CARMEN: A Cognitively Assistive Robot for Personalized Neurorehabilitation at Home

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ABSTRACT

Cognitively assistive robots (CARs) have great potential to extend the reach of clinical interventions to the home. Due to the wide variety of cognitive abilities and rehabilitation goals, these systems must be flexible to support rapid and accurate implementation of intervention content that is grounded in existing clinical practice. To this end, we detail the system architecture of CARMEN (Cognitively Assistive Robot for Motivation and Neurorehabilitation), a flexible robot system we developed in collaboration with our key stakeholders: clinicians and people with mild cognitive impairment (PwMCI). We implemented a well-validated compensatory cognitive training (CCT) intervention on CARMEN, which it autonomously delivers to PwMCI. We deployed CARMEN in the homes of these stakeholders to evaluate and gain initial feedback on the system. We found that CARMEN gave participants confidence to use cognitive strategies in their everyday life, and participants saw opportunities for CARMEN to exhibit greater levels of autonomy or be used for other applications. Furthermore, elements of CARMEN are open source to support flexible home-deployed robots. Thus, CARMEN will enable the HRI community to deploy quality interventions to robots, ultimately increasing their accessibility and extensibility.

CCS CONCEPTS

• **Computer systems organization → Robotics**; • **Human-centered computing → Interactive systems and tools**.

KEYWORDS

Human robot interaction, Robotics, Healthcare robotics, Neurorehabilitation, Robot system design, Digital health interventions

*Both authors contributed equally to this research.

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1 INTRODUCTION

Recent events, including the COVID-19 pandemic, have sparked a transition from in-person health interventions to those delivered at home via new technologies, such as robots [20, 38]. Successfully realizing this, however, requires a high level of technical (and clinical) knowhow on the part of both the clinicians, users, and family members [19, 30, 35]. Thus, many researchers in HRI and related fields have been exploring the potential of socially assistive robots (SARs) to reliably deliver these interventions, and are exploring their integration into these complex socio-technical settings [42].

One area of interest are CARs, such as to support people with cognitive impairments undergoing neurorehabilitation [17, 27]. Given the ever increasing number of people with MCI, dementia, and stroke (without comparable increases in available providers), CARs offer great potential to extend access to quality healthcare services.

To be effective and safe, especially for vulnerable populations, CAR-delivered interventions need to be grounded in established best-practices by domain experts. Cognitive interventions use specific goals, metrics, and practices which are carefully implemented in clinic by trained clinicians. Translating such interventions to be delivered autonomously by a CAR requires frequent iteration with stakeholders who deliver the intervention, as well as the users who receive it. The intervention also needs to be personalized to meet a person's individual needs and goals, and meet them where they are with regards to their abilities and motivation. In addition, the robot should interact with people longitudinally and autonomously without supervision from researchers, roboticists, or clinicians.

Prior work explores deploying social robots in homes [13, 23, 45]. Other work highlights how CARs can help users achieve intervention goals, further personalizing the intervention, and increasing their intrinsic motivation [28, 47]. Many researchers have explored developing social robots for education for children and mental health, including autonomously teaching children spelling and counting skills [13, 45], or supporting positive psychology [23].

While these systems show the potential of delivering these interventions in home settings, to our knowledge, there has not been

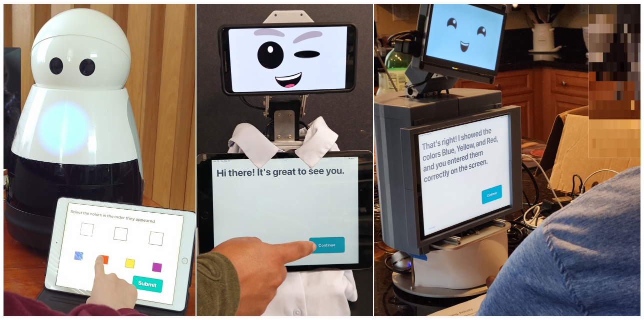

Figure 1: Design iterations of CARMEN from earliest (left) to the one used in our study (right). CARMEN delivers cognitive interventions to PwMCI, helping users practice cognitive strategies to minimize the impact of MCI on daily life.

a CAR presented in detail that supports the flexibility required to rapidly incorporate stakeholder requirements throughout the design process. We refer to "flexibility" as the ability to rapidly modify a system such as to integrate stakeholder input, such as changing or adding intervention content. This is critical, as developing CARs requires rapid iteration in close collaboration with stakeholders to ensure that it aligns with current clinical practice.

Thus, we developed CARMEN, a CAR that autonomously delivers CCT to PwMCI at home. In this work, we discuss CARMEN's design and development, informed by close collaboration with clinicians and PwMCI. CARMEN is centered on the principle of flexibility, allowing rapid integration of stakeholder feedback. It is also robust to operate in the homes without researcher intervention.

To demonstrate CARMEN's flexibility, we conducted a feasibility study with two stakeholder groups. The first group was clinicians who conduct Motivationally Enhanced CCT (ME-CCT) [22], the CCT intervention that CARMEN delivers. We modified CARMEN based on their feedback, and deployed it in the homes of PwMCI, the intended recipients of the intervention.

The contributions of this work are four-fold. First, we present CARMEN, a robot system that enables flexible interventions. Second, we discuss feedback from key stakeholders to inform how HRI researchers can design longitudinal CARs. Third, we provide insights into how to design CARs to align with the expectations and abilities of PwMCI. Lastly, we are releasing many elements of CARMEN as open source so other researchers can leverage this system for their work. This can be found at https://github.com/UCSD-RHC-Lab/CARMEN. This work will enable rapid and flexible deployment of cognitive interventions and beyond through social robots, ultimately extending accessibility of these interventions.

2 BACKGROUND

2.1 Compensatory Cognitive Training for MCI

MCI is a prodromal stage between typical aging and dementia [22]. It affects various areas of cognitive functioning, including memory, attention, and executive functioning [2]. About 20% of individuals over 65 have MCI, with up to 15% transitioning to dementia each year, a condition marked by irreversible cognitive decline [22, 41].

Existing pharmacological treatments have not been able to slow or prevent this conversion, but behavioral treatments can help [22]. CCT teaches metacognitive strategies that can help strengthen cognitive functioning, and minimize the effect of MCI on daily life [25, 46]. These strategies can give PwMCI new skills such as calendaring, note taking, and categorizing that can compensate for memory difficulties, allowing them to engage in tasks more independently. Studies show that CCT enhances cognitive performance and daily functioning in PwMCI, with lasting effects post-training [22].

Delivering CCT via a CAR requires a system that is adequately flexible to rapidly integrate stakeholder feedback from both clinicians and PwMCI.

2.2 Socially Assistive Robots in the Home

Researchers are increasingly exploring how SARs can be deployed to homes for various applications such as tutoring [13, 45], exercise encouragement [16, 50], and mental health support [6, 23, 44].

CARs are a subset of SARs, whose specific goal is to enhance the cognitive health of users [49]. Thus, it is crucial that these systems teach skills that can be used in the real world. While previous work in delivering cognitive training to PwMCI has established design requirements of such a system [27, 28, 31, 39], our work takes the first steps in deploying these robots, and gives key insights into how CARs can better support PwMCI in the real world. We also demonstrate CARMEN's flexibility, and how its modularity enables rapid implementation of intervention-specific behaviors.

3 DESIGN REQUIREMENTS

Over the past several years, we have collaborated closely with clinicians and PwMCI to ensure the robot is physically and cognitively accessible for this population, as well as a useful intervention tool. Our explorations into this space have revealed major design requirements that we considered as we developed the system [27, 28].

Autonomous Intervention Delivery: It is important that people can use CARMEN at home without constant mediation from researchers or clinicians. While clinicians expressed interest in manually adjusting its behavior to better suit a person's goals or abilities, it should also interact and deliver intervention content autonomously. Thus, CARMEN needs to automatically start and advance through the intervention to support a streamlined experience. This is particularly important for people with low technology literacy to help reduce frustration and minimize barriers to use.

Limited Internet Connectivity: Many PwMCI are older adults who may not have reliable internet access at home [21]. In addition, disability status is known to reduce internet adoption [21]. Therefore, to improve accessibility and ensure that CARMEN will be usable in homes, it needs to perform most of its processing locally to minimize its reliance on internet connectivity. Being primarily offline will also reduce its vulnerability to security threats, protecting user privacy in sensitive spaces such as their homes.

Longitudinally Robust: CARMEN will need to operate robustly throughout an intervention, which may last many weeks or months. Thus, it needs to execute its tasks robustly so PwMCI will not have to troubleshoot problems or rely on researchers for assistance. Clinicians suggested providing written instructions and a phone helpline for troubleshooting support. Thus, to minimize frustration for users, we designed CARMEN to be robust over a long period of time by implementing features such as saving progress and easily reconnecting the tablet if it disconnects from the robot.

Straightforward Physical Configuration: PwMCI may have difficulty maintaining focus, so systems with multiple components could cause confusion or break concentration. Thus, we aimed to keep CARMEN's physical setup straightforward by keeping the hardware compact and without additional components to keep track of or maintain. In addition, we adopted a plug-and-play system requiring minimal human intervention to set up and start the robot.

Accessible Communication Modalities: PwMCI are often older adults who may have varying physical and cognitive abilities which can impact how they can comfortably interact with technology. For example, PwMCI may experience tremors which can make pressing buttons difficult, or they may have audio or visual impairments. Therefore, we aimed to make CARMEN both physically and cognitively accessible for communication with PwMCI.

For instance, to support physical accessibility, clinicians indicated that many of the best technology design practices for older adults (e.g., large text, high contrast visuals) are also applicable for PwMCI. At the same time, they expressed the importance of letting people adjust these settings to match their abilities and preferences.

In addition, PwMCI may have difficulty with verbal comprehension or memory [36]. Therefore, to improve clarity and comprehension, we kept CARMEN's vocal utterances short and concise [14]. We also implemented means to have CARMEN repeat information, and let people advance through the intervention at their own pace.

Behavioral Requirements: A robot's behavior can influence a person's engagement and motivation throughout an intervention [27]. For instance, our clinical collaborators suggested showing empathy for a person's situation or taking a break after challenging tasks to help sustain engagement. Furthermore, rewarding a person for their effort in an intervention as opposed to their objective performance can help improve motivation, especially for people with cognitive impairments whose abilities may change over time.

4 CARMEN SYSTEM ARCHITECTURE

Our stakeholders envision CARMEN as a tool to supplement cognitive training at home in between weekly appointments with a human clinician. Depending on a person's needs and their confidence with each cognitive *strategy*, they may interact with CARMEN to practice the strategies multiple times each week throughout the intervention. We define each of these interactions as a *session*. During each session, the robot will explain a cognitive strategy and give the person an opportunity to practice that strategy via one or more *activities*. It will collect interaction and performance data from the person to support their engagement and goals.

4.1 Hardware

CARMEN is a system which comprises a social robot platform coupled with a tablet to support multimodal communication and promote accessibility. We have explored multiple robot embodiments for the system, including the Kuri and FLEXI [1] platforms (see Fig. 1). For customizability purposes, we decided to primarily develop CARMEN based on the FLEXI platform.

FLEXI is a low cost, open source social robot embodiment kit [1]. It is a tabletop social robot designed to be customizable so HRI researchers can use it for a range of applications. The touch screen tablet provides an avenue for the robot to display visual information, and enables users to communicate with it (e.g. pressing buttons, on-screen keyboard). FLEXI also leverages a smartphone which displays its face. To support movement, FLEXI has four degrees of freedom. One motor at the base enables it to swivel left and right, one in the neck allows it to lean forward and back, and a two-joint motor in the head allows it to tilt and rotate its face.

We modified the original FLEXI system to better suit our needs. While FLEXI uses a Microsoft Surface Tablet, we use a MeLE mini PC running Ubuntu 20.04 LTS so CARMEN can utilize the robot operating system (ROS) [43]. We integrated an Apple iPad as the tablet interface which connects to the mini PC via a websocket, and replaced the smartphone with an LCD monitor to minimize wireless connections between physical components. We also developed an alternative system to control the face locally, as the original FLEXI system requires an internet connection for this functionality. In addition, we connected an external speaker and microphone to support aural and verbal communication. Finally, we enclosed the hardware in a 3D printed case to secure the components.

One of our project goals is to eventually support longitudinal learning and adaptation, so to support this, CARMEN also has software which runs on two high performance supercomputer systems.

4.2 CARMEN Software

There are three main software components of CARMEN that control and transfer data between each hardware component (see Fig. 2). These are the robot platform, the tablet, and the supercomputer.

4.2.1 Robot Platform. The robot platform has three main types of software modules. We implemented each as a ROS node (version Noetic). We categorize these into intervention content modules, robot behavior modules, and human perception modules. To extend CARMEN's software to different robot platforms, we abstract the intended behaviors from the specific robot implementation, and run a single node that is specific to the current hardware.

Intervention Content Modules: The intervention content is controlled by a series of modules, including the order in which the robot presents cognitive training strategies, the activities used to practice those strategies, and the difficulty of activities.

Each session follows the same template within a finite state machine (FSM). We refer to this FSM as the Navigation Controller, as it guides the user through each part of the session. The states include 1) greeting the person, 2) giving an overview of that day's cognitive strategy, 3) giving instructions for the activity they will use to practice that strategy, 4) running the activity, 5) providing feedback about their performance on the activity, and 6) concluding the session. Edges correspond to the conclusion of the previous state. Each state of the FSM is written as its own ROS node which is executed by the Navigation Controller. The specific activity and its difficulty are determined at the beginning of the session.

Cognitive Training Strategies: Throughout the intervention, CARMEN teaches cognitive strategies from ME-CCT, which we implemented with guidance from our clinical collaborators. The strategies include: Routine Places, Calendar Systems, Mindfulness Exercise,

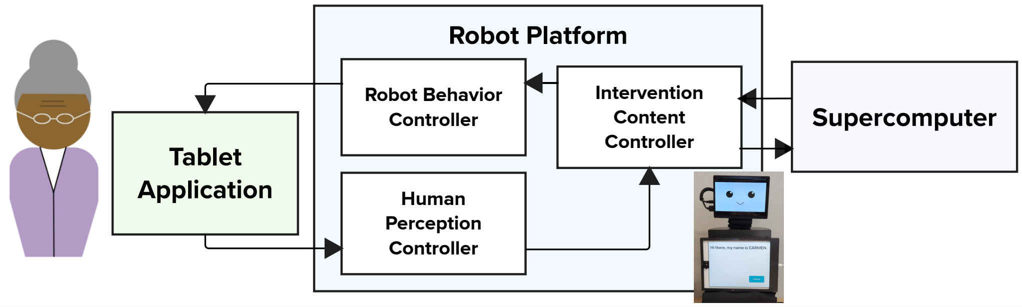

Figure 2: CARMEN's three software components control the robot platform, the tablet application, and the supercomputers.

Acronyms, Categorizing, Visual Imagery, Overlearning, Note Taking, Brainstorming, Evaluating Costs and Benefits (details in Supplement). CARMEN's modularity allowed us to quickly integrate the activities described below into these sessions to teach these strategies. We define specifications for each cognitive strategy in a configuration file (YAML), including a description of the strategy, how users might use it in their everyday life, and the activity they can use to practice it (see Supplement). In addition, we specify the overall order of the strategies in a configuration file, which follows the order in which PwMCI learn them in the in-person intervention.

Activities: We developed four main activities that users can engage in to practice the cognitive strategies. These include the Word Game, Color Game, Number Game, and Mindful Breathing Exercises. All aside from the Color Game were drawn directly from ME-CCT, and are employed by human clinicians when delivering it. The Color Game was co-designed with our clinical collaborators while exploring additional ways to practice each strategy. We translated these activities with clinicians to ensure the robot conducted them effectively and accessibly. In addition, each activity can be personalized to a person's goals and abilities (e.g. strategies they practice, difficulty or duration of the activity).

Robot Behavior Modules: Robot behavior modules work in real time to control its dialogue, tablet display, movement, and facial expressions. Each of these components work in tandem to create different animations the robot can execute to convey different emotions or personality traits when interacting with users.

Dialogue: Throughout the session, CARMEN speaks to the user and displays the words it says on the tablet to support accessible, multimodal communication. This also enables the user to reread what was said if they forgot or could not understand its speech.

We use a ROS service to handle the text to be spoken and/or displayed, which we refer to as the Dialogue Controller. The ROS node that is actively running (as defined by the current state) sends a message to the Dialogue Controller in JSON format. This message specifies 1) the text, 2) whether that text should be spoken aloud, displayed on the screen, or both, and 3) how the user can provide input back to the robot (e.g. buttons, keyboard).

The Dialogue Controller then forwards the message to the Speech Controller and Tablet Controller, which handle communication between the robot and their respective components. Upon receiving a user's response, the Dialogue Controller sends the response back to the current active node, and the session will proceed. CARMEN uses the CereVoice SDK [3] for text-to-speech synthesis. More details about the tablet application can be found in Section 4.2.2.

Motor Movement: To control CARMEN's movement, we leverage the Dynamixel motors SDK. We wrote our own wrapper class to more easily program the motors and create custom movements for different animations. We also limit motor speed and rotation range to minimize the risk of user harm and motor burnout.

Facial Expressions: We aimed to make CARMEN appear friendly and approachable. Thus, its primary facial features are eyes with pupils and a mouth, as robots with these features have been found to be perceived as more friendly [24]. In addition, most of CARMEN's facial expressions involve smiling, as people prefer robots in education contexts, such as CCT, to smile [24].

There are two main components to CARMEN's face. First, we developed a front-end module to design and display different facial expressions. This front-end module is implemented with PixiJS (a 2D WebGL renderer) and AngularJS (a Javascript framework).

Second, we created a back-end module that runs fully locally on CARMEN to serve and manage the front-end module. The back-end module allows REST API and websocket connections using NodeJS. Thus, to control which expression is currently displayed, a script sends a POST request to set the desired expression. Then the back-end uses websockets to communicate with the front-end client to display the proper facial expression animation.

Human Perception Modules: Human perception modules enable CARMEN to receive and respond to user input. At this time, CARMEN supports input via the tablet, which can be a button response or keyboard input depending on the activity. These responses may provide the robot with a variety of information, including a person's intention to advance the dialogue, their responses to an activity, or adjustments to system settings. The tablet sends these interactions back to the Tablet Controller. We chose to not record audio or video with this version of CARMEN to protect user privacy, as it was designed to be deployed in the homes of users.

4.2.2 Tablet Application. Users can interact with CARMEN through an iPad application we developed using Xcode. The tablet application serves two main functions. First, it displays the text that the robot speaks so users can follow along more easily. Second, it provides a means for users to interact with the robot, including advancing to the next set of dialogue and completing activities.

4.2.3 Database and Processing on Supercomputers. Throughout each session, CARMEN collects interaction and performance data from users in order to learn their preferences and abilities, and adjust its behavior and intervention content for the next session. Interaction data includes the frequency with which the user engages with the robot, the duration of the session, and the date and time of the session. Performance data includes which activity they completed (e.g., Word Game), how long it took them to complete that activity, and their score on that activity if applicable. After each session, CARMEN saves the collected data locally.

At the end of each day, the robot runs a cron job to securely transfer the interaction data file into a central location on a remote supercomputer. Once all files from each robot have been sent over, another job on the supercomputer runs a script that takes each data file from each robot, and inserts them into a SQLite database.

5 FEASIBILITY STUDY: METHODOLOGY

We ran a two phased feasibility study with CARMEN in order to evaluate usability and obtain initial impressions after completing an intervention with the system. In the first phase, clinicians completed ME-CCT in their home over the course of one week. They gave us feedback on the intervention, which we used to iterate on the system for the next phase. In phase two, we placed the robots in the homes of PwMCI for an additional week. Our study was approved by the UC San Diego IRB, under protocol number 800004.

5.1 Measures

All participants completed a technology familiarity questionnaire, demographics form, the General Attitudes Towards Robots Scale (GAToRS) [26], and the System Usability Scale (SUS) [10]. GAToRS encapsulates how CARMEN impacted users' positive attitudes (e.g., hopes, expectations) towards robots, on both a personal and societal level. SUS assesses usability through aspects such as the need for support, required training, and system complexity [10].

Participants with MCI completed a Cognitive Problems and Strategies Assessment, which measures the degree of cognitive problems they experience and the degree to which they use cognitive strategies in their everyday lives [40].

5.2 Procedure

For both clinicians and participants with MCI, we conducted a pre-intervention session where we set up the robot in their home, completed forms, and conducted a short interview. We engaged in a similar procedure post-intervention. With PwMCI, we conducted a midpoint check-in to ensure that everything was running smoothly.

5.2.1 Phase 1: Clinicians. Pre-Intervention Session: Clinicians completed a consent form, demographics form, technology familiarity questionnaire, and GAToRS while a researcher set up the robot. We then introduced them to CARMEN, and completed a short session where the robot introduced itself. We conducted a semi-structured interview to ascertain their first impressions of the robot.

Post-Intervention Session: Participants completed GAToRS and SUS. We then conducted semi-structured interviews to refine CARMEN's intervention content, and how to better deliver it to PwMCI.

Post-Clinician Changes: Clinicians suggested many improvements including adjusting dialogue to help clarify activities, and modifying the interaction to encourage greater focus from participants with MCI. Based on these suggestions, we modified the robot-delivered intervention before giving it to participants with MCI. For brevity, we summarize these findings here.

We made several changes to improve interactions with CARMEN and better support users. We added an example to the Categorization strategy to provide more explanation to users. In the Brainstorming strategy, we inserted a timer so participants would push themselves as opposed to skipping to the next page. We removed the Evaluating Costs and Benefits strategy as clinicians felt that, while helpful, it may be too challenging to complete with the robot.

We also improved overall system robustness, such as by implementing more graceful error recovery and incorporating additional hardware components (e.g., router). In addition, clinicians expressed discomfort that the robot's face was always on, so we modified it to display a black screen while it was idle.

5.2.2 Phase 2: PwMCI. Pre-Intervention Session: We walked PwMCI through the consent process, including a consent form and post-consent quiz to ensure they understood the study details. They then completed a demographics form, technology familiarity questionnaire, Cognitive Problems and Strategies Assessment, and GAToRS. One researcher helped participants with the forms if they needed assistance, while another set up the robot. We then conducted a short interview to understand their current use and familiarity of cognitive strategies. Similar to phase one, we introduced participants to the robot, completed an introductory session, and asked participants for their first impressions of the system.

Midpoint Check-in: We conducted a short, semi-structured interview by phone to check participants' intervention progress and assess any technical challenges. We also gathered preliminary information on their perceptions of the robot and completed activities.

Post-Intervention Session: Participants completed GAToRS and SUS. We then conducted semi-structured interviews centered on their experience with the robot, perceptions of the activities and strategies, as well as additional desired functionality of the robot.

5.3 Materials

In each home, we set up CARMEN along with an independent router we connected via WiFi to participants' home networks. While CARMEN would function without an internet connection, all participants had broadband internet access, which we used to back up interaction data. We gave participants a troubleshooting guide that detailed two simple steps to reconnect the tablet to the robot in the event that it disconnected, and included our contact information.

We also provided each participant with a companion activity workbook to complete as they worked with the robot. The robot instructed participants on how to use this workbook, using spaces provided to write down information that was necessary for the activity. Participants could also write down other thoughts during activities and any additional notes for themselves or the researchers.

5.4 Analysis

For interviews with participants with MCI, we followed Reflexive Thematic Analysis (RTA) as presented by Braun and Clarke [8]. Three coders cross split the transcripts such that each was independently reviewed by two coders in order to generate themes. We then met to iterate, discuss and resolve inconsistencies, and finalize themes. In line with Braun and Clarke's viewpoints on how inter-rater reliability does not align with RTA, and our aim to identify recurring themes and concepts of interest as opposed to complete agreement, we did not calculate inter-rater reliability [9, 37].

5.5 Participants

We recruited three clinicians (C1, C2, C3) who were familiar with ME-CCT. All were female. Two were neuropsychologists, and one was a research associate. Their average age was 32.33 years (SD=6.23). Each had several years of experience working with PwMCI.

We recruited three participants with MCI (P1, P2, P3) from a study testing MCI treatments. Inclusion criteria included having an MCI diagnosis and ability to work with the robot for one week. Two were male, and one was female. One identified as Black, and two as White. All were retired, with mean age of 70 years (SD=3.56).

Results from the Cognitive Problems and Strategies Assessment showed that participants with MCI had a mean cognitive problems score of 1.08 (SD=0.22) (out of 4, higher indicates more problems reported), and a mean cognitive strategy usage score of 1.29 (SD=0.56) (out of 4, higher indicates greater strategy use).

P2 had the highest technology literacy, using various forms of technology including a smart watch, phone, and computer. P1 followed, regularly using a smartphone, and occasionally voice assistants, while P3 regularly used only a smartphone.

6 FEASIBILITY STUDY: FINDINGS

6.1 Intervention Completion, GAToRS, and SUS

Intervention Completion: All clinicians, P1, and P2 completed the intervention and used the workbook. P3 completed 5/9 sessions, and wrote on three pages in the workbook. We suspect this is because they have Parkinson's, which may have physically made it challenging to interact with the system and write in the workbook. We did not have knowledge of this prior to starting the study.

Impressions: Overall, participants liked CARMEN, and described it as "interesting" (P1), "entertaining" (P2), "a nice tool" (P1), and "simple [to use]" (P3). Participants also expressed that its facial features made it more "approachable", "friendly", and "cute" (P2).

P1 compared CARMEN to their doctors. "I don't see much difference between [my doctors] and the robot except one is ran by electricity and the other one is a human being."

GAToRS: On a seven point scale (a higher positive attitude score indicates a more favorable attitude, while a higher negative attitude score indicates a more negative attitude), personal positive attitudes towards robots between pre and post sessions were: PwMCI: 4.6 $\rightarrow$ 5.3, Clinicians: 3.9 $\rightarrow$ 4.1, while personal negative were: PwMCI: 2.3 $\rightarrow$ 1.7, Clinicians: 4.4 $\rightarrow$ 4.1. Societal positive scores were: PwMCI: 5.4 $\rightarrow$ 6.7, Clinicians: 4.9 $\rightarrow$ 4.6, while societal negative scores were: PwMCI: 3.9 $\rightarrow$ 4.3, Clinicians: 5.3 $\rightarrow$ 5.3.

SUS: Clinicians gave the system an average SUS rating of 74.16/100 (SD=4.25), while participants with MCI gave an average score of 66.67/100 (SD=23.66) indicating average usability [4][1].

[1]Upon discussing the scale with P3, we found that they viewed using CARMEN to be simple, while the activities themselves were more difficult. Thus, participants may have been conflating the two when completing the scale, affecting their responses, explaining the wide variance we received.

6.2 Insights on Participant Contexts

6.2.1 Existing Cognitive Abilities and Goals. Participants discussed tasks and abilities they struggle with, and how they felt their memory was inhibiting them. P2 expressed, "It would be really nice if a lot of the chores that need to be done around here, that I wouldn't just dump them all on [my partner]. [...] I forget or don't do them. So a part of that's a little bit my personality, and part of that is that I really do forget." P1 explained, "[My vocabulary is] my main problem. That and being able to [...] point out diagrams and words and colors and things like that."

Participants set future hopes and goals for themselves as well. P1 stated, "I hope to stay on the same [cognitive level] that I am and try to improve from where I am." P3 gave an example of a cognitive strategy they could use: "[I could] put things in the same place every time to remember where it goes."

After completing the robot intervention, P2 discussed their existing use of cognitive strategies: "Probably 3/4 of [the strategies taught] are things I've already been doing, but not all of them."

6.2.2 Motivating Factors to Engage in CCT. Participants with MCI detailed many factors which motivate them to engage in CCT which could also motivate their use of robot-delivered interventions such as CARMEN. One major factor was the social connection that these interventions can facilitate. For instance, P2 wished to share their experiences with their family, stating, "I'm sort of sorry my granddaughter didn't get to see [CARMEN]. [My partner] took a picture, though [...] So she got to see her on the phone. So that worked."

Participants felt accountability to loved ones. When describing managing chores, P2 might "have some checks and balances on my phone or something and then maybe periodically [my partner and I could] go over those and see how that went."

Participants also expressed how seeing meaningful changes resulting from learning a new behavior motivated them to continue that behavior. P1 had been "eating plant based foods and discovered that it tastes good. Much of it tastes good, but the important part is that I'm avoiding the meat. [...] It's helped me. [...] It kind of stopped [my cognitive abilities] at a level." P2 shared this sentiment with respect to exercising, saying, "I felt better when I was exercising and that really helped me to keep up with [exercising]."

They also expressed intrinsic motivation and curiosity to learn, both with CARMEN, and in their daily lives. P2 expressed motivation to work with the robot, saying, "It's just kind of interesting to see what techniques you have recommended." P1 also described their intentions when working with CARMEN, saying, "I try to pick up a few pointers and intend to use that to help myself."

6.3 Strategies and Intervention Delivery

Participants made connections between the strategies CARMEN introduced, and also had feedback on the intervention delivery.

6.3.1 Real World Connections to CARMEN-Delivered Strategies. CARMEN motivated participants to try strategies they initially thought were too difficult and were avoiding. P2 said, "[CARMEN] also kind of challenged me, like I said, to not just say, 'well, I can't do that, so I'll work around it', you know, or 'I'll do something different.' [...] There certainly were things I hadn't thought about or that I had just decided not to do because they're hard."

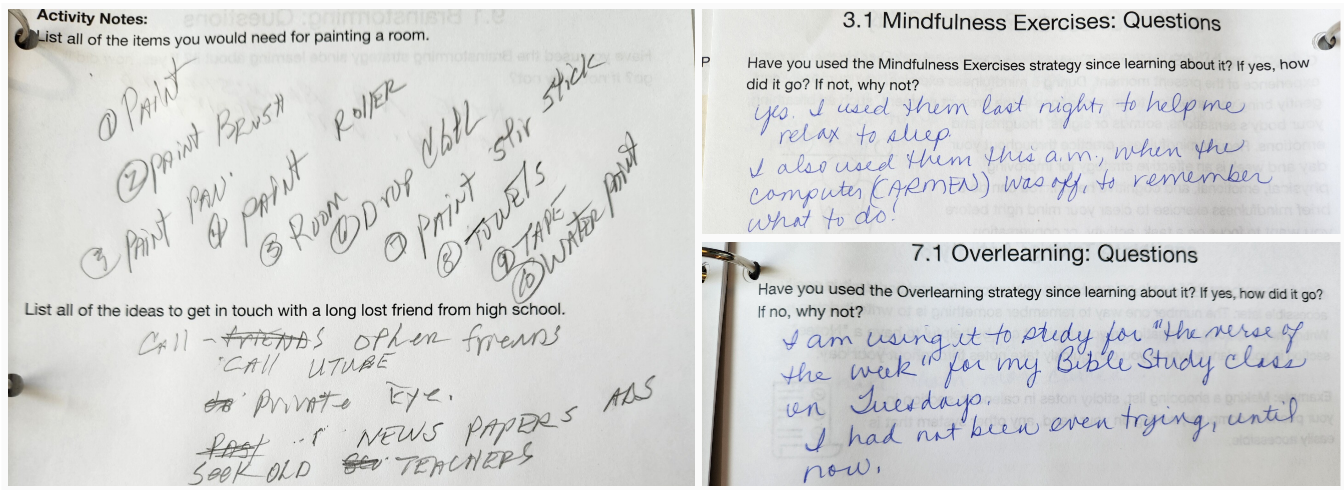

Figure 3: Participants completed a workbook during the intervention with CARMEN. P2 described using strategies in their life.

They also expressed how they used strategies that CARMEN introduced outside of the intervention in their daily life. In their workbook, being prompted of their use of the Mindfulness strategy, they wrote, "Yes. I used [the Mindfulness Exercise] last night to help me relax to sleep. I also used them this a.m., when the computer [CARMEN] was off, to remember what to do!" They also described in their workbook where they used the Overlearning strategy that they would not have otherwise done: "I am using [Overlearning] to study for 'the verse of the week' for my Bible Study class on Tuesdays. I had not been even trying, until now" (See Fig 3).

Participants were motivated to try new strategies. "[Notetaking would help to try] remembering names, instead of not trying" (P2).

6.3.2 Intervention Delivery Feedback. P2 expressed that the physical placement of CARMEN increased the motivation to use it, saying "she's right here by the kitchen." P2 also expressed completing "a couple [sessions] at a time [...] instead of reading or other [hobbies]," and that each session "doesn't take very long."

Participants reported a wide range of experiences with regards to difficulty understanding the intervention content. P2 "felt like the training that [CARMEN] gave was really reasonable and not too fast and not too complicated." P1 agreed, and said of the earlier activities, "they were good and and brought down to the level where a lot of people could [. . .] understand them as well." However, while P3 felt the operation of CARMEN was easy, they juxtaposed this to the difficulties they had with the activities in the strategies, saying, "Operation of the robot was simple. Figuring out [what to put in strategies] like Acronyms is difficult."

Participants wrote down emotional and physical reactions to the activities in the workbook, saying, "The time limit [in the Brainstorming activity] made me anxious!" (P2); another wrote they "start[ed] to fall asleep!" (P3).

6.4 Desire for Increased Autonomy

Participants envisioned ways that CARMEN could exhibit greater degrees of autonomy. This included increased levels of aid and involvement when presenting activities through collaboration with the PwMCI. Participants also envisioned that CARMEN would benefit from having conversational abilities.

6.4.1 How Participants Envision CARMEN's Autonomy. When conveying how the Acronyms strategy was very difficult, P3 expressed frustration with the lack of assistance CARMEN was able to give. "You can have a list of words you want to put into acronyms, but then you've got to figure out in your mind what words to put in there that make the acronym. Otherwise, it's not a problem. You got the answers in there. [CARMEN] is not figuring out any answers for you." P3 suggested that CARMEN could collaboratively come up with the acronym with the user, saying, "You need [CARMEN] to say, here's the word 'test'. Come up with an acronym [...] for the word test. So you'd start T and CARMEN could go, 'OK, here are all the words that start with T. [...] Do any of those fit?' "

P3 also imagined CARMEN could learn more about them over time, increasing its usefulness the more it knows. "You just have a huge amount of data in there that you'd have to put in CARMEN to make it truly useful." P1 had similar ideas, expecting more intelligence from the robot. "I wish[ed] it could think a little bit for itself," and could "make a decision [instead of] me."

P3 also imagined how CARMEN could aid him in tasks outside of the realm of CCT. He explained, "If CARMEN were able to straighten out the letters on the table here [gestures to mail], you'd have to start with letters and [...] sort all those real low level stuff, and then figure out how to organize that."

6.4.2 Conversational Abilities. Participants expected that CARMEN would understand when they spoke, saying that is "the trend of communications in the world today" (P1), and expressed confusion when the robot did not respond to them. P2 explained, "[CARMEN] didn't answer back. So I just figured, OK, whatever. It wasn't like a big problem where I was like, 'What do I do now?' "

They expressed that a system like this "needs to be [more interactive]" (P3). Participants also felt that writing was more labor intensive than simply speaking (P1), and that speaking may be "more friendly to people who are maybe computer-phobic" (P2).

7 DISCUSSION

7.1 CARs can Affect Real World Behaviors

Participants with MCI expressed their willingness to try strategies with CARMEN that they previously wrote off as "impossible." It gave them confidence to leverage these strategies to address real world problems. Our clinical participants expressed that even if PwMCI decided to not incorporate every strategy in their lives, learning and using a few new habits can lead to marked changes.

These real world behavior changes could also have broader impacts in other areas of their life, such as interpersonal relationships. By using the cognitive strategies CARMEN teaches, they may be able to reduce tensions with loved ones. For example, P2 expressed tensions when their spouse does all chores around the house. Integrating strategies that CARMEN teaches, such as Calendar Systems, could reduce these tensions. It could also increase a PwMCI's independence, such as helping them remember a doctor's appointment, or create a system to reduce clutter in their home.

The personal nature of these impacts, and a user's goals, also highlights the need to match the intervention's content to PwMCI's needs and abilities. In our context, CARMEN should give many opportunities to use strategies that they are likely to incorporate into their lives. It should also introduce a large variety of strategies as PwMCI might want to try ones they had not thought of using. This also applies to other applications, where CARs should be able to meet users where they are with respect to the intervention as opposed to assuming ability or lack thereof. This supports other findings in the HRI literature about adapting robot behavior and interactions to user's ability levels [12, 28]. In addition, other systems that deliver cognitive interventions (e.g., [18, 23]) may also benefit from the flexibility CARMEN affords.

7.2 Expectations of Language and Risks of LLMs

Participants had expectations of dialogue with the robot, likely because all were familiar with voice assistants and smart speakers. With the shift in expectations from AI systems with the onset of ChatGPT, integrating large language models (LLMs) with robot technologies presents an opportunity for HRI research and CARs.

Given the relatively well-defined role of CARs, constraining an LLM to relevant topics may be feasible to integrate into robot-delivered CCT. However, there are major concerns associated as well. LLMs are not trustworthy, and frequently "hallucinate" text that is false and not grounded in reality [5]. This is especially concerning for PwMCI, who are more vulnerable to being manipulated by technology or losing their autonomy [29].

In addition, many interventions (including the one CARMEN delivers) are delivered over several weeks or months. While researchers have cautioned that users may become reliant on SARs (e.g., socially, cognitively) [7], LLM-enabled CARs may accelerate this [32]. Extended use of LLM-enabled CARs may pose unforeseen risks, especially for PwMCI.

Furthermore, CARs aim to support older adults and PwMCI through evidence- and practice-based cognitive training. No access to large amounts of verifiable data may lead the model to hallucinate information and tell PwMCI information about a strategy that is incorrect, or even say something offensive. It is crucial to constrain the abilities to statements relevant and accurate pertaining to CCT.

7.3 Expanding CARMEN to other Populations

One clinician, C2, could see such a system being used beyond CCT, indicating that CARMEN could be adapted for children with ADHD. They imagined a scenario where a child must complete activities with the robot before "unlocking" screen time. They compared it to the first prescription video game, which is described as a "multimodal treatment approach for children with ADHD" [11].

The modularity of CARMEN enables the translation of other cognitive interventions to social robots. A developer or researcher would need to work alongside trained professionals in order to ensure the order of activities, and intervention content reflects fidelity to a clinic-based intervention. However, from a systems perspective, this would be quite straightforward to do with CARMEN.

7.4 Limitations and Future Work

There are limitations we will address in future work. First, our sample size was smaller than we would have liked, but recruiting PwMCI is challenging [34, 48]. Recent work suggests that small sample size is not a major drawback in accessibility research, as doing so may overburden small, vulnerable populations [33].

While a greater sample size is needed to draw conclusions on specific attitudes towards robots, our GAToRS scores imply that PwMCI's personal attitudes were more favorable after the intervention, while societal attitudes were less notable. As discussed in [15], positive attitudes about specific technologies a person uses (personal positive) are independent from their fears about how technology can broadly impact society (societal negative). As CARMEN functions as a teacher, we should expect personal attitudes towards robots to increase, and negative ones to decrease. As societal attitudes reflect perspectives on how robots can impact society and science, these are expected to be less influenced by CARMEN.

Another limitation is the deployment length in our study. However, the goal of the study was to understand initial impressions, and determine usability and efficacy of the system in order to prepare it for a longitudinal deployment. We plan to place CARMEN in the homes of PwMCI for eight weeks in order to explore the longer term perceptions and impacts of the robot-deployed intervention.

We were glad that participants already began to use strategies the robot taught in their daily lives after just one week. In future work, we might explore using wearables and privacy-preserving IoT sensors to detect real-world strategy usage. For example, a user could aim to remember their keys. Upon practicing Routine Places, a sensor could be placed in the home to track their usage of that strategy over time. The robot could provide reminders or encouragement based on strategy usage. This informs the needs of the PwMCI, increasing personalization and real world impact.

7.5 Conclusion

In this work, we presented CARMEN, a flexible robot system which autonomously delivers interventions which can ultimately be personalized to users. This paper presents a first evaluation with domain experts and end users, which informs how autonomous CARs can be designed and deployed to support more longitudinal interventions. These contributions will enhance the potential of robot systems to deliver more flexible, robust, and personalized behaviors for a wider variety of applications, user populations, and settings.

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