cARe: An Augmented Reality Support System for Geriatric Inpatients with Mild Cognitive Impairment

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Figure 1: Locations for in-situ instructions are positioned in the room via gaze pointer (i.e., the current location to be positioned is following the current gaze direction) and AirTap gesture (a). This way, virtual locations can be attached to their real-world counterpart (b) to present instructions at their corresponding position (c).

ABSTRACT

Cognitive impairment such as memory loss, an impaired executive function and decreasing motivation can gradually undermine instrumental activities of daily living (IADL). With an older growing population, previous works have explored assistive technologies (ATs) to automate repetitive components of therapy and thereby increase patients' autonomy and reduce dependence on carers. While most ATs were built around screens and projection-based augmented reality (AR), the potential of head-mounted displays (HMDs) for therapeutic assistance is still under-explored. As a contribution to this effort we present *cARe*, an HMD-based AR framework that uses in-situ instructions and a guidance mechanism to assist patients with manual tasks. In a case study with six geriatric patients, we investigated the prototype's feasibility during a cooking task in comparison to a regular paper-based recipe. Qualitative and quantitative results indicate that *cARe* has potential to offer assistance to older individuals with declining cognitive function in their day-to-day tasks and increase their independence in an enjoyable way.

CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**; *Mixed / augmented reality*; • **Applied computing** → Computer-assisted instruction.

KEYWORDS

assistive technology, dementia, augmented reality, mixed reality, IADL, in-situ

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1 INTRODUCTION

As to this day, dementia is a not fully explored condition that affected about 47 million people worldwide in 2015 and is expected to reach 75 millions by 2030 [59]. With a worldwide lack of caregivers, researchers are looking for ways to alleviate the burden on both, patients and caregivers via interventions [3] and assistive technologies [55]. This way, the independence of patients can be increased while the immense treatment costs for dementia can be reduced [60].

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With the development of stand-alone AR HMDs such as the Microsoft Hololens, AR became a promising platform for assistive technology [55]. AR support of manual tasks such as maintenance [26], assembly [1] or surgery [23] has been widely researched over the course of the last five decades. These setups usually consist of four key features: registration of objects and spaces via maker-based or marker-less tracking [1], object-fixed or world-fixed virtual content [45], step-by-step instructions [34], and guidance between points of interest [4]. With the development of the inside-out-tracking approach, AR applications for HMDs have found their way into non-instrumented environments such as private homes. The ability to augment every-day objects with visual and acoustic information opened a new path to assist occupational therapists and geriatric patients. However, while related work focused on target groups such as surgeons and industrial workers, usability requirements for cognitively impaired users are still being explored [38].

As a contribution to this effort, we developed a generic AR framework that can be set up by caregivers without any programming knowledge to assist patients with cognitive impairment such as dementia in various manual tasks. The framework's architecture allows it to support any sequence of manual tasks to be a flexible tool for both patients and caregivers. While the framework could theoretically support many tasks, cooking is one of the first IADLs that is affected by dementia and was therefore chosen as an example use-case for the case study [11, 58]. While preparing meals has been the focus of previous work targeting cognitively impaired individuals, to our best knowledge this is the first HMD-based approach [2, 42].

This work describes the design and implementation of an AR support system for cognitively impaired patients and presents insights into challenges during the iterative development process. A case study with six geriatric patients displaying mild cognitive impairment has shown that AR devices might offer assistance to older individuals with declining cognitive function in their day-to-day tasks. The main contributions of this work are therefore:

- Design and implementation of an AR framework for patients with declining cognitive function
- An application for therapists to quickly set up cARe with a new set of instructions without any programming knowledge
- Design guidelines for developing AR assistive technologies for cognitively impaired users
- A case study with 6 geriatric patients showing mild cognitive impairment

2 RELATED WORK

This work is grounded in the field of AR task support and draws from findings in the medical and industrial research which will be discussed in the following. Since *cARe* combines insights from different fields, this chapter is divided into four sections, namely suitability for the target group, guidance, in-situ instructions, and input modalities for AR.

2.1 Suitability of AR for a Cognitively Impaired Target Group

According to a survey of Madjaroff and Mentis, older adults with mild cognitive impairment see technology in their home as an "opportunity for autonomy and safety" [41] . This expresses a general openness of this target group towards assistive technology and motivates us to evaluate head-mounted augmented reality as a means of providing cognitively impaired patients with more independence in their daily life.

Augmented reality has been previously explored with a cognitively impaired target group with promising results. In 2015, Tartanas et al. evaluated a mobile phone based AR serious game as an objective tool to detect amnestic mild cognitive impairment (aMCI) [62]. Their results indicate that motor performance during everyday activities and dual-task walking could be a good marker for early diagnosis of aMCI. Similarly, Boletsis and McCallum proposed an AR serious game for cognitive screening to support early diagnosis of cognitive impairment [5]. They found that "Augmented Reality can be utilized in a meaningful way" and "help bridging the technology gap between ICTs and the elderly users". While not using augmented but virtual reality, Eisapour et al. demonstrated that head-mounted displays are well accepted by older adults with cognitive impairment [12].

2.2 Guidance in AR

To guide a user's attention between points of interest or provide general directional cues in augmented or virtual reality, previous work has explored different modalities. Sodnik et al. propose to register spatial sound with virtual objects [57], while Kaul and Rohs argue that directional cues generated by a head-worn vibrotactile grid are superior to spatial sound [32]. They admit, however, that visual cues are still superior in localization precision and speed. Early pilot tests of the *cARe* framework with geriatric patients wearing the Hololens proved that spatial audio cues could not be localized reliably by the patients. Head-worn feedback generators such as the vibrotactile grid by Kaul and Rohs could be encumbering the user and increase cognitive load. Therefore, no additional hardware was added to the Hololens and only visual navigation concepts were considered for the *cARe* framework.

Off-screen visualization techniques have been well explored for mobile devices but were mostly limited to 2D screens [6, 22]. To avoid visual clutter in HMDs peripheral vision was evaluated to get a user's attention via movement [44] or additional LEDs [21]. Similarly, a miniature map metaphor was suggested to display targets in a physical environment but was found to have a high cognitive load on the users [10]. Similarly, techniques that allow 360 degree vision via distorted vision [47] or visualizations [19] were considered too mentally demanding for the target group.

Since targets in a 3-dimensional environment have 3-dimensional coordinates, Chittaro and Burigat propose 3D arrows to guide users [9]. Their results showed that 3D arrows performed as well as 2D arrows in a walking scenario and even outperformed them in a flying scenario. While 2D arrows have been shown to be well accepted by cognitively impaired individuals for hand-held AR [40], Gruenefeld et al. compared a 3D arrow-based technique with comparable visualizations in AR and reached a lower mental load for the

3D arrow condition [20]. Bocca et al. proposed a funnel metaphor where 3-dimensional segments were placed in approx. 0.2 m distance from each other to create a visual navigation path [4]. Due to the limited space inside a kitchen room, straight guidance cues between instructions could lead to intersections with the user and therefore be more difficult to follow. A novel approach to create curved navigation paths between instructions was designed and implemented in the *cARe* framework (see subsubsection 3.2.1).

2.3 In-Situ Instructions in AR

Since digital and real-world objects are easily distinguishable in an AR HMD [49], the concept of localized instructions in AR has been explored since over two decades [8, 50]. The transition from printed manuals to AR instructions is usually either an adaptation of the printed text to an AR representation [13] or a set of purely graphical instructions via pictures and animations [43]. The advantage of AR instructions over paper-based and screen-based instructions in accuracy and speed has been shown by previous work [26]. This advantage was confirmed for a cognitively impaired user group by Funk et al. where in-situ instructions were compared to traditional pictorial instructions [16]. The benefit, however, seems to depend on the users' cognitive potential [37] and expertise [15]. Experts were found to achieve a lower benefit from AR in-situ instructions than novices and cognitively impaired users that require constant assistance [17].

While AR instructions are not yet well received in industrial settings [54] their benefit in a geriatric facility or private home is not yet fully explored. Although video-based instructions have been found to be superior to AR instructions regarding completion time [18], we argue that therapeutic activities are not a time-critical task and can still benefit from AR-specific advantages such as positioning instructions in an optimal position of the users' field-of-view (FoV) [67].

2.4 Input Modalities for AR

Since this framework is aiming to support a manual task, controllers and other hand-held devices for interaction were not considered in the design process. Wearable devices such as smartwatches have been explored for pointing and selection in previous work by using inertial sensors to control a ray cast from the users' perspective [27, 33]. Pointing tasks, however, are very susceptible to hand jitter [48]. This is a significant limitation considering that geriatric patients can also suffer from tremor that can affect mid-air pointing as well as touch input [51]. Wolf et al. compared gesture-based interaction in AR with an indirect cursor on a smartwatch [63]. Their results indicate that both approaches are feasible but suffer from delays and heavy fatigue effects. Although direct manipulation was fast and efficient, the maximum distance of AR content has to be at arm's length. Considering the cooking use-case and the limited mobility of geriatric patients, this limitation was too restrictive to be considered for the *cARe* framework.

All the aforementioned approaches focus on explicit input by the user. In an implicit interaction a tracking system could recognize the progress of the current manual task automatically. This can be realized via markers on the corresponding items [29] or via model-based recognition [36]. While this approach is promising for industrial use cases where tools and work pieces are standardized, cooking ingredients can be more difficult to track [66].

Speech interaction is considered to be the most natural way of interacting with machines for some people [61] considering that a sophisticated language model is available for the given language [7]. Since older adults often have difficulties using a desktop computer due to little knowledge of computing or impairments such as memory loss, Zajicek et al. explored a voice-based interface to provide internet access via a standard telephone [65]. An online survey by Pradhan et al. uncovered that voice-assistants such as Amazon Alexa are actively being used by users with impairments including cognitive impairment with improvement of independence and ease of use being the most mentioned benefits [52]. Wolters at al. evaluated the specific requirements of spoken dialogue interfaces for people with dementia and suggest an interface that acts like a 'patient, encouraging guide' [64]. This finding is supported by the caregivers that were interviewed during the development of the *cARe* framework. One goal of this work was to mimic this behavior in *cARe*'s voice interface.

3 *CARE* CONCEPT

The ability to perform tasks of daily living independently is a key aspect of an individual's quality of life [58]. Especially older people and patients with cognitive impairment are at risk of functional loss and require regular therapy to retain their independence. With a growing older population and a lack of personnel, caregivers will not be able to provide the same quality and quantity of therapy in the future [35, 53]. To alleviate the burden on caregivers and patients, we propose to outsource repetitive components of therapy sessions to assistive technology. Our vision is that a sophisticated AR system can lead patients through their day-to-day tasks in a caring way while giving them the feeling of independence. The system could be extended by real-time support from therapists or relatives to guide patients through potentially critical tasks such as sorting their pills for the week by providing visual cues in their field-of-view without giving them a feeling of "surveillance" [28]. To test the feasibility of this concept the *cARe* framework was implemented with a user-centered design approach that included repeated pilot studies with cognitively impaired patients and discussions with their caregivers to meet the requirements of both user groups. During discussions, caregivers acted as intermediators as proposed by Johansson et al. [30]. The insights gained during pilot tests and the final framework consisting of a caregiver and a patient application are described in the following.

3.1 Caregiver Application

The input required by caregivers to set up *cARe* for a patient can be seen as two steps: Content generation and room set-up.

3.1.1 Content Generation. Instructions for cognitively impaired patients are in general more detailed than those for users without cognitive impairment (e.g. due to limited memory retention) meaning that a simple cooking recipe can result in many individual instructions, e.g. 'Take a spoon from the drawer'. To facilitate the creation of these instructions a recipe editor was implemented in

WPF with a graphical user interface. Creating a new set of instructions from a given recipe consists of the following steps: First, key-locations required for the recipe are defined, e.g. 'fridge', 'drawer' and 'stove'. Then, individual instructions are created and each is assigned to its key-location, e.g. 'Take a spoon from the drawer' to 'drawer'. Pilot tests revealed that complex instructions that include the usage of a scale or measuring cup require additional assistance. To this end, each instruction can be assigned an image file to clarify complex tasks such as using a specific tool or to present a picture of the desired result (see Figure 1 c). Finally, the instructions are exported as an XML-file and copied to the HMD. This step has to be completed only once for each new recipe and concludes the content generation process.

3.1.2 Room Set-Up. Having completed the content generation and, thus, copied the instructions to the HMD, caregivers can now set up a new room for *cARe* support by assigning all key-locations from the list of instructions to their real-world positions. To this end, a Hololens application written in Unity3D displays a mesh of the environment and visualizes the intersection point of the user's current gaze direction with the mesh. Using the Hololens AirTap gesture, key-locations can be positioned in the room (see Figure 1 a). The application iterates over all key-locations until each has been assigned to a position (see Figure 1 b). Key-locations can be re-positioned using the same technique, namely gaze-cursor for pointing and AirTap for selection. Depending on the current recipe, the room set-up takes only a few seconds to complete and could be also performed by caregivers and relatives in the user's home in the future.

3.2 Patient Application

In consideration of the specific requirements of cognitively impaired patients reported by related work and experts interviewed during the development of this framework, several mechanisms were integrated into the patient application that was written in Unity3D: an intuitive guidance mechanism, a natural interaction concept, and a motivation mechanism to encourage patients.

3.2.1 Guidance. To provide location information and reduce mental load on the patients, *cARe* uses in-situ instructions, i.e. instructions are displayed at the location they should be executed at. To assist patients in discovering these locations a guidance mechanism was developed in an iterative process. Depending on the kitchen floor plan key-locations can be far from each other or on opposite sides of the room which is challenging considering that the FoV of the Hololens is limited to 30°. Pilot tests of spatial audio cues against visual cues resulted in lower error rates for the visual cues which is consistent with related work [32]. To prevent the visual cue from intersecting with the patient its shape is defined as a Bezier-curve around the patient and updated dynamically (see Figure 2). The curve is calculated via a quadratic Bezier-function that is described by the points P_0, P_1 and P_2:

$$\mathbf{B}(t) = (1-t)[(1-t)\mathbf{P}_0 + t\mathbf{P}_1] + t[(1-t)\mathbf{P}_1 + t\mathbf{P}_2]\,,\ 0 \leq t \leq 1 \quad (1)$$

In early prototypes the cue was drawn statically between two consecutive instructions which occasionally resulted in patients losing sight of the cue due to the small FoV. Recovering from this situation proved as challenging since patients were not familiar with the concept of a FoV. For the final prototype, the cue was re-designed to start at the patients' center-of-view and end at the new instruction position (see Figure 3 a-b). The cue is hidden as soon as the gaze cursor enters the next instruction (see Figure 3 c) and reappears if the patient finishes the current instruction, asks for help or is idle for too long (see Figure 3 d).

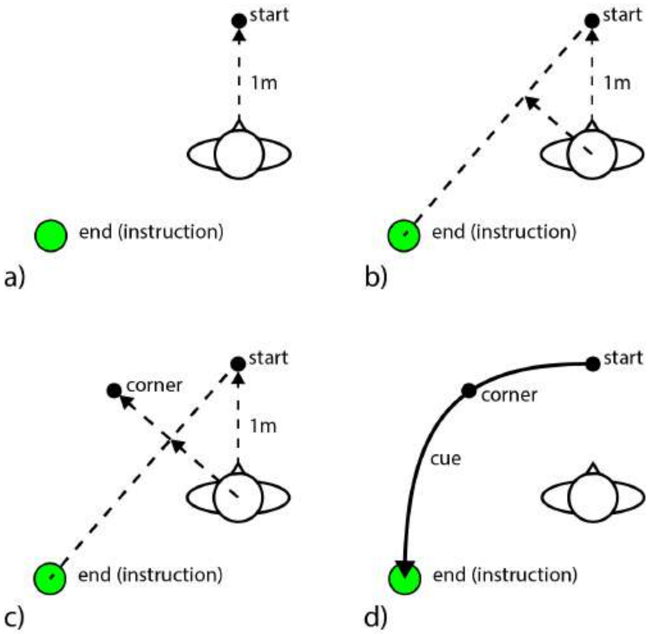

Figure 2: Guidance cues update their shape dynamically. The quadratic Bezier-function used to draw the shape expects three positions: a starting point, a corner point, and an end-point. In each frame, the starting point is defined as a position one meter in front of the patient's current gaze direction and the end point as the current instruction position (a). To determine a corner point that will curve the shape away from the patient, the HMD's position is first projected on the vector between start and end point (b). The normalized vector between HMD and the projected point is multiplied by a pre-set factor and added to the projected point (c). The resulting corner point can now be used to calculate a Bezier-curve (d).

3.2.2 Interaction. A low mental demand for the interaction concept was imperative due to the patients' cognitive impairment. Learning from related work, the interaction via gaze cursor and gestures is physically and mentally too demanding for cognitively impaired patients. Thus, voice input was chosen as the most intuitive and natural interaction modality. Designing an audio interface for cognitively impaired patients is challenging. First, the set of commands has to be kept low due to limited memory retention and be intuitive so that commands can be recalled by logic and instructions repeated if necessary [25]. Second, many cognitive impaired patients suffer from depression and reduced motivation meaning that speech recognition and response time has to be optimized to prevent frustration and confusion. With these requirements in

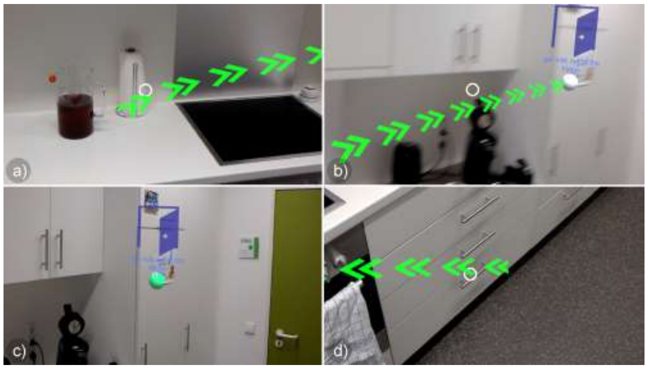

Figure 3: Patient's view of the system: When a new instruction is displayed, patients are guided via cues from their current center-of-view (a) towards the new instruction (b) until the gaze pointer enters the next instruction (c). Saying 'help' or staying idle for a certain amount of time will trigger a cue from the current center-of-view towards the current instruction (d).

mind, a small set of commands was defined in collaboration with patients and caregivers and validated in several pilot tests:

- **'start':** Initiates *cARe* assistance (if the room has been set up beforehand).
- **'next':** Displays the next instruction and draws guidance cues from the current center-of-view. A timeout mechanism prevents triggering this command twice in a row.
- **'back':** Displays the previous instruction and guides towards it.
- **'help':** Draws guidance cues towards the current instruction (if it has been found previously).

The 'back' command was added after some patients ended up skipping instructions while talking to themselves and accidentally saying 'next' in the pilot tests. To prevent frustration during the experiment, a WPF application was implemented as a wizard of Oz mechanism. This way the patient application can be controlled remotely in the case that the speech recognition fails to recognize a command.

3.2.3 Patient Motivation. As cognitively impaired patients often suffer from a feeling of insecurity and a low self-esteem, e.g. due to depression, they require additional motivation. During pilot tests, some patients stopped mid-task and needed additional assistance to continue. In a regular patient-caregiver cooking session caregivers provide regular praise and encourage patients to continue should they get frustrated or get lost in thoughts. Since natural voices are preferred by older adults, this behavior was integrated into the *cARe* framework by recording voice samples of the patients' caregiver containing praising phrases and encouraging words [39]. These voice samples are played back after each completed instruction when the patient triggers the 'next' command. Should patients stay idle for too long, an encouraging phrase is played back to remind them of their task and a visual cue guides them back to the current instruction.

4 CASE STUDY

To our best knowledge, HMD-based AR assistive technology for cognitively impaired geriatric patients has no yet been explored in previous works. To evaluate the potential benefits and risks of this approach we designed a case study with a limited number of subjects. The instruction type was defined as a variable with two levels: *Hololens* and *paper*. Although performance metrics such as cooking time were measured, the goal of this study was to measure the impact of the instruction type on the general ability of the patients to cook individually. The study was approved by the clinic's ethics board and participants were identified by a facility for functional assessment and therapeutic treatment of geriatric conditions. An informed consent was obtained from all patients directly, participants with substitute decision makers were excluded.

4.1 Participants

All participants were selected by a therapist working with the patients and a psychologist assessing cognitive performance. Overall cognitive function was assessed with the Mini-Mental Status Examination (MMSE; [14]). This is a global score with a range from 0 to 30 with 30 indicating no cognitive impairment. Planning capabilities were measured via the "Tower of London" test (ToL; [56]). Six patients (age 73 ± 7.5 years, all female) with mild cognitive impairment (MMSE 27.5 ± 2.1) participated in the case study. It is important to notice that the MMSE is merely a first assessment tool in clinical practice for the beginning of different types of cognitive impairments, which is complemented by others like the consideration of neuropsychiatric symptoms, impairment duration and trajectory as well as different brain functions. All but one participant showed depressive symptoms. One participant was diagnosed with symptoms of dementia. Two of the participants reported to cook on a daily basis, two participants sometimes, and two participants not at all. Only patients showing some impairment of working memory, attention span or planning were included in the study (ToL 14 ± 4). Participants estimated the versatility of using technical instruments on a 5-point Likert-scale with a score of 3.5 ± 1.8 (1: very difficult; 5: very easy). None of the participants had prior experience with HMDs nor AR technology.

4.2 Procedure

To establish a baseline for the case study and measure whether patients were able to cook independently without assistance, patients were instructed to cook with a *paper* recipe from a cooking book at least one day before the *Hololens* condition. Cooking pancakes was selected by therapists as a task being balanced in difficulty and duration. The amount of ingredients was adjusted to suffice for two pancakes. All trials for both conditions were performed in the station's kitchen where therapeutic cooking is usually performed with the patients. Therapists were observing the process via a live video from outside the kitchen. To provide equal conditions therapists were not allowed to intervene even when participants asked for help. If an intervention was necessary (e.g. due to danger or participants being stuck) the trial was aborted to simulate a real scenario. Technical questions and interventions non-related to the recipe (e.g. readjusting the HMD position) were permitted. Aborted trials could not be resumed again and the time of abortion was noted by the therapist. It is important to notice that in case of abortion, participants had no opportunity to practice the subsequent instructions for the next trial, thus reducing the learning bias.

During the *Hololens* condition the following real-time data was recorded: head rotation, head position, instruction position, search time. Both conditions were assessed by an occupational therapist with an experiment protocol that was designed by experts of the local institution. The categories found in Table 1 were created to rate user performance and behavior.

Time	total duration, time until the first question asked, finished with preparing pancake dough, finished first pancake, time of abortion, times looked into paper recipe/asked for help during the prototype condition
Result	a photograph of the end result
Procedure	a list of finished steps, comments regarding initiative, action planning and keeping to the original instructions
Usage of Tools	additional tools used, reasons for deviation from instructions
Hygiene and Safety	handling of tools and stove, additional instructions necessary
Issues	technical issues, reasons for abortion
Behavior	action planning
Self Reflection	post-hoc assessment of performance, comments on usability and issues by the patients
Additional Notes	comments by the therapist, e.g. HMD issues and individual patient background

Table 1: The experiment protocol was created by occupational therapists and was used to document all relevant information during both conditions.

For the *Hololens* condition participants received an extensive introduction by the therapists. First, participants watched a live video transmission from the Hololens perspective while a therapist was interacting with the application and explaining all concepts of the in-situ instruction, voice interaction, and navigation cues. This way, participants could focus on the application itself without coping with the cognitive load of wearing an HMD. After the concept was clear and participants had no more questions they were instructed on how to put on the Hololens. To get used to the interaction and try out all voice commands each participant had to complete a set of instructions to prepare bread and butter. Due to its simplicity the final goal of the recipe was not told in advance. This test recipe gave participants the opportunity to ask questions and therapists to identify mounting issues with the HMD. All voice commands including their functions were printed on a piece of paper and pinned to the kitchen wall.

A trial ended for both conditions upon completion of the meal or abortion by the therapist. After the *Hololens* trial technological competence and acceptance was measured using the TEAG questionnaire [31]. This questionnaire measures the negativity and positivity towards technology and technological enthusiasm and competence with 19 items on a 5-point Likert-scale. On a visual analogue scale participants were asked to rate their overall distress by assigning a score from 0 (no distress) to 100 (significant distress). Subjective workload was measured using the NASA-TLX questionnaire [24]. A custom questionnaire (CQ) was used to assess the general openness towards the prototype. The 7 items in Table 2 were rated on a 5-point Likert-scale (1 - 'strongly disagree', 5 - 'strongly agree').

CQ_Ease	It is easy for me to use technical devices.
CQ_Intro	The introduction to the usage of the Hololens was easy to comprehend.
CQ_Instr	It was easy to follow the instructions presented in the head-mounted display.
CQ_Comfort	The head-mounted display was comfortable.
CQ_Envir	The head-mounted display did not occlude the environment.
CQ_Daily	I would like to use such a head-mounted display in every day life.

Table 2: The general openness towards the prototype was assessed with this custom questionnaire. Items were created in the patients' native language and translated to English for this paper.

4.3 Results - Qualitative

All qualitative data is based on the experiment protocol filled out by an occupational therapist (see Table 1). Items three to seven contain categories created by the therapist to assess patient performance. The number of mentions of theses categories is described below or noted in brackets. Item eight contains patient comments that the therapist considered relevant from a therapeutic point of view. All but one participant were able to successfully prepare the meal using the Hololens, therefore one set of data from the experiment protocol is missing for the *Hololens* condition. We detailed the results in regard to the experiment protocol items.

4.3.1 Hygiene and Safety. The therapist rated the patients according to the categories 'not careful', 'careful', and 'very careful' about hygiene and safety. For the *paper* condition, five of six patients were considered 'careful' and one patient 'very careful'. For the *Hololens* condition, four of five patients were considered 'careful' and one 'very careful'. All six patients in the *paper* condition remembered to close the drawers after usage while one of five patients in the *Hololens* condition forgot to close a drawer. The patient's ability to operate the stove was rated according to the categories 'not able to operate independently' and 'operating confidently'. During the *paper* condition two patients were considered 'not able to operate independently' while four of six patients were rated 'operating confidently'. For the *Hololens* condition, all five patients were rated 'operating confidently'.

4.3.2 Issues. Technical issues appeared only during the *Hololens* conditions and were divided into the categories 'using glasses along with the HMD' (1), a 'slipping HMD' (4), 'loss of tracking (e.g. due to steam)' (2), 'unintentional gesture input' (3), and 'unintentional voice input' (1). Three of the five patients needed an additional explanation of the voice commands and two patients needed an additional explanation of the guidance cues.

4.3.3 Behavior. Patient behavior was rated in the categories 'unstructured', 'structured', and 'very structured'. During the *paper* condition, one out of six patients expressed 'unstructured' behavior, two patients were considered 'structured', and three patients 'very structured'. In the *Hololens* condition, three out of five patients were 'structured' and two patients were 'very structured'. Additionally, the therapist divided patients in the categories 'insecure about cooking independently' and 'cooked without additional help'. Five out of six patients were considered 'insecure about cooking independently' in the *paper* condition and one patient 'cooked without additional help'. All five patients in the *Hololens* condition 'cooked without additional help'.

4.3.4 Self Reflection. This item contains user comments that the therapist considered relevant from a therapeutic point of view. Based on axial coding, these comments were divided into subcategories. The number of mentions of each subcategory was counted and is presented below. In the *paper* condition, some patients were 'disappointed of their performance' (2) and complained about 'unfamiliar kitchen equipment' (2) and 'general insecurity with kitchen tools' (2). Some 'rely on their guts' (1) during cooking or 'use another recipe' (3) when cooking at home. Others considered the paper instruction as 'clear' (2) and cooking in general as 'easy' (1). They had 'no difficulties' (2) and were cooking 'the same way as at home' (2). Only one participant reported to have ceased cooking at home.

In the *Hololens* condition, some patients reported that they 'put themselves under pressure' (2), had 'issues with the arrows (i.e. guidance cues)' (1), perceived an 'uncomfortable weight on the nose' (2) and were 'unfamiliar with voice commands' (1). Some patients praised the concept for not having to 'look at the recipe' (1) and 'seeing the locations of ingredients and tools' (1). Instructions and illustrations were considered 'helpful' (2) and the prototype 'useful to learn how to cook' (3) although some reported to be 'able to cook without the [prototype]' (3). Some patients were 'happy that they tried out the [prototype]' (2) and felt that the '[prototype] took away their anxiety' (2). One patient reported to have enjoyed to 'be in union with the [prototype]'.

4.4 Results - Quantitative

The mean duration of the successful trials was 28 min (SD=15.45 min) for the *paper* and 36 min (SD=9.43 min) for the *Hololens* condition. On average patients asked 6 times (SD=7.6) for help during the *paper* condition and 4 times (SD=3.2) during the *Hololens* condition. One trial was aborted in the *paper* condition and one trial in the *Hololens* condition. The mean subjective workload using the Hololens was 40.83 (SD=12.8) and distress 38.0 (SD=24.0). Results of the custom questionnaire can be found in Figure 4.

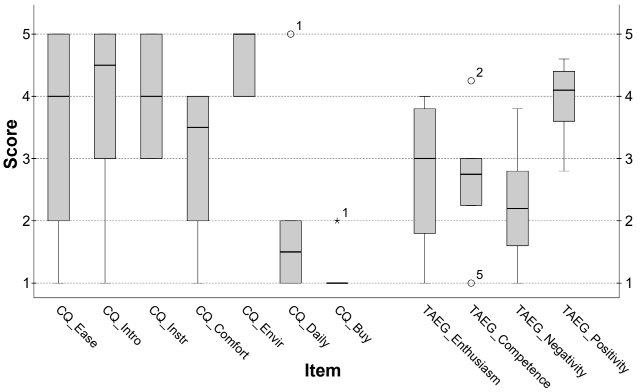

Figure 4: Left: Results of the custom questionnaire (see Table 2). Right: Results of the TAEG questionnaire.

Although the limited number of participants allows no reliable significance testing, the recorded quantitative measures were tested for tendencies. The p-values below are reported for the sake of completeness and should be viewed with caution. An analysis of the movement speed during target acquisition revealed no linear relationship between target distance (angle) and movement time. A Spearman's coefficient analysis revealed that the number of meals the participants cooked weekly showed a significant negative correlation with the times participants asked for help ($p = .008, r_s = 0.925$) and required encouragement during the *Hololens* condition ($p = .038, r_s = 0.836$). Furthermore, the self-reported cooking experience of the participants showed a significant negative correlation with the times they needed encouragement in the *Hololens* condition ($p = .034, r_s = 0.845$). The results of the TAEG questionnaire can be found in Figure 4. Overall, participants reached a high positivity score (M=3.93, SD=0.68) and a low negativity score (M=2.27, SD=1.04).

4.5 Limitations

Despite it being a case study the small and only female sample size is a limitation for the generalizability of our results. However, this case study is the very first validation of the prototype and aims to explore tendencies rather than significant results. All patients had no prior experience with HMDs. The impact of the additional workload of using this new technology and the novelty effect that comes with it is unknown. Both effects could cancel each other out or skew user performance in both directions. While all participants were exposed to AR for the first time in their life, this work aims at future generations of geriatric patients that have spent their life getting used to similar technology and interacts freely with it.

Patients had only minor to mild cognitive impairment so that some of the activities needed for cooking (e.g. measuring fluids) were performed independently without reliance on the assistive device. Therefore, a generalized conclusion on the benefit of *cARe* support on patients with more severe cognitive impairment can not be drawn. The benefit of *cARe* for patients with a higher degree of impairment might be larger due to a more affected memory retention.

Participants were performing the task for the second time during the prototype condition and might therefore have gained a certain advantage. It is important to note, however, that the trial was aborted in the baseline condition if the participants asked for help, making it impossible to learn from mistakes and prepare for the next condition. Furthermore, a learning effect would be expected to decrease the cooking time for the second condition, but the opposite was the case.

Although, potentially, *cARe* can support any manual task that can be described by in-situ instruction steps, there is no sophisticated process management system involved that could support parallel processes, e.g. cooking pasta while preparing the sauce at the same time. Furthermore, patients tended to skip instructions or jump several steps ahead to return later to where they left off. This kind of navigation between instructions is not supported yet. Some voice commands were not recognized properly when the environment was too loud, so that a wizard of OZ mechanism was required to trigger the next instruction in these cases and thereby reduce frustration on patient side. Steam seems to be problematic for the spatial tracking cameras of the Hololens which sometimes led to a loss of tracking while hovering over a steaming pot.

Since the focus of this work lies on the patients, the usability of the caregiver application was not considered and requires further optimization to be usable by non-instructed caregivers in the future. An important feature would be the automatic upload of instructions to the patient's application.

4.6 Discussion

Overall, patients expressed a high curiosity towards new technology which is reflected in above average scores for subjective technical versatility (see Figure 4 CQ_Ease) and high positivity scores in the TAEG questionnaire (see Figure 4 TAEG_Positivity). The prototype was well received and the introduction of its features rated as easy to understand (see Figure 4 CQ_Intro). P5 commented that 'cooking with the [prototype] was interesting and fun' and P1 was 'glad of the opportunity to try [...] out [the prototype]'.

Comfort of wearing the HMD was rated below average and could be a result of the 'heavy weight on the nose' (P6) perceived by some patients. Usually, this weight can be reduced by a tight fit of the Hololens head band. In this work, the HMD was adjusted by the therapist and had to be re-adjusted during the experiment on several occasions. With more experience, patients could learn how to readjust the HMD by themselves and thus require less assistance.

Half of the patients required additional explanation of the voice commands and commented that they were 'unfamiliar with voice commands' (P3) in general. Due to the requirement to 'speak louder than usual' (P3), some commands were not recognized properly and had to be triggered via a wizard-of-Oz mechanism. In general, most inquiries for explanations were of technical nature and could be reduced as patients get more familiar with the prototype. Self-reported cooking experience was a good indicator for the amount of help and encouragement needed by a patient. This could be a result of splitting limited resources between the cooking task and coping with a new technology.

While two patients needed an additional explanation for the guidance cues, the instructions were perceived as comfortable and helpful. Patients rated that instructions were easy to follow and did not occlude the environment (see Figure 4 CQ_Instr and C_Envir). P1 specifically liked that she did not have to 'look at a paper but rather get the recipe step-by-step and see the location of the ingredients'.

Although we could not find a statistical decrease of the time required to find an instruction, we believe that more data (e.g. of several cooking sessions per participant) could provide more insights on the changes over time. The higher average cooking time in the *Hololens* condition could be explained by the high granularity of instructions that is aiming at a population with higher cognitive impairment than patients in this sample. This result is consistent with previous work where cognitively non-impaired users were hindered by too much assistance [17].

While consideration for hygiene and safety was rated as similar for both conditions, one patient forgot to close a drawer during the *Hololens* condition which is a safety risk. This lack of caution could be explained by the additional cognitive resources necessary to 'understand the [prototype] and the process' (P5). Additionally, some patients stated that they put themselves under pressure and felt an 'initial nervousness and worry to not be able to comprehend the technology' (P3). This could be an explanation for the increased subjective workload and distress scores. Nevertheless, patients reported that although the '[prototype] felt unfamiliar, [they were] able to understand and execute each instruction' (P3). We expect that more experience with the prototype could reduce the anxiety of making mistakes and further reduce the cognitive workload of operating the prototype.

During the *paper* condition, some patients were rated as unstructured in their planning, insecure about using the stove, and as not able to operate the stove independently by the therapist. On the contrast, all patients were rated as structured, confident, and independent in operating the stove during the *Hololens* condition. An explanation was provided by P1 who reported that she was 'afraid of turning on the stove, but the instructions on how to operate the stove reduced [her] anxiety'.

Half of the patients reported that the prototype could be helpful to acquire or maintain the ability to cook. Since most patients had experience in cooking, half of them reported that they had no need for the prototype. This is also reflected in the low scores for a daily use of the prototype and the willingness to acquire it (see Figure 4 CQ_Daily and CQ_Buy). P6 explained that 'the [prototype] was slowing [her] down due to [her] cooking experience' but it would be 'ideal for people that can not cook'. Due to the mild cognitive impairment of the participants, P5 added that the prototype would be more beneficial for 'people with impairments'.

Overall, the independence of patients could be improved when cooking with the prototype. Most issues that required an intervention were of technical nature and could be reduced with a more advanced HMD. The guidance mechanism and instructions were rated as comprehensive and the concept as promising for a cognitively more limited user group. Further investigation is necessary to explore long-term effects of cooking with the prototype.

5 IMPLICATIONS FOR FUTURE WORK

As discussed above, patients expressed a generally positive attitude towards the concept but were concerned about cognitive load. For the purpose of person-centered care according to the NICE guidelines, it is of importance to know which features were considered helpful and how wearing the prototype made the participants feel. This feedback provides valuable insights for designers of future assistive technologies which might assist cognitively impaired patients in their independence as long as medically possible [46]. To assist future researchers in developing AR assistive technology, the findings of this case study were distilled into design implications.

5.1 Individualized Assistance

Some patients felt restricted by unfamiliar ingredients, recipes, and actions. Since *cARe* is not focusing on teaching patients new skills but rather helping them retain their existing knowledge, future versions could record point-of-view videos of users during their performance in early stages of cognitive degeneration and provide these videos as instructions as the degeneration progresses. This way, each patient would receive individual instructions that could trigger personal memories and help retain individual preferences.

5.2 Comfort

Many geriatric patients rely on glasses to read texts and perform day-to-day tasks. Since most HMDs such as the Hololens can not be used in unison with regular glasses without resulting in an uncomfortable pressure on the nose bridge, researchers should use an insert frame for lenses with individual prescription. Seeing how the HMD had to be re-adjusted on several occasions during the experiment, users should receive a proper training on how to adjust the HMD. Using a more light-weight device could further mitigate this problem.

5.3 Speech Recognition

We observed that memorizing voice commands was cognitively more demanding than using voice input in general. On several occasions, patients used commands that did not match the set of predefined commands but expressed the same semantic. Using a wider set of voice commands or a more natural speech recognition module could reduce the cognitive load on patients and improve the ‘dialogue’ between patient and assistive technology.

5.4 Illustrations

During the case study, we used illustrations of the actual tools and ingredients that were being used in the recipe. This detail seemed to increase the clarity of complex instructions such as using a scale to measure a certain weight and decrease anxiety of using tools such as the oven. Especially for cognitively impaired patients recognizing familiar objects could trigger memories and make it easier to retrieve the objects displayed on the illustrations. We therefore argue that pictorial instructions should be individualized for each patient. Exchanging media files for instruction steps is already realized as a feature in the therapist application or *cARe.*

6 CONCLUSION

We have presented *cARe*, an AR framework that can support caregivers in treatment of cognitively impaired patients by outsourcing task support and training for IADLs to an AR assistive system. The prototype was carefully designed in collaboration with experts, caregivers, and patients to meet all the necessary requirements for a support system that allows cognitively impaired patients to retain the ability to perform IADLs autonomously. In an iterative approach, we implemented and evaluated a novel guidance mechanism, a voice interface, and a motivation mechanism. Patients were generally positive towards the new technology and were successful in cooking with *cARe* support. From a geriatric point of view this case study clearly demonstrates that augmented reality may support those everyday functions that got lost in older persons with missing day-to-day practice, experience, or due to aging and disease.

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