Cognitively Assistive Robots at Home: HRI Design Patterns for Translational Science

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***Abstract*—Much research in healthcare robotics explores extending rehabilitative interventions to the home. However, for adults, little guidance exists on how to translate human-delivered, clinic-based interventions into robot-delivered, home-based ones to support longitudinal interaction. This is particularly problematic for neurorehabilitation, where adults with cognitive impairments require unique styles of interaction to avoid frustration or overstimulation. In this paper, we address this gap by exploring the design of robot-delivered neurorehabilitation interventions for people with mild cognitive impairment (PwMCI). Through a multi-year collaboration with clinical neuropsychologists and PwMCI, we developed robot prototypes which deliver cognitive training at home. We used these prototypes as design probes to understand how participants envision long-term deployment of the intervention, and how it can be contextualized to the lives of PwMCI. We report our findings and specify design patterns and considerations for translating neurorehabilitation interventions to robots. This work will serve as a basis for future endeavors to translate cognitive training and other clinical interventions onto a robot, support longitudinal engagement with home-deployed robots, and ultimately extend the accessibility of longitudinal health interventions for people with cognitive impairments.**

***Index Terms*—Cognitively assistive robots, Design patterns, Clinical interventions, Mild Cognitive Impairment**

I. Introduction

The COVID-19 pandemic has illustrated great health disparities worldwide, particularly for minoritized populations, who lack access to quality healthcare services [27, 28, 51, 61, 77]. While telemedical interventions have proliferated, they still require one-on-one clinician time (which has become even further reduced during the pandemic) and technology knowhow on the part of the clinician and user. Thus, many robotics researchers are motivated to explore how to extend clinic delivered interventions longitudinally into the home.

Researchers have explored long-term robot-delivered interventions at home for children to support social and academic learning [14, 34, 46, 54, 62, 67, 72], and young adults to support mental health [6, 8, 35]. Others have explored longitudinal, clinic or nursing-home based interventions for adults with social robots, e.g., to provide upper limb rehabilitation [20], music [73, 78] and behavioral therapy [12, 64], and assistance to clinicians [40]. These interventions illustrate the promise of using robots long term in real world contexts. However, for older adults with cognitive impairments (such as mild cognitive impairment (MCI)) undergoing neurorehabilitation, there is less guidance on translating provider-delivered interventions in clinic to robot-delivered ones at home.

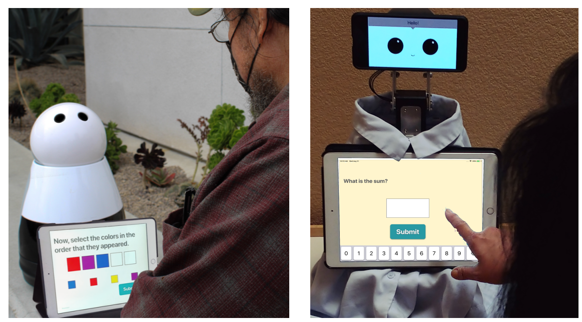

Fig. 1. We have developed social robot prototypes which deliver cognitive interventions longitudinally to PwMCI. The robots help users practice cognitive strategies with activities to minimize the impact MCI on daily life [30].

There are considerable barriers to developing robots for this purpose. First, roboticists typically lack the clinical expertise to safely and effectively translate interventions to a robot, and it can be challenging to locate clinical collaborators to ensure an intervention's success. Similarly, clinicians typically lack technology expertise to fully understand a robot's capabilities and limitations, and are rarely trained in interaction design, limiting their ability to co-design robot behaviors, roles, and functionalities. There are also well-known research-to-practice gaps when clinicians attempt to implement digital technology interventions without deep understanding of their contextual-

Research reported in this paper is supported by the National Science Foundation under Grant No. IIS-1915734.

ization in a user's life [23, 45]. These barriers can result in interventions ineffective on an intended population, and for some vulnerable individuals, such as people with dementia, they can be harmful [5, 41]. Thus, both HRI researchers and clinicians would benefit greatly from practical methods and examples on how to design robot-delivered home interventions.

Our work focuses on designing home-based, robot-delivered interventions for PwMCI. MCI can cause cognitive challenges, and is an intermediate state between normal aging and dementia (Section II-A). These interventions strengthen the memory and attention skills of PwMCI via cognitive stimulation and training [29]. Many researchers have delivered these interventions via computer programs [4, 21, 71], and explored how to improve engagement and motivation [16, 22, 50, 55, 66].

Physically embodied robots offer great potential to support engagement [15]. However, there is a lack of common techniques to support users and sustain engagement in longitudinal interventions delivered by a cognitively assistive robot (CAR), particularly without supervision from a clinician or researcher.

Another key challenge is *transfer* - can the PwMCI apply these skills broadly to their real life, outside the context of the computer-delivered intervention [24, 38]. Variation in how different populations (e.g. children vs. adults, people with cognitive vs. physical impairments) and individual users might engage with their respective interventions can make it difficult to ensure that they are effective when delivered by a CAR [19, 67]. Thus, establishing strategies for translating these interventions to a robot is crucial to ensuring that they are adopted by both clinicians and users, and the HRI community needs more systematic approaches to support this process.

For the past several years, our team has worked with neuropsychologists to develop CARs that administer compensatory cognitive training (CCT) autonomously and longitudinally to PwMCI at home. Our system helps users practice cognitive strategies to strengthen skills such as planning and executive functioning. In this paper, we report on how neuropsychologists envision translating CCT to a CAR, and features the robot intervention needs to be successful, such as supporting goal setting, content personalization, encouragement for real-world transfer, and ways to longitudinally maintain engagement. We also conducted interviews with PwMCI, the end users of the robot-administered intervention, which revealed how they envision using the CAR long term at home. This work establishes the foundations of translating neuropsychologist-delivered, clinic-based cognitive interventions to robot-delivered, home-based interventions, and provides a framework to researchers to support this process.

The contributions of this work are as follows. First, we provide insights for translating neurorehabilitation interventions to CARs in order to contextualize them to the lives of PwMCI. Second, we present new interaction design patterns for robot-delivered neurorehabilitation interventions to maintain longitudinal engagement and intervention efficacy. Finally, we propose design considerations for developing robots for PwMCI, a population with unique needs and abilities distinct from those of people with dementia and older adults. This work will guide roboticists through translating clinical interventions to robots, support their longitudinal efficacy and engagement, and ultimately extend the accessibility of longitudinal health interventions for people with cognitive impairments.

II. Background

A. Our context: CCT for PwMCI

MCI is a prodromal, or intermediate, state between normal aging and dementia [29]. It can impact numerous areas of cognitive functioning including memory, attention, and executive function [1]. PwMCI may struggle with instrumental activities of daily living including managing medication and finances. Around 20% of adults over age 65 experience MCI, and each year up to 15% of PwMCI convert to dementia, an irreversible syndrome entailing noticeable cognitive decline [29, 57].

No existing pharmacological treatments have been shown to slow or prevent this conversion, but behavioral treatments may help [29]. These treatments can prolong a person's independence and maintain quality of life. We focus on CCT, which teaches metacognitive strategies to help strengthen cognitive areas to minimize the impact of MCI on daily life [42]. These strategies include using new skills to compensate for memory difficulties, reorganizing one's environment, or integrating new tools into one's life. Studies show that CCT helps improve cognitive performance and daily functioning in PwMCI, which are sustained even after completing training [29].

Personalizing CCT is critical to improving engagement and adherence. Typically, neuropsychologists work closely with PwMCI to identify their needs and goals and tailor training accordingly [3]. Thus, understanding their perspectives can help ensure that robots adequately address the needs of PwMCI. In this work, we focus on how neuropsychologists and PwMCI envision CARs supporting CCT at home (see Section III).

B. Longitudinal robot-delivered health interventions

Many in-person health interventions for PwMCI are administered longitudinally, such as for months or years. To improve accessibility and efficacy, researchers have developed robots to administer interventions. In dementia care, CARs may help manage dementia symptoms, e.g., via sensory or behavioral therapy [12, 37, 40, 47, 59, 64, 73, 78, 81], and a clinician typically uses the CAR to supplement the intervention.

Robots have also been used to teach social skills to children with autism [54, 62, 67, 72], support adolescent mental health [9], or deliver physical rehabilitation [10, 18, 33] with guidance from clinicians or caregivers. Robots may also provide support in the homes of users, e.g., to support mental health [6, 35], or provide motivation for exercise [69] and weight management [39]. However, there is lack of guidance for providing cognitive interventions to adults with MCI at home.

While these works have made great strides toward delivering health interventions via robots, it is unclear how to translate an existing clinical intervention to a CAR for longitudinal interaction with PwMCI. Few works document this process, particularly for a robot autonomously delivering CCT without a human clinician or researcher overseeing the interaction.

Furthermore, it is unclear what robot behavior is appropriate for delivering a cognitive intervention to adults with MCI in order to minimize boredom or frustration and maintain engagement longitudinally. We explore these gaps in our work.

C. Design patterns in HRI

Design patterns are repeatable, general solutions for a specific design problem [60]. Software design patterns have been created for clinical contexts, such as to support system explainability [56, 68] or personalized care [79]. In HRI, design patterns describe social and physical interactions between humans and robots which can be used for interaction design. These patterns may be designed by observing human-human interactions or exploring how people expect robots to behave.

Prior work has defined patterns for various HRI applications, including modeling interactions and interactive storytelling [36, 48, 58, 60, 65]. For instance, Ligthart et al. [48] proposed design patterns to encourage engagement and agency of children in interactive storytelling (e.g. Co-reenactment: the robot animates the story and invites the child to join). These patterns are tools the robot can use to support engagement.

To our knowledge, there are no HRI design patterns for translational science, particularly to support adults with cognitive impairments during clinical interventions at home. Methods and examples based in current clinical practice are essential to translating these interventions to CARs effectively. We propose design patterns to address this in Section VI.

III. Overview of Current Robot Prototypes

Our system delivers longitudinal CCT [30] and helps users practice cognitive strategies to strengthen memory, planning, and executive functioning via activities, thus minimizing the impact of MCI on everyday life. We envision it being used at home for the duration of a clinic-based CCT intervention, traditionally 8 weeks [30]. It consists of a social robot coupled with a tablet display to support multimodal communication and promote accessibility. We are exploring different embodiments, including Kuri and EMAR [9] (see Fig. 1).

We implemented activities that teach and help PwMCI practice cognitive strategies. These activities were drawn from an existing CCT intervention [30], and are demonstrative of how a CAR and PwMCI might interact during CCT.

- *Word Game*. The robot tells the user a list of words, and the user verbally tells it as many as they can remember.
- *Color Game*. The robot shows a series of colors, and the user inputs them on the tablet in the order they appear.
- *Number Game*. The robot speaks a series of numbers, and the user adds the two most recent numbers.
- *Mindful Breathing Exercise*. The robot talks through a mindfulness exercise to help them relax and focus.

The difficulty of each activity can be configured to a person's cognitive abilities. E.g., a robot might give users a longer sequence of words to remember, or ask them to practice specific cognitive strategies that might be beneficial to them.

Using our system as a design probe, we worked with clinical experts and end users (PwMCI) to refine our ideas and understand how to effectively translate CCT to a CAR. In our interviews, we encouraged participants to envision possible use cases and ways of interacting with our probe. Thus, their responses inform both the translational and design processes.

IV. Methodology

Given our robot prototypes, our research has reached the point where we can shift our focus from functionality to an in-depth understanding of how to contextualize the CCT intervention into the homes and lives of PwMCI. We engaged in a collaborative design research process [7] with neuropsychologists and PwMCI to explore how to best translate clinician-delivered CCT into a robot-delivered intervention at home.

Using our prototypes as a design probe, we conducted interviews with our two key stakeholders: clinical researchers and PwMCI. We explored how clinical researchers deliver CCT and how they envision a CAR doing so. They were familiar with CCT, and could thus share key considerations for delivering it. For PwMCI, we focused on their use of technology, how they envision using a robot for support in an intervention, and initial impressions of our robot prototypes. Our study was approved by the UC San Diego IRB, under protocol number 800004. All participants gave informed consent to participate in the study, and agreed to be recorded.

A. Participants

Clinical researchers: We recruited six clinical researchers via word of mouth, all of whom work closely with and administer CCT to PwMCI. They included four neuropsychologists, a psychiatry faculty member, and a research coordinator. All were female and work at the same location. Their ages ranged from 24-51 years (mean = 34.83, SD = 9.20). They had between 18 months and 25 years of experience working with people with cognitive impairments (mean = 6.50, SD = 9.18).

PwMCI: We recruited three PwMCI via word of mouth. All completed CCT in a clinic-based setting. All were male[1], and their ages were 73 - 77 years old (mean = 74.33, SD = 2.31). They reported moderate familiarity with technology.

B. Procedure

Clinical researchers: We explored participants' experiences with CCT and their perception of using CARs to administer it at home. We used the same interview script to guide conversation with each participant, but adjusted the order and questions based on their responses. We conducted all interviews virtually to minimize risk from the pandemic.

First, we conducted individual semi-structured interviews to explore their experiences administering CCT to PwMCI. We first gave participants an overview of the study, and asked about how they interact with PwMCI in clinic. We also explored the unique space of designing for PwMCI, population-specific considerations, and ethical considerations.

[1] While we ideally would have more gender diversity in both participant groups, our recruitment strategy was limited due to gender skews in our local population of CCT practitioners and recipients of CCT interventions. We recruited PwMCI from a larger study testing MCI treatments, whose population is all veterans. In the US, veterans are approximately 90% male.

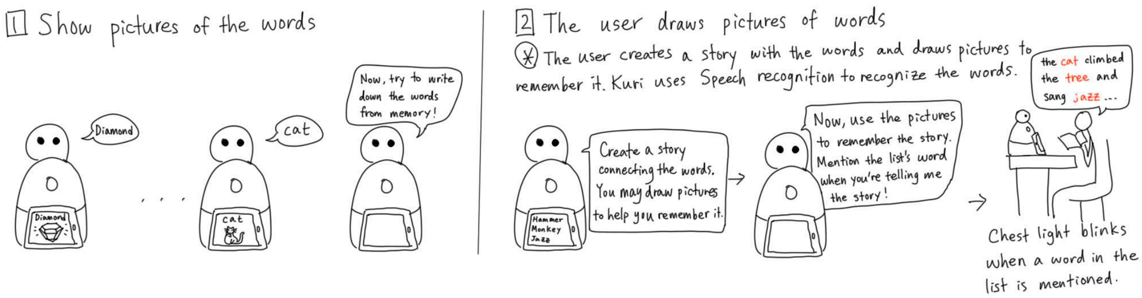

Fig. 2. Storyboards which demonstrate potential interactions with a robot during CCT. These activities were drawn from an existing CCT intervention [30] and aim to help users practice *using visual imagery* to improve memory. We showed these to clinicians to obtain feedback on their translation to the robot.

We did not show participants our robot prototypes during this phase to avoid biasing their responses, as the focus was on clinicians' general experiences working with PwMCI.

Following this, we conducted focus groups to understand how robots can longitudinally support PwMCI during CCT at home. Each consisted of two clinical researchers and three members of our team. We explored how PwMCI and a robot might interact during training, how to implement intervention strategies on a CAR, and obtained feedback on our prototypes.

We showed video demonstrations of our existing CCT activities on our robot prototypes, and storyboards of potential new activities to practice the strategies (see Fig. 2). We discussed roles a robot might play while longitudinally delivering CCT at home and explored how PwMCI might integrate a CAR into their lives, such as for people with low technology literacy.

PwMCI: We conducted individual, semi-structured interviews with PwMCI. We used a script to guide conversation, but adjusted the questions and their order based on the responses.

These interviews aimed to understand the context in which PwMCI might use a robot to support CCT. We asked about their daily lives, including their routines, challenges, and current use of technology to understand their context. Before moving on to the rest of the interview, we offered a short break as PwMCI may have difficulty focusing for extended periods.

We then explored how they imagine using a CAR for support in an intervention. As PwMCI may not be familiar with robots, we showed examples of social robots in the healthcare space, including Jibo, Mabu, and Pepper, and a demonstration of our prototypes leading CCT activities. These videos helped participants imagine how social robots could support their daily life and health. Then, we asked how they imagined incorporating the robot into their lives (e.g. when and where they would interact with it), how they envisioned using it to support CCT (e.g. cognitive areas to focus on), and additional capabilities they might want (e.g. reminders).

C. Analysis

We recorded and transcribed all interviews and focus groups. Three researchers each analyzed all the data using a grounded theory approach [11], enabling us to analyze for considerations that participants found important, rather than potentially interpreting them through preconceived ideas of what we thought was important. We individually coded the transcripts through an inductive coding process [76] to identify emerging themes before discussing the final themes together. Any inconsistencies were resolved through discussion.

V. Findings

A. Insights for translating a clinical intervention to a robot

Participants discussed several themes regarding how to implement CCT on a CAR. These themes included working together with PwMCI to identify their intervention goals, personalizing intervention content, encouraging the use of intervention concepts in the real world, providing feedback to PwMCI, and recognizing and maintaining engagement.

1) Help PwMCI identify intervention goals: Working with people to establish goals is essential for improving motivation to engage in an intervention and increasing its efficacy [2]. PwMCI may not explicitly report impairment, yet may show awareness of dysfunction when confronted with difficult tasks [80]. The PwMCI in our study may have anosognosia, or imperception of disease [52]. As one PwMCI expressed, *"I don't have [cognitive] issues. I don't need [reminders] at this stage in my life. Because my life is simple, the methods I'm using now fully compensate [for my memory]."* Thus, helping PwMCI set goals that reflect their needs can ensure they benefit from the intervention. Clinicians may help PwMCI identify initial goals, and during the intervention, the robot can suggest areas of improvement or update goals with PwMCI.

The robot can prompt people with guiding questions to help them form and evaluate their solution. One clinician suggested asking questions such as, *" 'Do you think that the [cognitive] skill would be helpful to you? How likely is it that the skill will help you meet your goals?' "* These questions allow people to consider why the goal is appropriate, which can increase long-term motivation, commitment, and belief that it is achievable.

A robot can then validate the solution and/or offer alternatives. Validating a person's ideas can improve motivation and self-confidence, but sometimes people may propose unrealistic goals. One clinician explained, *"It might be something like, 'I want to remember all my appointments for next week,' but [the person is] cognitively not able to do that. In which case, we might try to modify the goal."* The robot can help guide people to an attainable goal, thus uniting clinical expertise with the person's own knowledge of what is realistic for them.

PwMCI participants imagined that using the robot could be an interesting way to achieve goals they are unmotivated to work on. One PwMCI explained, *"I've been trying to learn Spanish for a long time, so [practicing with the robot] could definitely help."* Another stated, *"I need to take on more challenges. That's where I could see a robot being beneficial."*

2) Personalization of intervention content: CARs can personalize the intervention to a person's goals, which is crucial, as a person's needs may vary with the severity of their impairment, progress in the intervention, or other circumstances [13].

PwMCI have existing routines a robot should consider to improve adoption and engagement. One PwMCI stated, *"I don't need more creative avenues because I usually find a way to eat up my day. I could make room for [a robot] in some capacity, but how much? I'm not sure."* Thus, finding opportunities to incorporate the robot in their routine is essential to increasing its use. Another PwMCI imagined having *"the robot sit in as another person in a [multiplayer] game."*

Robots can also ask about their concerns to personalize intervention content. One clinician suggested, *"[A robot] might ask if sleep is a problem. And if it is, then [it] launches that content. That might help them work on it if it needs to be fixed, or not stress about it if it's fine."* People may have different needs and goals, so asking them what content they want to review can help them focus on activities that suit them.

Clinicians also emphasized letting users choose the content they focus on. As one clinician explained, *"The robot can say, 'You indicated that you want to try [these strategies]. Which one do you want to try today?' "*

In longitudinal interventions, a PwMCI's cognitive abilities can change over time. The goals and content of CCT, as well as the robot's behavior and role, must also adapt to sustain engagement. Over time, a robot may need to modify CCT content to avoid monotonous and predictable sessions. As one PwMCI said about a 6-week mindfulness intervention, *"At least 30 - 45 minutes, [the breathing exercise goes] through your whole body, over and over every week. That got boring."*

3) Encouraging real-world use of intervention concepts: One major benefit to using robots to administer clinical interventions in the home is their potential to encourage and facilitate intervention practice in a person's daily life. As one clinician explained, *"If [people] don't practice [the skills] in the real world, they're probably not going to get much better at them."* Clinicians suggested that a CAR can help people learn and practice the intervention content with examples from their lives, such as with their grocery list. *"[The robot could] say, 'How might you remember your grocery list for this week?' They're practicing their skills, but this is also the list they need to remember when they're going to the store."*

Furthermore, a CAR can help people practice content by relating it to a person's personal life, making it more actionable and concrete. Clinicians suggested that PwMCI identify opportunities to apply cognitive strategies to events outside of the home. *"Having [people] identify an opportunity to [practice], like, 'I'm going to church and am going to be meeting new people. What strategies am I going to use [to remember their names]?' "* Clinicians also proposed that a robot can help people recognize steps they can take in their daily life to support their goals, such as to improve sleep.

Clinicians also mentioned the importance of checking in and asking people to reflect on their experiences. *"If [PwMCI] identify a time and setting to try [a strategy], the robot can ask how it went so there's some accountability. Like, 'Hey, did you try learning some new names at this event you went to? Do you feel like you should practice that [strategy] again? Do you feel like you have it?' "* Asking PwMCI to reflect on their experience can help motivate them to continue applying the content in the future, while identifying what works best.

Using the intervention content in the real world may also give people the opportunity to involve family and/or caregivers which can improve motivation. PwMCI expressed interest in using the robot with friends and family, such as by practicing the intervention together. One PwMCI stated, *"I like to get [my wife] involved [with training]. I think [I could] engage better with the [robot] and we can learn together."*

4) Providing feedback to PwMCI: Clinicians identified feedback as important for increasing engagement and understanding of content. Thus, they provided a few suggestions for how a robot can give feedback to people, including focusing on effort over performance and showing progress over time.

Clinicians emphasized that robots should reward PwMCI for the effort they give, rather than their performance on a task. *"I might give rewards for consistent practice, like the amount of time they engage with the robot or complete exercises."* They expressed that rewarding people for interacting with the robot consistently can help improve their motivation to engage with the intervention. In addition, this behavior may be more attainable and fair, as *"it wouldn't be fair to those who are more cognitively impaired that they are not doing well."*

Clinicians also wanted to track a person's progress over time to show progress toward goals. This could be a relatively short-term comparison, such as informing PwMCI of improvement from their last session, or long term, such as throughout the intervention. These longitudinal statistics can help both PwMCI and clinicians keep track of their progress.

5) Strategies for recognizing and maintaining engagement: Maintaining engagement throughout an intervention is vital to improving its efficacy and retention of material [29]. Some clinical assessments can be long and tedious, so people may become frustrated or bored. Thus, clinicians shared ways they recognize and maintain engagement with PwMCI, as well as suggestions for how a robot can do so in an intervention.

For example, clinicians observe a PwMCI's speech and eye contact to identify engagement and disengagement. Active participation such as *"asking clarifying questions,"* or *"coming up with ideas or goals"* indicates engagement. In addition, clinicians suggested that a robot could identify engagement based on how long and often a person interacts with it. In contrast, PwMCI *"will vocalize that they don't want to do [a task] anymore,"* or *"close or roll their eyes"* when disengaged.

Taking breaks was a common way to maintain engagement, as it *"works for most people."* Breaks allow people to rest

TABLE I
DESIGN CONSIDERATIONS FOR COGNITIVELY ASSISTIVE ROBOTS FOR PWMCI.

	Consideration	Description
Cognitive	Simplicity of content	Information should be presented in a clear and concise manner to help PwMCI maintain focus.
	Visual aids	Visual aids may convey information more effectively and can help PwMCI focus on important points.
	Organization	Organizing important information in a logical manner can help PwMCI focus on those points.
	Repetition	Repeating information can help PwMCI review it if they do not remember or understand it the first time.
	Minimize distractions	Minimizing distractions from the robot and the environment can help PwMCI focus.
	Take breaks	Taking breaks can give PwMCI an opportunity to process the information or clear their minds.
Physical	Adjustable physical settings	Adjusting these attributes can improve communication with people with physical or sensory impairment.
	Physical size	The robot should be small enough to move between rooms easily, but large enough to not get lost.
	Straightforward physical setup	Minimizing the area that a PwMCI is expected to pay attention to can help reduce distraction.

and potentially address the cause of distraction (e.g. taking a bathroom break, answering a call). Thus, it is important that a person *"can take their own breaks and initiate their own breaks if they want to"* during a session with a robot, and that the robot *"checks in and sees when they need a break."*

Clinicians also use physical cues to draw attention and convey information. One clinician gave the example of raising her hand in a "stop" sign to convey that a person should slow down and focus on what she is saying. They suggest robots could similarly use cues to communicate with users.

Clinicians also use verbal cues, such as reminders or encouragement. For instance, a robot could cue people to continue if they get distracted. They also suggested providing encouragement, particularly if users get frustrated. Encouraging phrases they suggested included, *"Give it your best guess," "Thank you for hanging in there," "You're almost done."* Reminding people of intervention benefits can also motivate PwMCI to continue, even if they do not yet see improvement. One clinician recommended *"making [people] cognizant of why they're seeking treatment and what benefits they hope to see."*

B. Design considerations for PwMCI

Clinical researchers and PwMCI discussed key considerations to improve accessibility and usability of CARs for PwMCI. These included ways to improve both the physical and cognitive accessibility of robots for this population.

1) Making robots physically accessible to PwMCI: Clinicians were mindful that most PwMCI are older adults who may also have physical or sensory disabilities. Thus, they suggested spacing tablet buttons apart to avoid *"tapping the wrong [one],"* such as if someone has tremors. In addition, *"Visuals must be big, high contrast, clear, and not too busy,"* and *"speech must be clear and understandable."* They also warned, *"[loud, slow speech] might seem demeaning to someone without hearing loss or impaired mobility,"* so they proposed that people could adjust these attributes to their needs.

PwMCI may have low technology literacy, so a robot using familiar communication modalities, such as speech, can improve its usability [25]. These are easier to learn and may be more reliable. One PwMCI expressed, *"I definitely have a hesitancy about [my] ability to learn [new technology], getting it to work correctly, and figuring out why it's not working."*

The physical size of a robot is also important to consider. People may need to move it between rooms (e.g. if one room is too distracting because of a TV). Thus, clinicians suggested it be relatively small and lightweight *"to make it easier... to transfer it"* if necessary. However, PwMCI often misplace personal items, and *"[too small a device] could get lost."*

The physical setup of a robot can also help PwMCI focus. Narrowing the area of interest, such as by *"having [the robot and tablet] in one straight shot"* can promote a focused presentation. Additionally, as PwMCI cited technology as a challenge they face, a simple setup with few components can help reduce risk of error and increase usability [44].

2) Making robots cognitively accessible to PwMCI: Minimizing cognitive demand can help reduce cognitive fatigue.

Simple and succinct content is more digestible so people do not need to remember as much at once. *"If [the material] is too complicated, [the intervention] is going to be difficult because they'll feel like they're not able to master it."* Thus, a robot needs to be concise to help PwMCI maintain focus. *"The longer [PwMCI] are expected to follow along, the easier it is to lose their attention."* In addition, grouping important points together makes them easier to keep track of.

Visual aids can also help convey information without overwhelming PwMCI. In general, *"icons are more accessible than text"* if people have difficulty reading the font or understanding the text itself. Clinicians also explained, *"the visual component really clues you in to the main points."* As such, a robot might use gestures or facial cues to help emphasize important ideas.

Repetition can help PwMCI review material if they do not remember or understand it at first. Clinicians suggested asking if people would like anything repeated, such as after giving instructions, or reiterating important points during a session.

Furthermore, minimizing distractions from the robot and the environment can help PwMCI focus. Clinicians suggested that a robot's behavior could be minimal while providing information, *"because that might break their train of thought,"* but it

TABLE II
INTERACTION DESIGN PATTERNS FOR TRANSLATIONAL SCIENCE TO SUPPORT CLINICAL INTERVENTIONS DELIVERED VIA A CAR AT HOME.

Design Pattern	Examples
Promote engagement	Robots can offer breaks after long tasks, or use physical or verbal cues to sustain engagement.
Connect the intervention to the real world	Robots can use features from the real world (e.g. grocery lists), and encourage users to practice intervention content in their lives and with other people.
Relate the intervention to a user's interests	Robots can be incorporated into a person's existing routines, or use books or games that a person is familiar with to practice intervention strategies.
Reward perseverance over performance	A robot can reward users for engaging with it a certain number of times, maintaining a "streak", or for trying new intervention content.
Obtain feedback from users	Robots can obtain implicit feedback (e.g. performance), or ask for explicit feedback on preferences, etc.
Goal setting	Robots can ask users about any concerns and help identify solutions.
Reminders	Robots can verbally cue users to engage, or remind them of intervention goals.
Personalization	Robots can adjust activity difficulty based on performance, or communication modality to suit user abilities.

could be more engaging at other points. In addition, a robot could encourage PwMCI to engage in a *"quiet environment where they can pay attention."* One PwMCI envisioned using the robot *"in my computer room. That would be a quiet place [where I] can close the door and separate the noise."*

Breaks can also improve focus and engagement, such as by giving people time to process information or clear their minds, making the interaction more enjoyable and manageable.

VI. DESIGN PATTERNS FOR TRANSLATIONAL SCIENCE TO SUPPORT ROBOT-DELIVERED CLINICAL INTERVENTIONS

We propose interaction design patterns for translating clinical interventions to CARs to maintain longitudinal engagement and maximize efficacy (see Table II). They are intentionally broad so they can be applied to other contexts. They can be combined to be more complex, e.g. adjusting goals based on user feedback. For each pattern, we describe what it is, how human clinicians use it, and example robot implementations.

Promoting engagement is essential to improving adherence to an intervention over weeks or months. Clinicians use strategies including humor, showing empathy for a person's situation, redirecting conversation back to the intervention, or taking a break to help keep people motivated. A CAR can employ similar strategies, such as taking a break after long or challenging tasks, to help reduce cognitive load and minimize frustration. CARs can also use physical (e.g. gestures) or verbal cues (e.g. encouragement, sounds) to sustain engagement.

Generally, an intervention aims to enact change in a person's life. **Connecting the intervention to the real world** is essential to improving a person's ability to transfer the content. A clinician might ask a person to reflect on opportunities where they can practice a cognitive strategy. Similarly, a CAR could help users practice strategies with real world examples, such as asking them to recall their grocery list, or helping users identify opportunities to practice strategies in their life.

Relatedly, **relating an intervention to a person's interests** can make it more enjoyable. Clinicians might encourage people to consider scenarios that are meaningful to them during an intervention, such as family or music. A CAR might adjust the activities themselves, such as asking users to recall details about a book they are reading, or using games like chess to help users practice intervention skills. There may also be opportunities to incorporate the robot in their existing routines, such as engaging in conversation while they watch the news.

A person's progress in an intervention may not be linear, and it may be demotivating if they are not progressing as much as they would like. Thus, it is important to **reward perseverance over performance**. When administering cognitive assessments, clinicians may not tell people their performance to avoid influencing future performance. A CAR may reward users for engaging with the intervention a certain number of times, or for trying new strategies to keep them motivated.

To ensure the intervention is interesting, effective, and applicable to a person's life, it is important to **obtain feedback from users**. For instance, a clinician might ask people whether they would like to take a break to keep them focused on the intervention, or which cognitive strategies work best for them in order to evaluate their use of the strategies in their lives. Similarly, a CAR can ask users for feedback in order to personalize the intervention to their goals or preferences, or ask users to reflect on their experiences using a strategy.

Encouraging users to **set intervention goals** can sustain motivation and help them be more aware of its impacts. Clinicians often work closely with PwMCI to set achievable goals. CARs can also facilitate this by asking users to reflect on their concerns and helping them identify potential solutions.

Reminding people to engage in an intervention can also improve engagement. Clinicians might remind their clients of upcoming appointments. Similarly, a CAR could verbally ask people to complete a session together or cue users to continue a session. It might also remind PwMCI of their goals and benefits they hope to see to help keep them motivated.

Personalization can help ensure the intervention and robot behavior are appropriate for a person's preferences, goals, and abilities. A clinician might adjust the intervention based on a person's abilities. A CAR could also adjust the difficulty of activities based on their performance, or modify its communication modalities to suit a person's abilities.

VII. Discussion

A. Translating clinical interventions to robots

1) Opportunities to explore design patterns in other HRI contexts: While developed for home-based CCT for PwMCI, our proposed design patterns are also relevant to other HRI applications. Many robotic interventions emphasize *connecting skills to the real world*, e.g., including caregivers in interventions with children with autism [62, 67], encouraging students to identify personal strengths to support mental health [35], or conducting physical rehabilitation with everyday items [18]. This can help improve transfer of skills to a user's real life.

To our knowledge, no robots that deliver longitudinal interventions *reward perseverance over performance*. Users may become discouraged and stop using the robot if they perform poorly [14], whereas they may stay engaged if rewarded perseverance, e.g. maintaining a "streak" [53]. Rewarding effort, rather than objective performance, may improve motivation and engagement, especially in longitudinal applications.

More research is also needed on collaborative *goal setting* with robots, which clinicians cited as vital to increasing motivation in interventions. Identifying goals can also help focus an intervention, such as by focusing on strength vs. flexibility exercises in post-stroke rehabilitation. Clinicians or caregivers could also help with goal setting, such as for children who might not understand what goals are realistic.

2) Challenges to translating clinical interventions to robots: Design tensions arose from our discussions with clinicians and PwMCI. For instance, PwMCI participants thought a CAR would be most useful for people with severe cognitive impairment and were therefore unsure of how often they would use it. In contrast, clinicians envisioned PwMCI engaging with it regularly, perhaps multiple times a week. Clinicians also envisioned the robot primarily administering CCT, whereas PwMCI were excited by other potential functions (e.g. game partner). Clinicians were concerned that robot behaviors (e.g. lights, movement) could distract PwMCI, but no PwMCI indicated this. Continued research on balancing these tensions is essential to improving the efficacy of these interventions.

Clinicians emphasized the importance of PwMCI using the intervention content in real life, but a person's progress in a cognitive intervention is often more ambiguous to measure than in contexts such as physical rehabilitation. A robot cannot necessarily observe a person's everyday behavior to measure progress. Instead, it may need to infer progress from activities completed together, or feedback from the user or family members [67, 72]. Other sensors could be used to observe a person and gauge progress, but this may infringe on privacy.

Despite reporting low technology literacy, PwMCI viewed robots as an opportunity to improve their understanding of technology. In contrast to children who may be more curious about new technologies [74], older adults may be hesitant to adopt new technology, as evidenced by two PwMCI participants who did not own a computer. While others have suggested adapting the robot's role during an intervention [42], our findings suggest that a period before the intervention, where users can become familiar with the robot as a companion, may help improve adoption and acceptability.

Our discussions also touched on ethical concerns for robots for PwMCI / dementia, aligning with recent work [31, 32, 43, 70]. For instance, PwMCI imagined the robot as a companion, which could increase trust, but also lead to overreliance or social isolation. A robot may also influence (i.e. "nudge") users to support their goals, but this may be seen as manipulation [63]. Furthermore, users with anosognosia may not understand why they should use a CAR. If a clinician or caregiver requires that they use it, this could limit their decision-making ability and infringe on their autonomy. Further exploration is required to support ethical robot design for PwMCI.

3) Challenges co-designing with stakeholders: While PwMCI in our study showed interest in the robot, they stated they do not need assistance for their level of cognitive impairment. They believed a CAR would be most beneficial for people with severe impairment, either later in life or others in their age group. Thus, they had difficulty imagining how such a robot could fit in their lives. Researchers may need to rethink how they propose CARs to users, considering the possibility of anosognosia to improve adoption. E.g., a CAR may be introduced as a companion rather than cognitive support.

In addition, the pandemic highlighted the importance of remote solutions to collaborate with all stakeholders, such as clinicians and PwMCI with low technology literacy [26]. Others have explored co-designing with end-users remotely [17, 49], but more research is needed.

B. Limitations and Future Work

There are limitations we will address in future work. First, our sample size was small. Recruiting people with cognitive impairments can be challenging [49, 75], exacerbated by the pandemic. Additionally, our participants did not physically interact with the robot. While this may impact their perception of some physical attributes (e.g. size, volume), we believe the majority of our findings would not be impacted (e.g. translating clinician behaviors to robots). This was our first step to robot-deployed CCT, and we have a longitudinal in-home study planned with PwMCI to further explore using robots to transition interventions from clinic to home. We will implement our design patterns on robots to validate with users.

C. Conclusion

We presented interaction design patterns for translational science to support longitudinal clinical interventions deployed via CARs. We introduced design considerations for PwMCI, unique from those of older adults and people with dementia. These contributions will reduce barriers to robot-delivered clinical interventions, and enhance the potential for robots to expand telemedical solutions, which are invaluable during the pandemic. This work is a basis for supporting longitudinal interaction at home for intervention contexts and beyond.

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