A Collaborative Approach to Support Medication Management in Older Adults with Mild Cognitive Impairment Using Conversational Assistants (CAs)

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ABSTRACT

Improving medication management for older adults with Mild Cognitive Impairment (MCI) requires designing systems that support functional independence and provide compensatory strategies as their abilities change. Traditional medication management interventions emphasize forming new habits alongside the traditional path of learning to use new technologies. In this study, we navigate designing for older adults with gradual cognitive decline by creating a conversational "check-in" system for routine medication management. We present the design of MATCHA - Medication Action To Check-In for Health Application, informed by exploratory focus groups and design sessions conducted with older adults with MCI and their caregivers, alongside our evaluation based on a two-phased deployment period of 20 weeks. Our results indicate that a conversational "check-in" medication management assistant increased system acceptance while also potentially decreasing the likelihood of accidental over-medication, a common concern for older adults dealing with MCI.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in accessibility**.

KEYWORDS

mild cognitive impairment, older adults, medication management, conversational assistants

ASSETS '22, October 23–26, 2022, Athens, Greece

ACM ISBN 978-1-4503-9258-7/22/10.
https://doi.org/10.1145/3517428.3544830

ACM Reference Format:
Niharika Mathur, Kunal Dhodapkar, Tamara Zubatiy, Jiachen Li, Brian D.Jones, and Elizabeth D. Mynatt. 2022. A Collaborative Approach to Support Medication Management in Older Adults with Mild Cognitive Impairment Using Conversational Assistants (CAs). In *The 24th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '22), October 23–26, 2022, Athens, Greece.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3517428.3544830

1 INTRODUCTION

In this research, we explore the potential of supporting medication management in older adults with Mild Cognitive Impairment (MCI) through the use of Conversational Assistants (CAs) which include smart speakers and assistants such as the Google Assistant, Siri, Amazon Alexa or Microsoft Cortana. They provide a natural language based support to enable access to information and services for everyday interactions [7]. As of 2019, 20% of people over the age of 60 owned a smart speaker in their homes [18]. While adoption rates by older adults are lower, many older adults have reported feeling "supported" and "empowered" while interacting with any form of smart assistant in their homes [21, 46]. Assistants equipped with distinctive personality characteristics such as voice modulations, learning behaviors, and advanced natural language processing contribute to the anthropomorphization of these devices by users, particularly older adults, who tend to draw upon their experiences and behaviors cultivated over their lifetime. Our work is motivated by these observations, seeking to foster a welcome connection between users and CAs that can positively influence healthy behaviors such as effective medication management.

Most medication management interventions support building habits over time by providing an integrative system for reminders or alerts [5, 31]. An additional challenge we address in our work is designing an interactive medication management system for an aging population diagnosed with gradual cognitive decline. Mild Cognitive Impairment is defined as an intermediate stage of cognition situated between the expected decline due to aging and the more significant decline associated with dementia and Alzheimer's disease [33]. It is estimated that between the years 2012 and 2050, the US population over the age of 60 is expected to double [29], and about 16.6% of the population above 65 will develop MCI [34]. Symptoms of MCI, which include varying degrees of memory loss, language problems, and loss of attention among many others, have shown to gradually become worse, and very few patients show a significant cognitive improvement. It is estimated that approximately 14.9% of individuals with MCI will progress to dementia in over 2 years and 38% will progress to dementia in 5 years [16]. Therefore, while we do want to encourage and support habit-building in older adults with MCI through our design, we also attempt to understand an optimum level of persistence and support required. We are aiming to find a balance between a system that delivers repeated notifications (which may be suitable for people with dementia or a more advanced cognitive decline than MCI) and one that takes into account the varying cognitive strengths of people with MCI and remains optimally attentive to sustain healthy medication goals, including preventing accidentally taking the same medication twice (referred as "over-medication" throughout this paper). With our work, we aim to ground MCI as a critical period to empower older adults to develop habits and compensatory strategies that they can rely on if or when their cognitive abilities decline further.

A key foundation for our work are existing studies with older adults with MCI and their usage of CAs for daily activities, such as in [46]. CAs have shown to provide useful and usable support for older adults with MCI across a variety of functions, from information searching to calendaring, especially when sufficient training is provided. For the purpose of our study, we chose to use Google's CA, Google Home Hub, a visual assistant with an 8 x 6 inch touch screen and a built-in Google Assistant. A deciding factor in choosing this device was the display of voice commands and responses on the screen, eliminating the need for our participants to remember what they said. In this paper, we first describe our exploratory user research process, which informed our design of an interactive medication assistant system built within the Google Home Hub. We then discuss the deployment of this system in households that included older adults with MCI, focusing on their usage and engagement patterns over the course of 20 weeks divided between 2 Phases. In this two-phase research study, we explore the impact of 'learning from use' and inform design revisions based on usage and feedback from Phase 1. Finally, we summarize our findings from both phases and frame opportunities for future work.

1.1 Contributions

With this work, we aim to offer the following contributions to the larger research community:

- We offer insights into the existing medication management strategies and habits of older adults with MCI and their expectations for an interactive medication management system that integrates with these strategies. We also identify opportunities for this system to address gaps with existing strategies as well as limitations to traditional alarm and reminder based interventions.
- We present the design of an interactive system built within a CA for flexible medication management and deploy the design in a two-phase research study. Our system design is informed by possible usage scenarios drawn from exploratory user research sessions with older adults with MCI and their carepartners.
- We articulate how building a medication system which prompts reflection from its users and focuses on "checking-in" rather than traditional reminders or alarms led to increased engagement with the system over time while also discouraging accidental over-medication in older adults with MCI.

2 RELATED WORK

In this section, we discuss why medication management in older adults with MCI remains a challenging area of research and the various factors that can lead to the ineffectiveness of existing interventions in the context of older adults. We also discuss the additional and peripheral cognitive challenges that they face, and highlight the need for more empathetically designed systems. We then review and discuss the adoption of CAs by older adults and identify potential areas of opportunities.

2.1 Medication adherence in older adults: A persistent challenge

Many past studies have sought to reduce barriers to effective medication management in aging populations. In [25], Martin et al. discuss various psychological needs and requirements for medication-related artifacts representing information to older adults, such as text size, language used, and amount of information presented. Fulmer et al. note that cognitive power and mental health conditions such as depression can significantly impact medication behaviors [13]. Studies report that 25 to 59% older adults above 65 are not able to take medications as prescribed and report higher instances of complications arising as a result of those. [4, 39].

These challenges are further complicated by neurological issues associated with MCI and aging, such as dexterity limitations, vision and memory loss. Some older adults with MCI also struggle with reduced awareness of their circadian rhythms, placing additional stress on their ability to adhere to routines [8, 22]. Low adherence is also attributed to lack of personalized and alternate ways to keep track of medications and efficient contextual reminders despite feeling a need for it [14]. Medication management forms an integral component of the daily lives of older adults, they have scheduled medications not only for specific health issues, but also for preventive and maintenance use, such as vitamin and dietary supplements. Remembering to take medications multiple times a day can be challenging for older adults with MCI and also for their caregivers, who often have a parallel medication schedule of their own [2]. Medication management for older adults remains an essential area of research, as poor adherence to prescribed medicines is considered to be a significant health challenge [15] and one of the leading causes for emergency complications arising from issues related to heart disease, diabetes, hypertension and mental health [4, 15].

2.2 Role of technology in Medication management in older adults

A number of research prototypes and commercial products aim to incorporate technology into systems for medication management. However, the bulk of studies with older adults and their interactions with technology currently focus on the roadblocks stemming from the technological stereotypes associated with older adults, who are often "defined by their deficits rather than capabilities" [32, 44]. Currently, most commonly-available tech-based interventions to support medication management are aided by the use of smartphones [41], alarms, reminders [23], automated pill dispensers [28], and digital calendars [3]. Similar to other technologies oriented to the consumer market, there are many challenges associated with using these interventions with older adults. Some older adults, particularly those with a relatively recent diagnosis of MCI, report feeling distressed by a lack of control over their ability to maintain a schedule. This fear of losing control and independence also becomes a contributing factor in their hesitation to adopt newer technologies [32]. There is a need to develop systems that provide a degree of functional independence to individuals with MCI while also supporting them through the journey of cognitive transition stemming from MCI. The other challenges with technological interventions arise primarily out of the friction associated with their costs, on-boarding and technical complexity [31]. Patel et al. in [30] reviewed these challenges in a usability and workload comparison of 21 commercially-available electronic medication adherence products with older adults and caregivers such in [9]. They reported that the usability of these products is significantly lower than the national average usability scale score [30]. An analysis of 3 off-the-shelf commercially-available automatic pill dispensers - Hero, Pria and Medacube - revealed an average annual cost of more than $300 with additional on-boarding charges. The set up and maintenance requirements of pill dispensers are also challenging for older adults [37]. Additionally, most of the existing strategies, consisting of reminders and alarms, introduce the risk of accidental over-medication by simply reminding to take medication. When reminded about taking medication, older adults with MCI have a high chance of not being able to recall if they have already taken the medication and take it again [2]. Reminders and alarms also run the risk of becoming too persistent by requiring the user to keep snoozing or asking it to stop [38], leading to a drop in engagement levels over time resulting from alarm fatigue [32]. While there is some research about specialized medication management systems specific to older adults [31], very little, if any, research proposes the integration of such systems within existing practices of older adults with cognitive deficits, while also involving them in the design process. There is a potential to develop systems which integrate and utilize the connection that older adults form with CAs and provide them a more coherent experience [36]. Given this, our work strongly advocates and aims to represent an assets-based design approach [19] which effectively integrates within the existing strategies used by older adults to manage medications.

2.3 Adoption and use of CAs by older adults

In recent years, there has been a substantial amount of research that explores the potential of CAs, either embedded within smartphones or as standalone devices, in helping older adults for health and well-being, as well as for entertainment purposes given their interactive and multimodal input capability [6, 11, 45, 46]. In [27], Morrow et al. develop a framework adopting the use of CAs from pedagogical purposes to promoting self-care for older adults. Their framework highlights the assistant's need to function dynamically through the evolving stages of any type of cognitive deficit, from acceptance to establishing routines and finally sustaining engagement with the system. While most of the existing work focuses on older adults and their interactions with CAs, the challenge of designing for compensatory cognitive support is underexplored, with the exception of a few studies that address cognitive behaviors as a result of MCI [20, 45, 46]. These studies emphasize following a user-centered approach for personalization given the diversity in the MCI spectrum, accounting for hearing and dexterity limitations and to incorporate pleasant interactions that are able to sustain engagement beyond the study. Based on analyses from studies that have explored long-term interactions between older adults and CAs [10, 17, 46], it is observed that the initial interactions were mainly related to entertainment (music, searching, etc.), cooking related reminders, and alarms related to healthcare monitoring, highlighting the potential for CAs to aid the maintenance of routine tasks. An important aspect of older adults and their usage of CAs is their tendency to anthropomorphize the device as a companion within their home environment [6, 35]. They are likely to interact positively with the system through socially engendered responses as a result of the voice-based interaction that can facilitate a longer retention of healthcare related information, as demonstrated by Azevedo et al. in [1]. Waterschoot et al. [42] highlight the need to think about multi-stakeholder interactions with the CA such as the older adults, their caregivers and healthcare professionals with a controlled sharing of information. Designing for gradual behavioral change as a result of aging through multimodal interactions in the form of a conversational coach and a text-based system is explored in [12] and the results indicate that a system that provides multiple interaction affordances was positively accepted by the participants. Finally, a critical aspect of designing an interactive system for older adults with MCI is to retain a degree of autonomy and functional independence related to personal health routines and decisions through customizable interaction options [40].

We define our research and design goals to use these insights from existing studies and gaps identified within them to design a medication management system which reduces the complexity of the set up and maintenance process, works with the existing strategies that older adults are used to, takes the cognitive decline and the specific nature of the decline into account while also retaining a degree of control over their own system, is optimally persistent and not too repetitive, and finally, is designed to reduce the instances of over-medication to the extent possible.

3 OVERVIEW OF RESEARCH APPROACH

This research study is conducted within the context of a larger comprehensive cognitive program in a hospital for older adults diagnosed with MCI. This program provides lifestyle and therapeutic interventions with a focus on exercise, nutrition, functional independence, group therapy and compensatory cognitive strategies working with older adults with MCI and their caregivers, who are mostly their spouses or adult children. The program aims to "empower" older adults through an array of restorative activities such as yoga, meditation, group sessions, nutrition counseling, smart home installations, etc. with the aim of slowing cognitive decline and protecting overall brain health. The program refers to individuals with MCI as "members", not patients, and calls their caregivers as "carepartners" to signify a mutual partnership and an active commitment to each other. Within this context, the program has ongoing studies about the use of CAs to support members and carepartners in their daily lives. All the participants in our study were enrolled in this year-long program and had an existing diagnosis of MCI. More details about participant characteristics are mentioned in sections 4 and 6.

To gain a better understanding of the day-to-day experience of older adults living with MCI, we attended 4 weekly group sessions offered by the program. During these sessions, "dyads" of members and their carepartners interact with each other and the program staff via a Zoom call, keeping each other updated on their progress and occasionally sharing personal life events. During two of these sessions in Month 1, we introduced them to our study goals and scheduled user research sessions with interested participants. All the participating dyads were located in the same city, however, the research sessions were conducted remotely via Zoom due to COVID-19 research protocols. All members had a diagnosis of MCI from their neurologists and were actively enrolled in the program activities. As active participants, all the dyads in the study had the Google Home Hub installed in their homes for over a month and were aware of the keywords required to initiate conversation with it. We also worked through a Privacy Impact Assessment to understand privacy questions and concerns addressed by MacLeod et al. in [24] and provided a summary of data collection and management protocols to each participant. The purpose of these research sessions was to gain a better understanding of the existing strategies for medication management as well as the expectations from CAs in the context of medication management. In the next section, we describe these research sessions and the insights gathered, which informed the design goals for our system. We then deployed the system with 7 dyads, in 2 phases for a total period of 20 weeks. We evaluated usage mid-deployment and iterated on our design between the two phases. The Phase 1 deployment of our study lasted for 4 weeks. Following initial evaluation of usage and incorporating design revisions based on our findings, we then deployed the system for an additional period of 16 weeks (Phase 2). Finally at the end of Phase 2, we again conducted interaction logs analysis and interviews with the participants, which informed our final study takeaways. A visual timeline of the study is shown in Fig. 1.

4 EXPLORATORY USER RESEARCH

To understand existing medication practices and expectations for the system, we conducted two focus group sessions and one scenario-based design session with groups of older adults with MCI and their carepartners. The insights gathered from these user research sessions helped us to formulate concrete design goals for our system. In the following sections, we describe these sessions and our analysis. The participants for these sessions were all recruited and sampled from the cognitive program introduced in section 3. All participating dyads had a greater than 2 daily medication frequency and used a variety of strategies to manage medications that we were interested in learning more about.

4.1 Focus Group Sessions

We conducted 2 focus groups with our participants to understand their existing medication management strategies and to introduce them to our study goals. The sessions were conducted remotely via Zoom and adhered to COVID-19 research protocols in place at the time. Verbal consent was obtained from all the participants to record the session and share the data with the researchers on the team as described in the approved Institutional Review Board (IRB) protocol. The participants were all recruited from the cognitive program introduced in section 3. The 1st session had an attendance of 18 dyads, out of which 17 members had their respective spouses as carepartners and 1 member was in a member-daughter dyad structure (36 total participants). The second session was conducted in a similar format with 12 dyads, with 11 members with their respective spouses as carepartners and 1 member in a member-child structure with 3 adult children (1 male; 2 female), located in different cities (26 total participants). We divided the 45-minute sessions into 3 sections, shown to the participants through a shared screen presentation. The 1st section had multiple choice questions that prompted the participants to indicate how often they took medications, where in their home medications were located, and where the CA was situated in their house. In the 2nd section, we focused on facilitating a discussion among the participants around their personal habits or tips for remembering medications. This section also prompted a dialog among the carepartners and their involvement in the medication management routine of the members. In the 3rd section, we informally recruited members to be involved in subsequent design activities as well as the eventual deployment.

After the sessions, we made an affinity diagram from our notes and transcripts to extract key insights from the data gathered. This inductive approach helped us to group the learnings from the session into four categories (Expectations, Habits, Concerns, Current Techniques), presented in Fig. 2. This analysis then helped us to formulate the following design goals from this session:

(1) The traditional use of alarms or reminders that lack context or labels to signify the purpose of that alarm or reminder, often accompanied with a repetitive sound, is considered to be unreliable and ineffectual. Participants reported that they often had trouble recollecting what an alarm or a reminder was originally set for. This insight helped us understand the need for specific and unambiguous messaging associated with an alarm or reminder.
(2) Physical or digital spreadsheets, pillboxes, and paper calendars were the most common ways of keeping track of medications. Some members also reported relying on their carepartners to be in control of their medications. While these methods provided a certain level of robustness for the dyads, they also expressed interest in exploring how their CAs can help them streamline this process by reducing the need to remember to check their calendars or sheets every day, often multiple times in a day, and to also reduce the carepartner burden.
(3) Participants did not want to completely abandon their existing medication management methods such as using pillboxes, sticky notes, etc., since they had been a part of their routines for many years now. This suggested that any new

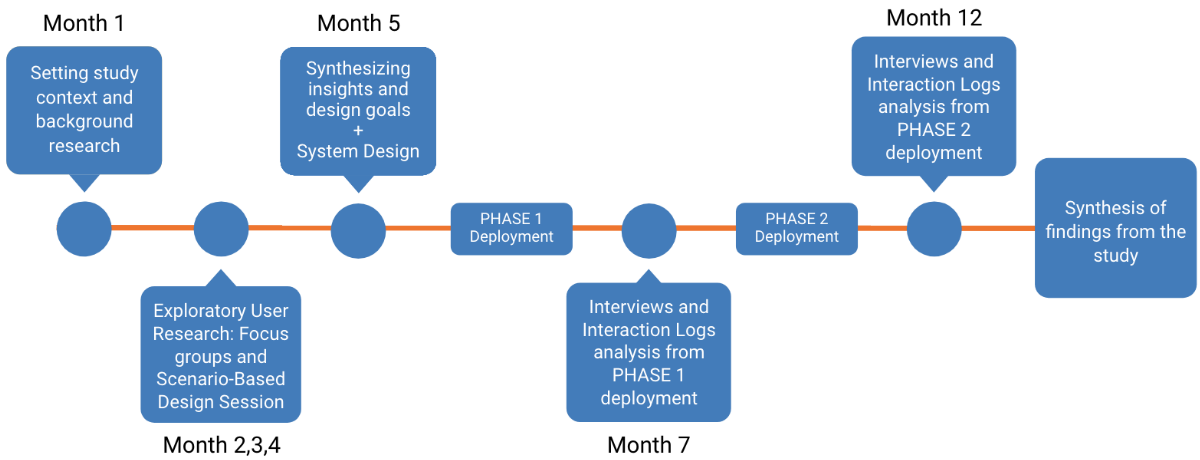

Figure 1: Month-wise research study timeline

digital medication management tools that we design for them should work with, and not replace, these existing methods.

4.2 Scenario-Based Design Session

To probe deeper into the learnings from the focus groups and to understand the expectations of the participants for CAs supporting medication tasks, we conducted a 45-minute design session with the goal of involving the participants in the design process. The session was conducted remotely via Zoom due to COVID-19 protocols and had 18 participants, all of whom also participated in the focus groups previously. The participants for this session were also recruited and sampled from the cognitive program and had a greater than 2 daily medication frequency. 8 members attended the session with their carepartners and 2 members attended unaccompanied. While designing the narrative structure of the session, we decided to partially anthropomorphize the CA as a humanoid robot called Rosey, inspired from the popular 60s animated sitcom The Jetsons, who worked as the Jetson family's housekeeper. This depiction helped spur engagement with participants during the session by grounding the discussions in a playful, familiar metaphor [43]. We divided the session into 3 parts. In the 1st part, we introduced the session structure and presented example scenarios, such as Rosey reminding them to call their kids. Building on this example, in the second part, we presented the participants with a storyboarded scenario of Rosey interacting with them at home. We kept the conversational aspects of the storyboard interactive using empty speech bubbles and giving the participants the chance to design the conversation between them and Rosey by talking about their dialog preferences and typing them in speech bubbles. This exercise helped us to understand their expectations for the system. In the 3rd part, we touched upon the degree of involvement that they expect from the system by presenting multiple scenarios through storyboards in which the robot varies its level of persistence with the reminders by asking once or twice or continually until an answer. We then asked the participants to think aloud and discuss their preferences for these interaction levels. This exploratory design session helped us in understanding their attitude and perception towards the involvement of CAs. We present the codes developed based on the analysis of insights from this session in Table 1 that later informed our system design. Using the codes in Table 1, we extracted the following tangible design goals from this session:

(1) In most scenarios, the participants hinted at their preference for a system that checks in with them as opposed to an alarm or reminder. In traditional alarms and reminders, the systems generally do not prompt the members to answer, since they are worded as "Time for medicine/take medicine" or similarly. An individual with MCI might not remember that they have taken the medication already, and in the moment, might unknowingly take it again. They could also unknowingly take the medication for the next day as a result of being told by the system to take it. Given that "over-medication" is also a challenge for them, our system needs to "check-in" and ask the member if they took the medication or not, and not "remind". This check-in introduces the possibility to prompt the member to think about whether they took the medication or not, go and check their pillbox or calendar if they need to, and then report back to the system.
(2) Another crucial expectation from the system is for it to have an understanding of the member's routines and dialog preferences. If the timing of initiation conflicts with an ongoing activity, it should have the functionality to check in again later, or allow the member to schedule it for a later time. If the assistant receives no response after initiating, there should be multiple channels of notifications to confirm the check-in. Suggestions for these channels included phone notifications, text messages, emails, and calls.
(3) When the member has already taken the medication, and if they choose to notify the system of it, it should generate positive feedback or reinforcement to motivate the user. This positive recognition can reinforce feelings of achievement of having accomplished the task beforehand.

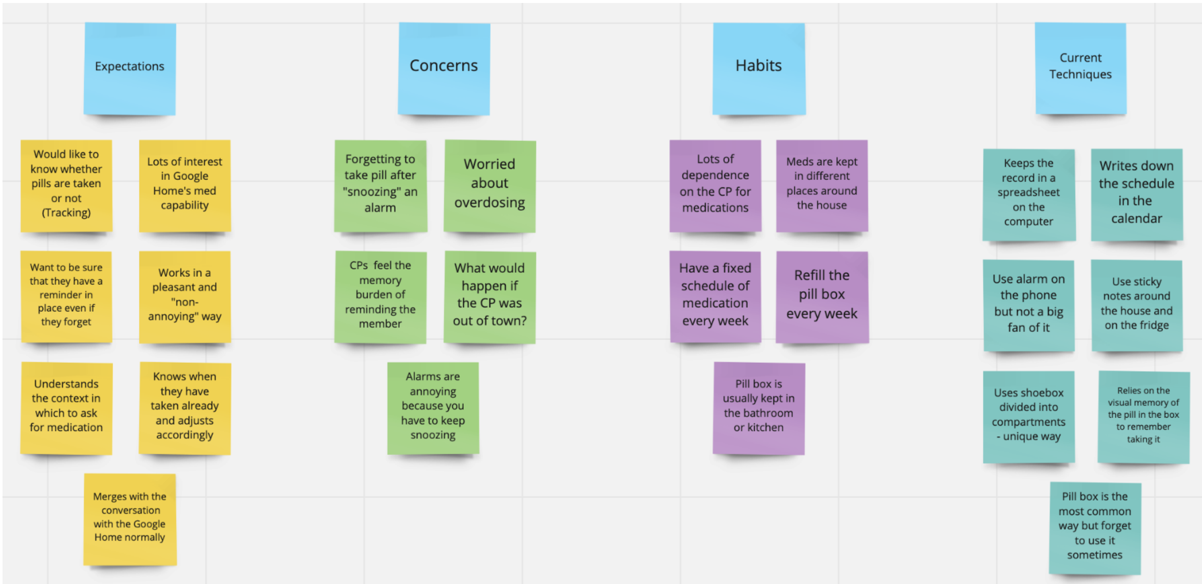

Figure 2: Insights from the focus group sessions categorized into expectations, concerns, habits and current techniques

Table 1: Codes and sample quotes from the scenario-based design session conducted with participants

Codes	Sample Quotes From the Scenario-Based Design Session ("She" refers to Rosey)
Positive feedback	*"Maybe it can play my favorite song after I answer it back.."* *"How about a movie star's voice to applaud me? Maybe James Earl Jones!"*
Lacking in current systems	*"Sometimes when I hear my phone alarm, I take the medicine and then later my wife tells me that I'd taken it before already"* *"I have to remember to check the calendar every day, my wife helps me with that.."* *"We set alarms for our medicines but it's hard to remember what the alarm was set for because we have many alarms"*
"Check-in" and not remind	*"She should ask me whether I have taken the pills because that way I can think about it or ask my wife, rather than telling me firmly that I should"* *"It should ask me to go check, its hard but it can help me making sure that I'm just not taking the same pill again"*
Dialog expectation	*"I hope she does not talk like the reminder in my phone, it's dull.."* *"She should be respectful and not nosey like my alarm I keep snoozing"*
Multiple channels of notification	*"If we're not at home, can she send a message to our phone?"* *"What if I'm outside walking the dog when she wakes up?"* *"Maybe it can send a message to my daughter's mobile saying that I have taken the medicine for the morning"*
Check again	*"I expect her to come back inside and check again after we're done with yoga"* *"But I hope she knows when is a good time. Can I tell her when to come back?"*

5 DESIGNING A GOOGLE HOME ACTION FOR MEDICATION

From the insights generated during the exploratory user research sessions, we designed our Google Action, "Medication Action To Check-In for Health Application" (MATCHA), using Google's Action Console, a web-based tool to manage the development, registration, configuration and analysis of Google Actions. A Google Action is an applet for Google Assistant that provides additional and extended functionality. Google Actions are coded in the Action Console and can be integrated into any device that supports Google Assistant.

We listed the scenarios and structured the dialog flow based on the design goals informed by the discussions during the focus group and exploratory design sessions, with appropriate paths for each scenario. Table 2 presents possible scenarios and the resulting MATCHA response, as well as the source of the insights that led to our designated response. Our system recognizes more than 200 possible unique responses from the dyads. The assistant's volume of

Table 2: Possible scenarios, MATCHA response and informing insight

No.	Possible Scenario	MATCHA Response	Corresponding Source of Insight
S1	Taken the medication before MATCHA checks-in	Plays cheering sounds and applauds them with positive affirmation	The need to foster positive engagement with MATCHA and reinforcement of medication management.
S2	Not taken the medication before MATCHA checks-in	Asks if they would like to repeat the check-in at a later time and guides them to specify a time period after which MATCHA should check-in again	The need for the check-in to be persistent and let the member specify a later time for check-in
S3&4	Does not remember if they have taken the medication or not before MATCHA checks-in AND/OR Needs to check the pillbox to confirm	Asks to check and waits for them to respond again and responds further according to scenario 1 or 2	The expectation to reduce cognitive burden on the member to remember whether they have taken the medication. Goal with the pillbox is to catch missing medications but also reduce risk of over-medication through specific reminders.
S5	Says something Google does not understand - unknown response	Lets them know that it has sent the feedback to the research team to rectify the error and we will be in touch soon	The preference to utilize the existing connection between the members and the conversational assistant to foster support and feedback
S6	Not around to respond or MATCHA receives no response until it is timed out	Sends a notification on the member and the care partner's phones to notify that the routine has started	The expectation to engage multiple channels of notifications to confirm the check-in

operation as well as the physical location of the Google Home Hub was influenced by house layout and preferences. Some members keep their medications closer to their Google Home Hub, while others keep the two on different levels in the house. Our data reported that the kitchen and the bathroom were the most common locations for the Google Home Hub and the medications respectively. These specifics of the location factored into the medication assistant's pitch, volume and time functions for the dyads. The assistant also addressed the member with a greeting and their name with every check-in.

We conducted the deployment in two successive phases. We first introduced MATCHA to the participating dyads by conducting training sessions at their houses and also provided them with a set of printed training materials explaining the purpose and interaction flow of MATCHA, and ways to contact us in case of questions. We then personalized the medication schedules for each dyad by obtaining medication routines during a pre-deployment interview and incorporated these individual routines into MATCHA through the Google Assistant backend on the Google Home app. After Phase 1, we conducted interviews and interaction logs analysis to inform design revisions for Phase 2. At the end of Phase 2, we conducted a final set of interviews and interaction logs analysis to inform overarching takeaways from the study.

6 LEARNING FROM USE: DEPLOYMENT PHASE 1

In Phase 1, we deployed MATCHA to the Google Home Hubs of 7 dyads for a period of 4 weeks. These 7 dyads were a subset of the dyads from the research sessions and were sampled on the basis of their willingness to participate in the study and their level of engagement with the CA. The dyads primarily belonged to suburban communities, and had a diverse professional background with 3 members having retired from technical professions, 2 from an art background, 1 from a clinical support background and 1 from academia. MATCHA triggered at specific times each day depending on the member's medication schedule. The average frequency of MATCHA reminders for the 7 dyads was twice a day, with the lowest frequency being once in a day and the highest being 5 times in a day. The medication frequency is the total number of times per day that a member takes a set of medicines, for example, if once in the morning and once in the evening, the medication frequency is 2. A summary of the demographic data including sex, age, medication frequency is provided in Table 3.

After Phase 1, we collected interaction log data from the 4 weeks and manually transcribed them from the "My Activity" toolbar in the Google Home app. We also sent a modified version of the System Usability Scale (SUS) to the members and carepartners to respond to, reworded to better represent our study context, with the goal of calibrating our assessment of the interaction log data. The SUS results gave us a usability score of 84.66 from the members, and 86.16 from the carepartners. Overall, the log data and SUS indicated sustained use for most participants but presented potential areas for improvement and revisions. Based on that input, we conducted qualitative interviews with the 7 dyads via Zoom lasting for 30-45 minutes, to gain an understanding of their experience with MATCHA so far and to contextualize the patterns seen in the interaction logs and SUS.

6.1 Phase 1 Analysis

The insights from the interviews, interaction logs and the SUS score after Phase 1 resulted in a set of design revisions that we incorporated before the deployment of Phase 2. Below, we present some interview quotes from Phase 1 analysis that, along with logs and SUS analysis, resulted in the design revisions as described in Section 6.2:

(1) *M6: "To be honest, the loud cheers were a little overwhelming. It kept going on and on."*
(2) *CP1: "Sometimes Google doesn't understand what I am saying, she keeps asking me to repeat."*
(3) *CP2: "I would like to get a text or email whenever he has taken a medicine."*
(4) *M5: "There are days when I take the pill after Google tells me, does she know that?"*

A breakdown of scenario-wise interactions, including the "Taking Now" scenario and engagement rate for Phase 1 is discussed further in the Results section.

6.2 Design revisions after Phase 1

Major design revisions informed by the interaction log analysis, SUS results and the interviews included tamping down the level of positive feedback from MATCHA - while some members found the length and nature of the positive reinforcement uplifting, others found it “overwhelming”. To be specific, the first positive feedback started with a 4-second loud cheering and celebratory sounds, followed by a 4-second clapping sound and ended with the assistant verbally appreciating the user saying "Yay! Good Job! I'll check-in at the next medication time". The feedback was overwhelming for some members, particularly for those with multiple medications through the day therefore, in Phase 2, we revised an adequate level of positive feedback, with a 2-second moderate cheer accompanied by the same verbal praise from the assistant. We also included a touch-based response option in which the members can press the corresponding button on the touch screen in lieu of answering verbally. We added 4 touch buttons - “Yes I did”, “No I did not”, “I don't remember” and “Taking Now” in Phase 2 based on the insights from the interviews. This modification also provided an alternate way of providing a response in the case of muffled speech or other speech-based issues. To distinguish between responses that were recorded through touch buttons and ones that were recorded through verbal response in the interaction logs, we added an emoji to every button text to recognize this response type in the logs.

Additionally, we increased the system time-out period to receive a response, and added an additional 'Taking now' scenario in which the member informs MATCHA of taking the medication right now as a result of the check-in. We noticed a large number of such responses and separated those from the unknowns and counted them manually through the backend under a new category called "Taking Now". We also revised the settings for phone notifications to be delivered every time MATCHA is triggered, as opposed to only when it receives no response. This was informed by the carepartners expressing the need to know every time the member has responded to the system. We further explain and contextualize these revisions with participant quotes in the results section (Section 8).

7 LEARNING FROM USE: DEPLOYMENT PHASE 2

For Phase 2, the revised version of MATCHA was deployed to the Google Home Hubs of 5 dyads for a period of 16 weeks, with 2 dyads wishing to drop out of the study between Phase 1 and 2. One dyad with a medication frequency of 5 times in a day found the frequent check-ins tiresome, and the other dyad was unavailable due to travel through the summer. We further plan to address the inactivity of the 2 dyads that dropped out of the study by exploring more about personal preferences and their incorporation into the system in our future work. A summary of the demographic data, including if they continued to Phase 2 is provided in Table 3.

We analyzed the interaction logs for the 16 weeks of the Phase 2 deployment to examine the continuing engagement patterns of the dyads resulting from the design revisions. Finally, we conducted interviews with the 5 dyads via Zoom for 45 minutes to understand their experience and contextualize patterns in the interaction logs. We used the inductive coding process to develop major themes across our interviews and usage data, grounded by our initial exploratory design sessions and their findings. For each interview, a team of 3 coders, all researchers with a background in Human-Computer Interaction, clustered the codes together and as patterns began to emerge, developed distinctive themes for these clusters. After initial coding, a process of inter-rater reliability was conducted to agree on the final themes. At the end of Phase 2, we verified and refined the existing themes by looking across the interviews from both phases and generated concise findings. We discuss the results from the interaction log analysis and the interviews from the two phases in the next section.

8 RESULTS

8.1 Interaction Log and Engagement Analysis

During Phase 1, MATCHA generated 476 initiations and we recorded a total of 84 interactions (responses) over the course of 4 weeks. The remaining initiations were left answered. This ratio results in an engagement rate of around 18% for Phase 1. These interactions are mapped on a normalized scale of 30 interactions per week for each scenario in Fig. 3. This normalization per week was done to account for the difference in the length of the phases. During the analysis, we noted that there were some responses in which the members indicated that they have not yet taken the medication but will take it now as a result of the MATCHA check-in. This scenario extended the existing functionality of MATCHA as a reminder in addition to the original check-in function. This scenario, which we call the “Taking Now” scenario, was not incorporated into MATCHA before Phase 1, and it prompted an “I don't understand what you just said” response from it. This also accounts for the significant number of unknown responses in Phase 1. We manually counted these interactions from the logs to define an additional 7th scenario for the design revision in Phase 2. To be clear, the “taking now” responses formed a part of the unknown responses by the dyads and as we had access to the backend of the system, we were able to count those separately. The unknown interactions do not include the responses that pertain to the “taking now” scenario and hence the separated unknowns are labelled as "other unknowns" in Fig. 3.

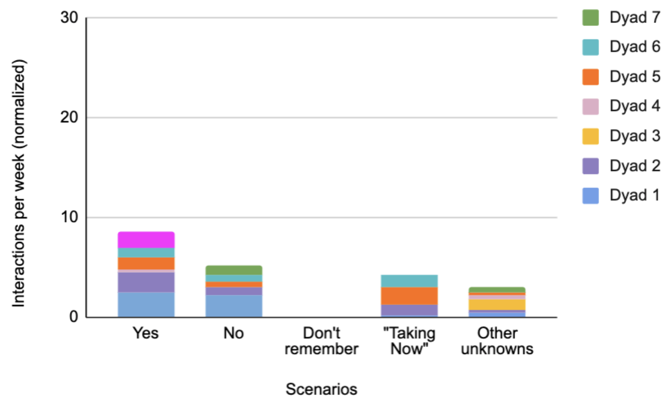

Figure 3: Normalized number of interactions by scenario in Phase 1 for 7 dyads (normalized per week)

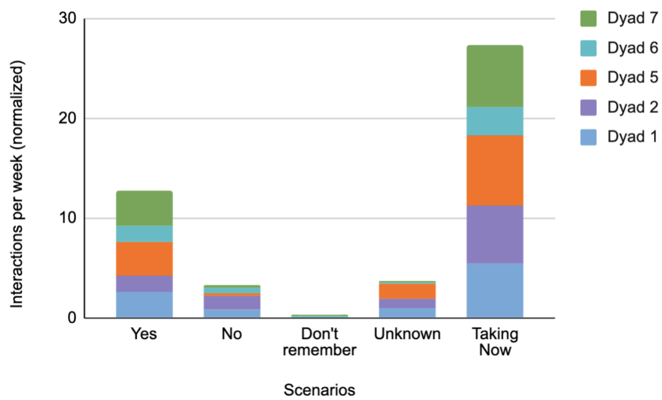

Figure 4: Normalized number of interactions by scenario in Phase 2 for 5 dyads (normalized per week)

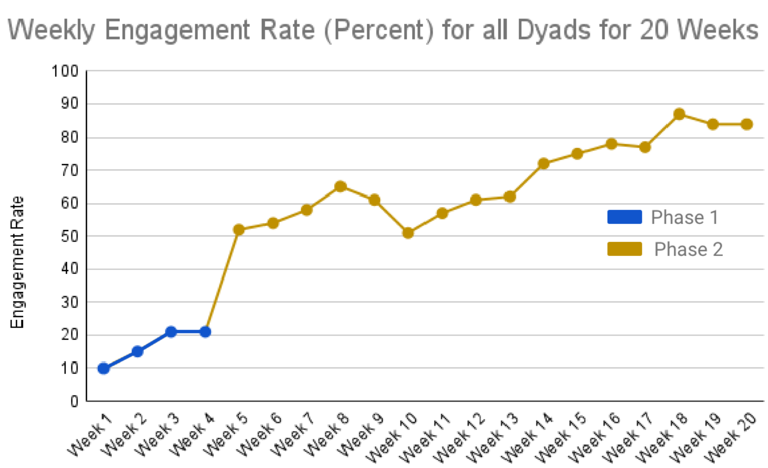

Figure 5: Weekly Engagement Rate Trend for all Dyads for 20 Weeks

Table 3: Summary table of participant demographics.

Member & Carepartner ID	Member Age	Member Sex	Daily Medication Frequency	Relation to member	Carepartner Age	Continued to Phase 2?
M1, CP1	62.6	Male	3	Spouse	60.9	Yes
M2, CP2	78	Male	2	Spouse	75	Yes
M3, CP3	75.4	Male	5	Spouse	70.6	No
M4, CP4	85.3	Male	2	Spouse	76.3	No
M5, CP5	70.8	Female	2	Daughter	45.7	Yes
M6, CP6	75.4	Male	1	Spouse	76.7	Yes
M7, CP7	74.3	Female	2	Spouse	74.6	Yes

During Phase 2, MATCHA generated 1120 initiations and we recorded a total of 760 interactions (responses) over the course of 16 weeks. This ratio of interactions to all initiations results in an engagement rate of around 67% for Phase 2, showing an increase from the engagement rate of 18% from Phase 1. We attribute this increase in engagement to the design revisions we incorporated to improve the user experience and also an increase in the comfort level and familiarity with MATCHA forming a part of their daily routine over time within their CA. If we treat dyads 3 and 4 (from Phase 1) as outliers that did not adopt the use of MATCHA, we nevertheless still see an uptick in engagement from Phase 1 to Phase 2, from 27% (without outliers) to 67%. These interactions are mapped on a normalized scale of 30 interactions per week for each scenario in Fig. 4.

To account for the variability in study phase duration and medication frequency for each dyad, we calculated the weekly engagement rate for the dyads over the course of the study shown in Fig. 5. This weekly engagement rate was calculated by adding all the times that MATCHA initiated for all dyads in 1 week (using each member's medication frequency per day), adding all the interactions counted for all dyads in that week from the log data, and then calculating the engagement rate for every week of the study. It can be seen from the figure that the weekly engagement rate increased significantly right at the start of Phase 2, was sustained during Phase 2 and then increased towards the end of Phase 2, indicating an overall positive attitude and a sustained level of comfort with the system over the course of the study. The slight dip in engagement around Week 10 coincides with a holiday weekend (4th of July). Some dyads were away from home and only getting reminders on their phones, which they may or may not have had the time to respond to. The slight uptick of engagement in the final weeks is also correlated with scheduling interviews at the conclusion of the study.

8.2 Findings from Interviews

In addition to analyzing data from interaction logs, we also conducted interviews with the members and carepartners at the conclusion of the study with the goal to understand their perception towards the system. We asked questions that prompted them to talk through their experience of using MATCHA and whether they would like to continue using it. We present the following findings from synthesizing our design insights, observed usage and mid deployment interviews, and integrating our final set of participant interviews with the 5 dyads at the end of Week 20.

8.2.1 The system induced feelings of "confidence" and support to the dyads while being sufficiently persistent in its interactions.

The dyads reported feeling "confident" about their medication routines as a result of the medication assistant being integrated into their existing Google Home Hub routines. This kind of support also reduced the need to set up external systems such as automatic medication dispensers that are significantly more expensive and have complex set-up as highlighted in section 2.2. The integration of the medication system within the CA reduced the on-boarding friction experienced by our participants with other technologies. The conversational and unambiguous nature of the check-in as opposed to the non-contextual and repetitive nature of alarms and reminders led to a relatively faster adoption of MATCHA through the course of the study.

- ***M5:*** *"I like that Google kind of feels like a part of the house, and not something that I have to keep answering to all the time like my morning alarm.."*
- ***M7:*** *"I feel assured that if I were to forget my pill, she [MATCHA] will ask me and that's important because I feel less pressure to remember my routine.."*

Some members also recollected instances when MATCHA prompted them to think about or confirm the medication status before responding as a result of the check-in functionality. In some cases, they went and checked their pillboxes before reporting completion if they did not remember taking the medication. The positive affirmation from MATCHA after reporting completion also generated assurance of having a degree of control over their own memory and subsequently getting rewarded for it.

- ***M5:*** *"When I hear Google praise me, I feel good and like I have accomplished something and that she is happy with me.."*

All the participating dyads in Phase 2 expressed the desire to continue using MATCHA in their Google Home Hubs after the completion of the study. Their use, now at around 55 weeks, continues through the writing of this paper, which is a significant result for us given the need to sustain long-term engagement of technology with older adults, as mentioned in section 2.2 in [38]. We discuss the long-term engagement requirement further in the discussion section.

8.2.2 The medication assistant provided an alternate way for the carepartner to monitor member's medication schedule.

We noted that most members reported being supported by their carepartner in managing their medication schedules. During the interviews, the carepartners reported having MATCHA as a way for them to use its capabilities to support their goals for medication management of their partner. They also reported instances when they were not around or were unavailable. In such cases, MATCHA supported an effective integration with external channels such as phone notifications and calls at the medication time by sending notification alerts to the member as well as the carepartner's phones. While carepartners expressed that they would still like to sometimes physically check-in with the member as they do regularly, they also followed it up by feeling a sense of peace that if they were to someday forget checking-in, there was a system in place to do it for them.

- ***CP6:*** *"I'm usually outside when it's his medication time in the evening but I get the alert on my phone which is good because then I can know that he has taken the medications.."*
- ***CP5:*** *"It is great that I get mom's medication notifications on my phone and can keep a check on her. I also double check with her sometimes just in case.."*

8.2.3 Members and carepartners liked that the system was aware of their preferences and individual medication schedules.
Based on the diversity in medication schedules and preferences revealed during pre-deployment interviews with the dyads, we attempted to personalize some parameters of the assistant such as the volume, location, personalized greeting for time of the day, etc. This personalization was appreciated because it took into account individual cognitive behaviors to some extent and incorporating these individual variations into the system helped in making the experience more pleasant for the dyads. For example, while some dyads preferred a lively and playful interaction, others wanted a more straightforward and simple check-in and the positive feedback. In addition, some dyads also expressed their desire to have access to their reported medication data and have it shared with their clinical teams at differing intervals.

- ***M2:*** *"I like that it's kind of playful and talks to me but also not too much or too loud that it starts to annoy me.."*
- ***M1:*** *"I think it's helpful because it reminds me every night before I go upstairs that I need to get the medicine out. Sometimes I keep the medicine out on the counter for the next day too. In the morning, I'm usually sitting right next to it in the kitchen so I can respond directly to it while I'm having coffee."*
- ***M2:*** *"Our doctor always asks us if we have been taking our medicines regularly and we always feel like we have to say yes whether we did or not because it's hard to recall perfectly, so it would be useful if Google could tell him that directly.."*

8.2.4 Adding touch-buttons to provide an alternate way of interaction in addition to voice interaction was appreciated.
After adding touch-buttons on the Google Home Hub screen as an alternate way to account for Phase 1 feedback, we saw that the number of touch-based interactions hovered at a range of 20-35% of total interactions for each dyad through the study. While some dyads used the buttons more than others, a combination of the two forms of responses was appreciated and used consistently by the dyads. It also helped to alleviate the requirement to speak clearly during every interaction.

- ***CP1:*** *"We did notice that you added the buttons there, they weren't on there before. I quite like them, specially with the smileys. We can now touch the buttons to answer and I do that a lot because I sit very close to it mostly.."*
- ***M7:*** *"Sometimes Google does not catch what I'm saying, I don't know if it's my fault or hers, but when that happens, I go and touch the button and she can hear me fine again. So I definitely like having the buttons.."*

9 DISCUSSION

In this section, we reflect upon our results and discuss their importance from the context of the gaps and opportunities identified at the end of section 2 and from user research.

9.1 Personalization Matters

A key insight from related work and the user research conducted with older adults with MCI is that the lived experience of MCI is highly diverse. It is shaped and characterized by various factors such as age, personality, caregiving network and the existence of a supporting environment, both physically and emotionally. MCI is a different and a unique experience for everyone and incorporating individual preferences for interaction to the extent possible is critical for improving user experience and system acceptance. The result of these individual circumstances is a customized functionality incorporated into the assistant that works in accordance with individual preferences identified through following a user-centered approach to research. As highlighted in [20], user research should be conducted in a way that facilitates this level of personalization in volume, medication routines for different types of medications, preferred mode of greeting, etc. Before deploying MATCHA, we conducted a series of pre-deployment interviews with the dyads to understand their medication schedules and behaviors and the location of their Google Home Hubs and pillboxes within the house. These schedules revealed the diversity of medication habits based on personal preferences. Integrating these preferences in the system helped in providing a coherent support to their existing medication habits and strategies eliminating the need to abandon them entirely. Adequate personalization also helped in navigating the initial hesitation to adoption of new technologies by older adults [32], and provided a compensatory support system that resulted in faster acceptance of it during the course of the study. With respect to the need for personalization, as the system deployment expands, we plan on studying the interaction patterns based on frequency and also the scenarios of usage based on the type of interactions, with the aim of informing frameworks that can be used for groups of users. This can be a way to ensure practical scalability while also retaining personalization to the extent possible.

9.2 Sustaining long-term engagement

It is crucial that any technical intervention aiming to provide routine-based support during MCI to older adults needs to be effective in the long-term and also account for the often aggravating decline. In most cases, the primary caregiver supporting their partner with MCI is also of an advanced age, and have medical issues of their own. This can induce feelings of anxiety related to their ability to continue providing support to their partner. As identified in [32, 38], sustaining long-term engagement beyond study duration is a critical issue that leads to the failure of most interventions deployed for older adults. These failures could be a result of poor user experience that does not provide error prevention, alarm fatigue as a result of frequent reminders or inadequate amount of training and functional support to the older adults and their partners while introducing the system. Increased technical complexity and difficulty in understanding the instructions also leads to drop in engagement after a while for most commercial medication management devices [37]. Our study worked towards addressing these issues by incorporating the medication system within the Google Home Hubs, CAs that the participants already felt a degree of comfort towards and also reduced the interaction complexity by having an interactive voice as the primary affordance. We also highlight the need to provide comprehensive written and printed training materials and personal support to older adults at every step in the process of deploying such systems, and creating a safe environment for them to ask questions and have their concerns addressed. Error prevention was addressed through transmission of unknown responses to the research team, and a feedback response from the system requesting the user to repeat their last sentence. Given the high-risk nature of medication mishaps, we also made sure that the system had alternate ways to notify to carepartner of the medication time (phone notifications) and regularly checked the backend to make sure the check-ins were generated at the right time for each dyad. Finally, the most pivotal aspect of MATCHA that contributed towards the long-term engagement was the clear and unambiguous check-in functionality as opposed to the traditional reminders and alarms. As discussed in section 4, over-medication is often a result of non-contextual reminders and is a critical concern for older adults with MCI, and the check-in functionality of the assistant helped to alleviate this concern by prompting reflection at the medication time, notifying the carepartner and incorporating existing strategies such as prompting them to check their pillbox as part of the interaction.

9.3 User autonomy and freedom

Given the occurrence of MCI at the juncture of normal aging and dementia, its diagnosis can be accompanied by feeling a lack of control [26] as a result of altered memory capacity and functional abilities while also retaining some cognitive power. As a result of this, the cognitive program as well as the individuals with MCI and their carepartners feel a significant desire to maintain a certain level of autonomy and functional independence, while also being open to compensatory support. The interventions need to support flexibility of medication routines as a result of changing life circumstances. Dyads, specifically the carepartners, expressed the willingness to get more training to be able to provide the needs of their partner to the assistant in a way which makes the interaction more effective. There are days when they know in advance that their schedule is going to be different from usual, and having the control to schedule their own check-ins a day before will make the experience more independent. We demonstrated this to them through the Google Home App. Any intervention for medication management needs to strike a balance between the identical basic structure of the conversational flow for all participants, while also providing the participants the option to personalize check-in timings, and notification preferences for their individual uses. Another way to facilitate more autonomy in the system is by generating transparent explanations regarding the check-in purpose by the assistant and the nature of specific medication information given to it [40]. Additionally, it is also important to provide users the functionality to record, share and review medication data. While this ability is not currently supported by Google's actions console, there are workarounds to incorporate this feature into the medication assistant that our team is currently exploring, discussed more in section 9.5. Recording and sharing of medication routine history over a period of time can also be beneficial to the clinical staff to monitor adherence and efficiency of a new medication routine in order to make informed clinical decisions.

9.4 Multiple interactions modalities for improved compensatory support

While this forms a part of designing for personalized interactions in 9.1, it is important to address this separately as an important construct in providing individualized support to older adults with MCI. Multimodal interactions were positively accepted by participants in [12], as a result, we explored the addition of touch-based feedback in the system in addition to voice response. The Google Home Hub has a screen to provide visual feedback to the user and the members have a strong mental model that stems from the touchscreen capabilities of their smartphones and tablets that they extended to the CA. The touch-buttons also provided an alternate interaction option to the participants in the cases when their speech was not recognized by the assistant or they had issues with verbal communication. However, we highlight the need to make these multiple interaction modalities clear to the users by having them designed to be adequately visible to avoid multiple responses and the resulting confusion.

9.5 Adaptive functionality and external integrations

While MATCHA relied primarily on the check-in functionality, there were also instances in Phase 1 when the participants used it as a reminder to inform the assistant of taking medication as a result of the check-in, effectively making the check-in work as an effective reminder to take medication. Recurring instances of this adaptive functionality, although initially prompting an unknown response from the assistant, was then incorporated into Phase 2 as a separate interaction stream and the assistant provided positive feedback by playing cheering sounds leading to increased interaction success between the member and the assistant.

Finally, as a closing contribution of the study and to set up future directions for this work, we recommend the need to incorporate external integration with the CA to effectively extend its use for health and well-being of older adults with MCI. A proposed external integration for the purpose of recording medication behavior as well as to verify ground truth of medication ingestion are smart pillboxes. These pillboxes would integrate with the medication assistant in a way that the presence of the pill in the pillbox compartment would be known to the assistant through sensors. This will also lead to lesser medication check-ins throughout the day for individuals with more than average number of medications in a day. The smart pillbox and the CA would work together in the same ecosystem to notify the users in the case of a delayed or missed medication and report it whenever asked. There are also other ways in which the pillbox status can be verified with the medication assistant such as smart buttons pinned to the pillbox, an integration that we are hoping to explore in future studies. Added integrations can be with smart home devices, smart phones, tablets, sensors, etc. which provide a more robust functionality to the CA by creating a networked interaction ecosystem.

10 LIMITATIONS

While we are encouraged to see our study results, specifically the sustained engagement of the medication system, we would like to address some limitations of our work. The development of MATCHA was a contributing part of a larger ongoing study that is aimed at understanding the usage of CAs to support functional independence and provide compensatory support to the individuals with MCI and their carepartners. As a result of this, most of our participants had been interacting with a CA for over a month before our study. It would require more research to analyze the engagement and usage when the system is newly introduced to the participants. Additionally, we would also like to point out that recruitment for the participants for the purpose of this study was limited to the participating dyads in the cognitive program who are able to afford long-term therapeutic healthcare and primarily belong to upper-middle and high-income households. While we are currently in the process of working towards extending the study with CAs to other healthcare institutions serving a more broader population, the study results at the time of this paper are only representative of the dyads within this cognitive program. In the future, we also plan on reaching out to assisted living facilities and establishing connections with the community partners who work in those facilities. The commercial nature of the system, i.e., being a Google product, ensures that the technological infrastructure is well supported and can be accessed through a central Google email. Finally, we would also like to point out that all of our participating dyads included a 2-person team - the member and the carepartner (spouse or adult child). Our goal for future research is to understand multi-carepartner teams consisting of more than one adult child or extended family members in different locations.

11 CONCLUSION

As older adults with MCI continue to age and advance through varying levels of cognitive progression, and with increasing numbers of new diagnoses of MCI every year, it is crucial to design new technologies and adapt existing ones to support aging adults in important tasks such as medication management. In this study, we explored the idea of supporting these tasks using CAs and designed a medication management system while keeping the needs and cognitive behaviors of our participant population central to our design. We observed that a design centered on specific medication management scenarios, personalized to individual routines, and broadly focused on "checking-in" regarding medication actions in contrast to narrow alerts and reminders, generated sustained and positive engagement. Working from this foundation, participants saw additional avenues for future work including integration with smart devices and augmented pillboxes, and the creation of medication records to share with clinical care teams.

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