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Designing a Reminders System in Highly Automated Vehicles' Interfaces for Individuals With Mild Cognitive Impairment

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Many individuals with mild cognitive impairment (MCI) struggle with the decision to cease driving prematurely due to cognitive deficiencies in processing speed, memory, attention, judgment, or visuospatial skills. Highly automated vehicles (AVs) can be used as assistive technologies for individuals with MCI, performing all driving tasks for them, and extending their safe and independent mobility. However, use of highly AVs introduces a different set of challenges than manual driving. These challenges rely more heavily on memory and decision-making abilities of its users. Therefore, the objective of this study was to investigate the barriers that individuals with MCI face when interacting with highly AVs to support the design of in-vehicle interfaces that will help users with non-driving related travel tasks. Specifically, we aimed to design a system for providing reminders and other guidance to individuals with MCI during solo trips in personally owned or private AVs. To achieve this goal, we conducted individual interviews with experts in driving rehabilitation, rehabilitation professionals, and academics with a focus on assistive technologies, rehabilitation sciences, engineering, and inclusive design ($N = 7$). The thematic analysis of the data from these subject matter experts highlighted the necessity for reminders, defined as system-initiated prompts that assist individuals with remembering or acknowledging a specific piece of information, and resulted in a set of user needs. We then created a set of prototype interfaces based on these user needs that help individuals with MCI complete their trips by providing reminders of important trip related information. The reminders system was designed to be displayed on a central dashboard display placed in front of the passenger's seat and present important information that address the users' difficulties with prospective memory, remembering and understanding the features of the highly AV, and understanding the current trip status. This study serves as an initial investigation into ensuring that the experience of using highly AVs is inclusive and can support the needs of individuals with MCI. The designed interactions proposed by the reminders system can serve as a platform for future in-vehicle interfaces.

Keywords: mild cognitive impairment, highly automated vehicles, reminders system, user centered design, thematic analysis, inclusive design

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1 INTRODUCTION

Mild cognitive impairment (MCI) or mild neurocognitive disorder is considered an intermediate stage between normal cognition and dementia (DSM-5, 2013), characterized by changes in cognitive functions above and beyond what is expected from normal age-related cognitive decline. MCI can be further classified into amnestic and non-amnestic subtypes. Older adults with amnestic MCI report difficulties retrieving stored information, whereas those with non-amnestic MCI report changes in executive function, attention, visuospatial skills, or language with preserved memory functions (Overton et al., 2019). The cognitive impairments associated with MCI are not severe enough to require help with activities of daily living (ADL) and instrumental activities of daily living (iADL) (Langa and Levine, 2014). However, individuals with MCI may perform less efficiently or make more errors in those ADL and iADL than previous performance (Langa and Levine, 2014).

Researchers have investigated how assistive technology through reminders can compensate for memory impairment and support independent living for people with cognitive impairments. Medication reminder devices have been developed to prompt individuals with MCI to enhance medication adherence (Buckwalter et al., 2004; Kamimura et al., 2012). Smartphone-based applications have been developed to facilitate everyday tasks completion using prompts and reminders (Chu et al., 2012; Igual et al., 2014), although frequent interventions or insufficient training can overwhelm the individuals' cognitive resources and result in poor performance (Lam et al., 2011; Hackett et al., 2020). One area where assistive technologies for individuals with MCI has yet to be explored is driving. About 16 million people in the US living with cognitive impairments cannot drive or need to stop driving prematurely due to deficits in processing speed, memory, attention, judgment, and visuospatial skills (Mapstone et al., 2003; Gauthier et al., 2006; Perneczky et al., 2006; Saunders and Summers, 2010; Haworth et al., 2016; Lazar et al., 2016; Ranchet et al., 2017). Several studies have investigated the links between cognitive impairment and fitness to drive. Pyun et al. (2018) concluded that poor attention and working memory is correlated with driving cessation for more than 30 percent of older adults with MCI. Wadley et al. (2009) suggested that individuals with MCI have impaired driving skills and performance decrements such as poor lane and speed control or gap judgement. Due to these performance decrements, individuals with MCI end up restricting or quitting driving, which results in reduced access to social activities, health and medical services, or employment opportunities (Stanley et al., 2011); and therefore, limited independence (Bascom and Christensen, 2017). Driving cessation of individuals with MCI can also impact their care partners as they often depend on them for transportation (Taylor and Tripodes, 2001).

Automated vehicles (AV) offer great promise for improving safety, mobility, and accessibility as these can remove human errors or mitigate congestion (Fagnant and Kockelman, 2015). Highly AVs that correspond to levels 4 and 5 as defined by the Society of Automotive Engineers (SAE International, 2021) offer full driving automation, with no requirement for the users to take over driving. As such, highly AVs can serve as assistive technologies that perform all basic driving tasks for individuals with MCI or dementia, and therefore, relieve them from manual control of the vehicle (Haghzare et al., 2021). This can allow individuals with MCI to travel by themselves and possibly increase their independence and mobility. Highly AVs change the nature of the driving task away from operational (e.g., maintaining lane position and speed) and tactical (e.g., choice of lane) control of the vehicle and towards strategic control (e.g., destination and route selection). Highly AVs will also allow users to focus on other trip related tasks such as entertainment, keeping awareness of the trip status and preparing for the destination (e.g., navigation from drop-off location to destination), or dealing with non-driving related emergencies. Thus, highly AVs automate the basic driving task of vehicle control, but users of these vehicles may still be responsible for other higher-level activities. However, these types of higher order activities may introduce new challenges since they may be dependent on memory and decision-making ability and present a new barrier to safe and efficient use by individuals with MCI. For example, a study by Haghzare et al. (2021) exploring dementia patients' care partners' perceptions of AVs revealed that people with dementia may face challenges in navigating any pre-trip- or post-trip-related tasks, such as negotiating pick-up and drop-off locations. They also concluded that these shortcomings are due to the fact that AVs are not designed as assistive technologies specifically for people with cognitive impairments. Highly AVs also have new human-machine interfaces that differ from manual driving that would be unfamiliar to drivers. Fraade-Blanar et al. (2021) examined required features of AVs and suggested that people with cognitive impairments require easy-to-understand interfaces. It is important to note that SAE level 4 and 5 systems are not currently available and may still take years of development before they are fully deployed, but it is important to consider the design of user experiences for these future vehicles to ensure that they are inclusive for populations who may benefit from these technologies.

Therefore, the objectives of this study are to investigate the barriers that individuals with MCI face when interacting with highly AVs to support the design of in-vehicle interfaces that will help users with non-driving related travel tasks. Specifically, we aim to design a system for providing reminders and other guidance to individuals with MCI during solo trips in personally owned or private AVs. To accomplish these objectives, we first conducted interviews with subject matter experts (SMEs) to get a better understanding of our users and to generate a list of user needs. We then created a set of prototype interfaces based on these user needs that help individuals with MCI complete their trips by providing reminders of important trip related information. As such, this paper summarizes the user needs elicitation process conducted with SMEs and a user-centered design of in-vehicle user interfaces that facilitate the use of highly AVs for individuals with MCI.

2 SUBJECT MATTER EXPERT INTERVIEW STUDY FOR USER NEEDS ELICITATION

This project used a user-centered design approach in generating the interface design of highly AVs that are adapted for individuals

TABLE 1 | Demographics and background information of subject matter experts.

ID	Age	Location	Occupation	Training and certifications	Level of experience with MCI[1]	Level of experience with older Adults[1]	Level of experience with AVs[1]
1	30	Quebec	Academic	OT[2], Rehabilitation Science	5	5	2
2	45	Missouri	Driving Instructor	OT[2], DRS[4]	4	5	1
3	45	Florida	Academic	Rehabilitation Science	4	3	3
4	48	Florida	Clinician	Rehabilitation Science, CDRS[3]	5	5	2
5	33	Arizona	Clinician	OT[2], CDRS[3]	5	5	3
6	42	New York	Academic	Industrial Engineering	2	4	3
7	40	New Jersey	Clinician	OT[2], DRS[4]	5	5	2

1: 1 = not experienced, 5 = very experienced. 2: Occupational Therapy. 3: Certified Driving Rehabilitation Specialist. 4: Driving Rehabilitation Specialist.

with MCI. The first step in user-center design approach is understanding users and their needs for having a good experience with the design. This section describes the method we used to collect data about our users and the approach we adopted to analyze the collected data.

2.1 Materials and Methods

2.1.1 Participants

We conducted individual interviews with SMEs ($N = 7$) as the first step in understanding users and gathering their needs for the design. SMEs were recruited sequentially, and recruitment stopped once saturation was reached. 15 potential SMEs were contacted in order to recruit our final set of 7 participants. SMEs have been used to collect rich information across a variety of domains and have been proven useful at the needs assessment stage (Preusse et al., 2015). Individuals with MCI are known to be extremely heterogeneous in terms of patient characteristics (Farias et al., 2006; Klekociuk and Summers, 2014), thus SMEs are an especially valuable resource because they can provide insights about a broad range of possible users. The study was approved by the University of Kansas Medical Center (KUMC) Institutional Review Board (IRB # STUDY00147148).

The SMEs were recruited from professional organizations of driving rehabilitation specialists (DRS), rehabilitation professionals, and academics with a focus on assistive technologies, rehabilitation sciences, engineering, and inclusive design. We reached out to experts that are part of the Alzheimer's Disease Task Force of the American Congress of Rehabilitation Medicine, which is a nationwide organization focused on developing and disseminating research relevant to treatment of at-risk and diagnosed Alzheimer's disease populations. Potential SMEs were identified based on their background and experience working with people with cognitive disabilities. These experts were selected so that we have a good balance between the various professional organizations and obtain variability of perspectives. A pre-screening questionnaire was first administered to obtain their demographics information, geographical locations, training and certifications, level of experience working with individuals with MCI and/or dementia, level of experience with working with older adults, and level of experience with working on highly AVs (see **Table 1**). Our SMEs had some experience with AVs but none of them were highly experienced with this technology. To bring our participants up to the same level of understanding about AVs, they received a brief introduction to the technology at the beginning of the interview. The introduction covered the SAE levels of automation, and differences between partially automated (levels 2–3) and highly AVs (levels 4–5). SMEs were also told that highly AVs are not currently available, and the full scope of what is handled by this technology is not set in stone.

2.1.2 Data Collection Approach

We used a phenomenological approach to understand the perspectives of SMEs on the potential challenges that individuals with MCI may face in interacting with highly AVs (Creswell, 2014). This investigative approach allowed for an in-depth understanding of this novel topic from the target population. Considering the goals for the data generated from the SME interviews, we iteratively developed interview questions to elicit discussion regarding the symptoms, general behaviors, attitudes toward technologies, and needs for utilizing highly AVs of individuals with MCI.

Each semi-structured interview was conducted with a single SME. Interviews were conducted remotely over Zoom from 18 June 2021 to 29 July 2021. Each session was approximately 60 min long, and participants were not monetarily compensated for their time. During each session, one interviewer and one note taker were present, with other members of the research team observing. Both interviewer and note taker remained the same throughout all seven interviews. All interview sessions were audio recorded, and an automated transcript was generated from the Zoom software. Machine transcription errors or missing words were corrected, and the transcripts were anonymized by removing any personal information (e.g., participant name).

2.1.3 Data Analysis

Data analysis occurred concurrently with data collection using thematic analysis (Braun and Clarke, 2019). Transcript segments related to user symptoms, general behavior, attitudes towards technology, experience and knowledge related to technology, and motivations and capabilities for using highly AVs, were identified inductively (Patton, 1990; Bradley et al., 2007; Elo and Kyngäs, 2008). Descriptive codes were generated to capture the underlying concept (e.g., "people with MCI may need an alert to indicate that they have arrived at their destination"). If segments were not meaningful on their own, the preceding and following sentences, and the context of the discussion were used for interpretation and classification. Identified segments were aggregated into higher order themes and each theme was then

assigned a descriptive name and a definition of the underlying concept or idea. All transcripts were coded by a team that included the first author (ME) and four trained undergraduate research assistants. Each of the first five transcripts were coded by at least two researchers independently, one of which was the first author. Discrepancies in the codes were discussed and a consensus was reached with the coding team for each transcript. After this initial analysis, the first author completed coding of the remaining transcripts and identified when saturation was reached in the generated themes.

Once all transcripts were analyzed, the goals and characteristics of individuals with MCI were identified that would help with understanding our users. The initial analysis identified that reminders were important for this population, so we used the thematic analysis to define user needs that will be used in the creation of the prototype interfaces to support individuals with MCI. We defined user needs as specific types of information that an individual with MCI may require to remember during a trip. The research team examined the identified themes and sub-themes from the thematic analysis and generated the user needs based on this definition and the team's previous experience as human factors and automated vehicle interface designers.

2.2 Results - Identification of User Needs for Reminders in the Highly Automated Vehicles

2.2.1 User Characteristics of Individuals With Mild Cognitive Impairment

In terms of goals, our SMEs stated that individuals with MCI wanted to regain their independence and improve socialization. They also suggested that individuals with MCI may use highly AVs without their care partners for purposes such as visiting their doctors, friends or family members, going out for shopping or receiving services, and attending gatherings and events. Individuals with MCI are a heterogeneous population with various impairments and degree of impairment. Some of the frequently mentioned impairments included aphasia, hearing issues, visual impairment, and difficulties in accessing the vehicle. SMEs also brought up the decreased information processing, decreased response time, difficulties with learning new things, difficulties with decision making, prospective memory issues, and short-term memory issues as commonly seen cognitive impairments. They may also show different attitudes towards acknowledging their disease and elicit different perspectives about the level of support they need. Finally, individuals with MCI are more comfortable in a vehicle that is driven with a slow speed and light intensity of braking on the smaller roads rather than highways.

2.2.2 Initial Analysis of SME Interview Themes

Besides identifying the characteristics of our targeted user group, we found the following major themes in our initial analysis of the SME transcripts.

1) Individuals with MCI who have a care partner are highly dependent on them for transportation, decision making, and feel safer and more comfortable in their presence.
2) Although individuals with MCI need to be trained to use highly AVs, they can have impaired ability to learn and have different preferences for how they learn new technologies (e.g., experiencing it, being trained by care partners, or having assistive learning technology).
3) Highly AVs need to provide support for individuals with MCI during unexpected and emergency events. This support can include instructing users on how to seek help, offering them solutions for solving the issue, and connecting them to their care partners or other sources of assistance.
4) Individuals with MCI may have privacy concerns about the information they share with their highly AVs. They may want to know how, when, and by whom their information will be used.
5) Individuals with MCI are susceptible to forgetting important information (e.g., their destination) during their trip and they may require reminders of this information.

The final theme, of users requiring reminders, stood out because it was brought up by almost all of the SMEs (6/7). Furthermore, reminders were not part of the research team's initial specification of the in-vehicle system functionality that primarily focused on normal and emergency car operations. Thus, the reminders served as an opportunity to produce a new in-vehicle experience that may benefit individuals with MCI. To highlight the importance of this theme in our analysis, we provide some examples of related quotes.

> *SME [4]: Once memory loss [occurs], we don't get that back through any kind of training, so we just teach people compensatory strategies. This definitely could be incorporated into any technology.*
>
> *SME [3]: You need to have like something integrated. Your interface, would have it, integrated with the reminders. So [the reminders] pop in, and constantly remind them that this is what they're doing.*

The reminder theme included 12 subthemes and 41 codes. Four of the subthemes discussed the users' need for reminders, the users' attitude towards reminders, if the users would use their own generated reminders, and if the users would want to customize reminders. The remaining subthemes referred to types of information individuals with MCI were susceptible to forgetting that may affect their experience during a trip with a highly AV. These subthemes were used in the generation of user informational needs for a reminders system. The generated user needs are presented below in the order of descending frequency as mentioned by SMEs:

1) User Need 1: Individuals with MCI may not remember where they are going, why they are travelling, and when they will arrive.
2) User Need 2: Once the vehicle has arrived, individuals with MCI may have difficulties with identifying, orienting, and navigating to their destination.

TABLE 2 | Common user needs identified by subject matter experts with examples.

#	User Needs	% Discussed by SMEs (*N* = 7)	Example Quotes
1	Trip information (destination, purpose, arrival time)	6/7 = 86%	SME [7]: So just some prompting of reassurance [for] where they're going, what they're doing, what the next step is, and then, when they get there
2	Destination orientation	5/7 = 71%	SME [6]: Knowing where they go for that last mile from the drop zone to their final destination. In a foreign place, you get disoriented, you know? Do I cross the street this way? Where is my destination from here?
3	Belongings	4/7 = 57%	SME [2]: The vehicle maybe [be] able to detect a cup was put in the cup holder or a purse was placed on the floor, or something of that nature or even just a simple reminder: 'please gather your valuables from the vehicle'
4	Trip completion	4/7 = 57%	SME [6]: I think there should be some indication that they have, in fact, arrived at their destination and that it is safe to stand up and exit the vehicle
5	Current location in trip	3/7 = 43%	SME [7]: It's a good idea, [if] they had a screen in front of them shows where they are [on] a map that routes where they're at and when they're at their destination, it might show the name of the place
6	Functionalities and features of the vehicles	3/7 = 43%	SME [4]: They may forget that you can talk to the vehicle or you can change the radio station, or how to change radio station, or how to, turn on the AC or how to turn the heat on or the defroster
7	Required vehicle safety actions	3/7 = 43%	SME [7]: Reminding the person just general safety of the vehicle, don't just open the car
8	Time and date	3/7 = 43%	SME [4]: You know, what time of day it is, is it daytime, is it nighttime, morning is it, because they often have trouble with that

3) User Need 3: Individuals with MCI may forget to bring their belongings, such as cell phones, purses, or grocery bags, to the vehicle and take these belongings with them when they exit.
4) User Need 4: Once the vehicle has arrived, individuals with MCI may not recognize that the trip has completed, and they need to exit the vehicle.
5) User Need 5: Individuals with MCI may not recognize where they are in their trip.
6) User Need 6: When individuals with MCI use highly AVs, they may forget what functionalities and features their vehicles have and how they can use them.
7) User Need 7: At the start and end of the trip, individuals with MCI may forget to perform required safety actions such as ensuring doors are fully closed, buckling their seat belts, etc.
8) User Need 8: Individuals with MCI may forget what day and what time it currently is.

The identified user needs largely focused on pre- and post-trip procedures, higher level strategic goals in driving (i.e., navigation), and general situation awareness. **Table 2** shows the proportion of participants who mentioned each of identified user needs (i.e., subcategories of information that users may be susceptible to forgetting during a trip), and examples of supporting quotes.

All the SME quotes related to each user needs, stated that the information was important for individuals with MCI to remember during a trip. Only one SME disagreed with one of the identified user needs. For User Need 5, current location in a trip, one SME stated that individuals with MCI do not need to know their current location during a trip, as indicated by the quote below; this SME was not included in the count for User Need 5:

> *SME [6]: A large percentage of the population who does not [need] anything more sophisticated, they do not care where they are along the route, they do not need to know what landmarks they are passing, or you know, they are on the vehicle, they are at their destination, everything in the middle, is not important.*

3 USER-CENTERED DESIGN OF A PROTOTYPE REMINDERS SYSTEM IN HIGHLY AUTOMATED VEHICLES

The user needs identified based on the SME interviews were used to produce prototype interface designs for a reminders system for use by individuals with MCI in highly AVs. We defined "reminders" as visual or auditory information provided by a system to assist individuals with remembering or acknowledging a specific piece of information. Within our project, the reminders system was designed to be a part of a larger in-vehicle system that supports individuals with MCI in highly AVs. The highly AV allows users to plan their trips prior to entering the vehicle via a connected phone and web application, provides trip information, and helps them deal with unexpected or emergency events (e.g., medical emergencies, vehicle malfunctions) through in-vehicle displays to improve the overall user experience and safety. These features will be provided through other interface systems within the vehicle (i.e., an emergency event system) that are outside of the scope of the reminders system described within this paper.

3.1 Information Architecture

The first step of the user-centered design process was selecting the content of the reminders provided by the AV through the design of the information architecture. The goal of information architecture design is to "*organize, simplify, and integrate information to assist people with finding and interacting with the information content*" (Ding and Lin, 2009). While the thematic analysis provided a detailed set of information that our SMEs identified as important for our target users, designing reminders specifically for those elements could result in a disjointed system that may be challenging for the users to

understand. To address this limitation, we brainstormed and identified larger categories of information that would satisfy the user informational needs suggested by the SMEs. This ideation phase resulted in three categories of reminders:

3.1.1 Reminders That Help Users With Issues of Prospective Memory

Prospective memory refers to memory to execute future intentions that can be triggered either based on some event or after some amount of time. Individuals with MCI have been found to have impairments in prospective memory compared to healthy controls (Troyer and Murphy, 2007; Costa et al., 2010; Thompson et al., 2010; Costa et al., 2011). A number of the user needs identified by the SMEs dealt with prospective memory. For example, remembering required safety actions, such as closing the door and buckling their seat belt (User Need 7: required vehicle safety actions), and remembering to take their belongings with them on their trip and when they leave the car (User Need 3: belongings) are both examples of event-based prospective memory that could be supported by the in-vehicle interface, as these actions occur at easily detected events (upon entry to the vehicle and arrival at the destination).

3.1.2 Reminders That Help Users in Identifying and Understanding System Functions and Features and When to Use Them

This set of reminders is derived from User Need 6, which states that individuals with MCI may forget the functionalities and features of their highly AVs. For example, they may be unaware that they can adjust climate control settings, change destinations, or ask the vehicle for help. Both misuse and disuse of the highly AV's functions and features can compromise the users' experience. Previous research has found that older adults may avoid using AV and advanced driving assistance system features, either due to lack of knowledge or trust in the system (Owens et al., 2015; Abraham et al., 2017; Lee et al., 2019). Individuals with MCI may be especially susceptible to this type of behavior because they may forget that a feature exists and may be less likely to explore the features present within the highly AV.

3.1.3 Reminders That Help Users Understand Their Current Trip Status

Recalling time and day (User Need 8: time and date), where they are along their trip (User Need 5: current location in trip), where they are going and when they will arrive (User Need 1: trip information and User Need 4: trip completion), and how to enter their final destination (User Need 2: destination orientation) all support the goal of helping users understand their current trip status. Orienting individuals with MCI about their time and place is of high importance, since disorientation can be a source of anxiety. The SME interviews suggested that individuals with MCI may forget and become confused about some of the context information (e.g., the purpose of their trip, where they are going) that would normally help an individual identify where they are and what they are doing. Thus, reminders should provide additional information to help orient the users during the trip.

3.2 Visual Design

The next stage of the user-centered design process was visual design, which focused on arranging and presenting the identified information items in an aesthetically pleasing, attractive, and easy to understand visual format (Watzman, 2003; Vanderdonckt, 2014). To develop the visual design of our reminders, we considered commonly used visual design patterns and principles in similar technologies and modified them to accommodate individuals with MCI.

Naujoks et al. (2019) in their guideline for designing AVs' interfaces found that color contrast can improve legibility and consequently increase the efficiency of information processing. Thus, we used a white background color with black text to increase the legibility of our interfaces (Ramadan, 2011; Naujoks et al., 2019). We also assigned a blue color to the buttons with positive content (e.g., yes button), a neutral color to the buttons with negative and neutral content (e.g., no and cancel buttons), and red color to buttons that dealt with emergencies (Campbell et al., 2016). The colors' hex codes were checked using online contrast calculators to have at least a contrast of 7 with their background and foreground, to be as visible and salient as possible (Ramadan, 2011; Naujoks et al., 2019). Furthermore, using our prototyping tool, Figma[1], we checked if our selected color scheme would be distinguishable for individuals with color blindness. Buttons were designed to be larger than 19.05 mm in both length and width, with the goal of being easily selectable for older adults and individuals with MCI (Jin et al., 2007). Finally, we tried to adopt a minimalist design for reminder interfaces to avoid overwhelming our users with unnecessary visual elements.

3.3 Interaction Design

The interaction design stage of the user-centered design focused on "*creating digital interactive systems for people to interact and communicate with during their everyday and working activities*" (Sharp et al., 2015, p. 9). Our team created the interactive reminders system in Figma, based on the outputs of the thematic analysis, user needs, information architecture, and visual design. During this process, we conducted heuristic evaluations, informal analyses of the reminders' design and gathering feedback and suggestions in terms of usability, user experience, and feasibility of the prototypes (Nielsen and Molich, 1990). Thus, the prototypes were continually revised through multiple rounds of changes to ensure consistency in design language and content.

Since individuals with MCI may suffer from a wide range of cognitive impairments, such as decreased processing speed, difficulties with learning new things, decision making issues, and confusion when completing tasks with multiple steps, we aimed to reduce the required cognitive load of the reminders system (Carr et al., 2006; Costa et al., 2011; Pertl et al., 2015). This was also repeatedly suggested by our SMEs.

[1]www.figma.com.

SME [7]: Processing speed tends to be slowed with people in mild cognitive impairment; so, allowing it [interface display elements] to be given in chunks of information; so that they have time to process what is [. . .] being given to them.

To reduce the cognitive workload, we minimized the amount of information provided on any one screen, broke information into separate easier to process sections, and used simpler language. We also tried to simplify the decision-making tasks for individuals with MCI. Whenever, users are required to decide or choose an option, we mostly limited the number of choices to one positive option (e.g., yes or good) and one negative option (e.g., no or bad) (Pertl et al., 2015).

SME [2]: Simplicity of choice. I do believe that there needs to be choice involved at some, definitely at some level, but I think the [. . .] simplicity is very important.

Simplicity and intuitiveness of the interface was another design recommendation directly mentioned by all of our interviewees. For example.

SME [3]: It should be intuitive, it should be simple, very simple, even a child could use it, something that is super user friendly, I think, on the usability score, it should be like, you know, at the child levels.

SME [6]: Like simple menu structure, intuitive, you know. Menu, very clear information [. . .] consistent menu structure.

SME [4]: I think that the user interface needs to be a little bit simpler than a lot of [existing] technologies and cars [for example, when] I think about my Cadillac, there is lots of things on the screen, so many different buttons, which can be confusing.

SME [7]: Once [individuals with MCI] get in the vehicle, there need to be very clear interfaces, simple buttons, very easy to understood and identifiable icons.

To keep the design simple and intuitive, we made all of the features supported by the in-vehicle system visible. The visibility of the features can improve discoverability of these functions, minimize the number of steps required, and reinforce the understandability of how to use them (Norman, 2010). At last, we labeled all buttons with clear names and familiar icons to clearly convey what a button does, and to improve learnability (Wiedenbeck, 1999).

Finally, SMEs stated that some individuals with MCI may realize that they have memory and cognitive decline, while some may not acknowledge that. Thus, although reminders may be a useful feature within highly AVs, individuals with MCI may exhibit vastly varying attitudes towards receiving reminders. Some individuals may be comfortable with the presence and usage of reminders, while others may have defensive attitudes towards receiving reminders, as they may find them annoying or they may be perceived as a critique of their ability to remember information, leading to lack of use or frustration.

Interviewer: For those who are not aware [of their memory and cognitive decline] how did they respond to reminders? Is it something emotional, or something annoying?

SME [4]: [They are] so defensive, very defensive, they certainly do not like any criticism or negative results from an evaluation, because they certainly do not want to hear that they should not try, because there is nothing wrong with them.

To help mitigate these effects, the language used in reminders was framed to not specifically target those with MCI, but framed as normal interactions within the highly AV's human-machine interface. Consequently, the proposed reminders system not only can help individuals with MCI, but also can remind other users of specific pieces of information such as buckling their seat belts or bringing their belongings.

4 PROTOTYPE INTERFACES FOR THE REMINDERS SYSTEM

The information architecture, visual design, and interaction design process resulted in the reminder prototype interfaces that provided users with relevant information, operation procedures and reminders of vehicle features. We defined reminders as visual or auditory information provided by a system to assist individuals with remembering specific pieces of information. Specifically, these reminders assisted the users with maintaining awareness of their current tasks and goals by providing system-initiated prompts and notifications, rather than relying on passive information displays that required user-initiated requests for information (e.g., having the user decide to look for more information by scanning the display).

We designed the reminders system as a primarily visual interface, with additional audio cues and voice messages for prompts that were related to users' safety and required timely responses (e.g., buckling the seat belt or refueling the vehicle) to increase the chance of capturing the user's attention (Campbell et al., 2016). Furthermore, we tried to simplify user responses by presenting questions that had simple responses (e.g., yes/no) in the form of large buttons on the display (Pertl et al., 2015).

4.1 In-Vehicle User Interface

This visual/auditory reminders system was designed to be displayed on a central dashboard display placed in front of the front passenger's seat. This display would normally present information from the in-vehicle interface such as climate control, entertainment, and communication options (**Figure 1**). The screen of the in-vehicle interface was divided into three main sections: 1) a quick access bar for vehicle features, 2) a main display area for information, and 3) a notification area that provides transient information (**Figure 1**). The reminders

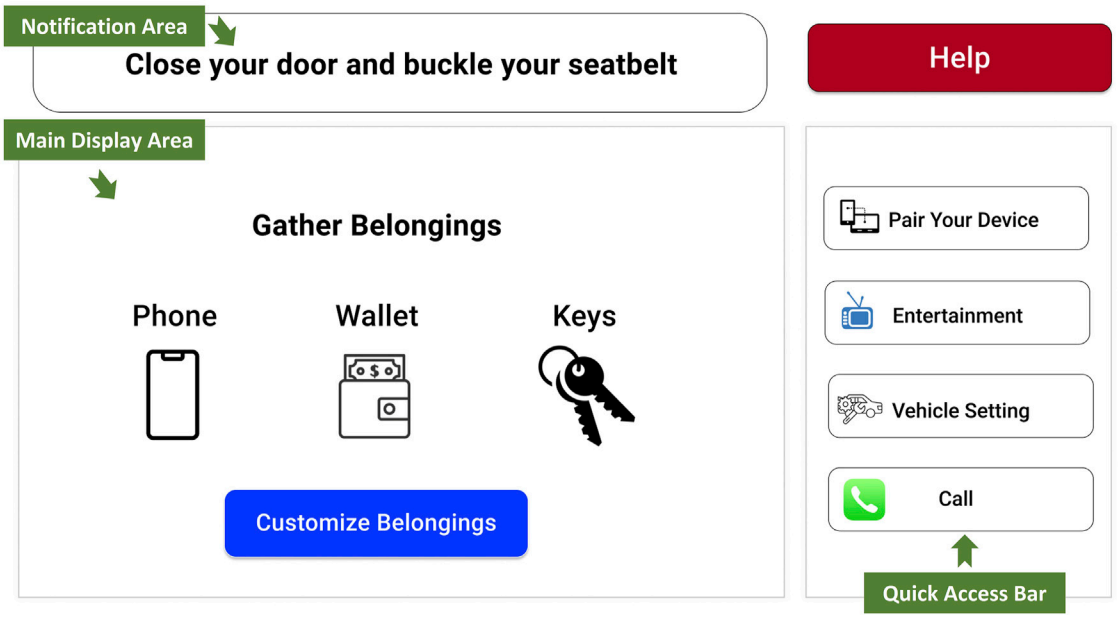

FIGURE 1 | Prototype of the in-vehicle interface.

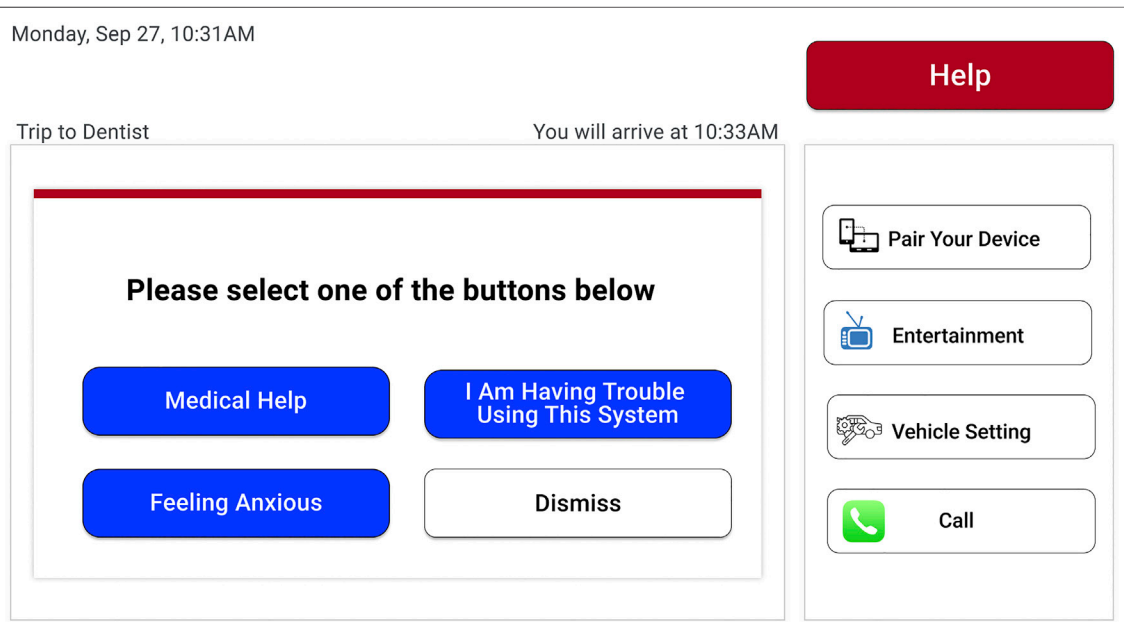

FIGURE 2 | Prototype of the help button interface.

made use of both the main display area and the notification area to provide their information, depending on the type of reminder and its importance. Typically, reminders that had to communicate large amounts of information in response to specific events made use of the main display area, while reminders that were prompts for the user to engage with the system to maintain situation awareness used the notification area.

One especially important feature of the in-vehicle interface is the "help" button, suggested by the SMEs. For example, one SME stated:

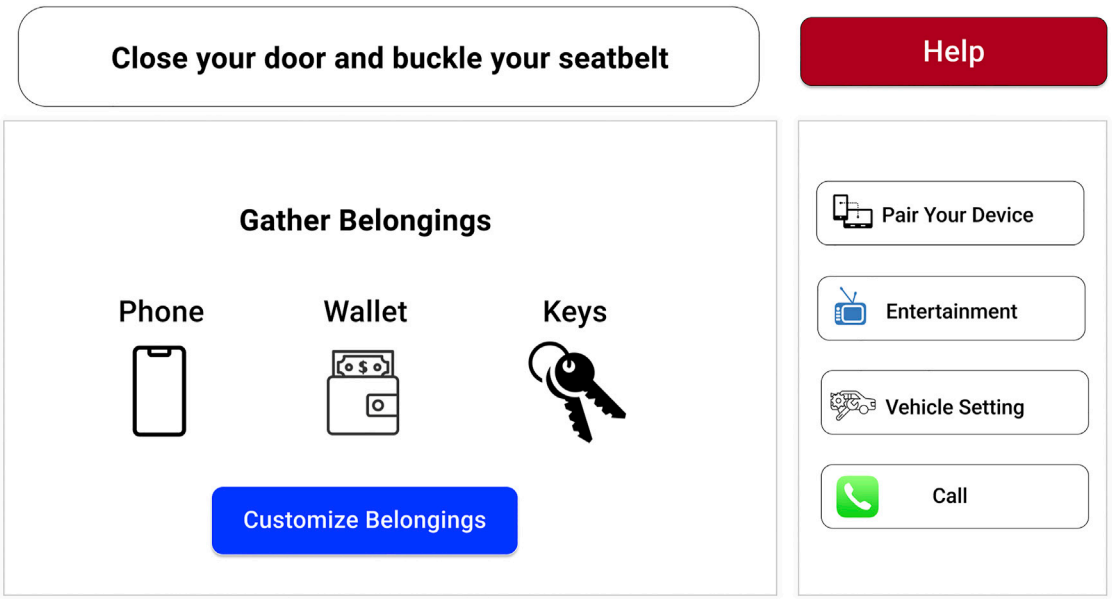

FIGURE 3 | Prototype of users' safety steps and belongings checking reminders.

SME [7]: It sounds kind of silly, but I would love to see a help button in the interface, and that would be connected to a live dispatcher; so that, if the passenger did start to panic or have a medical condition [or confused] someone is in there.

The help button allows users to indicate they need assistance, not just for emergencies but also when they are confused about how to use the in-vehicle interface. We specifically chose to make the help button the only button that had color. The salient red color of this button was also chosen due to its high contrast with the background. These features of the help button may be useful in increasing the chance of grabbing the user's attention, which is critical during times of stress or high workload that may occur when a user needs help. The help button interface (**Figure 2**) was designed to help the users with their medical emergencies, anxiety, or when the user was experiencing a problem with using the vehicle by providing visual and auditory instructions. Again, we limited the number of options presented on the help button interface with the goal of reducing decision complexity (Pertl et al., 2015).

In the following sections, we discuss the three categories of reminders that were identified in the information architecture section. To highlight the necessity of these reminders, we describe each reminder in the context of a specific use case: a solo trip for an individual with MCI to visit a dentist. We consider a hypothetical user, Joseph, who is suffering from short-term memory issues during his daily activities and has a hard time using technologies. Here, we aim to compensate for his short-term memory issues by using the reminders system.

4.2 Reminders That Help Users With Dealing With Issues of Prospective Memory

4.2.1 Safety Steps and Belongings Checking

The first set of reminders dealt specifically with steps that are taken when the user first enters or exits the vehicle. When the user first enters the vehicle, the reminders system provides a checklist of safety-oriented procedures by asking the user to close the door and buckle their seatbelt (**Figure 3**). Since these reminders were about users' safety and required users' timely response, we added an auditory message for redundancy (Campbell et al., 2016). The auditory reminder states "please close the door and buckle your seatbelt". The visual interface also asks the user to check if they have their belongings with them when they first enter the vehicle, with the goal of decreasing the chance that the user forget any necessary items for their trip. The belongings that are prompted are generated automatically based on the planned trip and are customized prior to entering the vehicle, during the trip planning process. The safety steps reminder is presented in the notifications area until the vehicle determines that the door is closed and the seat belt is fastened. The belongings reminder is presented in the main display area for a set amount of time before transitioning to presenting information about the trip.

At the end of the trip, after the vehicle has arrived at the drop-off location and the user is ready to leave the vehicle, a similar safety reminder appears in the notification area asking the user to unbuckle their seatbelt and be careful when opening the door and exiting the vehicle. Again, an auditory message was added to may be helpful for orienting the user's attention toward the visual interface. Their customized belongings are shown on the interface at the end of their trip, to remind the users to collect them.

In the case of Joseph's visit to his dentist, the reminder prompts him to bring his phone, wallet, keys. Joseph and his care partners can customize the belonging reminders by

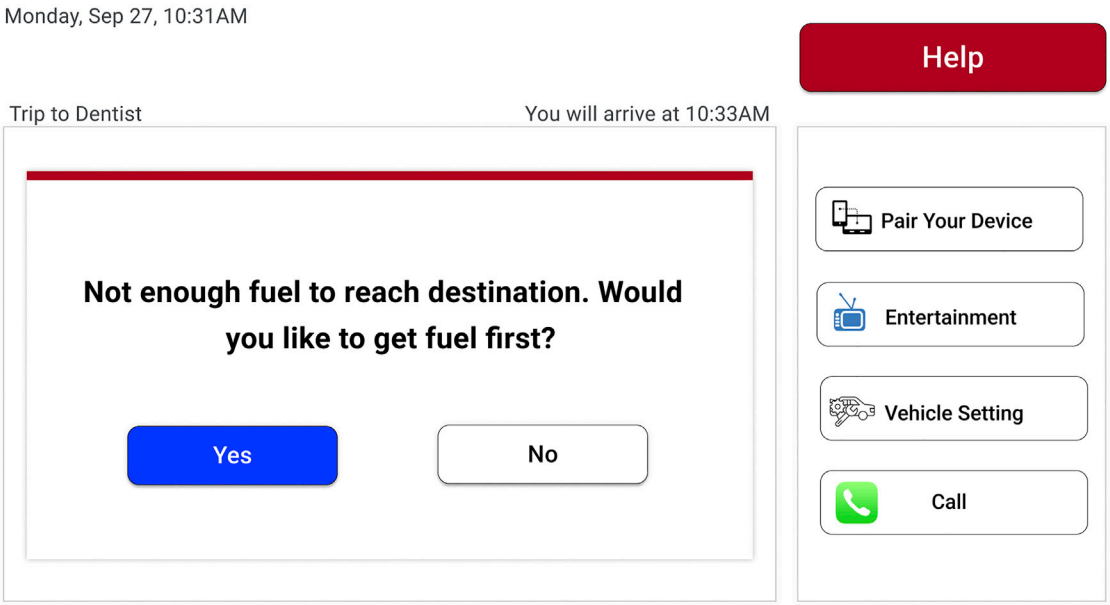

FIGURE 4 | Prototype of the refuel/recharge the vehicle reminder.

eliminating ones that are not relevant and adding items he typically carries. Joseph decides to add a prescription that he needs for his dentist appointment to this list. The safety warning for buckling his seatbelt disappears after it is fastened.

After Joseph arrives at the dentist, he picks up his phone, wallet, and keys, but forgets his prescription since it is buried under some papers. The belongings reminder prompts him to take his belongings including his prescription. Joseph searches for his prescription and finds it before checking his surroundings while leaving the vehicle and closing the door.

4.2.2 Reminders to Refuel/Recharge the Vehicle for a Given Trip

Future highly AVs may require users to refuel or recharge the vehicle, especially if vehicles are owned by the users. Although refueling was not a stated user need from our SME interviews, we considered it as another example of a situation where prospective memory (e.g., needing to refuel the vehicle before the trip) could be aided by the in-vehicle reminders system. We included a fuel level check at the start of the trip. The required fuel/charge for the trip is estimated based on the provided trip destination information, the planned route, and a fuel/charge consumption algorithm. If the algorithm estimates that there is not enough fuel/charge for the trip, then the system provides a reminder (**Figure 4**) and asks the user to respond to a simple "Yes" or "No" question on whether they would like to refuel/recharge prior to starting the trip. This reminder and the response prompts are provided in the main display area of the interface along with an auditory chime and audio message repeating the asked question.

If the user responds yes, then the vehicle immediately proceeds to the nearest refueling/recharging location and offers instructions on how to refuel/recharge, prior to resuming the originally planned trip. If the user says no, the vehicle proceeds with the originally planned trip, and only reroutes to the nearest refueling/recharging location once the vehicle has reached a critical level (**Figure 5**). The critical level is determined dynamically based on the vehicle's proximity to refueling/recharging locations and whether the vehicle can reach these locations with the remaining fuel.

When Joseph first enters his vehicle, it tells him that there is not enough fuel to complete his trip and asks him if he wants to refuel at the start of his trip. Joseph selects "yes" because he is worried about running out of fuel when he is on his trip and not making it to his destination. The in-vehicle interface updates the destination, and estimated time of arrival and informs him that the vehicle is heading to the gas station.

4.3 Reminders That Help Users in Identifying and Understanding System Functions and Features and When to Use Them

4.3.1 User Health and Status Checking

The in-vehicle interface serves as the main point of contact between the user and the highly AV. However, individuals with MCI may not engage with the in-vehicle interface if they do not understand its functionality or if they forget what functionalities are present. Thus, one goal of the reminders interface is to initiate communication prompts between the vehicle and the user and direct users towards relevant information and options provided by the AV. To provide this kind of communication prompt, we designed a health and status check reminder that asks the user if the trip is proceeding in a satisfactory manner and if they have any concerns. This reminder is shown in the notification area of the display, along with an auditory chime and audio message "How is your trip going?" (**Figure 6**). The reminder appears during the trip at set intervals

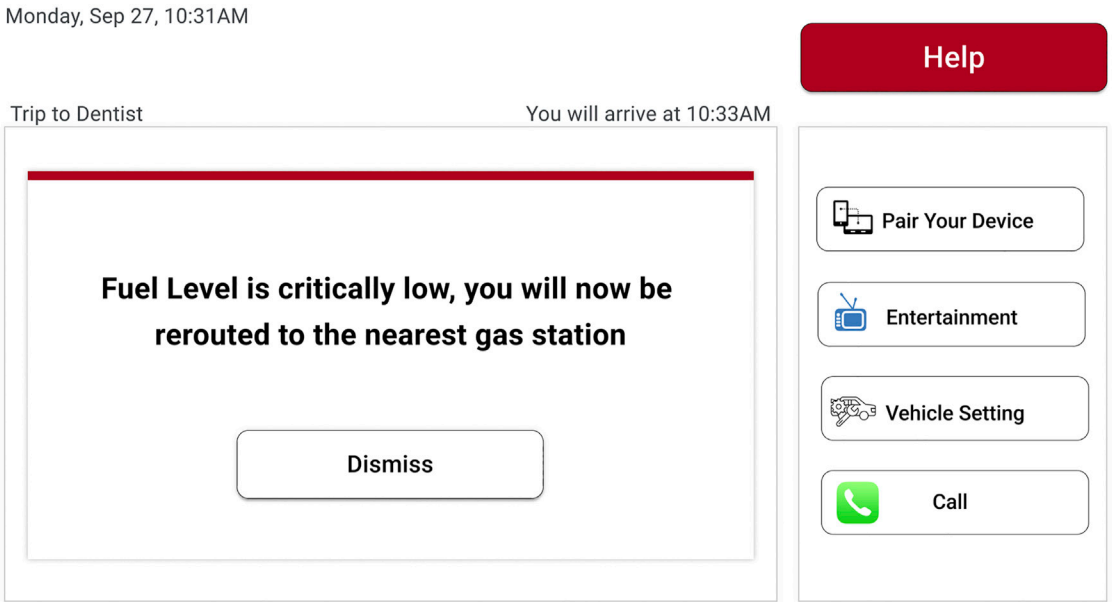

FIGURE 5 | Prototype of the refuel/recharge the vehicle reminder (vehicle is rerouting to the nearest gas station).

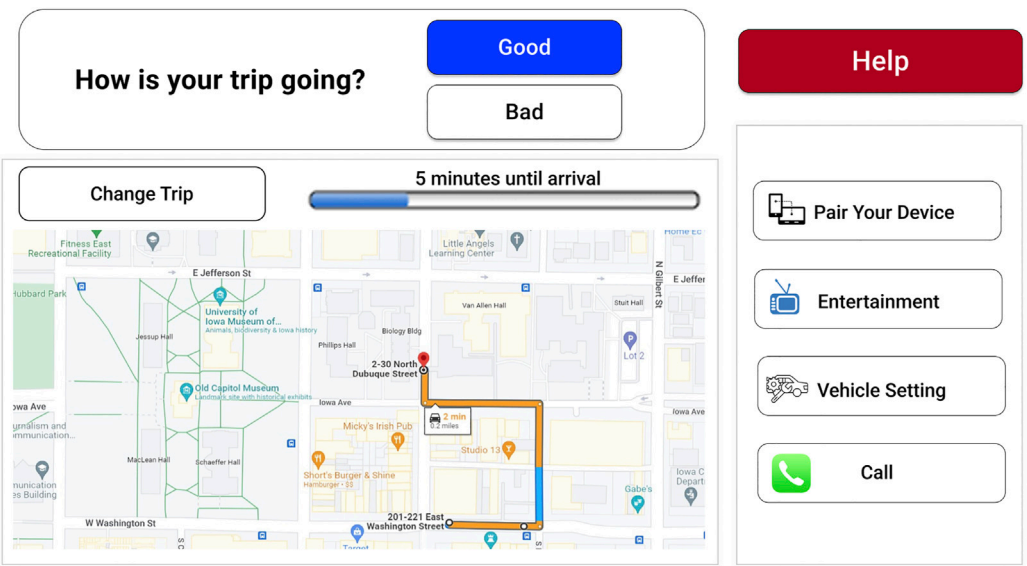

FIGURE 6 | Prototype of the health and status checking Reminder.

(e.g., every 15 min), the duration of which can be customized by the user and their care partners.

The prompt (e.g., "How is the trip going?") is tried to be worded in a general manner to encompass a wide range of events that can affect the users' trip quality. The provided options for responding to this question are just "Good" and "Bad" to simplify the user's decision (Pertl et al., 2015). If the user selects "Good", the reminder would be dismissed with no further actions occurring. At this point, the user's attention is redirected to the in-vehicle interface. However, if the user selects "Bad", the user is then directed to the help button interface (**Figure 2**), to help identify options to overcome their uncomfortable situation.

Midway on Joseph's trip to the dentist's office, he starts feeling anxious about being late for his appointment, but he doesn't know what to do. After a set duration, the in-vehicle system asks him how the trip is going, which reminds Joseph that he can get help from his vehicle. Joseph responds "Bad" because of his anxiety, and the in-vehicle system shows the help screen

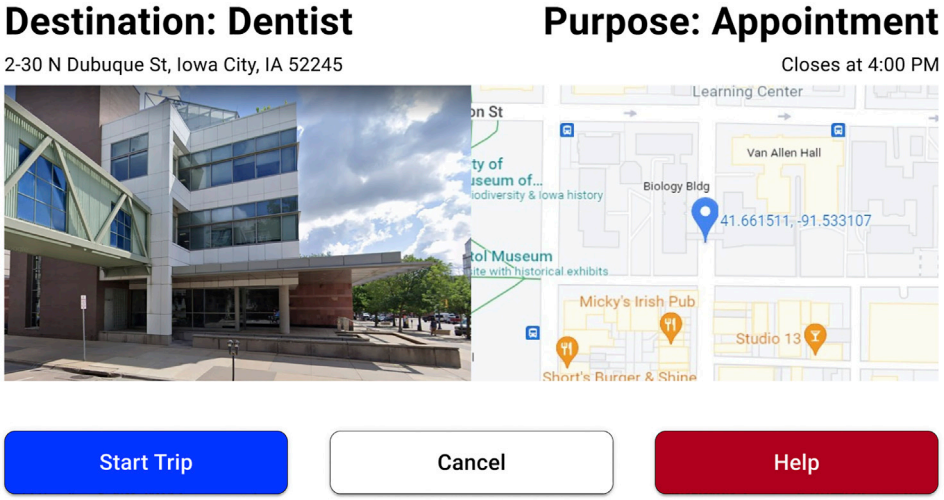

FIGURE 7 | Prototype of the destination confirmation reminder.

allowing Joseph to call his dentist to tell them that he may be late. This helps Joseph feel less anxious, and he is glad that his car checked up on him.

4.4 Reminders That Help Users Understand Their Current Trip Status

4.4.1 Destination Confirmation and Arrival Orientation Reminders

Our SMEs stated that individuals with MCI may need additional support in getting from their vehicle to the door of their destination (User Need 2, **Table 2**). Helping users orient themselves upon arrival is especially challenging for future highly AVs because the user may not be completely aware of the drop-off location. Also, since they are not manually driving the vehicle, they may have lower situation awareness of their location relative to the destination. Finally, because trips may be planned prior to getting into the vehicle, users may forget where they are headed or the purpose of the trip, two pieces of contextual information that would normally help with self-orienting upon arrival at the destination. Thus, two reminders were created to address this issue. The first asks the user to confirm their destination when they first enter the vehicle, and the second assists the user with finding their destination once they arrive.

Destination Confirmation: The destination confirmation reminder provides information about where the destination is and why the user is going there at the start of the trip (**Figure 7**). The required information is automatically generated based on the trip information provided to the vehicle. The reminder describes the destination in multiple ways, first by providing the address as both text and visualized on the map. Also, the name and a picture of the destination is shown. This information is presented in the main display area after the safety steps and belongings reminder described in **Section 4.2**. This reminder also provides users an opportunity to confirm their destination or change it if there was an error or change in plans. These options are shown below the reminder information (**Figure 7**). The help button is also available if the user requires further assistance from the in-vehicle interface or from their care partners.

When Joseph first gets into his vehicle, the in-vehicle system shows him a picture of the dentist's office, a map with the address, and the purpose of the trip (dentist visit for his gum infection). Joseph doesn't remember the address, but the picture of the office looks familiar, and he knows that his gums are hurting, so he is pretty sure it is correct. He selects the "Start Trip" button to confirm his destination.

Arrival Orientation: The arrival orientation reminder is designed to assist users with identifying their destination. The reminder also provides contextual information with the aim of helping the user navigate to the destination once they exit the vehicle. This reminder is presented to the users upon arrival and after the safety steps and belongings reminder is shown and is displayed in the main display area. The interface provides the same information provided during the trip confirmation reminder including the purpose of the trip, the current location, and a photo of their destination (**Figure 8**). The hours of operation of the destination are also provided, if available, with a warning if the location may be currently closed. If the user chooses the "Finish Trip" option, then the trip is concluded and the screen is dismissed.

However, this reminder also provides an opportunity for the user to ask for additional help in case they fail to locate their destination by selecting the "Destination Not Found" option. Additional information is presented (**Figure 9**) through a street-level view of the building (e.g., similar to Google Street View). Users and their care partners may also provide a custom picture of the destination during the trip planning process to be displayed on this screen. These visual cues can be used by

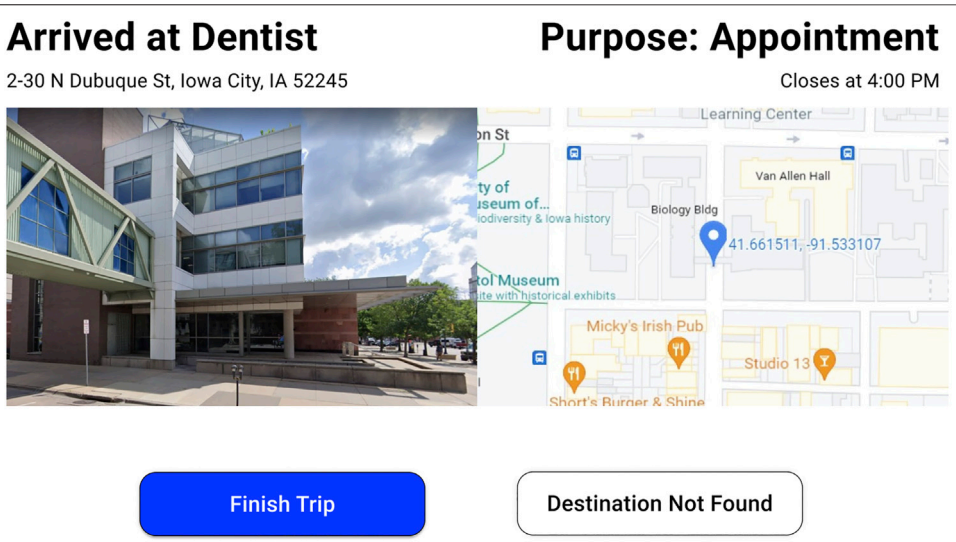

FIGURE 8 | Prototype of the arrival orientation reminder.

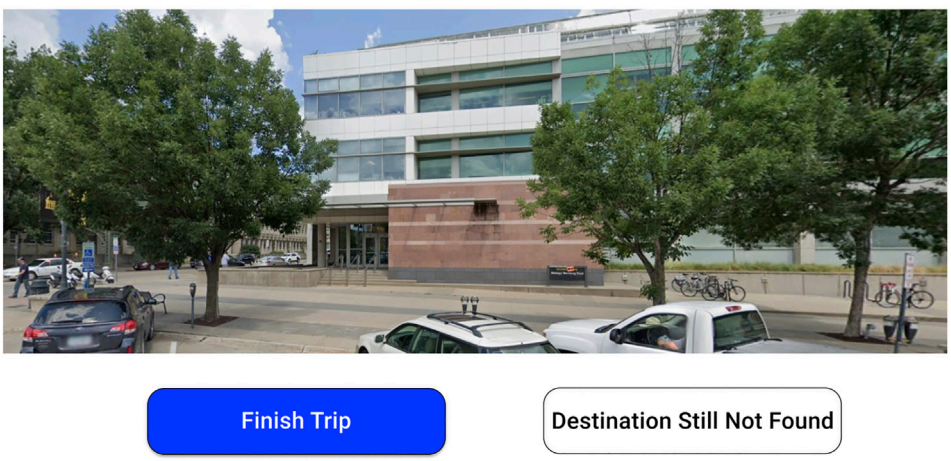

FIGURE 9 | Prototype of the arrival orientation reminder (Google Street View).

the user to locate the correct destination and plan their path when exiting the vehicle. If the user is still unable to locate the destination, then they are given an option to call their point of contact or return home by choosing the "Destination Still Not Found" button.

Once Joseph arrives at his destination, the in-vehicle system shows a picture of the dentist's office. Joseph looks out his window at the building, but he fails to find the door of the dentist's office shown in the picture. He responds that he is unable to find the destination. The reminders system provides an additional, street-level photo of the dentist's office for him. Joseph is confused at first, but then notices a mailbox that is shown in the picture to the right of the dentist's office that he can also see from his car. Happy to have spotted the correct location, he selects "Finish Trip".

4.4.2 Arrival Preparation Reminder

The idea of preparing the user for reaching their destination was originally suggested by several of our SMEs. For example:

> *SME [4]: Also [the system can] through the car audio tell them that they have arrived and that is why [they are here]. I think it would be good to give a reminder 5 minutes before [their arrival], so that [the system] gives them time to wake up, get ready to exit, and pay attention to where they are at.*

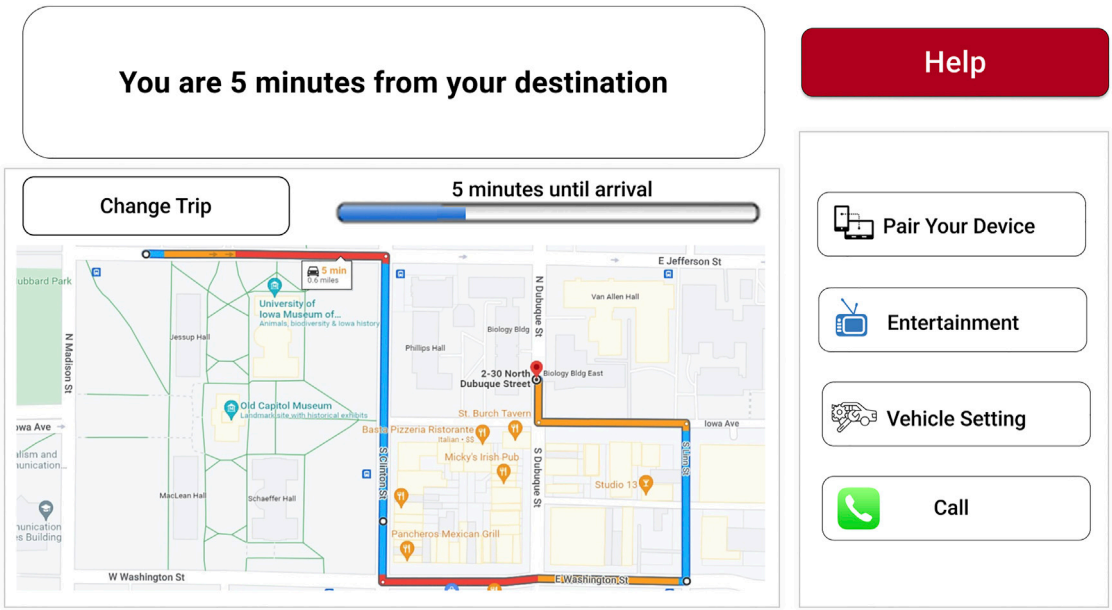

FIGURE 10 | Prototype of the arrival preparation reminder.

Our experts noted that individuals with MCI may need additional time to orient themselves before arriving at the destination and leaving the vehicle. The arrival preparation reminder would inform the users that their destination is close, and it would provide information to help them prepare for their arrival through the reminders described previously. This reminder is shown in the notification area of the display, along with an auditory chime and audio message "You will arrive at your destination in 5 min, please see the display for information about your trip" (**Figure 10**). The main purpose of this reminder is to bring the user's attention towards the in-vehicle interface and provide them time to finish any activities they are engaged in (e.g., napping, reading, talking on the phone) during the trip. In this way, they would be able to see the relevant trip information, including the estimated time of arrival, the destination, and their current location on the map. The additional time provided to prepare the user for arrival is meant to help reduce anxiety and time pressure once the user arrives at the destination.

When Joseph is 5 min from his destination, a reminder pops up and informs him that his destination is close. Joseph looks up from a book that he was reading after he hears the auditory message, puts his book away, and starts gathering the items he brought with him for his dentist appointment. He sees on the in-vehicle interface that he is not too far away, and the estimated time of arrival shows that he will not be late for his appointment. Feeling relieved, he is glad that the vehicle helped him with his trip by providing reminders.

5 DISCUSSION

This paper proposed a design for a reminders system to assist individuals with MCI with maintaining awareness of their current trip and vehicle-related tasks and goals, by providing system-initiated prompts and notifications while using highly AVs. The need for reminders to be incorporated into the highly AVs was one of the main identified themes from our interviews with SMEs ($N = 7$) that examined the barriers that individuals with MCI face when using highly AVs. Since individuals with MCI are highly susceptible to forgetting important information during their trip, three categories of reminders were identified that could be integrated in AVs' in-vehicle interface: 1) reminders that helped with prospective memory, 2) reminders that helped users remember and understand the features of the highly AVs, and 3) reminders that helped users understand the current trip status. These reminders may be able to promote MCI individuals' trust and acceptance of highly AVs leading to increased adoption, with the end goal of improving their quality of life through enhanced independent mobility (Bascom and Christensen, 2017). One important innovation of the reminders system is that it focused on a type of user-vehicle interaction style that was not previously common in highly AVs. Reminders are different from alerts, warnings, or alarms which are extensively used in lower-level AVs that are currently available in the market (i.e., Level 1–2). Alerts, warnings, or alarms typically inform users when some functions go wrong and may need user intervention (e.g., blind spot warning systems alert drivers with mostly an audio warning of vehicles present in adjacent lanes when making a lane change). However, reminders are information provided by a system to assist individuals with remembering or acknowledging a specific piece of information in relation to their world and surrounding (e.g., orienting individuals about time and place). Reminders also differ from typical in-vehicle displays that require user-initiated requests for information (e.g., having the user

decide to look for more information by scanning the dashboard). Instead, the reminders system would initiate the interaction with the user, a type of interaction that may be beneficial for individuals with MCI.

Besides focusing on the specific user needs and features that may best serve the target population, this project also aimed at creating visual and auditory designs that were usable and easy to understand. Since driving is a cognitively demanding task, special consideration is required when designing how vehicle alerts, warnings, or alarms are communicated to the user. Due to the visually intensive nature of the driving task, the auditory modality (i.e., beeping) is commonly used for alerts and alarms in lower-level AVs (Nees and Walker, 2011; McDonald et al., 2019); however, using the auditory modality across multiple systems to communicate different information can be confusing for users, specifically when multiple systems are having issues simultaneously. Since visual distraction is not a concern in highly AVs, we were able to use the visual modality to communicate our reminders information. We also added auditory messages to the critical information, such as required vehicle safety actions, to increase the chance of bringing users' attention to that information.

Another contribution of this study was the creation of an in-vehicle user experience for highly AVs that was targeted towards individuals with MCI. MCI individuals may use different memory aids tools on a daily basis to remember to do things, to store and find information, and so on (Buckwalter et al., 2004; Chu et al., 2012; Kamimura et al., 2012; Igual et al., 2014). However, individuals with MCI are typically older adults with previous driving experience, and they may use this experience when learning how to interact with highly AVs. Individuals with MCI have also been found to have reduced performance in learning new information (Farias et al., 2006; Klekociuk and Summers, 2014) and therefore may prefer to stay with familiar systems where they have already developed knowledge. Therefore, for promoting technology acceptance, new interfaces designed for highly AVs should follow the targeted population's conceptual understanding about how the technology should work and their previous experience (Motamedi et al., 2021). Within our system, we display our passenger-vehicle interactions through a single device, the in-vehicle display, since it may be more familiar for our users to get information from one source, the vehicle rather than other devices such as a mobile phone. Also, we adopted a user-centered design process and elicited an understanding of our users from SMEs who have both knowledge and experience with our target users.

Moreover, having a trip without the presence of care partners or family members in highly AVs would be a new experience for individuals with MCI. Interactions with novel technologies without the care partners or family members' assistance during their trip, can be a matter of concern for individuals with MCI, especially in situations where there are issues with the vehicle, trip, or their own health. This highlights a specific design requirement for the in-vehicle interface and reminders systems, which is compensating for the lack of care partners or family members' presence by providing assistive features, such as the help button.

This study has a number of limitations that can be addressed in future work. Although the main focus of this research was on individuals with MCI, we may have overlooked some needs of the target population since our study was based on interviews with SMEs. In a follow-up study, we will conduct focus groups with individuals with MCI and their care partners to address this limitation. In addition, our study lacks user evaluation of the proposed reminders from individuals with MCI. Individuals with MCI may exhibit different attitudes toward reminders, particularly if they have different views about their own condition, such as not acknowledging their cognitive disabilities, as mentioned by our SMEs. Also, previous research has shown that MCI has extremely heterogeneous outcomes, resulting in a wide range of end-user abilities, desires, and needs (Farias et al., 2006; Klekociuk and Summers, 2014). While our SMEs were able to provide insight into a larger range of possible users, our final designs may not be as useful for all individuals within the target user group. The next step of this research is to conduct participatory design sessions where MCI individuals will interact with the designed reminders system and become involved in the design process based on their actual needs and attitudes. Since the type of highly AVs designed for in this study do not currently exist, these revised designs would then be evaluated with users with MCI using either driving simulator or wizard-of-oz approaches.

Furthermore, one aspect of the in-vehicle interface design not discussed within this paper was the customizability of the user interface that will allow it to support a wider range of outcomes. For example, users will be able to customize which reminders the system will provide and the timing and frequency of the reminders. This degree of customizability may help tackle some of the challenges of addressing a wide target user group. Furthermore, our current system focused on a single passenger with MCI who would be supported by the vehicle during a solo trip. Future highly AVs may have multiple passengers who require support, and interfaces will need to be adapted for this purpose and should be investigated in future studies. Lastly, highly AVs are at an early stage of development and their actual functionality is unclear. While here we hypothesized their functionality based on the SAE levels of automation (SAE International, 2021), future studies are needed to provide further insights to researchers, designers, and manufacturers about the users' needs, perceptions, and design solutions.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of participant privacy and data sharing consent. Requests to access the de-identified datasets should be directed to wayne.giang@ise.ufl.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Kansas Medical Center Insitutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ME: Methodology, Data Collection, Analysis, Prototyping, Writing—Original Draft, Writing—Review & Editing, Writing—Revision. WG: Conceptualization, Methodology, Data Collection, Analysis, Writing—Original Draft, Writing—Review & Editing, Writing—Revision, Supervision. SM: Writing—Original Draft, Writing—Review & Editing, Project Administration. HD: Writing—Original Draft, Writing—Review & Editing. LK: Methodology, Writing—Review & Editing. AA: Data Collection, Project Administration. AK: Conceptualization, Methodology, Data Collection, Writing—Original Draft, Writing—Review & Editing, Writing—Revision, Project Administration, Funding Acquisition.

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