepper impression and how sociable they found the robot to be (Pearson's $\mathbf{r} = .831$), which is visible in the



(a) Evaluation of human-robot interaction for yes/no questions



(b) Average user perception on Pepper, with average of 3.57/5 and 4.025/5 for overall robot impression and game interaction respectively

Figure 13: Yes-no survey answers and average results

histogram of Figure 14. There was significant correlation on how facilitating they found the feedback with the overall impression on games (Pearson's **r** = .865).

Table 6: Significant correlations between different survey questions. Correlation is significant at p <0.01 level (2-tailed)

Correlation features	**Pearson's correlation**
Overall Pepper impression & robot looks sociable	.831**
Overall game perception & facilitating feedback	.865**
Overall game perception & tablet interaction	.830**
Facilitating feedback & tablet interaction	.702**
Robot looks sociable & game understanding	.622

Figure 15a shows the correlation between tablet interaction and feedback perception. Generally participants who found the feedback more helpful found it easier to interact with the tablet.

The qualitative part of the assessment (semi-structured questions) provided various results about whether participants would consider Pepper to be a useful tool at care homes or in their private homes (Figure 15b). All the participants that responded (85%) agreed about its usefulness, a 25% mentioning that a robot could help "save time" when a caregiver needs to attend multiple people; with a 13% highlighting that it would be "useful" for people that are "bored or lonely".

Lastly, they were asked on possible improvements to the demo (Figure 16). A 66.67% emphasised that the tablet "should have a better responsiveness",

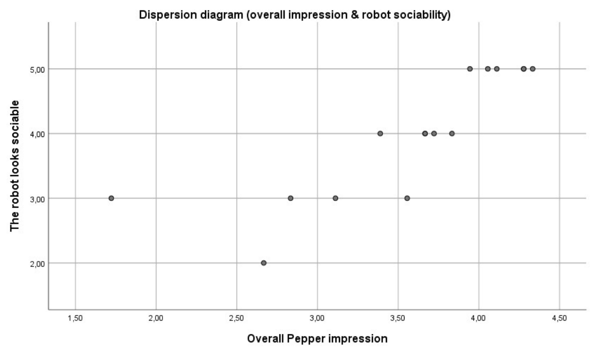


Figure 14: Dispersion diagram for overall impression rating and robot sociability. The higher the perceived sociability the better is user impression

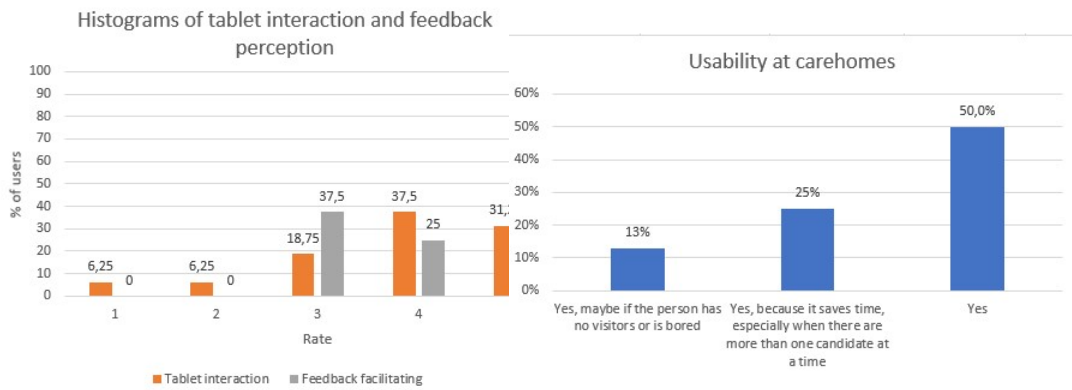
as they had issues selecting the right choice at the first try (this was also because many were unfamiliar with tablets or were pressing too hard). Others commented on the necessity of “making Pepper’s speech clearer,” among other things by making it speak slower, including a repeat button, and even to have the option to change the accent to British English.

5.4. Discussion

While most participants responded positively to the interaction (68.7% rated it above 3.5/5), a few were sceptical (18.75% rated below 3.5/5), most likely because it was their first interaction with a robot. There is also a general preconception about robots replacing human staff in the work environment. We believe that awareness regarding the benefits of using a therapeutic robot should be raised in order to counteract this feeling, which is not rooted in reality.

Overall, subjects found the method of delivering the cognitive games suitable to the purpose, with a score of 8.478 out of 10. According to the qualitative and quantitative analyses, participants believed that Pepper could be useful in private homes, but even more in care homes, for delivering cognitive games and to offer entertainment for short time periods. Among others, situations where Pepper was thought to be especially helpful are:

- When a person is living alone or is bored, to extend the range of activities they can engage with.
- When a caregiver needs to attend multiple users at once, Pepper can help reduce their work load.



(a) Histogram of tablet interaction and feedback perception. The better feedback perceived the better tablet interaction

(b) Open-ended questions regarding usability of robots at carehomes

Figure 15

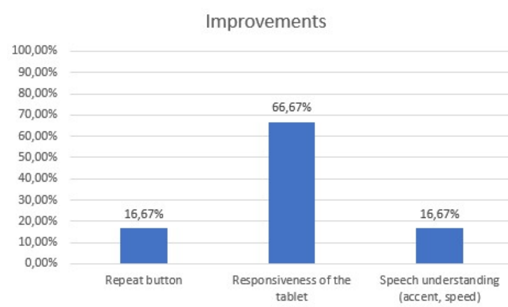


Figure 16: Main improvements mentioned by participants

Our statistical analysis shows that the more sociable a robot seems to be, the better impression it gives to participants. Moreover, feedback seems to be key when designing user-friendly cognitive games, as well as designing a suitable tablet interface. Oral feedback also appears to help in enriching the tablet interaction. This suggests that the more sociable an agent appears to be, where oral feedback and help is key, user impression during game playing improves, which can help increase their motivation and engagement.

The main struggle for our users was with the use of the tablet. This is in part due to the touch reaction being slow, but probably also to lack of practice, as after a few trials subjects tended to improve their effectiveness. In any case, a more user-friendly interface should be taken into consideration, by creating more games that are not tablet-dependent. Conducting some user-tests with the gesture recognition system could show if participants find a gesture-based interaction more convenient. The tablet-based test may be more user-friendly for those with speech-disorders, as they do not need to reply verbally and therefore does not take the person's pronunciation into account. In order to improve the responsiveness of the screen, it could be better to use images instead of Javascript games. Increasing speech volume and reducing speed, or offering a repeat button, could increase speech understanding. It would also be beneficial if the user could choose an accent for the robot. Moreover, aside from providing cognitive games targeted at the cognitive impaired, it was suggested that games for healthy older adults could be included as well. Table 7 summarises the improvements that could be done to the demo.

Table 7: Recommended improvements to the demo based on the received feedback

Feedback	**Improvement**
"Improve the responsiveness of the screen"	-Obtain user response via touch coordinates -Offer more time to get used to the tablet
"I did not understand what the robot said"	-Increase Pepper's speech volume and reduce speed - Improve Pepper's speech clarity -Include a repeat button
"Listening problems"	Write all the questions on the tablet
"The accent is difficult"	Change Pepper's accent to British or give the opportunity to the user to select
"More challenging games"	Design other games, not just targeting those with cognitive decline

6. Conclusions

We have proposed here a framework for cognitive rehabilitation based on the robot Pepper, supporting and enhancing cognitive abilities, and the quality of life of people dealing with cognitive impairments.

The system includes games targeting different cognitive domains, by creating a positive patient-system and caregiver-system interaction. In addition, personalisation of the treatment is achieved through a linked external database, making it possible to identify and store all data corresponding to each person, as well as visualising them on a dedicated web page for professionals to keep track of the data and progress. Among other things, Pepper's behaviour is adapted based on person's cognitive abilities, introverted/extroverted personality, and preferred hobbies.

Following a user-study, results were generally positive regarding users' impression of the robot and in the way the games were delivered, highlighting Pepper's feedback and game understanding. A significant relationship in how sociable they found the robot with the overall impression has been noticed, especially for those subjects that considered the robot's verbal feedback and encouragement helpful when playing games using a tablet. Most participants believed such solutions to be suitable for use in private and care homes to relieve boredom and caregiver burden, for instance.

In order to evaluate efficiency of the treatment, it would be necessary to test it with users who are cognitive impaired and with professionals, as well as during a real rehabilitation session. Further research on the usability of the web page for clinicians would also give us valuable insights on how to further shape the interface. Future works could also explore the option of adapting the robot behaviour based on the user's mood - through the Geriatric Depression Scale (GDS) test, emotion recognition -, optimise gesture recognition systems and make the system more user-friendly for people with other impairments (sight, hearing problems).

Overall, based on the results of this work, it can been said that a humanoid robot is a potentially useful tool to assist in the delivery of cognitive personalised games to support older adults with cognitive and behavioural needs, and may complement the work of professionals. What is more, such robotic solutions may become particularly useful in the fight against COVID19, in order to reduce physical contact between people to reduce the chance of spreading the disease, and attend the needs of persons that are confined at homes, hospital rooms or care homes [49]. Tommy the robot is an example of a social robot that has been deployed at some Italian hospitals to monitor isolated users [10].

Asides from delivering cognitive games and transmit user progress to the medical professionals, robots like Pepper may help to monitor users' health both through surveys and interconnecting with smart sensors such as thermal cameras; the tablet could enable remote communication between patients and doctors, or help engage with the community. In addition, the robot may reduce user loneliness by providing other forms of entertainment - videos, music, games, news reading, etc.

[10]https://www.pri.org/stories/2020-04-08/tommy-robot-nurse-helps-italian-doctors-care-covid-19-patients

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