Get SMART: Collaborative Goal Setting with Cognitively Assistive Robots

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ABSTRACT

Many robot-delivered health interventions aim to support people longitudinally at home to complement or replace in-clinic treatments. However, there is little guidance on how robots can support collaborative goal setting (CGS). CGS is the process in which a person works with a clinician to set and modify their goals for care; it can improve treatment adherence and efficacy. However, for home-deployed robots, clinicians will have limited availability to help set and modify goals over time, which necessitates that robots support CGS on their own. In this work, we explore how robots can facilitate CGS in the context of our robot CARMEN (Cognitively Assistive Robot for Motivation and Neurorehabilitation), which delivers neurorehabilitation to people with mild cognitive impairment (PwMCI). We co-designed robot behaviors for supporting CGS with clinical neuropsychologists and PwMCI, and prototyped them on CARMEN. We present feedback on how PwMCI envision these behaviors supporting goal progress and motivation during an intervention. We report insights on how to support this process with home-deployed robots and propose a framework to support HRI researchers interested in exploring this both in the context of cognitively assistive robots and beyond. This work supports designing and implementing CGS on robots, which will ultimately extend the efficacy of robot-delivered health interventions.

CCS CONCEPTS

• **Computer systems organization** → *Robotics*; • **Human-centered computing** → *Interaction design.*

KEYWORDS

Human robot interaction, Robotics, Healthcare robotics, Neurorehabilitation, Collaborative goal setting, Digital health interventions

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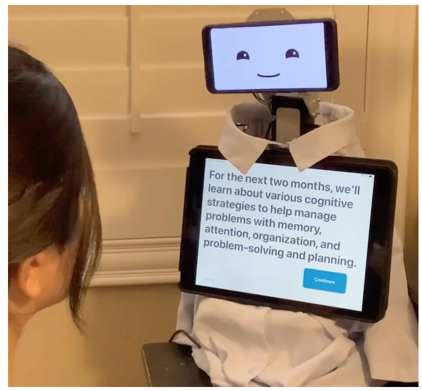

Figure 1: We developed a Cognitively Assistive Robot for Motivation and Neurorehabilitation (CARMEN), a social robot which administers a cognitive intervention by teaching people cognitive strategies to support their goals and minimize the impact of MCI on their daily life.

1 INTRODUCTION

The COVID-19 pandemic has sparked a widespread transition from in-person healthcare services to digital health interventions at home [22, 41]. One area where this has been particularly successful is for delivering cognitive interventions via robots. They have the potential to extend access to quality care for people [18, 21, 40, 48, 49]. HRI researchers have explored how to longitudinally deploy robot-delivered cognitive interventions, such as for mental health and cognitive training [4, 6, 28, 31, 64]. Such systems can leverage the benefits of physical embodiment, such as immersive, engaging behaviors and customizable morphology [17, 36], which can help with a person's adoption and adherence to an intervention [34, 64].

When translating clinician-led interventions to robot-delivered ones, one key aspect to consider is CGS. CGS is the process in which people receiving a cognitive intervention work closely with a clinician to identify and modify their goals [42]. CGS can increase motivation, confidence, and self-efficacy among patients, and lead to more concrete and achievable expectations of an intervention's impact [19, 51, 60]. Thus, cognitively assistive robots (CAR) should support CGS to ensure their efficacy. This may also enable these systems to tailor intervention content for a more personalized experience that focuses on a person's most pertinent needs and goals.

Clinicians usually help people develop goals using the SMART framework (specific, measurable, achievable, relevant, and time-based), which is essential to establishing appropriate and realistic goals for an intervention [9, 62]. However, clinicians may not be available to help people using a robot at home. Even if a robot supports goal setting, people may set goals that are unrealistic for their current abilities without clinician guidance. This can lead to decreased motivation and engagement with the intervention if people do not see the therapeutic outcomes they expect [35].

There are many digital health technologies that autonomously deliver health interventions, many of which enable users to set goals. For instance, many cognitive training games incorporate in-game reward systems which may serve as goals for users [5, 20, 47].

While this work illustrates the importance of integrating goals with technology-delivered health interventions, there are still many open questions with regard to designing CARs that can autonomously support CGS. First, measuring goal progress can be challenging due to a wide variety of possible rehabilitation goals, and variation in what progress might look like for each person. This is particularly difficult for cognitive interventions, as performance on robot-led activities does not necessarily correlate with ability to transfer intervention skills to real life. Robots need to be able to help a person set, measure, and manage goals, as this is vital to improving efficacy of and adherence to the intervention, and possibly supplement what a human clinician is able to observe in an intervention.

In addition, with many existing systems, users must choose from a set of goals pre-defined by clinicians or developers, limiting applicability to their context and abilities. Allowing users to set their own real world goals can also help improve motivation and adherence to an intervention, particularly over long periods of time. One open question is how robots can help users develop their own SMART goals and adapt an intervention to support those goals.

In this work, we address these challenges in the context of administering compensatory cognitive training (CCT) to PwMCI via a CAR (see Fig. 1). We interviewed neuropsychologists to explore how robots can support CGS. We also conducted co-design workshops with PwMCI to explore robot behaviors in an intervention, including how users can convey goals to a robot, how to measure goal progress, and how to adapt intervention content to support goals. We prototyped several of these behaviors on our robot CARMEN (see Sec. 3.1), and obtained additional feedback from PwMCI.

The contributions of this work are four-fold. First, we report insights, grounded in current clinical practice, on how robots can support CGS during longitudinal interventions at home. Second, we present a framework which will support HRI researchers to develop robot-delivered health interventions which can help users set and meet their goals. Third, we present concrete examples of how robots can interact with people during the goal setting process, which were co-designed with clinicians and PwMCI. Fourth, to support reproducibility within HRI, we have submitted these interactions as supplementary materials. This work will help researchers design CARs which can support CGS with clinicians, users, and a robot to improve the efficacy of robot-delivered health interventions.

2 BACKGROUND

2.1 Goal Setting with PwMCI

MCI is a prodromal state between normal aging and dementia which can impact numerous areas of cognitive functioning, including memory, attention, and executive functioning [2, 24]. Each year, up to 15% of PwMCI convert to some form of dementia, a syndrome entailing noticeable cognitive decline [24, 46]. MCI may impact people's ability to perform instrumental activities of daily living such as managing medication or health appointments [27].

While there have been no pharmacological treatments shown to prevent this conversion, behavioral treatments may help delay it [24]. CCT is one kind of behavioral treatment that teaches people metacognitive strategies to help strengthen cognitive functioning and minimize the impact of impairment on daily life, thereby helping maintain their independence [14, 24]. For instance, some strategies might include making a habit of placing keys next to the door upon returning home, or using acronyms to compensate for memory difficulties. We focus on Motivational Enhanced CCT (ME-CCT), which links skills taught during the intervention with a person's rehabilitation goals within the context of MCI [25].

As MCI may impact each person differently, PwMCI often have unique goals they wish to achieve. *Rehabilitation goals* refer to the real-world outcomes a person wishes to see from the intervention [38]. For instance, PwMCI may wish to remember to attend their doctor's appointments, get a job, or improve their relationship with their family. This is in contrast to *cognitive training goals*, such as practicing a certain strategy some number of times. While cognitive training goals typically aim to help a person reach their larger rehabilitation goals, this is not guaranteed. In this work, we focus on enabling technology to help people achieve their rehabilitation goals, as these are the most relevant to their everyday life.

2.2 Goal Setting in Technology-Delivered Health Interventions

Many existing cognitive training systems for older adults incorporate gamification features to improve and sustain engagement, motivation, and intervention effects [20, 37, 47]. In-game reward systems can increase intrinsic motivation and encourage users to continue using the system [39, 58]. The benefits of applying gamification to cognitive training systems are varied. Gamified interventions can challenge and support various overarching goals, such as challenging and exercising different cognitive and motor functions (e.g. attention, memory, perceptuomotor skills) [61]. Although gamification efforts can be a strong motivator for people to achieve their self-set goals, achieving in-game rewards does not necessarily translate to real world changes, which can reduce the efficacy of these interventions [45].

In addition, there are a multitude of technology-delivered health interventions [13], many of which include goal-setting as a key component and strategy [15, 55, 63]. For example, UbiFit [15] is a mobile, persuasive technology meant to encourage individuals to incorporate physical activity into their lives. They found that participants were more motivated to work towards goals they set for themselves or in collaboration with a domain expert. [55], who created a patient-center tablet app, noted CGS is a key aspect of the rehabilitation process between healthcare professionals and patients, and that it is important patients feel in control of their healthcare decisions during the rehabilitation process.

Longitudinal robot interventions are becoming more widespread, including helping autistic children learn neurotypical social cues, supporting mental health, or delivering physical rehabilitation [4, 16, 29–31, 44, 52]. Kidd and Breazeal [30] introduced Autom, a robot that interacts with people to support their weight management goals over time. Autom facilitates goal setting by enabling users to input and update their daily exercise and calorie goals in accordance with their weight management goals. While Autom does support goal setting and participant motivation toward goals, it was specific to the context of weight loss (e.g., daily exercise, calorie intake). In contrast, we aim to enable robots to support broader, real-world goals in order to help improve intervention efficacy and motivation.

Thus, while there exist robots which can deliver longitudinal interventions, it is still unclear how these systems can support people with identifying, measuring, and achieving their real world goals throughout an intervention. Users should be able to effectively interact with the robot in order to progress towards and assess the goals they set. In this work, we explore how robots can support the CGS process for longitudinal health interventions.

3 METHODOLOGY

We explored how to support CGS with a robot-delivered intervention at home. We employed a collaborative design research process with clinical neuropsychologists (CN) and PwMCI. We conducted interviews with CNs to explore how they facilitate CGS in clinic and how they envision a CAR doing so. With PwMCI, we explored the goals that they might have for a cognitive intervention and co-designed robot interactions for supporting CGS at home. Our study was approved by the UC San Diego IRB, under protocol number 800004. All participants gave informed consent to participate.

3.1 Robot Platform

Over the past several years, we have worked with neuropsychologists to develop a CAR for Motivation and Neurorehabilitation (CARMEN), which we implemented on the tabletop social robot FLEXI [1, 8] (see Fig. 1). CARMEN (San Diego) delivers ME-CCT [25] longitudinally to PwMCI by teaching compensatory strategies (e.g. using a calendar, mindfulness exercises) to users. It gives them an opportunity to practice these strategies via activities such as recalling a list of words or scheduling their day with the robot, thus minimizing the impact of MCI on daily life. In each interaction, or intervention session, with CARMEN, PwMCI will learn and practice a new compensatory strategy. It leverages a tablet display to promote multimodal communication and accessibility. In this work, we use our system as a design probe to explore how a social robot can support CGS during a longitudinal cognitive intervention.

3.2 Participants

CNs: We recruited two CNs who administer CCT to PwMCI. They include a psychiatry faculty member and a neuropsychologist, and both work in the same location. Both were female, with a mean age of 45 years (SD=9.9). They had on average 16 years (SD=14.1) of experience working with people with cognitive impairments.

PwMCI: We recruited 5 PwMCI via word of mouth. 4 were male and 1 was female[1], aged 65-80 years (mean=73.4, SD=5.5). All previously completed CCT in clinic, and most (n=4) reported moderate to high technology familiarity, e.g. computers and smartphones.

[1]We recruited PwMCI from a larger study exploring MCI treatments with veterans. In our country, veterans are about 90% male, leading to a gender skew in our local population of CCT practitioners and recipients.

3.3 Procedure

CNs: We virtually conducted individual semi-structured interviews to explore CNs' experiences with CGS during a longitudinal intervention and how they envision CARs can support this process. We used an interview script to guide conversation with each participant, but adjusted the order and questions based on their responses.

We asked CNs about how they conduct CGS in clinic, including how they determine what goals are achievable for each person, how they measure goal progress, and how they modify goals during the intervention. Following this, we explored how a robot can help people achieve their goals during an intervention, and co-designed appropriate robot interactions with participants. We presented a hypothetical scenario about a PwMCI following CCT with a robot at home. This helped contextualize the robot and its interactions during the intervention, which was important because clinicians may be unfamiliar with robotic technology and may therefore have difficulty imagining how people might interact with it [56]. For these scenarios, we intentionally chose a name that is considered gender neutral in our country, "Sam," as the name for the PwMCI.

We conducted live sketching sessions with participants, where we presented a scenario, and a member of our research team sketched storyboards and designs based on ideas the participant discussed. Then, we showed them the sketch and iterated based on their feedback. In this way, we collaboratively explored how a robot can interact with users to set up their goals, adapt its behavior to support user goals and encourage engagement throughout the intervention.

PwMCI: We performed a two-phase study with PwMCI. First, we conducted individual semi-structured interviews to explore goals that participants may have had during their in-person intervention and how they envision a robot supporting those goals during a longitudinal intervention at home. We used a script to guide the conversation, but adjusted the questions and order based on their responses. Throughout the interview, we periodically offered breaks as PwMCI may have difficulty focusing for extended periods of time. In the second phase, we showed video demonstrations of these behaviors and got feedback from participants.

In our interviews with PwMCI, we asked about their intervention goals in clinic, including their motivation for beginning the intervention, goals during the intervention, and what progress towards those goals looked like. Then, we showed examples of home-deployed social robots (e.g. Jibo, Kuri), and a video demonstration of CARMEN delivering CCT to help them imagine the capabilities of these robots. We then conducted live sketching sessions with participants, where we explored how they would collaboratively set goals with a robot, and how a robot could provide motivation during an intervention. A member of our research team sketched storyboards and designs based on the participants' responses, showed them the sketch, and then iterated based on their feedback. To co-design longitudinal interactions, we focused on PwMCI's experiences setting and managing goals during the 8 week ME-CCT intervention. We asked them to recall when they felt unmotivated to work on their goal, and how they managed that situation. Thus, we captured how a robot can support CGS across an intervention.

We selected six robot behaviors that PwMCI designed which were common across multiple PwMCI and/or aligned with our discussions with CNs, and implemented them on CARMEN (see

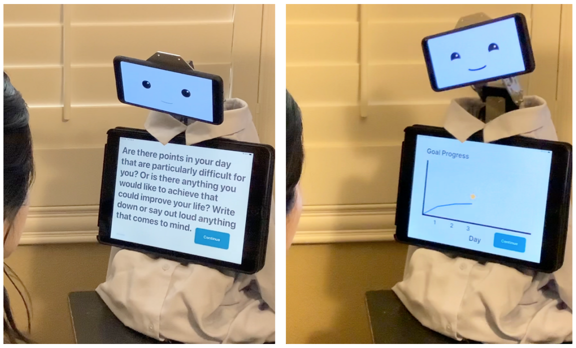

Figure 2: *Left:* CARMEN helping a user identify their intervention goals. *Right:* CARMEN showing the user a mock graph of their progress toward their goal.

Fig. 2). These included how a robot can: a) help people identify intervention goals, b) suggest goals if people do not have a specific goal in mind, c) respond if people complete a (sub)goal, d) support people if they do not complete a (sub)goal, e) connect a goal to the intervention content, and f) show goal progress visually. We have submitted videos of these behaviors as supplementary material.

We recorded videos of these interactions and showed them to the same PwMCI[2]. We virtually conducted individual, semi-structured interviews to get feedback, including whether these interactions could support their goals and motivation during an intervention.

3.4 Analysis

We recorded and transcribed all interviews. We analyzed all the data using a reflexive thematic analysis (RTA) approach [10, 11]. This enabled us to center the perspectives of our participants, and helped limit interpretation of the data through preconceived ideas of what we may have thought was important. We coded the transcripts through an inductive coding process [57] individually, then discussed the final themes as a group. Inconsistencies were resolved via discussion. As we aimed to generate recurring themes and salient concepts, we did not calculate inter-rater reliability, as per current best practices in the RTA literature [12, 43].

As the focus was different for each participant group (leading CGS with CNs, and designing these interactions with PwMCI), we analyzed each set of interviews separately. Two researchers analyzed each interview, and one researcher analyzed both sets.

4 INSIGHTS FOR CGS WITH ROBOTS

4.1 Robot Behaviors to Support Users

Robot Roles: Passive and Active. PwMCI imagined a robot could play both passive and active roles in setting and supporting goals. For instance, PwMCI ldexplained how they would like imagined a more passive robot to offer suggestions to help them identify their own tasks and goals. *"I'd like to maybe start out having the robot suggest some [strategies or goals] and then I can, as I get more comfortable, [...] start coming up with my own ideas" (PwMCI-2). "If it could suggest some strategies, that would be good. Like, 'Would it work if you were to do such and such?' " (PwMCI-3).*

[2] Due to scheduling constraints, we met with three of the original five PwMCI.

PwMCI also imagined a robot could take a more active role, such as by providing solutions to questions a person might have about their goals. For instance, in response to a video where a robot asked guiding questions to a user, one participant noted, *"The robot was asking questions that should have been answered by the robot, like [...], 'Okay, how do I get organized?' " (PwMCI-5).* They later emphasized, *"Just keep it light and try to give answers, because that's what [the user is] there for. They're looking for answers to their issues." (PwMCI-5).*

In most CAR scenarios though, the robot will be in a person's life temporarily [7]. *"We want to train people to be their own [neuropsychologist], so we want to have them take on all the skills themselves and not be dependent on the robot for anything really" (CN-1).*

PwMCI expressed that a robot could serve as a companion throughout the intervention to encourage them to achieve their goals. *"It's like having some support to help you reach your goals, you know. You're not all alone trying to do it." (PwMCI-3).* They imagined the robot could be like a friend, *"I think that it would be good for me and be like, 'My friend the robot is going to check up on me and I've done a really good job and I can't wait to tell it.' [...] When the robot checks in and asks me, 'How'd it go? Did you get it done?' Then I could say, 'Yes, I did.' I rarely finish things, so if I'm with someone who would check up on me, maybe it would be motivating." (PwMCI-3).*

Robot Having a Positive Personality: Participants expressed the importance of a robot providing encouragement and motivation. *"It's encouraging. The interaction makes me feel like I could actually do things, you know?" (PwMCI-3).* It was also important that a robot is not judgmental if they do not accomplish their goals. *"I think the biggest thing for me was, there isn't a big stress on accomplishing everything right now. More laid back. 'Okay, we'll try again tomorrow. Maybe look at some different ways to do it.' " (PwMCI-2).* Another PwMCI stated, *" Even if I didn't complete my goal for the day, the robot's not gonna say, 'Well you screwed up,' you know?" (PwMCI-3).*

In addition, PwMCI suggested ways that a robot could be more humanized in its interactions. *"Might put some laughter in there. A scoff or a giggle." (PwMCI-5).* Participants also pointed out its appearance. *"He's as cute as he can be all dressed up" (PwMCI-3).*

They also suggested adding humor and more expressions. *"There might be some things that you could pull in that seem funny to people, just to keep them on a bit of a light side. Wise cracks or something. [...] Like, 'Good morning, Sam. I can't be much help today. I'm a little hungover' " (PwMCI-5). "Actually it'd be funny if when you're going through, 'Here's the progress you've made on your goal,' for the next screen, the robot's eyes get really big. 'Whoaa' " (PwMCI-5).*

Privacy Considerations: Participants discussed privacy, particularly when collecting data from participants. For instance, they wanted it to be more clear when a robot was recording a user. *"When [the user] is talking, is it being recorded on [the tablet display] or is it just what the robot is saying?' " (PwMCI-5).* Furthermore, CNs believed that maintaining privacy could help reduce bias in user responses. *"If [goal progress is] just saying internal to themselves, I think it's a lot less prone to that bias of trying to look good." (CN-2).*

4.2 Identifying Goals

Set Priorities: Due to the variety of ways that MCI can impact a person's cognitive abilities and life, PwMCI may have many goals they would like to accomplish. *"There's a whole list of things I want to do, but I just don't know where to start" (PwMCI-5).* Throughout the course of an intervention, CNs emphasized the importance of working towards a few goals at a time. When it comes to identifying goals with a robot, *"You want to limit it. You don't want people to be working on a dozen different goals at the same time, so they should select probably their top [...] four would be the maximum. Two or three is probably best [...], so you'd have them rank their most prioritized goals" (CN-1).* Then once people have learned the skills to accomplish their goals with the robot, *"they can hopefully take this education and then apply it to their next round of goals" (CN-2).*

Enable Users to Identify Their Own Goals: To ensure that a goal is relevant and useful to a person's life, it is important for a robot to let users identify goals that matter for them. *"Setting a goal that is important to [the person] is probably a good idea" (PwMCI-5).* This can help improve a person's motivation to achieve those goals.

If users are unsure what goals they might want to work towards, participants proposed that the robot could provide possible goal suggestions. One CN stated, *"We could probably give them a list of examples, like example goals, and have them select" (CN-1).* One PwMCI imagines a robot leading such an interaction as follows: *" 'What are your goals?' Input my goals and hopefully it can come [up] with a strategy to help me reinforce those. Maybe come up with some suggestions for other things that I haven't tried" (PwMCI-2).*

However, CNs were aware of the limitations of supporting such open-ended goals on robots. *"I think the problem might arise that if the person lists a goal that the robot doesn't have [in its knowledge base], the robot's not going to understand that" (CN-1).*

Create Specific and Achievable Goals: Enabling a robot to support users with fitting their goals to the SMART framework is an essential part of CGS. *"In terms of measuring the goals or figuring out some outcomes, [...] the goal should be specific, measurable, achievable, relevant, and time based. [...] Having those goals be specific and measurable can help create a system that's better" (CN-2).*

Robots can ask questions to help users reflect and step through fitting their goals to this framework. *"What's your goal? All right, is it measurable? How are you going to measure [it]? Is it achievable? Is it relevant? Is it time-based? What is your timeframe?" (CN-2).*

PwMCI also thought setting a time limit on goals could be helpful. *"As long as I know I've got a time limit, I can dedicate myself more to accomplish it (PwMCI-2).* Another noted, *"My desire [is] to actually accomplish the goal, even if it's a small thing like cleaning off my desk. It might take me two times, but I'll get it done, you know? (PwMCI-3).*

Set Subgoals: To help ensure that goals are achievable, participants suggested setting subgoals. *"If you want to get a job, for example, you're going to have to get yourself organized, you're going to have to do some job searching, you're going to have to create a resume, you're going to have to apply for a job, and so on. So there are all these subgoals" (CN-1).* A PwMCI noted, *"I need to look at things connecting to the big picture. Take things a step at a time [...]. I like that better than, I have to do all of this today." (PwMCI-3).*

Several PwMCI imagined setting daily subgoals that align with their overarching goals with a robot. *"That way, [the goals] are broken down into smaller steps that can be done in a short period" (PwMCI-5).* One PwMCI imagined a robot *"to just start out in the morning saying, 'Okay, today is the 1st of September. What are your goals today?' " (PwMCI-2).* This can help people identify concrete and achievable tasks to work on during the day. *"If they had a suggestion and concrete path to take toward [achieving their goal], [...] that would definitely be helpful, I think. And then you start narrowing it down from 'get organized' to 'store your screwdrivers' " (PwMCI-5).*

Set Goals Based On Existing Behavior: To help identify goals that are realistic, robots can encourage people to base their goals around existing behavior. *"Achievable might be taking what they're doing now and expanding it by 10-20%" (CN-2).* They stepped through an example of helping someone remember to check their calendar. *"How are you going to remember to check your calendar? And so we might set up some systems around that. Maybe he checks it during meals, maybe it's checked in the morning and then in the evening, maybe it's checked when he has [his] morning coffee" (CN-2).*

4.3 Goal Progress Measurement

Scaling Goals for an Individual: Goal progress can be difficult to measure as it can vary widely based on individual goals. Thus, CNs expressed how HRI researchers might use goal scaling techniques to measure and set appropriate goals for PwMCI. *"[Asking] 'How far are you toward your goal now?' at the start and end of the training can be a way of 'goal attainment scaling,' allowing for a better understanding of what strategies work" (CN-1).* They also expressed how a standard self rating measurement would allow for easier data collection, which can lead to better understanding of which strategies work for each goal. *"If you keep it simple and you just measure self rated progress toward a goal on a one to ten scale, it puts every goal on the same metric which is really useful for data analysis later on, because they're all going to be on the same scale" (CN-1).*

Highlight the Wins: PwMCI feel more encouraged to incorporate strategies presented by the robot when they feel like they are improving. One PwMCI discussed how it felt *"reward[ing] if you do something" (PwMCI-3).* During the intervention, CNs suggested giving positive feedback on a person's improvement to encourage PwMCI to try strategies in their lives. *"In an ideal world, they're going to do better when they use more strategies and so you'd be able to give feedback to them that their performance improved when they categorize the information, when they wrote it down, when they use visual imagery, and so on. Then you would encourage them to try the strategies that just helped them" (CN-1).*

Visualize Progress: PwMCI stated that seeing progress and feedback can help them advance towards their goals. *"The feedback is good. And I can see how it would help me progress" (PwMCI-3).* Visualization of progress can positively reinforce working towards goals. *"If the person is motivated to do the goal, it would be a handy thing to have a motivational point. You do something and you go, wow, I didn't know that I got that far. It was kind of like, yay" (PwMCI-5).*

4.4 Intervention Delivery

Highlight Goals Throughout Intervention: Participants expressed how reminders about their goals can keep them on track to complete their goals. PwMCI discussed how reminders about their goals (both overarching and subgoals) at the start and end of sessions could help them focus. *"I think if you're working towards the goals, then it's a good idea to keep indicating, here's a small goal or here's a larger goal, whatever. You emphasize the goal thing because it's where it seems to be going" (PwMCI-5).*

Participants found repetition to be a key part of retaining memory and focus on their goals. *"If I go over something more than one* *time, it helps my memory. If I say my goal is to do that this afternoon [...] to myself, it goes right in and right out of my brain, you know? And I forget that I was going to do that this afternoon. So a reminder is good" (PwMCI-3).* A CN also suggested using repetition in terms of having users, *"do some writing about using [. . .] strategies to improve this domain is going to help with the real world goal" (CN-1).*

Reflecting on their goals can also help keep PwMCI focused. *"[Reflecting can] make me think about progressing toward getting my life more organized, rather just drifting, not actually accomplishing anything" (PwMCI-3).* Another PwMCI suggested the robot could ask, *" 'Were you able to use this strategy anywhere else?' [...] That way it would be a daily thing to get that new task embedded" (PwMCI-5).*

Cover All Intervention Content: It is important for PwMCI to try all strategies presented by the robot to determine the most applicable strategies for them. *"With these cognitive [interventions], I've taken the approach that we want to offer everything. So we want to at least expose them to all the strategies and then see what they find helpful, even if they don't initially report a problem in that domain [...] There's usually a few things that at first blush, it doesn't feel natural to the person, or it doesn't feel like something that they would use, but we really want to encourage them to try it anyway" (CN-1).*

4.5 Transfer to the Real World

Build Good Routines: Participants stated how the robot could help them practice cognitive strategies that incorporate into their daily routines. *"Once I get something attached in my morning routine and I keep working on it, hopefully it will become more ingrained. And then I can add something else" (PwMCI-2).* A CN gave an example of connecting strategies to a daily routine. *"Attaching this calendar planning to something you do everyday. And then you have a little note on your coffee pot say[ing], 'So let's check your calendar.' And so, Sam looks at it, [they go] to get the coffee in the morning and it says to check your calendar. And that's [their] cue to review [their] calendar that day" (CN-2).* PwMCI also expressed interest in having flexibility when practicing with the robot and completing goals on their own time. *"I like the idea that [...] you're busy this morning but you have time this afternoon to organize your desk" (PwMCI-3).*

Check In and Reflect: Participants imagined that the robot can check in with their goals and help PwMCI reflect on the strategies they have been using. This provides direction with goals, understanding which strategies work, and strengthening the investment levels of PwMCI. *"Having Sam be a part of the solution and having Sam generate some of those solutions can be really helpful to support that investment level and that level of interaction and kind of bolster it a little bit" (CN-2). "Every once in a while the robot can check in. 'Now you've finished this module on prospective memory. How do you think this list of strategies is going to help you with your goals over here? Take some time, think about it, jot down some notes. Which strategies do you need to practice more?' " (CN-1).*

Connecting With Other People: PwMCI articulated how practicing strategies with others would be helpful. A PwMCI expressed, *"if it's a home task? It might be a good idea to have the other person in the house working on it with you" (PwMCI-5).* The same PwMCI also stated, *"if it is something somebody wants to do, it would be motivational" (PwMCI-5)* and how goals can be *"embed[ed] [...] especially if you're in a group situation working on a common task" (PwMCI-5).*

4.6 Providing Motivation

Be Empathetic: Enabling a robot to exhibit empathy can be motivating for users to achieve their goals regardless of any discouragement they may experience. For instance, PwMCI stated that reinforcement and guidance from the robot can be encouraging if they did not complete the goal they set for the day. *"It's like saying, you know, to me, 'It's OK if you didn't quite make your goal. We'll try again tomorrow.' " And maybe, you know, 'Just rethink how we want to accomplish it."' (PwMCI-2).* CNs also stated that empathetic phrasing from the robot can prevent PwMCI from feeling a sense of failure if they do not accomplish their goals. *"Normalizing the likelihood that they won't have achieved [their goals] 100% right off the bat can be a good way to phrase it" (CN-2).*

Show Goal Progress: Participants expressed that being able to see their goal progress can also increase their motivation. For example, a PwMCI stated that seeing their progress can inspire them to strive for more, and *"[it would feel like] now you can move on to something more challenging" (PwMCI-2).* Similarly, a CN suggested having dialogue that can encourage participants to keep working towards their cognitive goals. *"Just kind of being like, 'Look, these are all the things you've done so far. Let's try one more' " (CN-2).* Additionally, a participant felt as if seeing progress is a form of positive feedback that shows the impactful progress they have made. *"Especially seeing [a] chart that shows what my accomplishments were will [make me] more likely to want to do more" (PwMCI-2).*

Provide Check-Ins: Participants suggested having the robot check on them at some point during the day to increase their motivation. *"I think that it would be good for me and be like sort of, my friend the robot is going to check up on me and I've done a really good job and I can't wait to tell it, you know?" (PwMCI-3).*

5 DISCUSSION

5.1 Proposed Framework for CGS in HRI

We propose a framework for developing longitudinal, robot-delivered health interventions with CGS capabilities. We provide key considerations for each step of the CGS process to support goal achievement and motivation. While we discuss this framework with respect to our population and intervention context (PwMCI, ME-CCT), our conversations with CNs suggest that it could be helpful for other health conditions of interest to the HRI community.

Support Self-Identified Goals: When helping people identify goals for an intervention, it is important to allow space for self-identified goals. For some people, this may be straightforward (they may already have a goal in mind), but others might be unsure about what they want to achieve. Thus, robots can ask open-ended questions to help people reflect on particular challenges they face, or changes they might want to see in their life. If people are still unsure, robots may suggest goals to start with, such as recommendations from professionals. Either way, robots should encourage people to focus on just a few goals for the duration of the intervention so they do not get too overwhelmed. In particular, asking users to identify a daily task that is in service of their larger goals can help them set achievable and time-based subgoals.

Goal Progress Measurement: Due to the highly individualized nature of goals and what success might look like for each person, it is important that robots measure and scale goals based on the

Table 1: Our proposed framework for supporting collaborative goal setting in HRI.

Goal Setting Component	Robot Considerations
Support Self-Identified Goals	Robots should allow people to self-identify intervention goals, and provide goal suggestions if needed. They can help users set SMART goals with preset questions, or ask users to set daily goals.
Goal Progress Measurement	Robots can scale goals and progress to an individual using the Goal Attainment Scale. People can then track their own progress, and this will also simplify progress visualization. Robots might use sensors to observe user behavior, or use visual aids (e.g. facial expressions, gestures) to highlight wins.
Intervention Delivery	Robots can remind people of their goals and encourage them to connect their goals to the intervention content via multiple communication modalities (e.g. speech, tablet, gestures). Roboticists may explore additional modalities to support different goals and abilities, e.g. a memory game where users speak aloud vs. touch the robot.
Transfer to the Real World	Robots should let people identify their own"homework" that is specific to their lives and goals, possibly based on their existing behaviors or involving other people. Robots might cue users to build routines verbally or nonverbally. And as a social presence, they may facilitate the inclusion of family with intervention activities or discussion of goal progress.
Provide Motivation	Robots can adjust facial expressions, movements, or tone of voice to convey empathy or excitement, remind them of the "bigger picture", or provide positive reinforcement.

individual. CNs suggested using the Goal Attainment Scale [59] which allows for each person to set their own goals and what success means for them, set around their current and expected levels of performance. Then, robots can ask people to track their own behaviors that may correspond to their progress between sessions, such as how many times they took their medication or whether they completed their daily goal. Robots can check in periodically and record progress, enabling people to view their progress over time, which can also help with motivation. Or depending on a robot's capabilities, it might observe a person's behaviors relevant to that activity and possibly give feedback (e.g. as one PwMCI suggested, giving specific instructions for how to organize a desk).

Intervention Delivery: Robots can also support goals in how they deliver intervention content. For instance, they can remind or ask users to reflect on their goals throughout the intervention, including at the beginning and end of a session. In doing so, they can encourage users to connect the intervention content to their goals and promote motivation to follow through with the intervention. This is especially important for contexts such as ME-CCT where it is beneficial to expose people to all of the content from the intervention, and they can choose for themselves which strategies to integrate into their lives. On the other hand, it is important to not overload people so robots could focus on content that may be most relevant or interesting to the individual. This could help maintain adherence, especially at the beginning of an intervention.

Transfer to the Real World: Providing people with opportunities to consider how they can put the ideas they learn with a robot into practice is key to enabling them to transfer those skills to the real world. This may come in the form of assigning or helping them identify "homework" where they can try out the skills. These homework assignments should be specific and fit into a person's existing life so it is easy to achieve and can become a new habit over time if they see fit. If applicable, robots might also encourage them to engage other people in their lives as they complete their goal. Then, in the following session, robots can ask open-ended questions to help people reflect on how it went, including identifying any challenges they faced and possible solutions for the future.

Provide Motivation: Motivating people to achieve their goals is key to maintaining adherence to an intervention and improving its efficacy. Robots can leverage many strategies that CNs use, including showing empathy if people do not show progress towards their goals, reminding people of "big picture" goals and changes they want to see in their life, and providing positive feedback such as by highlighting any progress or celebrating when people show progress (e.g. dancing, playing music, telling a family member). It may also be beneficial to modify goals if the original goal turns out to be unattainable, or if their priorities change over time.

5.2 Connection with Other HRI Contexts

We developed this goal setting framework in the context of a robot administering CCT to PwMCI, but we hope that researchers can apply it to other populations and applications. Our population very much wanted to be able to set goals in collaboration with a robot, and we expect this to be true more broadly as well. CGS can help people determine what real world behaviors will help achieve those goals, and likely will be more inclined to follow a robot's suggestions for reaching those goals. This is particularly important for HRI applications where interactions with a robot do not necessarily correspond to goal progress or how well a person can transfer the skills to their real life. In these cases, it is important for people to be truthful with themselves and the robot about goal progress, and decide for themselves what is useful for their lives.

For example, consider a scenario proposed by Jeong et al. [28, 29], where a robot aims to support the mental health of students. If a student aims to improve their social relationships, identifying personal strengths might improve their confidence and indirectly help their social life. Applying the CGS framework, the robot can further help a student identify and scale their goals to their behaviors to ensure those goals are achievable and relevant (e.g. joining a club or messaging an old friend). Letting individuals define and scale their goals around their existing life and priorities can help improve motivation and confidence that they can achieve those goals.

Furthermore, CGS with robots may need to support input from other stakeholders, including domain experts (e.g. clinicians) who may have intervention goals, or family members who can provide support if someone cannot set achievable goals for themselves. Supporting all stakeholders in the CGS process will be crucial to improving the efficacy of these interventions in numerous contexts, such as for academic and social learning for children [52, 54], or interventions for people with cognitive impairments [31, 53].

5.3 Robot Implementation Considerations

PwMCI suggested additional robot implementation considerations that would help support goal achievement and motivation. For instance, they suggested the robot ask open ended questions to help people reflect on their day. In this case, the robot does not need to necessarily understand what the person says in response. For example, the robot can ask people if they accomplished their goal(s) for the day, and if there were any challenges they faced. Providing an opportunity for them to reflect can help them contextualize their goals and increase motivation in working towards their goals regardless of whether or not they accomplished it for the day.

Roboticists can also simplify implementation of robot behaviors through goal scaling and similar self-report measures. Since goal progress varies based on an individual, this can enable the robot to easily help people assess progress without implementing a system that can handle all permutations of robot content and goals.

Participants also suggested that the robot record audio and play it back to the person. For example, people could record themselves saying their goals and the robot would store that audio recordingto play back to the person later. This feature can help people keep accountability to their goals and provide an additional motivational push to reach their goals. As technology advances, robots could use many abilities to enhance CGS, such as open-ended discussion to lead motivational interviews and personalized conversation.

In addition to the goals PwMCI have for the intervention, other stakeholders, including clinicians and family, may have different, possibly conflicting goals [32]. Some challenges that may arise include implementing a system which can consider and balance these differing goals and priorities. For example, clinicians expressed how PwMCI should try all of the strategies to gain a sense of which strategies work the best for them. However, this may be demotivating for PwMCI who may not see success with strategies they do not think are applicable or can be integrated into their life. More research needs to be done in order to determine methods that can be used to support the multiple, differing goals of each stakeholder.

Design tensions also emerged from discussions with CNs and PwMCI. For instance, they differed in how integrated the robot would be in their lives. CNs recommended more independence from the robot through shorter, more user-led interactions. In contast, PwMCI seemed to prefer if the robot provided daily support in their lives indefinitely, e.g., an alarm clock, daily reminders, or answering questions and giving recommendations on how to do tasks.

Another tension was how to use the intervention to achieve goals. CNs imagined concrete "homework" where people can directly apply and practice the strategies in their lives. However, PwMCI imagined tasks that were not necessarily related to the strategies. For example, PwMCI focused on goals such as making their bed or doing dishes, where their main barriers were motivation rather than cognitive abilities. Practicing the strategies would not necessarily contribute to achieving these goals, so the question arises whether a robot should still encourage the use of the strategies.

Ethical considerations also arose in our discussions, which HRI researchers will need to thoroughly explore before deploying CGS on robots longitudinally in the real world, particularly for people with cognitive impairments. For instance, PwMCI had high expectations for the support a robot could provide, such as holding full conversations, knowing details about their lives and abilities, and providing support with various tasks throughout the day. Realistically, clinicians and possibly robot developers will be in-the-loop while robots complement care, so more research is needed on how to set appropriate expectations while considering user privacy and technical limitations [23, 26]. Furthermore, most robot-delivered interventions will only be in a person's life for the duration of the intervention. While CNs envisioned PwMCI learning the skills but ultimately being independent of the robot, PwMCI envisioned the robot integrated in their lives indefinitely. This raises questions regarding how to design robot behaviors to promote independence from the robot, especially if people begin to see it as a companion that motivates them to achieve their goals [7, 33, 50].

5.4 Limitations and Future Work

There are some limitations we will address in future work. First, we kept our sample size small to avoid burdening the community, following recommendations from participatory health research [3]. As MCI affects people differently, participants had a diversity of behavioral and motivational factors which arose in the challenges and goals they shared (e.g. improved organization vs. prospective memory). While we were mindful of these differences in our analysis, PwMCI expressed commonalities in how they set and manage goals over time (e.g. daily subgoals), and how robots can provide support, (e.g. reminders). In this work, we aimed to establish generalizable CGS concepts and approaches for robotic technologies, and we will explore how CARMEN can support personalized CGS in future work In addition, due to the pandemic, participants viewed video demonstrations of robot interactions rather than physically interacting with it. While participants would ideally interact with CARMEN to understand its abilities, we aimed to design robot interactions and explore their potential to support CGS. Thus, we do not believe video demonstrations impacted our findings significantly.

5.5 Conclusion

In this paper, we presented our findings from co-designing robot behaviors with PwMCI and CNs on how CARs can support CGS in the context of supporting a home-deployed cognitive intervention. Based on these insights, we introduced a CGS framework, which we hope other HRI researchers can use within their application domains. We also introduced CARMEN, a CAR which longitudinally administers ME-CCT to PwMCI at home. We demonstrated concrete examples of goal-setting interactions with CARMEN, co-designed with stakeholders, to support reproducibility and extensibility in HRI. These contributions lay the foundation for enabling robots to support motivation and goal achievement throughout a longitudinal intervention at home, which will ultimately extend their efficacy, support accessibility, and improve care for countless people.

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