Augmented Reality Action Assistance and Learning for Cognitively Impaired People - A Systematic Literature Review*

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ABSTRACT

Augmented reality (AR) is a promising tool for many situations in which assistance is needed, as it allows for instructions and feedback to be contextualized. While research and development in this area have been primarily driven by industry, AR could also have a huge impact on those who need assistance the most: cognitively impaired people of all ages. In recent years some primary research on applying AR for action assistance and learning in the context of this target group has been conducted. However, the research field is sparsely covered and contributions are hard to categorize. An overview of the current state of research is missing. We contribute to filling this gap by providing a systematic literature review covering 52 publications. We describe the often rather technical publications on an abstract level and quantitatively assess their usage purpose, the targeted age group and the type of AR device used. Additionally, we provide insights on the current challenges and chances of AR learning and action assistance for people with cognitive impairments. We discuss trends in the research field, including potential future work for researchers to focus on.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Augmented Reality; Assistance; Training; Education; Cognitive impairments; Overview; Survey

ACM Reference Format:
Jonas Blattgerste, Patrick Renner & Thies Pfeiffer. 2019. Augmented Reality Action Assistance and Learning for Cognitively Impaired People - A Systematic Literature Review. In *The 12th PErvasive Technologies Related to Assistive Environments Conference (PETRA '19), June 5–7, 2019, Rhodes, Greece.* ACM, New York, NY, USA, Article 4, 10 pages. https://doi.org/10.1145/3316782.3316789

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PETRA '19, June 5–7, 2019, Rhodes, Greece

ACM ISBN 978-1-4503-6232-0/19/06…$15.00
https://doi.org/10.1145/3316782.3316789

1 INTRODUCTION

Augmented Reality (AR) is a powerful tool for supporting people in a broad variety of areas: improving learning [20, 21, 26], training people to solve complex tasks[33, 70], improving rehabilitation [9, 17, 62] and assisting people at their workplace [29, 69, 71, 72].

In this review we focus on approaches that make use of AR techniques to create solutions for the cognitively impaired. As the review shows, this area has only been sparsely covered by research. This might be due to the fact that devices powerful enough to support high-quality AR are only recently available at reasonable prices, and enabling technologies, such as ARCore and ARKit, have been released as free SDKs to developers only starting in 2017. In this light, we believe that it is timely to provide a quantitative assessment of what has been done and what is next to provide a step-stone for future research. We particularly address two fields, learning and action assistance, as they promise to give insights into a broad spectrum of research, also including elderly people.

In learning, AR can be used to create multimodal sensations that support learning through visualization, animation and contextualization. Many concepts for learning have been realized before with different types of media, some even with tangible elements. While compared to the latter most AR solutions have deprived haptic feedback, AR offers the advantage that software based solutions scale better to large communities and are thus less costly while maintaining visual and acoustic fidelity. Advantages of AR can be seen, for example, in the support for storytelling and animations which make AR solutions viable for sessions of self-learning.

As action assistance, AR can help giving more autonomy to cognitively impaired people, e.g., by giving precise support where otherwise caregivers would be necessary. Instructions for cognitively impaired people are also often given on paper, e.g., in form of text and instructive images. AR technology allows for more flexible instruction designs, supporting spatial visualizations or audio.

Other recent survey or overview publications covered rather narrow fields: VR and AR assistance was reviewed in the specific context of dementia by Hayhurst [35]. In the field of Psychiatry and Neuropsychology for ASD, VR and AR techniques were reviewed by Fridhi [27]. Wu et al. [75] gave an overview over AR in education, however the scope was people without cognitive impairments. Büttner et al. [10] proposed a visual approach to better assess the design space of Augmented and Virtual Reality, also including publications about cognitively impaired workers but not as a main focus. Therefore, we conclude that a comprehensive overview of AR to benefit cognitively impaired people with a broader scope is missing, thus we aim for this goal in our paper.

The main contributions of this paper are: *1)* Giving a systematic overview over literature on AR for cognitively impaired people in the areas of action assistance and learning. A systematic review approach was chosen as it ensures an objective compilation of research. Moreover, it allows us to quantitatively assess current endeavours and trends. *2)* Describing the often rather technical research literature in a more high level and abstract and concise way. *3)* Identifying chances, challenges and gaps in the current literature as a starting point for new research ideas.

2 METHODOLOGY

To provide an unbiased overview of the literature available, we conducted a systematic literature review based on a database search combined with snowballing.

Google scholar was used for the database search as it is the most comprehensive database [34] and prevents publication bias [73]. For the database search, we used the following search string:

```
(intitle:"augmented reality"
    OR intitle:"smart glasses")
AND ("cognitive impairment"
    OR "cognitive impairments"
    OR "cognitively impaired"
    OR "cognitive disability"
    OR "cognitive disabilities"
    OR "cognitively disabled")
```

The database search was conducted on December 5th, 2018. Patents and citations were excluded but no date restrictions were used. To our best knowledge, this search string should cover most of the augmented reality related publications that state cognitively impaired people as one of their target groups.

This initial database search retrieved (duplicates removed) 154 publications, which were reviewed and filtered using the following inclusion criteria:

- Must use Augmented Reality technology (e.g. Smartglasses, handheld devices, projection/screen based approaches)
- Must target people with cognitive impairments
- Must be written in English
- Must be primary research
- Must be from a peer reviewed source
- Must be a poster, short, long, or journal publication

After reviewing abstract, discussion and conclusion of each publication, 55 publications were identified to satisfy our criteria. From those publications, 14 targeted people with cognitive impairment, but focused on motor rehabilitation and therefore were also excluded, resulting in 41 publications after the database search.

From reviewing the publications, three categories emerged: learning, action assistance or cognitive screening / rehabilitation. The publications were grouped accordingly, and as a basis for the snowballing, one influential paper from each category was selected: [56] for learning, [32] for action assistance and [7] for cognitive rehabilitation. After performing the snowballing as proposed by Wohlin et al. [73] and combining the results with our already performed database search, 26 additional publications (9 for learning, 9 for action assistance, and 8 for cognitive rehabilitation) that satisfy our inclusion criteria were identified, resulting in 67 publications.

To narrow the scope of this work, we decided to furthermore exclude the category of cognitive screening/rehabilitation with its

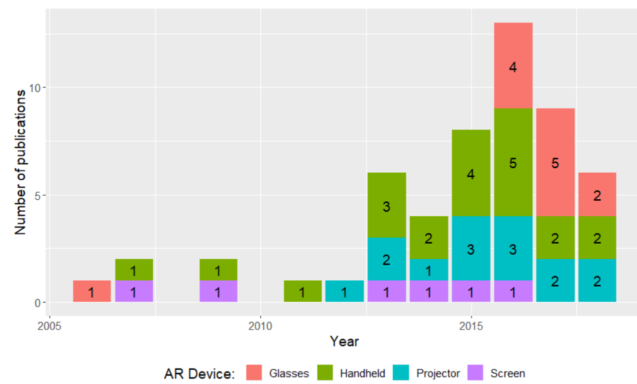

Figure 1: The 52 publications sorted by their publication year and categorized according to the type of AR device.

15 publications, resulting in the final 52 publications included in this systematic literature review on learning and action assistance.

3 THE LITERATURE

After reviewing all 52 publications which were published between 2006 and 2018 (see Figure 1), several possible categories emerged. The literature could be categorized into the usage purpose, the type of AR device used and the targeted age group, covering "why", "how", and "for whom" augmented reality is currently used in the context of cognitively impaired people.

Regarding the usage purpose, the literature was categorized into 27 publications mainly focusing on action assistance and 25 publications focusing on learning. Considering the type of AR device used, 12 of the publications used glasses (sometimes referred to as smartglasses or head-mounted displays), 20 publications used handheld devices (e.g. tablets or smartphones), 14 publications used projection-based approaches, and 5 publications used screen-based approaches. When categorizing the literature into age groups the proposed application was targeted at, 13 publications targeted children, 25 publications targeted adults, and 12 publications targeted elderly citizens. Additionally, one targeted both children and adults and one targeted both adults and elderly (see Figure 2).

After categorization regarding their usage purpose, the literature was further split according to the type of AR device used. For action assistance, 5 publications used glasses, 7 publications used handheld devices, 12 publications were projection-based, and 3 publications were screen-based. For learning, 7 publications used glasses, 13 publications used handheld devices, 2 publications were projection-based, and 3 publications were screen-based (see Figure 3).

Furthermore, when categorized into the targeted age group and then again split into the type of AR device used, in the context of adults 7 publications used glasses, 8 publications handheld devices, 11 projection-based approaches, and one used a screen-based approach. In the context of children 3 used glasses, 7 used handheld devices, 2 used projection-based approaches, and 2 used screen-based approaches. For elderly people, 4 used glasses, 5 used handheld devices, one used a projection-based approach, and 3 used screen-based approaches (see Figure 4).

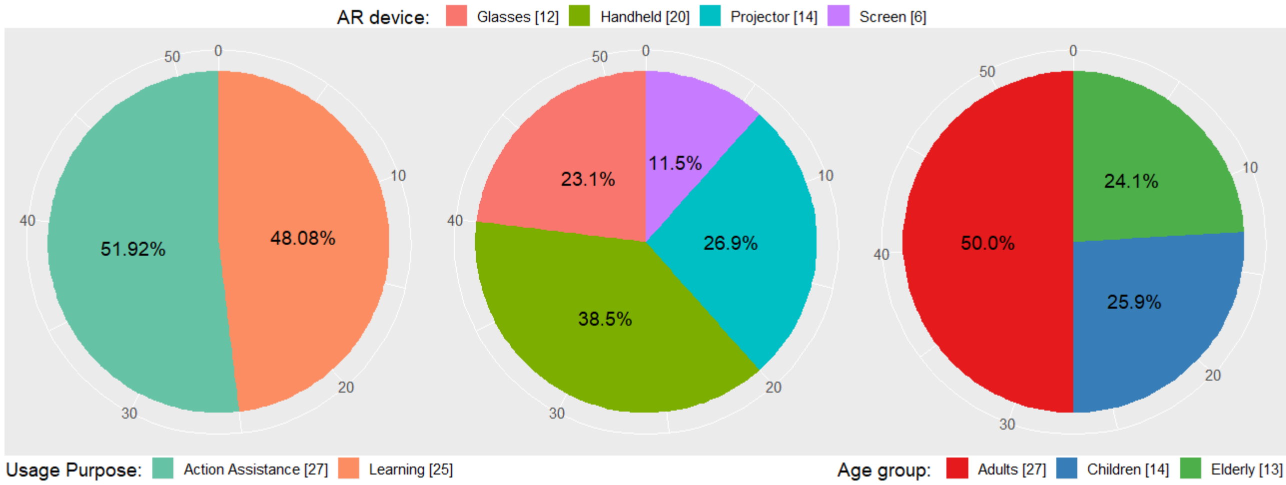

Figure 2: The 52 publications categorized by: Usage purpose, type of AR device, and the target age group.

To provide an uncluttered overview of all publications, the main body of this literature review is structured as follows: First the publications are split into action assistance and learning and then their targeted age group respectively. Furthermore, for each age group, the publications are additionally grouped by the type of AR device used, resulting in the structure:
Usage purpose ⟶ *Target age group* ⟶ *Type of AR device*

4 LEARNING

While for children learning is an obvious usage purpose of AR systems, also many AR learning systems for adults were described in the literature. Interestingly, no publications on learning for elderly were identified. It is important to note that publications on cognitive screening and skill retention were reviewed during the review process but are not included in this work (see Section 2).

4.1 Children

4.1.1 Handheld. Brandao et al. [8] proposed an AR application on handheld devices combined with a storybook to encourage interactive learning and to promote the cognitive and social skills in autistic children. In line with those endeavors, Chen et al. [14] developed a storybook for children with autism that displayed videos based on recognized images in the storybook through a handheld device. They show that this increases the focus of and subsequently learning of non-verbal social queues.

To support children with autism to independently learn chain-tasks, Cihak et al. [16] developed an AR application on a handheld device. In a study, three autistic children used the application to learn brushing their teeth. They show that the AR application was a highly effective intervention method but discuss that AR might not be a universally good fit for all chain tasks and more studies have to be conducted.

Furthermore, [23] developed a handheld AR application overlaying physical objects with computer generated content to mimic strategies that are already used in attention management for children with autism. After conducting a five week long study incorporating cognitively impaired students, they found that the application was received positively and that the children's selective attention improved.

The AR application for handheld devices by Lin et al. [49] aimed to improve the understanding and learning of geometry in children with disabilities. An experiment with 21 participants showed that children were better at independently solving a puzzle task using the handheld AR application compared to paper-based instructions. From the results, they concluded that AR can help enhancing motivation and frustration tolerance while learning.

Lin et al. [50] developed an AR application based on handheld devices to improve vocabulary learning and aid reading disabilities in children with attention deficit hyperactivity disorder. They observed two effected students over the period of three month and found that their reading disabilities improved considerably using the AR application. With a similar goal but a different target group in mind, Ramli et al. [60] designed a coursework for handheld devices based on observations and interviews to support children with down syndrome in learning basic reading.

4.1.2 Glasses. A study conducted by Liu et al. [51] evaluated the suitability of smartglasses used for social communication coaching targeted at children with autism. Findings from using the application in a study with 2 autistic children suggested improvement in non-verbal communication and increased social engagement (e.g. eye contact). In line with those endeavours, Sahin et al. [64] conducted a study with 18 children to assess their Empowered Brain system, an AR application using smartglasses and emotion detection to help autistic children learn social communication skills. The authors focused on safety and potential negative effects of their system. The results revealed no significant risks or health concerns and even indicated a high acceptance among users and caregivers.

4.1.3 Screen. As a stationary approach, Cifuentes et al. [15] proposed a screen-based AR solution on a laptop to quantitatively assess the impact of AR on learning for special needs students.

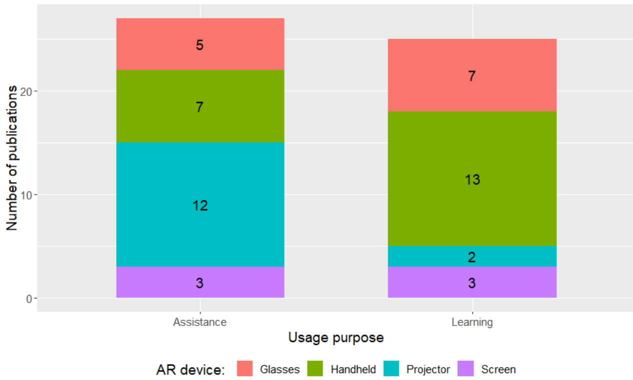

Figure 3: The 52 publications categorized by their usage purpose, split into the type of AR device used.

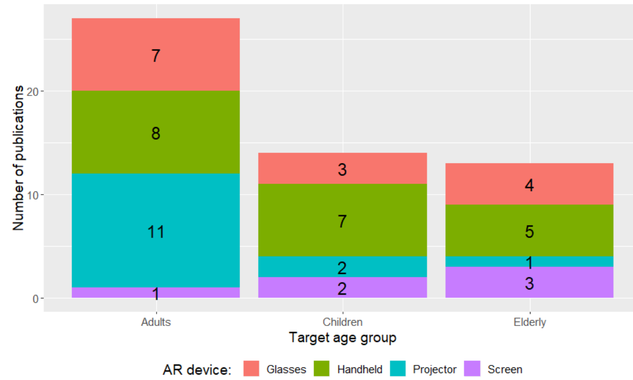

Figure 4: The 52 publications categorized by their target age group, split into the type of AR device used.

After conducting a pre- and post-test in form of two exams and a questionnaire with 88 participants split into experimental and control group, they found that the incorporation of AR significantly increased the academic performance and motivation of the students.

Richard et al. [62] developed a stationary screen-based AR application to help normal and cognitively impaired children learning names and pairings of plant entities in the vegetal field. They conducted a study with 93 children, including 11 children with cognitive disabilities. They found that the children with cognitive disabilities elicited more enthusiasm towards the new learning approach compared to the other children and had a higher motivational increase.

4.1.4 Projector. Cascales-Martinez et al. [11] evaluated a projector-based AR platform with touch recognition to help students with learning disabilities understanding mathematics. They conducted a study with 22 children that had to count and manage virtual money by interacting with the projection and found that it increased the motivation, knowledge acquired, and was well accepted among the children as a teaching tool.

Papadaki et al. [58] developed an application combining an AR projector and tangible objects to teach children with cognitive impairments how to prepare simple meals in a playful way. Their application can furthermore be personalized and incorporate personal preferences and the diverse needs of specific disabilities.

4.2 Children & Adults

4.2.1 Glasses. Keshav et al. [41] accessed the tolerability and usability of Augmented Reality glasses for children and adults with autism while using a social coaching application to improve social communication skills. After conducting a usability study they found that 19 out of 21 participants were able to use the glasses for a whole 60 - 90 minute long session and afterwards reported to feel comfortable using them.

4.3 Adults

4.3.1 Handheld. McMahon et al. [56] proposed an AR application for handheld devices that showed additional content like 3D models or videos based on recognized images to teach science related vocabulary to college students with intellectual disabilities. An evaluation with three cognitively impaired students showed the application to be well accepted and improve vocabulary learning.

Furthermore, McMahon et al. [55] developed an AR application for handheld devices that helped cognitively impaired people to learn how to identify potential food allergens through highlighting them with text recognition. In their evaluation with 7 cognitively impaired participants, all were able to successfully identify possible food allergens and even maintained the acquired ability six weeks later.

McMahon et al. [54] examined the learning effects of an AR navigation aid on handheld devices that used location based information to display waypoints for cognitively impaired people to follow. A study with 4 cognitively impaired adults showed that the navigation aid through the AR application resulted in more successful traveling and more independent navigation decisions made. In a followup study [57] incorporating 6 cognitively impaired adults, they compared the learning effects of their handheld AR application to a paper map and to Google Maps. They found that their application was the functionally most effective condition in terms of successful travel and subsequent learning.

Benda et al. [3] developed an AR application for handheld devices to experimentally verify the possibility of using AR in combination with GPS-based tracking in the context of horticulture education for cognitively disabled young adults. Based on an evaluation with 8 cognitively impaired young adults, they conclude that the application of AR in this context is too demanding and potentially confusing for most cognitively impaired people.

The handheld AR application by Martin-Sabaris et al. [53] explored the utility of using AR in the context of communication and learning for people with Down Syndrome with immersive audiovisual tools. Through an evaluation conducted with 15 participants in which a museum was augmented with additional content, they found that some participants were more focused on the exhibits using their AR application.

4.3.2 Glasses. Reardon et al. [61] proposed a context aware learning application on smartglasses that helps young adults to perform and learn vocational tasks to be utilizable in the context of a work environment. Based on an experiment including 3 vocational tasks (using a copy machine, download a specific document, and completing an assembly task) with 3 participants, they concluded that the application is capable of providing sufficient assistance to each participant to complete all of the tasks with a 100% success rate.

In another experiment by Chang et al. [13], they evaluated an AR game they created by combining smartglasses and tangible objects to teach people food preparation through a decision making game. They conducted an experiment with 3 participants over 17 learning sessions and found that participants improved their food preparation performance and maintained the acquired skills after the experiment.

Kelly et al. [40] developed systematic instructions for the usage of smartglasses specifically for cognitively impaired adults to test the usability of smartglasses in the context of cognitive impairments. In an experiment with 3 participants who were asked to solve a simple task, Kelly et al. found that they were able to use the smartglasses independently.

Doswell et al. [19] proposed an application for lifelong learning in adults by providing continuous and autonomous instructions to human learners through animation, graphics, text, video, or voice instructions and feedback.

4.3.3 Screen. Using a stationary AR solution, Chang et al. [12] developed an application enabling young adults to acquire vocational job skills through playing a decision making game with feedback prompting. After conducting an experiment with 2 cognitively impaired adults, they showed that participants not only improved but also maintained acquired job skills after the experiment.

5 ACTION ASSISTANCE

Literature about AR action assistance was found for adults as well as for elderly people. No publications regarded action assistance for children were identified.

5.1 Adults

5.1.1 Handheld. For handheld devices, Hervas et al. [36] developed an AR application that assists cognitively impaired people in orientation and way finding through adaptively identifying user-friendly routes while additionally allowing caregivers to remotely supervise and instruct the user through the application.

Smith et al. [67] proposed a mobile handheld AR application to assist navigation of young adults with cognitive disabilities in the context of way-finding on a university campus. Through their evaluation of the application with 3 participants with cognitive impairments, they concluded that the application not only reduced planning times but also encouraged more independence in the users.

5.1.2 Projector. Regarding projection based approaches, Korn et al. [45] developed a stationary AR in-situ projection approach to evaluate the potential of AR projection in the context of assisting cognitively impaired workers. They conducted a preliminary study based on a novel evaluation toolkit specifically aimed to evaluate assembly assistance for impaired individuals [46] with 40 cognitively impaired participants. Results indicated that participants were slightly faster using the AR projection approach but were not conclusive about errors made. They describe this as an "catalytic effect" [44], that is caused by the differentiating cognitive potential of the impaired individuals based on a study, where 20 cognitively impaired workers had to assemble a LEGO Duplo scenario with the help of an AR projection. Afterwards, Korn et al. [43] developed a framework for a stationary, context-aware AR projection based approach that was evaluated in a study with 20 impaired participants. Their findings confirmed the findings from [45] that participants were faster using the AR projection compared to state of the art instructions, but made more errors.

Funk et al. [32] analyzed state of the art work environments in sheltered factories for cognitively impaired workers and developed a stationary AR application using projectors and depth cameras to support performing assembly tasks. They compare displaying a novel "contour visualization" to video and pictorial approaches [28] and after conducting an experiment letting 64 cognitively impaired participants compare the different visualization approaches, they found that participants using their novel visualization were faster, made less errors and reported less perceived cognitive load.

Baechler et al. [2] followed a user-centered development approach by evaluating 78 questionnaires filled out by pedagogical staff for cognitively impaired adults in work environments and concluded that a projector-based AR assistive system is a suitable choice for assisting work environments and that most disabled workers provide the skills required for the assistive technology to be beneficial. Based on this framework, Baechler et al. [1] developed an assistive projector-based application that helps workers with cognitive impairments while executing order picking tasks. Their evaluation with 24 participants with cognitive disabilities revealed that the projection-based approach outperformed traditional approaches and was well accepted among the users.

Kosch et al. [47] developed a context-aware, stationary projector for assembly scenarios that would give error feedback through different modalities to compare whether visual, auditory or haptic feedback would be the best suited modality for cognitively impaired workers. A study with 16 cognitively impaired participants revealed the visual approach to be the fastest, which also resulted in the least errors made.

Elkomy et al. [22] tested four different biofeedback modalities (EEG, HRV, GSR, EMG) in combination with a stationary AR projection-based approach to provide adaptive assistance for cognitively impaired workers only when they show symptoms of stress. Their experiment with 12 participants revealed that Galvanic Skin Response (GSR) was the most feasible modality to approximate the stress levels of the cognitively impaired workers.

D'Agostini et al. [18] combined object and action recognition with in-situ projection for a stationary projector AR solution for assisting people with mild cognitive impairments to perform basic food preparation and cooking in assisted living scenarios.

5.2 Adults & Elderly

5.2.1 Glasses. Essig et al. [24] developed an AR application using smartglasses, object recognition and eye-tracking, to support cognitively impaired and especially elderly people in everyday situations by providing pictorial assistance. In a preliminary study with the glasses, they indicated that they were not physically constraining and the pictorial instructions shown were described as helpful.

5.3 Elderly

5.3.1 Handheld. In terms of handheld devices, Hervas et al. [38] combined Augmented Reality with a semantic web approach to assist elderly people with cognitive impairments in ambient assisted living scenarios. In their application context dependent and personalized assistance is given through AR in-situ cues. They propose a framework for contextual information retrieval through ontological context models that further helps understanding and incorporating the environment into the handheld AR application [37].

Quintana et al. [59] developed a handheld AR application that caregivers can use to annotate the environment with helpful queues or instructions for elderly people with mild cognitive impairments like Alzheimer's disease. This approach is inspired by the current approach used, where caregivers use post-it notes as reminders for the elderly people.

Another handheld AR application by Kanno et al. [39] not only helps cognitively impaired people to identify objects and other people but also tracks medication intake and the current location as a safety measure for their caregivers. An evaluation revealed their approach to be easy to understand and feasible in the context of dementia care.

Lehman et al. [48] used a handheld AR approach to develop an assistive technology in form of a motivational game for the encouragement of hydration in elderly people with cognitive impairments or dementia. In their application a virtual AR agent is used to encourage and reward participants for drinking enough water.

5.3.2 Glasses. Firouzian et al. [25] developed an eyeglass-type AR wearable device using RGB LEDs on the frame of the glasses to evaluate the possibility of using simple color cues as a means of remote navigation for elderly people with cognitive impairment. A study with 4 elderly participants with cognitive impairments showed that participants with mild impairments were able to follow the displayed instructions, participants with severe dementia failed to understand and follow them.

Sejunaite et al. [65] used smartglasses to display in-view instructions in form of a map to assist elderly inhabitants of sheltered communities in autonomous wayfinding. The results indicated that participants improved their wayfinding abilities and reported the willingness to use this technology in their everyday life.

Stirenko et al. [68] combined AR smartglasses with a brain-machine interface (BMI) to evaluate the feasibility of low cost BMI devices as an input modality for AR devices when used by elderly people with cognitive disabilities in elderly care. They concluded that using BMI could improve interaction capabilities of people with elderly people with cognitive disabilities by more carefully incorporating the users' current mental state.

Wolf et al. [74] developed a holistic AR application for smartglasses that can be used to create new pictorial AR in-situ instructions freely in new environments, that can then be used by elderly people with cognitive impairments like dementia to assist them in performing everyday tasks like cooking.

5.3.3 Screen. For stationary approaches, Kim et al. [42] developed a stationary windshield AR application to help elderly people with mild cognitive impairments in terms of navigation and accident prevention. They developed an application displaying in-situ navigation cues and warnings that were tested inside a Virtual Reality AR simulator with 12 elderly drivers. Their results showed that participants made fewer navigation errors and had improved selective attention using the AR windshield compared to a control group.

Rusch et al. [63] developed a stationary windshield AR application to assist elderly drivers with cognitive impairments in challenging situations as for example the gap estimation on intersections when trying to perform a left turn. An experiment with 18 cognitively impaired older drivers revealed that the AR projected in-situ warnings where rated as being beneficial without causing additional distraction.

Schall et al. [52] evaluated the potential of AR as a means to improve safety for elderly drivers with cognitive impairments by highlighting important road signs and display warning signals for gap estimation on a stationary AR windshield. Their evaluation with 20 cognitively impaired elders showed that to improve their hazard detection without adding additional distraction or occlusion.

5.3.4 Projector. Simao et al. [66] developed a gaming platform combining a mobile robot with an AR projection approach. Their application assists caregivers in the fight against sedentary lifestyle in elderly inhabitants with cognitive disabilities.

6 LIMITATIONS

A systematic literature review inherently has limitations due to the structured approach which can be summarized as follows:

This systematic literature review is not comprehensive. The matching publications had to explicitly state cognitively impaired people as at least one of the target groups. Publications only describing their target as "elderly people" or "people with autism" may thus also target cognitive impairments, yet without explicitly stating so. These publications were potentially not found during the database search and if they have not cited or have not been cited by the literature processed in the snowball process, they will have been omitted by the systematic review.

The analysis of publications was not normalized for authors, thus multiple publications by the same author may have introduced a bias towards specific target groups, devices or application areas. However, publications without a novel contribution were excluded to control at least partially for this bias. This procedure made sure to identify publications on the considered topics instead of counting how many researchers work on them. Of course, this has to be taken into consideration when interpreting the results.

Finally, some papers target learning through providing action assistance for people with cognitive impairments or the other way around. In those cases, these papers were grouped regarding their main usage purpose.

7 DISCUSSION

The review reveals several trends in AR action assistance and learning for people with cognitive impairments, and allows us to infer some indications for possible best practices.

Looking at the different types of AR hardware used, handheld devices and projectors were used in the majority of research papers. However, about one third of the literature taken into consideration uses glasses or screen-based devices. As glasses are currently in evolution, starting with devices like the Epson Moverio and now the Microsoft HoloLens, one can assume that future research will have a stronger focus on these devices. The increased number of publications on glasses in the last three years shown in Figure 1 underlines this trend. Screen- and projection-based devices, in contrast, inherently do not comprise all the advantages of AR as they cannot be moved around. Thus, they can only offer a small window for augmentations.

In general, the literature gives strong evidence that people of all ages and different cognitive disabilities respond well to glasses, projectors and handheld devices eliciting AR assistance. In comparison to people without cognitive impairments, cognitively impaired people seem to be even more motivated to use AR assistance.

However, the choice of hardware depends on age group and purpose:

Handheld devices are cheap and widely available which makes them an obvious choice, especially in learning scenarios for children. Therefore, in the literature they are mostly used for this purpose. Children are especially used to these devices and bring preexisting knowledge, which minimizes the time for getting accustomed to the hardware. Assisted learning is mostly independent of the environment and should be available to a larger number of users which makes mobile handheld devices an excellent choice. The literature suggests that for children, AR assisted learning should lead to better learning results. In most publications this is at least partially argued to be due to increased motivation. Additionally, it is argued that for autistic children, AR can help to increase the focus on the learned content through the additional visual augmentation.

Projection-based approaches are usually bound to a specific environment, are more expensive than handheld devices and are more difficult to set up. However, the majority of literature for assisting cognitively impaired adults focuses on these devices. This could be explained by the dominating scenario of assisting adults at the workplace. Especially manual workplaces are mostly stationary and can thus easily be equipped with hardware like projectors. Then, the advantage over handheld devices is being able to work with both hands instead of holding an additional device. Current smartglasses still suffer from a small field-of-view. Thus, only a small area of the workplace can be augmented leading to people possibly missing relevant instructions. This makes projectors – at least considering the current state of AR hardware – an ideal technique for assisting at the workplace. In general, assistance in work environments is well received and people report they would like to work using AR instructions. This might be due to a "gamification" effect and long-term studies are needed to check whether this effect is stable for adults with cognitive impairments. Comparable endeavours were already started for people without cognitive impairments [29]. Interestingly, projection-based approaches seem to have a "catalytic effect" in work environments [44]: The error rate of some people increased due to high cognitive load, for all others the error rate improved. Still, all could solve their task faster.

Many papers target specific diseases (e.g. dementia or autism) in specific scenarios like assistance for workplaces. Even if it can be assumed that a large share of the general results are valid for people with other impairments, this remains to be proven by future research. Additionally, studies reported in the reviewed literature often focus on short term effects and risks. We also perceive a large number of studies with a very low number of participants. Long-term studies with larger groups could help to get clearer evidence. AR simulation approaches could help to virtually increase group sizes by conducting studies as a joint effort of multiple facilities, which is difficult to realize with hardware prototypes.

7.1 Future Trends

From the discussion, we can infer several trends of AR and assistance for the next years. In the following, we describe predictions which in our view are likely to eventuate.

Devices capable of AR have reached the mainstream years ago with the comeuppance of smartphones. Nearly everyone owns a smartphone nowadays and carries it with him constantly. People also have become familiar with AR technologies since games like Pokemon Go appeared on the market. This lowers the barrier of using AR-based assistance on these everyday devices. Simple assistance systems are already used today, e.g. personal assistants like Apple's Siri. Thus, in general a more comprehensive usage of AR-based assistance can be expected in the future, also leading to an increase of applications for people with disabilities. This could be described with the term "Accessibility 2.0": Not enhancing the usage of a device, but a device for enhancing other tasks.

In spite of the wide availability of AR-capable devices, assistance systems are often evaluated in very small populations. A central service to collect assistive software and distribute it for application and evaluation would be necessary to solve this problem. Especially in the light of the trend of making research more reproducible, we believe that such a central hub will have to be created in the near future. An additional solution would be common benchmarks for similar scenarios, e.g. as proposed by Funk et al. [30].

Smartglasses for AR-based assistance are still expensive high-end devices like the Microsoft HoloLens. In line with our review, we suppose that this will not change during the next few years, as a price decline is not yet likely. Thus, currently assistive systems using smartglasses will continue to be focused on industrial scenarios. On the long run, as soon as smartglasses become affordable for the end-user, a similar trend as for smartphones during the last years is likely. New developments in the area of smartglasses are particularly interesting for people with (cognitive) disabilities. For these people, often specific modalities are not available or impaired. E.g. stroke patients might not be able to normally move their hands, making gesture detection unfeasible. New devices like HoloLens 2 do not only support visual and auditive output as well as hand-tracking input, but e.g. also eye-tracking which can be used for efficient interaction [4].

Finally, as soon as assistive systems leave the state of being prototypes, we expect an extensive discussion about ethics: Which sensors may be used to be in line with privacy issues? What is the goal of an assistive system? It could either support a person individually to solve a task better, or it could increase the efficiency of work.

8 CONCLUSION

In this paper, a systematic literature review was conducted in order to find out about the state of the art in AR action assistance and learning systems for people with cognitive impairments. We put a specific focus on how and in which scenarios AR is used for different age groups and categorized the papers into systems for children, adults and elderly people. Additionally, the type of AR device was differentiated between glasses, handheld devices, projectors and screen-based devices.

From the 52 papers that were included in this literature review, several quantitative insights could be made:

- In the time span of the considered literature, the primary hardware used for AR assistance and learning systems was handheld devices and projectors.
- Handheld devices are mostly used for learning, as they are widely available and cheap. Especially children (the target group for which most learning applications are designed) are used to operate handheld devices.
- Projectors are mostly used for assistance at the workplace. They can be set-up for a specific workplace and task and allow hands-free assistance in a rather large space.
- Glasses have received increased attention during the last three years, thus we predict a broader usage of these devices in the future.
- In general, all target groups could profit from using AR.

Furthermore, several qualitative insights based on the results of the reviewed literature can be gained: Especially for people with cognitive impairments, AR does increase motivation. It improves learning, especially for children, and can reduce task completion times in assistance at the workplace. However, there is also some evidence that at the workplace in some cases more errors were made due to higher cognitive load for people with some cognitive impairments. This, however, does not mean that AR in general is not appropriate for these tasks, but that more research on design principles for successful AR assistance systems is needed. Chances are, that with AR becoming mainstream, more disciplines will identify the potential of AR and join into this interdisciplinary effort.

8.1 Future Work

While the systematic approach allows for a quantitative assessment of the literature, it also inherently has limitations in regard to the literature found. As stated in the limitations, while systematic, this literature review is not comprehensive. The fact that the literature often targets very specific diseases (e.g. Alzheimer's disease, Autism, Down Syndrome), became only apparent after having conducted the review. Therefore, future work should focus on expanding the included literature by additionally searching for AR in the context of those specific diseases to expand this work towards a comprehensive literature review. At best it would require an expert in such diseases to identify those with potential for AR support.

The recent emergence of glasses as a viable hardware choice for AR applications results in a growing use in the literature (see Figure 1). However, this is just the beginning and many more experiments have to be conducted using AR glasses. It is observable that glasses are successfully used across all age groups and for both usage purposes (see Figure 3, 4). Critical insights could be gained by studying the transferability of results between different scenarios. Endeavors towards comparing AR hardware in standardized scenarios are already started with AR benchmark scenarios, such as the one introduced by Funk et al. [30]. They compared different types of AR hardware like projection-based approaches [31] and AR Glasses [5, 6]. However, those only focus on action assistance in industrial scenarios and do not address cognitive impairments or specific age groups. More work towards contextualizing the different findings from the literature specifically for people with cognitive impairments are needed to "draw the bigger picture" and advance towards actual best practices and guidelines for AR applications in the context of cognitively impaired people of all ages.

While the discussed trend in the literature to not only target specific age groups but also often very specific diseases is a good approach for early exploratory research, as is the case with the young field of AR research, it does not describe realistic usage scenarios. In reality, people with cognitive impairments will have cognitive impairments that are not classified as easily or have differing levels of impairment that are highly individual for that person. Ideally, developed AR applications should be usable for a wider variety of tasks and cover a wide variety of cognitive impairments.

ACKNOWLEDGMENTS

This research was supported by the Cluster of Excellence Cognitive Interaction Technology - "CITEC" (EXC 277) at Bielefeld University, which is funded by the German Research Foundation (DFG).

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