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Towards augmented reality coaching for daily routines: Participatory design with individuals with cognitive disabilities and their caregivers

Varsha Koushik *, Shaun K. Kane

University of Colorado Boulder, USA

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ABSTRACT

People with cognitive disabilities often use reminder applications on smartphones and tablets to complete everyday activities. However, these devices lack the capabilities to provide customized contextual prompts, essential to support individuals during their activities. As smart home devices, like voice assistants and "smart" appliances, become mainstream, they could support individuals with cognitive disabilities by presenting prompts and reminders in place. To understand how smart devices can expand their features to support customized prompts, we conducted remote participatory design interviews with adults with cognitive disabilities and their caregivers or parents. Participants described and designed multimodal interactive prompts to illustrate how an augmented reality-based smart display can motivate individuals to track progress and complete everyday activities. Designs included features, like avatar coaches, gameplay mechanics, and riveting animations. This paper provides novel prompting strategies and feedback techniques designed by participants and guidelines for making future smart devices more accessible.

1. Introduction

There are more than 28 million people with cognitive disabilities in the United States, including people with intellectual and developmental disabilities, learning disabilities, and neuro-diversities (World Report on Disability, 2011). They often face difficulties that impact everyday life, such as remembering, learning, and making decisions (Perneczky et al., 2006). One effect of these difficulties is that people often struggle with starting or finishing everyday tasks. To support their needs, many individuals use reminder applications on smartphones or tablets that provide a reminder to start a task, along with pictures or video instructions for each step of the task (Carmien, 2006; Cihak et al., 2008; Sohlberg et al., 2007). However, these devices often use a combination of audio, images, and text to prompt steps. Such prompts are less engaging, and devices do not present them continuously throughout the task. Thus, they may abandon assistive devices that cannot adapt prompts and feedback to their specific needs around remembering steps, tracking progress, paying attention, staying on-task, and motivating activity completion (Baxter et al., 2012; Kintsch & Depaula, 2002; Martin & McCormack, 1999; Murphy et al., 1996; Riemer-reiss & Wacker, 2000; Verza et al., 2006). This can lead to negative consequences like increased dependency on caregivers and irregular practice or discontinuation of their everyday activities.

People with cognitive disabilities are widely adopting smart home devices, like voice assistants and "smart" appliances, to receive in situ support during their everyday activities. Smart devices that overlay augmented reality (AR) based information can limit contextual switching within tasks (Korn et al., 2014). Besides contextualized prompts, people with cognitive disabilities need prompts that engage individuals and capture their attention to help them stay on and complete tasks. Existing smart assistants, like Alexa or Google Home, supplement their conversational capabilities with visual screens that break down tasks and show multimedia, like videos. This functionality offers numerous opportunities for creating AR-based displays that track activities and provide in situ prompts and feedback using stylized representations embodying positive reinforcements (Consolvo et al., 2008). However, we lack a clear understanding of how AR-based smart displays can support a spectrum of customized prompts and feedback that help individuals remember steps and motivate them to complete activities.

To gather insights on effective designs and modalities for presenting engaging, contextual prompts within AR-based smart displays, we conducted participatory design interviews with adults with cognitive disabilities and their caregivers or parents. In this paper, we describe a participatory design protocol for creating prompts using persona-based

* Corresponding author at: University of Colorado Boulder, USA.
E-mail addresses: varsha.koushik@colorado.edu (V. Koushik), shaun.kane@colorado.edu (S.K. Kane).

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scenarios, present artifacts, including novel prompting strategies and feedback techniques, and discuss design implications for future smart devices. The main contributions of this work include (1) design artifacts that emphasize personalized support through motivating prompts and feedback, (2) participant insights on supporting their needs during everyday routines, and (3) design implications for making future smart devices accessible to people with cognitive disabilities.

2. Related work

This work draws on the literature on designing accessible prompting systems, motivational strategies for tracking activities, and best practices for engaging people with cognitive disabilities in participatory design.

2.1. Prompting systems

People with cognitive disabilities often use prompting systems to support their everyday routines, like dressing, brushing, cooking, and cleaning (Carmien, 2006). Prompting is breaking down a task into simple steps and creating individual instructions consisting of images and textual instructions (Carmien, 2006). Traditional prompting systems include reminder and scheduler applications on personal computers (Mechling & Ortega-Hurndon, 2007; Sabielny & Cannella-Malone, 2014; Van Laarhoven & Van Laarhoven-Myers, 2006) or handheld devices (Cihak et al., 2008; Sohlberg et al., 2007). Multimodal prompting systems have been useful to support individuals with cognitive disabilities to teach vocational and everyday skills (Cannella-Malone et al., 2006; Van Laarhoven et al., 2018; Van Laarhoven & Van Laarhoven-Myers, 2006). These devices are compact and present pre-designed prompts, that have limited scope for customizations. Individuals require support beyond reminders or stepwise instructions, like indicating their progress, showing how long they need to do a particular step, encouraging them to stay on task, and constantly providing feedback during a task. To overcome the constraints within prompting systems, individuals often seek assistance from their caregivers, which prevents them from being independent in their homes (Chang et al., 2013).

2.1.1. In situ instructions

Machine learning and computer-vision-based prompting systems can promote independence by adapting cues from activities. COACH is a computer-vision-based system to assist older adults with dementia in washing their hands (Mihailidis et al., 2008). Key features of this system include tracking hands to show verbal and video-based prompts. TEBRA is a novel ATC (Assistive Technology for Cognition) to support individuals with cognitive disabilities while brushing their teeth (Peters et al., 2014). ATC systems use contextual awareness about users to prompt steps. TEBRA provides video-based instructions by learning spatial and temporal variances in performing tasks. Research has also explored a Kinect-based vocational training system to assist people with cognitive disabilities in preparing pizzas (Chang et al., 2013). This system uses an RGB camera and depth sensors to recognize gestures and uses a combination of text, picture, and sound, to provide cues.

Besides research prototypes, everyday smart devices are developing into mainstream prompting systems for this population. Researchers have examined how voice assistants can support people with dementia and people with cognitive disabilities in their homes (Pradhan et al., 2018). Robin is a voice assistant that supports individuals with dementia in managing their daily activities (Carroll et al., 2017). It can remind people to finish a task, provide stepwise guidance, and recommend activities.

Prompting for people with cognitive disabilities often depends heavily on contextual information. While smart assistants show promise in adapting prompts for individuals, they need to present information in-situ through multiple modalities. To integrate explicit, contextual feedback, researchers have explored augmented reality. Specifically, hands-free devices that overlay visual information can greatly benefit individuals with cognitive disabilities in completing tasks (Funk, Bächler, et al., 2015; Funk, Mayer, et al., 2015; Kosch et al., 2018). Incorporating AR-based gamification elements can help people in assembly-based tasks that are often done at a workstation (Korn et al., 2014). Furthermore, individuals in this community perceive visual contextual feedback to be more effective than auditory or tactile methods (Kosch et al., 2016).

While AR-based smart devices, like displays, present opportunities for customizing contextual prompts and feedback, there is limited knowledge on using such devices to support users with a range of abilities. To understand how AR-based smart devices can customize support, we engage adults with cognitive disabilities and their caregivers or parents in participatory design activities to create examples for motivating on-task prompts.

2.1.2. Tracking and monitoring activities

Research in activity tracking and monitoring can help us understand effective approaches to present progress through prompts and feedback. Setting goals has often encouraged people to regularly practice activities. Specifically, concrete goals can generate higher performance than wider goals. Consolvo et al. found that self-set goals are more popular than assigned goals as individuals tend to set goals that they will likely achieve and develop self-efficacy (Consolvo et al., 2008). Locke and Latham identified the complex relationship between goals and performance (Locke & Latham, 2002). Extremely easy or challenging goals garner less motivation to complete activities. Goals are valuable when they are personally meaningful, and individuals identify their importance and develop motivation to achieve them. Coupling goals with incentives can increase commitment toward activities. Incentives or rewards generate higher performance when they're offered throughout the activity and not just when the activity is completed (Consolvo et al., 2009).

Prior research has explored stylized displays and positive reinforcements to motivate physical activity (Consolvo et al., 2006; Consolvo et al., 2008; Gasser et al., 2006; Jafarinaimi et al., 2005; Maitland et al., 2006; Toscos et al., 2008). Fish'n'Steps (Lin et al., 2006) integrates an individual's step count into the emotional state, growth, and activity of a virtual fish in a shared fish tank on an ambient display. This system requires individuals to keep their fish happy by being physically active. However, this work found that negative feedback often resulted in abandonment, where individuals would ignore the ambient display. To create a compelling activity tracking experience, UbiFit garden uses a glanceable, stylized display that shows a non-literal and aesthetic representation of goals on a mobile phone (Consolvo et al., 2008). By residing in the phone background, it can subtly remind individuals about their progress. Similarly, popular activity tracking applications, like Fitbit, motivate individuals to practice activities through personalized goals and challenges. Rewards, like positive messages and badges, enable individuals to be more physically active.

Activity awareness is another useful metric to influence and improve practice (Consolvo et al., 2008). Displays that use representational metaphors can persistently present information while providing a sense of privacy. Furthermore, metaphors tied to individual interests can increase awareness and motivate individuals to work towards their goals.

Drawing inspiration from existing literature, AR-based smart devices can include adaptive visual prompts, customized goal-based rewards, and real-time feedback through engaging media, like animations and games, to encourage individuals with cognitive disabilities to regularly practice tasks. Specifically, this work explores motivating designs to track steps and present on-task feedback for everyday routines.

2.2. Engaging people with cognitive disabilities in participatory design

Participatory design is a useful method to understand the goals, motivations, and needs of people with cognitive disabilities (Bødker & Kyng, 2018; Muller, 2002; Muller & Kuhn, 1993). Research has explored participatory-design-based methods to create prompting systems. One example of such a prototype is a sound and image planner for people with aphasia (Moffatt et al., 2004). Individuals engaged in a user-centered design process, where they brainstormed designs for a planner, created low-fidelity prototypes, helped build a medium-fidelity prototype on a personal digital assistant, and tested a high-fidelity prototype. Participatory design has also been useful in engaging other user groups with overlapping difficulties. Researchers have used participatory design methods with older adults (who often have age-induced cognitive impairments) to elicit privacy preferences for adaptive assistive technologies when accessing the internet (Hamidi et al., 2020). Involving individuals with intellectual disabilities in group-based design sessions can enable more social interactions (Bayor et al., 2019).

Participatory design often involves a lot of abstract thinking and reasoning which may be challenging for individuals with cognitive disabilities (Committee to Evaluate the Supplemental Security Income Disability Program for Children with Mental Disorders et al., 2015; Dawe, 2007a, 2006; Frauenberger et al., 2017; Hendriks et al., 2015, 2014; Prior, 2010; Sitbon & Farhin, 2017; Spiel et al., 2017). To support accessible design methods, previous research recommends low-fidelity prototyping (Colin Gibson et al., 2020). Furthermore, asking individuals to retrospectively walk through their designs can be more effective than think-aloud procedures. Methods that foster empathy between designers and participants have been useful in engaging people with mild to moderate dementia in designing an individualized digital aid for walking safely (Lindsay et al., 2012). Scoping challenges and design opportunities before design sessions can scaffold the designing process and reduce abstract thinking (Hodge et al., 2018).

Besides adapting research methods, engaging caregivers in the design cycle can be valuable as they are familiar with the experiences of their clients and have expertise in supporting everyday activities (Brereton et al., 2015; Dawe, 2007a; Sitbon, 2018; Sitbon & Farhin, 2017). Prior research has engaged caregivers to design prompting systems. MAPS is an interactive prompting system co-designed with caregivers to support everyday activities (Carmien & Fischer, 2008). In designing MAPS, caregivers provided insights on prompting techniques and tested multiple iterations of a high-fidelity prototype. Dawe engaged individuals with cognitive disabilities and their family members or caregivers in a design study to create mobile-based prompting systems (Dawe, 2007b). While caregivers add value to the design process, researchers have recommended striking a balance, because their goals and motivations tend to be different from individuals with cognitive disabilities (Dawe, 2006). Underlying assumptions, expectations, and knowledge of the role of technology often influence its use (Orlikowski, 1992; Pinch & Bijker, 1984). Organizations and support staff often have a strong influence on how individuals adopt technologies, which could be driven by their objectives on what is important or needed for their clients (Orlikowski & Gash, 1994). This can often conflict with an individual's perceptions and needs about assistive technologies and independent living. To gain a holistic perspective, we engage both, adults with cognitive disabilities and their caregivers or parents in a novel remote participatory design protocol to create motivating examples for AR-based prompting and feedback.

3. Method

To understand how AR-based smart devices can support people with cognitive disabilities in tracking and completing activities, we conducted nine 90-minute remote participatory design interviews with a total of 15 participants. Prior work indicated that individuals in this community perceived visual-based contextual feedback to be more helpful during tasks [20]. Therefore, we wanted to brainstorm motivating prompts and feedback for a customizable AR-based smart display. Our goals were to explore: (1) types of customizations that could assist and motivate individuals to stay on tasks and complete them more independently and (2) perspectives and concerns of this community in using a smart display for everyday routines.

We used email listservs to recruit participants from local organizations that primarily serve adults with cognitive disabilities. Participants in this study included 7 adults with cognitive disabilities, 6 caregivers, and 2 parents, between the ages of 24 and 68 years. All participants have experience with training to live independently, which involves using assistive technologies and working with a caregiver to design prompts. Individuals lived either in a community home or with a parent. We did not collect individual diagnoses from participants as our research goals primarily focus on the functional abilities of individuals. All individuals were able to communicate their everyday activities, including accessibility challenges and strategies to overcome those challenges. Individuals often requested assistance from caregivers or parents to complete their everyday activities. Therefore, we recruited both individuals and their caregivers or parents to understand role-related perspectives in training to live independently. Table 1 describes the demographic information of all participants.

3.1. Consent process

We received approval from our university's institutional review board before contacting any of the organizations or their members. Our initial contact with individuals was through the organization liaison. Although all participants were over the age of 18, some participants were not their legal guardians due to their disability. We emailed consent forms to all participants who were their legal guardians. Those who weren't their guardian completed an assent form and we contacted their guardian to complete a corresponding consent form.

Our consent forms requested the ability to audio and video record video-conferencing screens; take notes during study sessions; interview participants; and collect screenshots to document design artifacts. All

Table. 1
Our study participants included adults with cognitive disabilities (assigned code A), caregivers (assigned code C), and parents (assigned code P).

Group	Participant	Age	Gender	Role	Assistive Technology
A	C1	28	Female	Caregiver	
B	P1	68	Female	Parent	
	A1	37	Female	Adult with cognitive disabilities	Wheelchair, communication device
C	C2	33	Male	Caregiver	
	A2	45	Female	Adult with cognitive disabilities	Wheelchair, oversized keyboard with bright colors, and a switch to operate appliances
D	A3	38	Female	Adult with cognitive disabilities	Alexa, reminder applications on the iPad
	P2	68	Female	Parent	
E	A4	30	Male	Adult with cognitive disabilities	Applications on the iPhone and iPad and a medicine dispenser
	C3	30	Male	Caregiver	
F	C4	50	Female	Caregiver	
G	A5	24	Male	Adult with cognitive disabilities	Communication device with pictures
	C5	32	Female	Caregiver	
H	A6	62	Female	Adult with cognitive disabilities	Applications on the iPad
	C6	23	Female	Caregiver	
I	A7	26	Female	Adult with cognitive disabilities	Wheelchair and switches to operate appliances
	C2	34	Male	Caregiver	

participants indicated their assent or consent to participate in the research.

3.2. Study design

We conducted the study over a Zoom video conference call, where we presented multiple persona-based design scenarios that described challenges within activities of daily living and participants created designs to depict how an AR-based smart display could support individuals through those challenges. The study began with a semi-structured interview to understand current practices during daily routines. It was followed by a virtual design activity to sketch prompts for multiple scenarios in three daily tasks that outlined challenges in tracking progress within tasks. The study concluded with a discussion about the benefits and concerns of adopting an AR-based smart display.

Interview (15 minutes): We conducted a semi-structured interview to understand how individuals with cognitive disabilities and their caregivers currently practice and support everyday routines. We asked individuals about their routines, including accessibility challenges and strategies to overcome those challenges. We asked parents and caregivers to describe their roles and responsibilities in supporting individuals and common strategies they used to help individuals during their daily routines.

Design Activity (60 minutes): To explore strategies for motivating people to complete tasks, we engaged participants in low-fidelity sketching activities. Participatory-based design often involves abstracting thinking, which can be difficult for this community (Committee to Evaluate the Supplemental Security Income Disability Program for Children with Mental Disorders et al., 2015; Dawe, 2007a, 2006; Hendriks et al., 2015; Prior, 2010; Sitbon & Farhin, 2017). To help create designs, we provided two instructional documents on Zoom, that describe personas and potential features for an AR-based display. Designing a novel device can create an open design space with numerous choices and possibilities. Providing an explicit, structured, and constrained creative space can help individuals feel less overwhelmed (Rose & Meyer, 2002). Therefore, we provided a list of personas for three young adults with cognitive disabilities who were between the ages of 25 and 35 years. The personas included a list of goals, hobbies, interests, and common challenges during daily routines, such as the inability to complete tasks and difficulty with tracking progress. Table 2 summarizes the three personas. We specifically wanted to focus on strategies to overcome difficulties in completing tasks. Therefore, we included the same set of challenges across personas. Participants were given approximately 2 minutes to read and choose a persona for the design activity.

Participants were familiar with smart devices, so we wanted to utilize a similar design space and provide ample opportunities for creative exploration. Therefore, we shared a system design document that explained the potential capabilities of a customizable AR-based smart display. This device would include a webcam, voice and touch-based interactions, and the ability to take pictures and augment the text, animations, media, and gamification elements. We encouraged participants to reference both documents throughout the design activity.

To support remote participatory design, we shared a blank PowerPoint slide that can support low-fidelity visual design elements, like sketches and images. Additionally, a shared PowerPoint slide on Zoom can facilitate the collaborative design. Due to their diverse abilities, participants were given two options to design: (1) participants could use annotation features on Zoom like text, draw, or stamp (predefined icons), to sketch their ideas, or (2) participants could describe their idea to the researcher who would act as a proxy designer. Within the slide, we added a rectangle to highlight the design area for an AR-based smart display (Fig. 1). We showed participants an example design for motivating practice and explained the scope of the activity (Fig. 1).

Participants spent the first 10-minutes practicing designs for an example scenario, *to help their persona apply sunscreen on all sides of the face*. Participants then created designs for a series of scenarios (Table 3) in three common personal daily tasks: hand washing, teeth brushing, and hair brushing. We asked participants to reference the system design document to design prompts and feedback for their persona. For each of these tasks, we wanted to specifically focus on challenges in completing tasks and difficulties in organizing, planning, and tracking progress. We presented scenarios that fit into two categories:

1 Tracking progress: time and steps completed (e.g., *washing hands for 20 seconds*)
2 Motivation: reinforcements to continue a task and complete it.

Instead of the think-aloud procedure, we asked participants to walk through their designs and asked follow-up questions as this was a more accessible method to engage individuals (Bjorneseth et al., 2010; Colin Gibson et al., 2020).

Discussion (15 minutes): Participants described their overall experiences in the study and discussed potential advantages and concerns about the privacy and security implications of using an AR-based smart display.

3.3. Data collection and analysis

All study sessions were video recorded and transcribed. The data collected during the study included audio-video screen recordings, screenshots of design artifacts generated by participants, responses to interviews, and researcher notes. We qualitatively analyzed our data using open-coding techniques (Corbin & Strauss, 2008) and inductive thematic analysis (Braun & Clarke, 2006, 2019). We iteratively grouped initial codes into categories, like motivating practice, tracking progress, custom designs, interactions, and perceptions around privacy, then clustered the categories into high-level themes.

4. Findings

4.1. Designing through collaboration

Participants in paired groups used several collaborative strategies as part of their design process. Individuals with cognitive disabilities contributed to the initial design idea. Caregivers and parents worked with individuals to expand the initial idea into their final design. Most individuals verbally described their designs. A1 used her communication board to describe designs. P1 asked her questions, and she pointed to her communication board to explain her design. Caregivers and parents supported individuals by repeating the scenario and asking them how they would help their personas. Most groups chose the second design option, where they verbally described their designs and instructed the researcher to create their designs. Descriptions included the overall design idea, the types of visual and interactive elements, the placement of those elements within the display, and how the system behaved based on the user's actions. One group, I, chose option 1 where they created designs on their own (Fig. 3b). In this case, A7 described her design to C2, who drew it on the screen, while constantly checking with A7 if his representation of her design was accurate.

4.2. Existing strategies to overcome accessibility barriers

Most individuals faced cognitive accessibility barriers, like requiring reminders to do activities, stepwise instructions, and the lack of motivation to complete essential activities. A1, A3, and A6 mentioned needing physical assistance from caregivers to do activities. Some individuals also had communication challenges - A1 requires a communication board to talk with their caregivers or parents; A5 can verbally communicate, but struggles with communicating effectively, so he occasionally uses picture-based communication boards.

Caregivers routinely helped individuals by verbally prompting and

Table. 2
Summary of three personas of adults with cognitive disabilities that outline goals, interests, hobbies, and challenges with everyday activities.

Persona	Description	Goal	Interests	Hobbies	Challenges
Marcy	25 years old with long hair and braces	A chef	Drake and cooking	Listening to hip-hop music, watching sitcoms like Friends, making 3D printed art, following friends on Instagram	Trouble switching between tasks -after finishing one, sometimes moves on without completing the next one, and difficulty tracking progress.
Jimmy	30 years old with short hair and wears glasses	An environmentalist	Caring for the environment and playing with his dog, Scrubby	Gardening, exploring funny videos on Instagram and watching anime	Trouble switching between tasks -after finishing one, sometimes moves on without completing the next one, and difficulty tracking progress.
Sarah	35 years old with short, purple hair	A gamer	Stardew Valley and Animal Crossing	Playing video games, exploring Snapchat filters and painting	Trouble switching between tasks -after finishing one, sometimes moves on without completing the next one, and difficulty tracking progress.

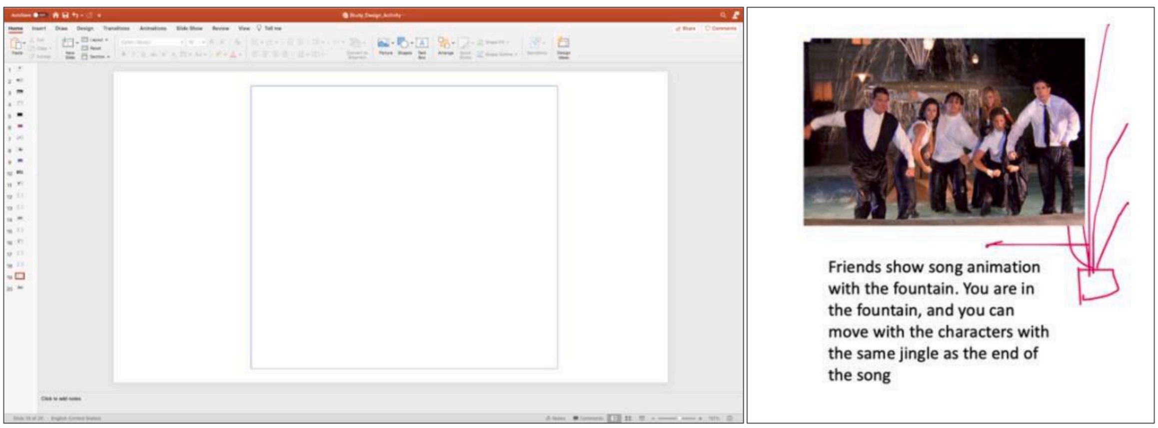

Fig. 1. (left) Shared PowerPoint slide with a rectangular design space that symbolizes a display (right) An example motivational design created using the design tool. The image shows a picture from the sitcom Friends and a description below with a sketch of a fountain. The idea depicted here is to show an animation where the display can augment the person into their favorite song from the TV show Friends to motivate them every day.

Table. 3
Summary of scenario-based prompts that guided participants throughout the design activity.

Personal Daily Task	Design Scenarios
Washing hands	"How can this display help [persona name] in washing hands for an entire 20 seconds? How can the display motivate them to stay on task and not leave midway?" "While washing hands, [persona name] might be looking at their hands, away from the hair. How can the display prompt steps or give feedback?" "How can this display motivate them to wash their hands regularly?"
Brushing teeth	"How can this display help [persona name] in brushing their teeth for 2 minutes? How can the display motivate them to stay on task and not leave midway?" "How can this display encourage [persona name] to brush all sides of the teeth?" "How can this display motivate them to brush their teeth regularly?"
Brushing hair	"How can you encourage [persona name] to brush all sides of the hair?" "[Persona name] won't be able to see how well the back of the hair is brushed. So how could he/she check how well they've brushed their hair?" "How would [persona name] know when they're done brushing their hair? "How can this display motivate them to brush their hair every day?"

motivating them to complete tasks. P1 mentioned how she prompted individuals through tasks, like brushing teeth, by breaking it down into smaller steps and constantly motivating individuals to complete the task, "If they were successful, giving them lots of praise and if they weren't, saying it's okay you tried, that is all that matters, and you want to continue to try."

Individuals used numerous assistive devices to support their needs. For example, A2 regularly uses Alexa to communicate with her caregivers and has a resizable sink. A3 uses applications to remind her of activities and show her stepwise instructions with pictures and audio for cooking. She also uses Alexa to find recipes. Similarly, A4 uses applications on his iPad or phone for scheduling activities and providing motivation to complete house chores through music or TV shows. C4 mentioned that her client often uses an iPad to unlock doors and independently move. He also pairs his microwave with an Amazon Echo [1] and a smart button so he can heat coffee independently. He also uses the Echo to decide his outfits based on the weather.

4.3. System design and interaction features

Participants designed multiple features for an AR-smart display including form factors, interaction techniques, and capabilities to interface with existing assistive devices

4.3.1. Desired form factors

Many participants lived in community homes with roommates, so we wanted to understand the possibilities and desired capabilities of using an AR-based display in individual and group settings. Participants preferred the display to be multidimensional - a horizontal, half-length device in the bathroom, a vertical, full-length device for dressing, and a small device as a checklist reminder by the front door. Additionally, we found portability to be an important feature for wheelchair users. P1 wanted a portable system that could pair with A1's communication device. Thinking of A1's needs as a wheelchair user, P1 hoped the device would be durable to withstand any collisions. Most tasks in the

[1] https://developer.amazon.com/en-US/alexa

bathroom or the kitchen involve using water. Accordingly, C5 wanted the device to be water-resistant to handle wet or soapy interactions.

4.3.2. Supporting multi-modal interactions

We observed that both, the type of task and the abilities of individuals, influenced interactions with the AR-based display. For time-based tasks, like washing hands or brushing teeth, participants wanted the system to observe them and analyze their progress. Whereas, for hair brushing, participants felt that individuals could brush and style their hair for a long time, so the system might not know when they have finished. Therefore, participants wanted the system to show them touchscreen buttons and support voice-based interactions with check words, like *"Okay"*, or *"Done"*, to initiate prompts or indicate completion. By supporting both touchscreen and voice-based interactions, participants felt both, individuals using a wheelchair and/or individuals with dysarthric speech can interact with the display. Participants also wanted functionalities for scheduling infrequent tasks, like cleaning hairbrushes or using a Waterpik, which are only done a few times per week.

4.3.3. Compatibility with existing assistive technologies and third-party sources

Some participants designed features that resembled existing smart assistants, like Alexa and Google Home. They wanted the device to access social media, shop online, and connect to other smart appliances in the house. Some participants wanted the device to observe and assist individuals by recommending improvements. For example, if an individual struggled to use a bar soap, Group I hoped the device would recommend a soap pump, *"Hey, here's this Amazon soap pump that you can buy. It'll be at your house by tomorrow."* We learned that participants used other smart appliances at home to support activities, like turning off lights or opening doors. Group, I envisioned the device to be part of a smart hub, for example, it prompts a user to verbally turn off the lights before leaving the bathroom and completes it using the application of the smart light.

4.4. Motivating strategies for tracking activities

We found various types of motivational strategies from participant artifacts for tracking activities. Participants designed on-screen elements to prompt steps and encourage practice using positive reinforcements.

4.4.1. Choosing relatable characters

Participants designed avatars, engaging animations, and games, to prompt and motivate individuals to complete tasks. We found that 7 participant groups designed avatars to support everyday routines. Most groups chose their persona's favorite celebrity or animation character to be avatars, while 2 groups, D and H, chose themselves as avatars. Some participants also chose different avatars for different tasks based on the type of activity. For example, groups E and F chose two avatars for the study, one for washing hands and brushing teeth, and a second gender-specific avatar for brushing hair as they thought prompting and styling suggestions were dependent on gender and hair length.

4.4.2. Strategies to motivate task completion

Story-based games can compel individuals to finish activities. Group C designed a game for flossing, where an anime character walks on a tightrope (signifying the dental floss) over a gorge containing alligators. The user must completely floss their mouth to help their character be safe. C2, excitedly described his and A2's design, *"As he's flossing his anime character evolves into a full person transported onto this tight rope that's on this gorge with hungry alligators or sharks down below. Flossing, flossing, flossing! The closer he gets to clean all of his teeth, the closer his avatar gets towards the end, and once he's all done, the avatar jumps, to the edge of the cliff and he's saved."*

Participants designed animations with representational metaphors (Consolvo et al., 2008) to make routines more enjoyable and push individuals to complete activities. For example, Fig. 2a shows a design to flourish a dead forest by washing hands. In this design, the user initially sees a dead forest. As the user washes their hands, the forest starts to flourish with flora and fauna to become a tropical area. Creating personal metaphors, like *"pets seeking attention,"* can compel individuals to stay on task and complete. For example, Fig. 2b shows a design that uses pets to stimulate hair brushing. In this design, the user sees a messy dog and needs to brush their hair to clean the dog. The design integrated audio cues to further emphasize brushing all sides of the head. Initially, the user sees the dog panting and being irritated, but as they brush their hair, it calms down and gets excited. Visual metaphors could also help individuals achieve target-based goals. C2 described a scenario where the display could help one of his clients stand longer as part of her physical therapy training, *"Another client has to stand up and stand as long she could, but if she was sitting in front of a mirror, she loves horses so on this horse, I feel like it could help her push past that time limit she has set for herself even further. "*

4.4.3. Tracking to monitor and prompt activities

We found that onscreen elements acted as virtual coaches, where they prompted individuals by demonstrating steps (Fig. 3a). This included teaching steps by incorporating music, animations, and social media. For example, C5 and A5 designed a non-visual, audio-based avatar that showed an augmented dial and reminded individuals to check the water temperature before washing hands. The dial showed temperature markings and prompted individuals to practice good safety measures by starting with cold water and appropriately switching to warm water. Fig. 3b shows another example, where individuals can scan Snapchat-based filters to select hairstyles. In this design, an individual sees a set of hairstyles and swipes to *"try on"* several choices before selecting one.

All onscreen characters had a pleasant disposition and used friendly prompts to collect data for tracking progress. Furthermore, participants expected their avatars to observe and analyze steps to figure out if a step was completed properly. For example, Fig. 4 shows an avatar that observes the user as they brush their teeth, prompts them to smile, and pretends to take a picture to check their teeth. This focuses on checking an individual's progress through compliments. Some avatars could track and recognize objects in real-time to provide interactive feedback. C5 described how A5 works at a local pizza eatery and an avatar that checks attires could be helpful. This avatar can individuals get dressed, *'yep you've got your hat.'* It could be able to recognize that you're wearing a certain logo shirt, *'oh the wrong kind of shirt! Got to get our work shirt.'"*

4.4.4. Rewards

We found that participants wanted avatars or "*virtual buddies*" to appreciate and reward their practice. This included showing animations or positive messages or playing music. For example, Fig. 5a shows an avatar that rewards an individual for completing their task by displaying glitter and fireworks with a celebratory song. Interactive elements like giving virtual high-fives or clicking selfies can motivate individuals to regularly practice routines. Fig. 5b depicts an avatar that motivates an individual by exchanging a virtual high-five. Fig. 5b shows an avatar that applauds an individual by displaying a tiara and prompting them to do a beauty pageant wave. To make this experience more engaging, the avatar mirrors the individual by waving at them with a tiara.

Progress toward activity-based goals can also act as a reward. Participants thought activity summaries could motivate individuals to track their progress over time and continue practicing activities. However, they only wanted positive summaries because negative feedback can demotivate individuals and lead to abandonment.

C3 said, "They wouldn't want to see if they've had bad days. That would only discourage them from wanting to do it. Oh, man! I screwed up all month. This is not helping me." Participants created multiple representations of "progress-based" rewards. Some participants

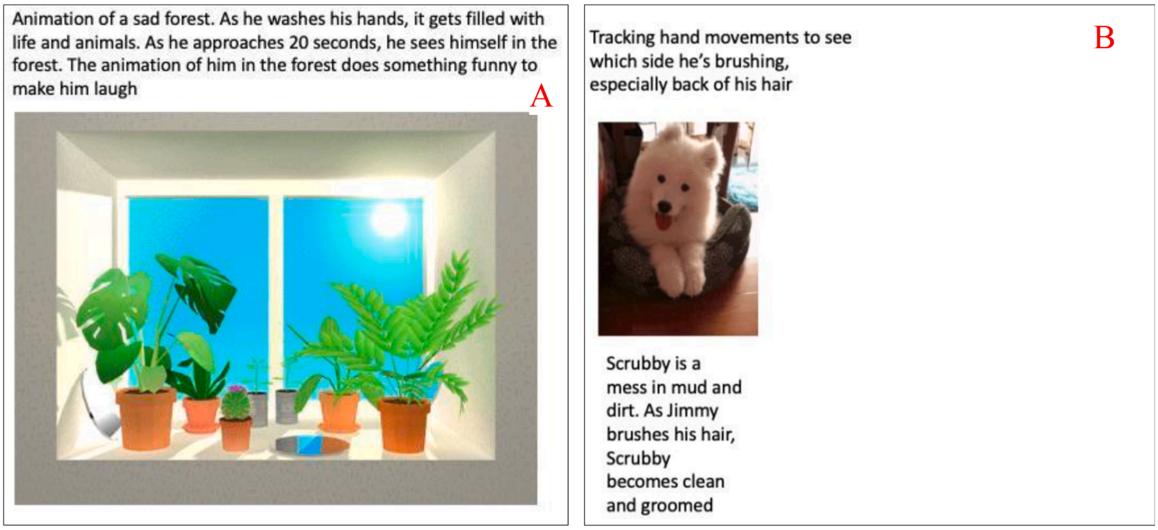

Fig. 2. Immersive Visual Experiences. (a) Group C designed a visual experience to motivate washing hands, where an individual needs to wash their hands for 20 seconds to flourish a dead forest (b) Group C designed another visual experience where an individual should brush their hair to clean and groom their pet. These designs focus on experiences that motivate individuals to stay on-task and reward them with captivating visuals on completion.

designed snapshots of their practice over time or made games. C2 and A5 suggested creating skill-based levels of achievement, where game levels are unlocked based on completion of tasks, “The more independent you become in a certain task it could track you and see that you’re doing the majority of it, congratulations you’ve achieved this level you could have a cute little animation pop up.” Individuals could work with their caregivers or parents to figure out appropriate skills and game levels.

Participants felt that it was important to design rewards specifically for adults. C2 mentioned that he previously used toy horses to motivate his client during physical therapy. However, he found the toys to be elementary and inappropriate for adults. He thought an AR-based smart display could replace the tangible reward system with virtual coins that one could collect by completing routines. For example, C2 designed a game for motivating individuals to stay dry for longer periods before going to the bathroom. Based on the number of times they go to the bathroom, individuals received virtual coins to watch videos.

4.5. Concerns around privacy and data security

We asked participants about privacy concerns when using an interactive AR-based smart display in a community home. Participants acknowledged the importance of privacy but viewed it as an individual preference. We found caregivers to be more accepting of displays during private tasks like dressing or showering. C1 found it to be “less invasive than someone being in the room with you watching you get changed.” C2 thought this device could be beneficial in motivating individuals to practice private tasks that they otherwise might not, “A client absolutely hates showering, but if we can incorporate a mirror into that routine, where it kind of immerses them into an environment to escape the torture of showering and makes it a more enjoyable experience for him”. We found that current practices in community homes informed caregiver views on privacy, where they generally assist individuals in all tasks and have access to their data. They felt a legally compliant device could be useful to provide information to case managers or medical professionals. For example, C2 saw video recordings to be particularly useful for doctors to diagnose individuals with seizures.

Conversely, parents wanted the device to only provide an illusion of tracking without storing visual data. P2 said, “Definitely not want a video camera to observe someone.” Parents were worried that displays might accidentally record information in private spaces, like the bathroom, where an individual might not be dressed properly. P1 described how this could potentially result in security issues and raises the need for more awareness, “If you have to go to the bathroom, somebody may be partially clothed, they need to know what that means”. This led to her suggesting that the device could pretend to record data and not store any information. All participants wanted their data to be password protected with limited access to individuals, their caregivers or parents, and community home supervisors. C5 says I think it would be like an access code - a caregiver is given this code and uses it in the same way as a monitor so in that case, it’s okay.” While caregivers and parents differed on storing data, all of them wanted an auto-sleep feature to avoid being constantly recorded. She also suggested automatically stopping the video after a couple of hours if individuals forget to turn off their camera.

5. Discussion

Our findings illustrate motivating examples for interactive AR-based smart displays to support daily routines and identify potential concerns about their use at home. Here we discuss the need for designing customizations based on interests and needs, describe the need to expand awareness about privacy and data security within this community, and present lessons learned in engaging individuals with cognitive disabilities and their caregivers.

5.1. Designing customizations as a combination of interests and needs

We found avatars to be the most popular strategy to support everyday tasks. Individuals wanted their avatars to be “virtual coaches’’, that demonstrate and prompt steps. Most individuals picked their favorite celebrities or friends or animated characters to be their virtual coaches. Two participants wanted to be the avatars for self-prompting. This tells us that individuals wanted their coaches to be either someone they admire, celebrate, or an aspirational version of themselves. Furthermore, we discovered that most virtual coaches were designed to possess friendly personality traits: 1) constantly applauding individuals using encouraging words, animations, music, or virtual interest-based rewards, like unlocking recipes or videos, and 2) presenting weekly summaries of activities more positively, by emphasizing achievements over improvements. This indicates that personally compelling coaches or support staff could motivate tracking and completing activities. Concurrently, our findings also highlight the fragile relationship between individuals and their caregivers (Dawe, 2006). Individuals might be more comfortable performing certain tasks, like showering or

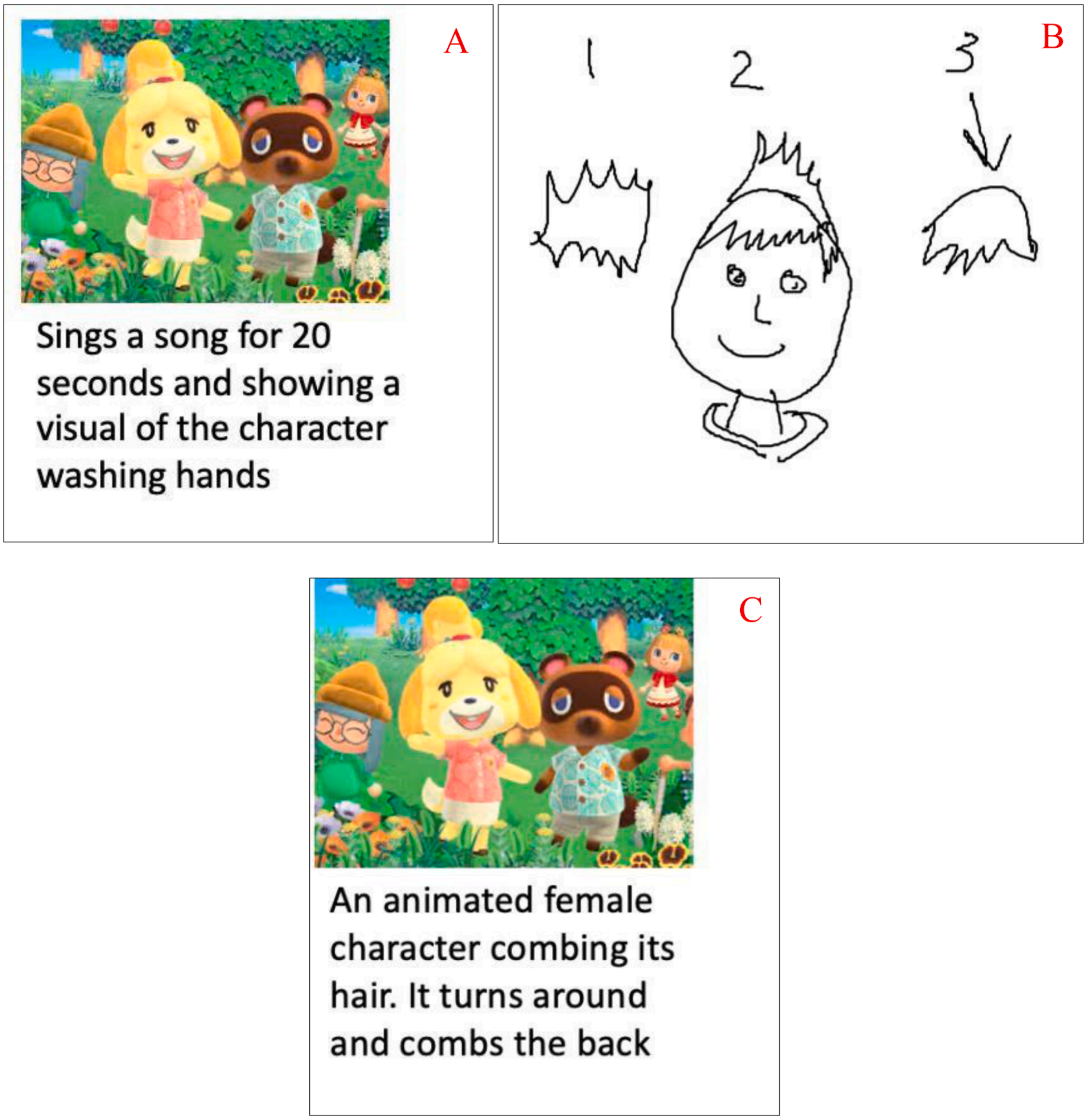

Fig. 3. Prompting avatars (a) Group F designed an avatar that will sing a song for 20 seconds and demonstrate steps (b) Group I used Snap filters to enable users to scan and select hairstyles (c) Group E twirled to prompt users to brush the back of their head.

dressing, in front of their virtual coaches rather than their caregivers. While virtual coaches may be equally invasive as a caregiver, some participants felt that with restricted access these devices could compel individuals and act as intermediaries, where prompts depend on an individual's practice and they can reach out to caregivers if they struggle or needs physical assistance.

Besides inspirational virtual coaches, we found that games and captivating animations can make activities "fun" and motivate individuals to complete tasks. Most participants focused on creating designs that developed throughout the task and provided continuous feedback. This can compel participants to stay on task and complete it to view the finished animation or win the game. Contrarily, some designs followed the traditional gameplay features, like receiving virtual points or badges that further unlocked rewards, like videos.

Likewise, smart systems should also accommodate an individual's needs while customizing prompts and feedback. Devices should support multimodal interactions, schedule non-regular activities like laundry, and be compatible with other assistive technologies and third-party vendors. Creating smart devices with many customization features could limit the need for specialized devices for each activity and help retain assistive devices within this community (Hamidi et al., 2018; Hook et al., 2014).

5.2. Expanding privacy awareness

We found limited community awareness about privacy. Individuals wanted a mirror to motivate showering through immersive visual feedback and prompt steps. Individuals thought it was acceptable for systems with cameras to record video data during private activities, like processing video data with restricted access. However, caregivers and parents had divergent views about tracking and storing data. Caregivers were more willing to record and store visual data because they viewed smart devices as useful tools for case managers and doctors to obtain meta-data about individuals. However, parents maintained a protective stance and lacked trust in AI-based systems. They wanted devices to store limited non-visual data about routines. This highlights the importance of providers and their role in influencing the use of smart devices.

The varying perceptions of caregivers, parents, and individuals can be shaped by their purposes as facilitators or users, their knowledge of

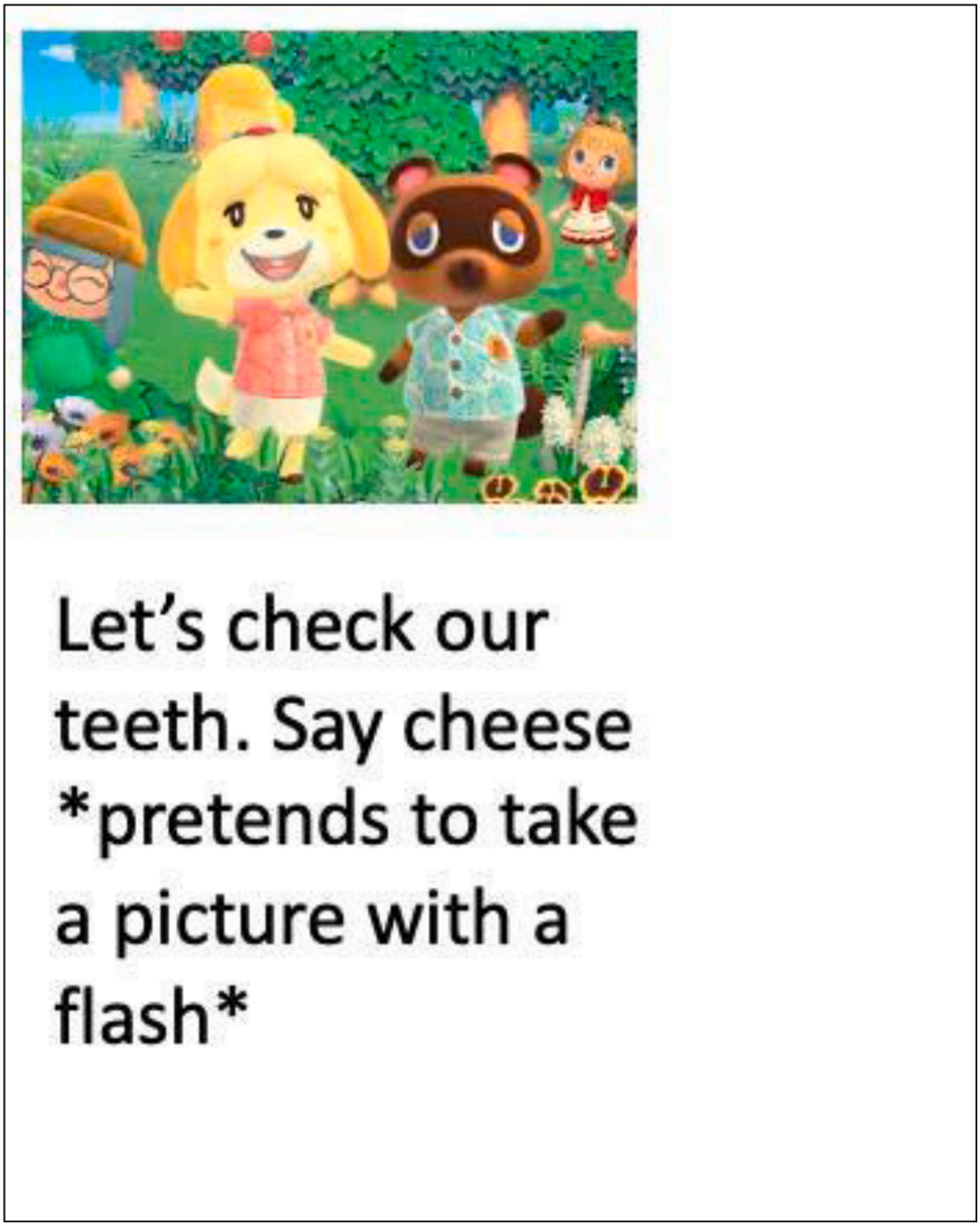

Fig. 4. Group F designed an interactive avatar observing the user as they brush their teeth, prompts them to smile, and pretends to take a picture to check their teeth. This design emphasizes positive cues and self-appreciation to prompt an individual to check their teeth through selfies.

these devices, the context around using these devices, and the underlying power in their role (Pinch & Bijker, 1984). Contrary to conventional wisdom, individuals may want greater control over their data and may seek to protect aspects of their life from their caregivers or parents by logging information into their smart devices (Petelka et al., 2020). Like voice assistants, individuals may view AR-based smart displays as their friends (Pradhan et al., 2019). Person-centered support hinges on helping individuals feel included and maintaining their sense of identity (Kitwood, 1997). However, this also creates several design challenges for smart displays: 1) individuals need to understand the types of data being recorded or tracked; 2) individuals should be able to choose when data gets recorded, and 3) devices should enable individuals to limit data access to their caregivers and parents. It is unclear whether individuals fully understand the moral and ethical implications of using smart devices. Promoting knowledge and awareness about data security and privacy could better equip this community in using smart devices (Hamidi et al., 2020).

5.3. *Engaging individuals with cognitive disabilities in virtual participatory design*

Like the in-person participatory design, virtual sessions require adaptive methods. To compensate for the benefits of tangible materials (Colin Gibson et al., 2020), we provide two options to design – active or paired. Participants could design actively using annotation tools, or pair design with a researcher by describing their ideas. We found that most participants chose the latter as they were more comfortable describing their ideas rather than drawing using their trackpad. While participants

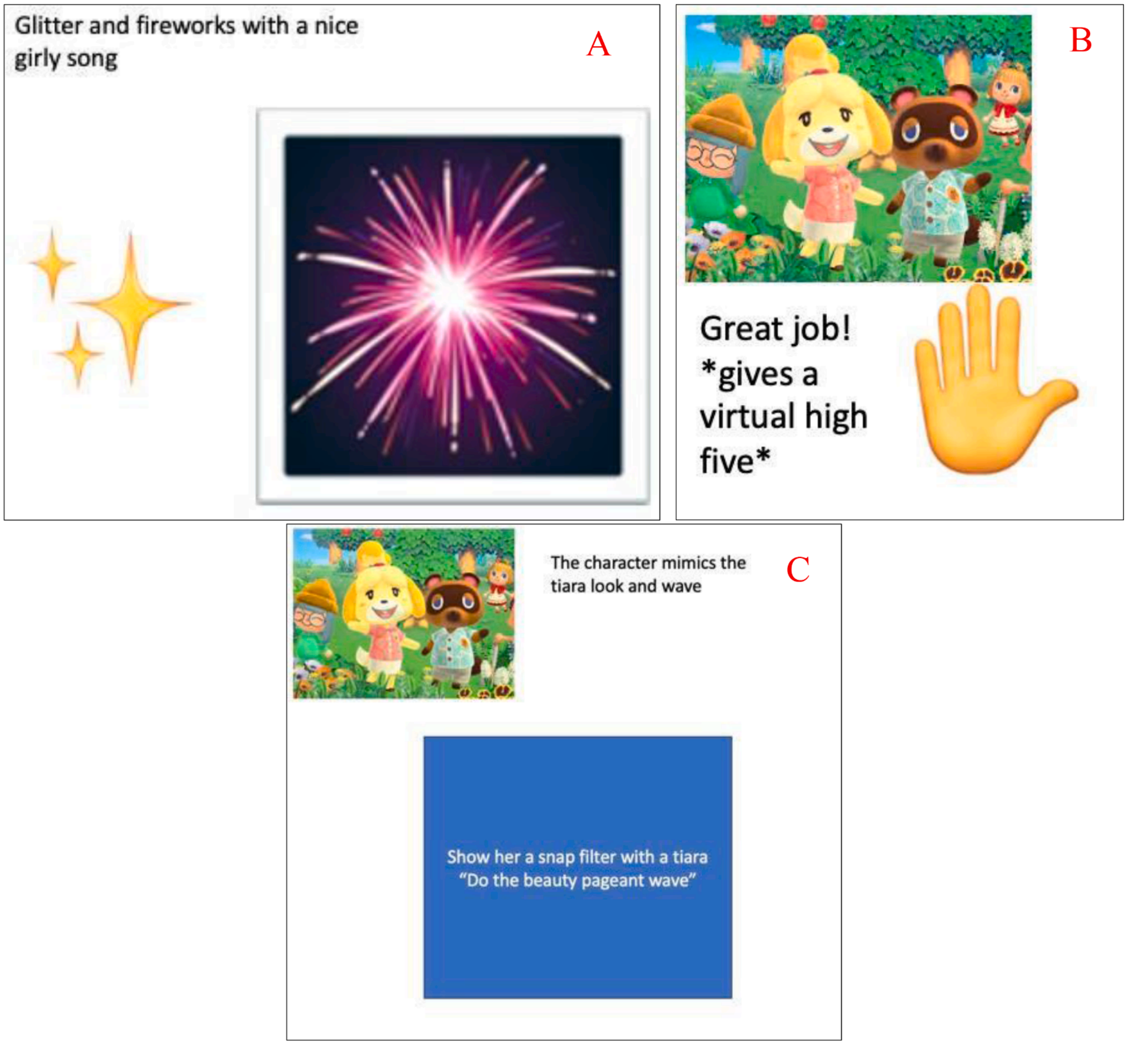

Fig. 5. Rewarding progress through positive reinforcements. Group F created (a) ambient display designs including glitter and fireworks to celebrate the completion of tasks, (b) an avatar giving a virtual high-five as a token of appreciation, and (c) an avatar that can click pictures and add snap filters. In this design, the avatar prompts the user to do a pageant and imitates them to applaud their progress.

were part of groups, all caregivers and parents acknowledged and respected that everyone in the group was an individual participant. They ensured that individuals with cognitive disabilities contributed distinct ideas by starting each activity with them and rephrasing design prompts into questions if individuals struggled with a particular prompt.

6. Future work

This work represents an initial step toward designing customizable accessible smart devices for people with cognitive disabilities. Our study has revealed numerous opportunities for improving current smart devices, including exploring ability-based customizations, features to track activities, creating resources to develop this community's awareness around privacy and data security, and understanding the role of caregivers in adopting and facilitating smart devices.

6.1. Adaptive form factors

We want to understand how smart devices can support adaptive form factors for a range of abilities. This will include exploring smart displays that can be resizable with multimodal interactions to support stationary and mobile activities. We also want to explore devices with dual interfaces to support both individual and caregiver interactions.

6.2. Activity tracking

We plan to explore on-task tracking, monitoring, and feedback for a range of abilities This will include designing tracking techniques for multi-person and multi-location everyday activities. Additionally, we want to explore different ways of motivating individuals to perform non-frequent everyday tasks like cleaning the bathroom or laundry.

6.3. Privacy

We want to explore ways to expand awareness of privacy and data security among individuals with cognitive disabilities. This can involve creating engaging educational resources to enable individuals to assess and evaluate existing devices for privacy implications. Furthermore, we also want to explore tracking methods that are less intrusive but support easy data management for both caregivers and individuals.

6.4. Role of caregivers

We found that caregivers play an important role in supporting the use of smart devices, acting as a liaison between the individual and the device. Caregivers are involved in various aspects of using smart devices, whether that's setting it up, adding prompts, or compensating the device with their support. Additionally, caregivers could actively review and evaluate everyday routines to help smart devices improve and learn an individual's abilities and needs. This presents interesting human-in-the-loop research opportunities for future designers and developers of ubiquitous technologies.

7. Conclusion

As people with cognitive disabilities widely adopt smart devices in their homes, we must continue to identify ways in which technologies can accommodate their diverse abilities. We engaged individuals with cognitive disabilities and their caregivers or parents in a remote participatory design process. We presented multiple design artifacts on how AR-based smart devices can motivate task completion and encourage regular practice of everyday routines. Understanding the needs of this community can lead to more accessible smart devices for supporting everyday activities.

CRediT authorship contribution statement

Varsha Koushik: Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Shaun K. Kane:** Conceptualization, Methodology, Investigation, Formal analysis, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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