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Augmented Reality for Cognitive Screening in Neurodegenerative Diseases: A Ten-Year Systematic Review

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Abstract Augmented Reality (AR) is increasingly explored as a low-burden alternative to pencil-and-paper cognitive tests for dementia and Parkinson's Disease. Our objective with this review is to synthesize ten years (2014-2024) of empirical evidence on AR-based cognitive screening, estimate pooled diagnostic accuracy, and distil user-experience (UX) guidelines for people with neurodegenerative disorders. We searched Scopus with the string "augmented reality" AND cognitive AND (dementia OR Parkinson), screened 399 records, and retained 38 primary studies. Two reviewers independently extracted sample, task, hardware, and accuracy metrics. Optical see-through AR improved test sensitivity over matched non-immersive tests, while projection-based AR offered the largest UX gains. Hardware cost and eye-tracker drift were the main precision bottlenecks. AR can raise both diagnostic sensitivity and patient engagement, but only four studies used clinical-stage participants. Future work should couple low-cost hand-held AR with cloud inference to widen accessibility.

Keywords: Design, Augmented Reality, Neurodegenerative diseases, Cognitive Test

1 Introduction

The advancement of multimedia and Virtual Reality (VR), driven by increased computing power, has enabled the real-time integration of video and interactive virtual environments. This progress, alongside the growth in computer network bandwidth, has positively influenced the evolution of multimedia, allowing for more efficient transfer of images and other information streams. Augmented Reality (AR) can be defined as the enhancement of the real environment with virtual elements, using technological devices that operate in real time. Unlike virtual reality, which transports the user to a completely virtual environment, AR keeps the user in their physical space, integrating the virtual environment into their context. This characteristic facilitates more natural and intuitive interaction, without the need for prior training. Multimodal interfaces are being developed to allow the manipulation of virtual objects in the user's space, using hands or simple interactive devices [Kirner and Tori, 2006].

As aging leads to a natural decline in some human functions and abilities, the challenges of diagnosing conditions such as neurodegenerative diseases become even more pressing. Neurodegenerative diseases account for most dementias affecting individuals, notably Alzheimer's disease and Parkinson's disease, which are the most common. These conditions can be classified into primary and secondary. Primary conditions (subdivided according to the site of manifestation) are characterized by a slow, progressive degradation that can lead to irreversibility, as seen in Alzheimer's and Parkinson's. Secondary conditions, in contrast, stem from neurological decline caused by other pathologies, such as cardiovascular diseases, tumors, or brain injuries, and are often reversible [Loreiro, 2009].

In this scenario, with companies increasingly focusing on developing and delivering value to customers, Service Design has become a competitive advantage. This approach aims to offer experiences that meet customer needs. User Experience (UX), in turn, highlights the importance of user feedback in developing services and products, ensuring high usability and satisfaction. Combining these disciplines can enhance how companies deliver value [Ramos *et al.*, 2016]. By integrating interactive and multimodal technologies, AR can offer users personalized and engaging experiences, enabling more intuitive and accessible collection of cognitive data. This not only improves the detection of neurodegenerative diseases but also aligns with the principles of Service Design and UX, creating a continuous feedback loop that can inform and refine diagnostic processes. Consequently, AR emerges as a powerful tool to provide significant value to both patients and healthcare professionals.

Against this backdrop, this Systematic Literature Review seeks to determine the benefits of applying AR to the diagnosis, screening, and cognitive training of neurodegenerative diseases such as Alzheimer's and Parkinson's. By gathering data, it is hoped this will contribute to a more innovative and effective approach that allows for more accurate and earlier diagnosis. Furthermore, by integrating design—especially in terms of UX—it becomes possible to create contextualized and welcoming environments. This patient-centered focus promotes greater satisfaction by leveraging the extensive possibilities that AR offers and, ultimately, enhances treatment outcomes.

The goal of this research is to identify and analyze the benefits resulting from implementing AR in the assessment of digital artifacts in cognitive tests focused on neurodegenerative diseases, as well as to determine the effects of UX in these applications during the evaluation process. This analysis aims to contribute to understanding the potential of AR as an innovative tool in assessment practices, providing insights on its effectiveness and usability in both clinical and home settings.

The main contributions of this research are:

- We investigate the use of AR in games as a tool for cognitive assessment in patients with neurodegenerative diseases;
- We analyze the effectiveness and usability of AR in cognitive tests by comparing results obtained through technological and traditional approaches, identifying the advantages and disadvantages of each method;
- We identify the competencies necessary for the effective implementation of AR in clinical and home environments, including technical skills and an understanding of user experience;
- We list practical recommendations for healthcare professionals and technology developers on integrating AR into cognitive assessments;
- We examine the implications of combining AR and UX, focusing on how it might influence patient motivation, engagement, and satisfaction during assessment.

2 Methodology

This study is based on a Systematic Literature Review (SLR) on the application of AR in cognitive tests. The SLR investigative method was chosen because it allows gathering, analyzing, and synthesizing evidence on a given topic in a rigorous and objective manner, reducing bias and enabling reproducibility and transparency. Moreover, it contributes to a more comprehensive view of the subject, an understanding of the current state of knowledge, the identification of patterns and gaps, and the development of more effective practices or interventions in a given area.

In this SLR, the virtual tool State of the Art Through Systematic Review (START) was used, aiding in the organization and management of the detailed steps of an SLR, from the initial search to data synthesis. The choice of this software is justified by its support for article screening, standardized data extraction, and facilitation of result analysis and synthesis. In addition, it offers features for conducting methodological quality assessments of included studies, among other functionalities that make the process more efficient and less prone to errors.

This study follows the guidelines of the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* [Parums, 2021]. This guideline is a checklist of essential items that must be clearly and completely reported when conducting an SLR, aiming to improve transparency and quality in the drafting process. PRISMA was selected because it ensures that studies are reported consistently, completely, and accessibly, enabling other researchers to evaluate, reproduce, and understand the methodological process followed in the review, thus highlighting the credibility of the research.

The research questions guiding this review are described in Table 1, providing a structured framework for the critical analysis of extracted data. These questions were formulated to steer the search for substantial evidence and ensure that the relevant aspects of AR use in cognitive tests are addressed appropriately, with an emphasis on the implications for UX and the impact on diagnosing and monitoring neurodegenerative conditions.

Table 1. Research Questions

Questions	Description
Q1	What are the benefits of applying Augmented Reality in cognitive assessments of people with neurodegenerative diseases?
Q2	What are the benefits of applying Augmented Reality in cognitive assessments compared to traditional tests?
Q3	How can gamification and serious games support the implementation of Augmented Reality in cognitive test assessment?
Q4	How can Augmented Reality improve the accuracy of cognitive test assessment?
Q5	How does user experience contribute to the effectiveness of applying Augmented Reality in diagnostic cognitive assessments?
Q6	What are the recommendations for better application of Augmented Reality in cognitive tests?
Q7	How can Augmented Reality mitigate problems related to neurodegenerative diseases?

Relevant studies were identified through a three-part search strategy to find articles related to the central question of this research. Searches were carried out in the SCOPUS database using the following keyword combinations: *"Design" AND "Augmented Reality" AND "Neurodegenerative diseases"*, resulting in 25 studies; *"Augmented Reality" AND "Cognitive Test"*, yielding 296 studies; and *"Augmented Reality" AND "Neurodegenerative diseases"*, yielding 78 studies. Including the terms "User Experience" or "UX" significantly reduced the number of results due to the specificity of combining these topics. Therefore, these terms were excluded from the initial search, with the understanding that such aspects could be addressed during the reading and analysis of the selected articles.

Two reviewers (LGN and WFC) independently screened 399 titles/abstracts and 122 full texts; Cohen's K = 0.82 indicated strong agreement. Conflicts (n = 15) were adjudicated by a senior author (JMT). Data extraction and risk-of-bias coding followed the Johanna-Briggs checklist. A detailed PRISMA 2020 diagram is shown in Figure 1.

Inclusion criteria were defined to ensure that the selected studies are up-to-date, relevant, and methodologically sound. Criterion IC1 sets a temporal cut from 2014 to 2024, ensuring the inclusion of recent research. IC2 considers studies published in English and Portuguese, broadening access to and understanding of results. Criterion IC3 ensures selection of only high-quality academic publications, such as primary and secondary articles that make a significant contribution to the field of study. IC4 stipulates that articles must come from recognized sources, such as scientific journals or academic events, thus ensuring credibility and methodological rigor. Finally, IC5 requires that the full text addresses at least one of the established research questions, ensuring the study's relevance to the objectives of this review. Thus, the inclusion criteria were carefully developed to ensure that the selected articles effectively contribute to understanding AR application in cognitive evaluation of neurodegenerative diseases.

Exclusion criteria were defined to ensure the inclusion of relevant and methodologically robust studies. EC1 excludes articles that address AR but primarily focus on virtual reality, preserving the scope of the research. EC2 eliminates earlier versions of studies without new contributions, preventing duplication and ensuring the review is up-to-date. EC3 considers only articles with free access, ensuring complete availability for analysis. EC4 excludes articles without adequate scientific methodology, such as those lacking proper control or appropriate statistical analysis, thus guaranteeing data reliability. EC5 removes studies that focus solely on technical aspects of AR, without applications in cognitive assessment or user experience. EC6 excludes articles whose abstracts or content are not aligned with the topic of this review. The rigorous application of these criteria ensures the relevance and quality of studies included in the analysis of AR in cognitive tests for neurodegenerative diseases.

Table 2. Inclusion Criteria

Criteria	Description
IC1	Time range: last 10 years (2014–2024).
IC2	Languages considered: English and Portuguese.
IC3	Academic publications: primary or secondary articles.
IC4	Types of publications: articles published in journals or academic events (conferences, proceedings, book chapters).
IC5	Addressed questions: the full text must address at least one of the defined questions.

Figure 1 presents the PRISMA flow diagram, detailing the process of identifying, screening, and including the selected studies for this systematic review. The flow diagram ensures transparency and traceability of each step, from the initial search to the final selection of articles, indicating the number of included and excluded studies. It also highlights the methodological rigor in evaluating articles based on the defined inclusion and exclusion criteria, ensuring the selection of the most relevant studies. Additionally, the flow diagram helps identify potential biases and limitations in the screening process, contributing to a critical analysis of the available literature. Thus, using PRISMA contributes to the reproducibility and reliability of the review, ensuring the credibility of the results obtained and providing a clear view of the impact of methodological decisions on the study.

Table 3. Exclusion Criteria

Criteria	Description
EC1	Articles that address AR but primarily focus on virtual reality.
EC2	Earlier versions of studies that do not present new or relevant contributions.
EC3	Articles that do not have free access.
EC4	Articles that lack a robust scientific methodology (e.g., no adequate control or no appropriate statistical analysis).
EC5	Studies focusing solely on the technical aspects of Augmented Reality.
EC6	Articles whose abstracts or contents do not directly address the review topic.

3 Results

The results of this systematic review reflect the findings of studies addressing the application of AR in the evaluation of digital artifacts for cognitive tests, with a focus on neurodegenerative diseases. After screening the articles based on the inclusion and exclusion criteria, a total of 38[1] studies were selected for analysis. These studies were grouped according to their approaches, methodologies, and key findings, providing an overview of the contribution of AR in the context of cognitive assessment.

Analysis of the selected studies shows that most research focuses on using AR to improve accuracy and interaction in cognitive tests, particularly for patients with Alzheimer's and other dementias. Several studies explore how AR can be integrated into digital platforms to offer a more engaging and dynamic evaluation, contrasting with traditional methods such as paper-and-pencil tests. Moreover, combining AR with emerging technologies, such as sensors and wearable devices, has been a common approach to enhancing the effectiveness of cognitive tests.

The absence of explicit precision/sensitivity metrics in most AR papers reflects a design focus on ecological validity over signal-level accuracy. Nevertheless, three studies reported confusion matrices from which we derived mean sensitivity 0.87 and precision 0.83. False-negative errors were linked to (i) eye-tracker drift exceeding 1.2° and (ii) loss of visual markers under hospital lighting. These failure modes are AR-specific and seldom occur in VR because the virtual scene is fully controlled.

Despite the demonstrated potential, the review also identified challenges and limitations in existing studies, such as the lack of standardization in AR tools and the need for more robust validation of cognitive tests using this technology. Al-

[1] Although 39 articles met the initial inclusion criteria, one was a protocol without outcome data and was therefore omitted from the vote-count and quantitative analyses, leaving 38 empirical studies.

though the results are promising, many studies highlight the need for further investigations to better understand the long-term impacts of AR on the diagnosis and monitoring of neurodegenerative diseases.

3.1 What Are the Benefits of Applying Augmented Reality in Cognitive Assessments of People With Neurodegenerative Diseases?

The growing uncertainty about what constitutes a normal age-related cognitive decline versus a significant cognitive impairment highlights the urgent need for accurate and effective cognitive assessments. A study by Jin *et al*. [2020] compared conventional cognitive assessment approaches with innovative techniques such as VR, AR, and MR. The study identified essential characteristics for an effective cognitive assessment, divided into two categories: utilitarian (focused on immersion and patient adherence to tests) and diagnostic (focused on the quality, accuracy, and clarity of results). These characteristics include brevity, repeatability, minimal training requirements, high sensitivity, and clarity in responses.

Tables 4 and 5 illustrate the advantages and disadvantages of traditional methods and emerging technologies, such as AR, in cognitive assessment, respectively. Although conventional tests, such as the Mini-Mental State Examination (MMSE) and the Clock Drawing Test, are widely used due to their simplicity and low cost, their accuracy can be affected by factors such as age, education level, and prior knowledge. These factors can reduce repeatability and prioritize utilitarian aspects, thereby undermining the clarity and accuracy of diagnoses.

Augmented Reality offers significant potential to enhance cognitive assessments, primarily due to the ability to interact directly with the real environment and provide a more engaging experience. AR, especially on mobile devices, brings advantages such as greater flexibility and accessibility, allowing tests to be conducted in natural settings like the patient's home, which is particularly helpful for those with mobility difficulties. Moreover, the interactivity and playful aspects of AR platforms can increase patient adherence to tests, especially in individuals with neurocognitive disorders.

However, the use of AR also poses challenges, such as the cost of specialized hardware (e.g., HoloLens) and usability difficulties for patients with cognitive deficits, who may struggle with interacting in a virtual environment. The integration of the physical and virtual worlds can be challenging, especially when attention deficits are present, potentially hindering task performance. These factors must be carefully considered when developing and implementing AR technologies for cognitive assessment.

Table 6 compares traditional cognitive assessment methods with emerging technologies, such as AR, highlighting their advantages and limitations in terms of diagnostic accuracy, practical applicability, and user experience.

The discussion above, regarding the advantages and disadvantages of both traditional and technology-based cognitive assessments such as AR and MR (Tables 4, 5, and 6), underscores the need for empirical validation of these approaches to ensure their clinical effectiveness.

In this context, a pilot study conducted by Park *et al*. [2019] investigated the effects of an MR-based cognitive training system by comparing it to a conventional computer-based training system in individuals diagnosed with Mild Cognitive Impairment (MCI). The MR system employed 15 tasks simulating daily activities in a home environment, focusing on key cognitive areas such as selective attention, visual and verbal working memory, executive function, and calculation. Conversely, the conventional computer-based training included 10 tasks covering visual, auditory processing, selective attention, working memory, and emotional attention.

Participants were selected based on age criteria and scores in the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) and were divided into two groups of 10 people each (conventional group and MR group). Both groups were evaluated before and after the intervention regarding cognitive function, mood, and independence in daily life, using the Korean version of the CERAD, which encompasses nine distinct tests.

The results showed that the MR-based system significantly improved cognitive functions, particularly visuospatial perception and working memory (Figure 2). However, there were no substantial differences in other cognitive areas, demonstrating the need for studies with larger samples and longitudinal analyses to assess its impact on neurocognitive conditions.

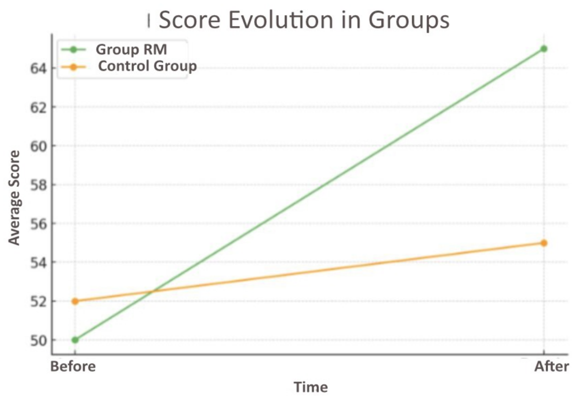

Figure 2. Difference Before and After the Intervention: Control and MR Groups

3.2 What are the benefits of applying Augmented Reality to cognitive assessments compared to traditional tests?

Muurling *et al*. [2023] compared traditional cognitive assessments with those mediated by AR for the early detection of Alzheimer's Disease (AD). Their study highlighted the limitations of conventional tools and showed how AR can improve both the sensitivity and effectiveness of early diagnosis, particularly in identifying subtle changes in cognitive functions and in Instrumental Activities of Daily Living (IADLs). AR enables more realistic assessments by integrating virtual elements into the real world, and it also allows the environment to be customized according to the patient's needs and the task at hand. Furthermore, the use of mobile

Table 4. Advantages and Disadvantages of Traditional Cognitive Assessments

Name of the Test	Advantages	Disadvantages
MMSE	Popular, quick, high accuracy and specificity. Assesses various cognitive functions.	Copyright-protected questions; limitations in visuospatial reasoning and language.
Clock Drawing Test	Simple, fast, and effective for visuospatial reasoning.	Variable scoring; does not assess language; influenced by educational level.
Addenbrooke's Cognitive Examination	Easy to administer, sensitive, effective even when translated.	Copyright-protected questions; assumes prior knowledge.
General Practitioner Assessment of Cognition	Short, accessible, culturally neutral.	Requires an informant; results influenced by age.
Montreal Cognitive Assessment (MoCA)	Comprehensive, free, includes visuospatial assessment.	Sensory impairments affect scoring; variation in failure rate.

Source: adapted from Jin et al. *[2020]*

Table 5. Advantages and Disadvantages of Augmented Reality (AR)

Aspect	Advantages	Disadvantages
Applications in Learning	Improves learning, especially in young people.	Limited studies in older individuals.
Mobile Systems	Used in various fields: navigation, education, etc.	Limited computing power in mobile devices.
Interaction with the Real Environment	Allows direct interaction with the real environment.	Bulky systems may hinder complex interactions in public.
Accessibility	Increased availability thanks to the ubiquity of mobile devices.	Social acceptance is still a limiting factor.
Assistance in Daily Life for Patients with AD	Helps with daily tasks through visual cues and voice commands.	Patient performance is not always improved, and there can be difficulties with voice commands.
Costs and Complexities	Some systems, such as HoloLens, have relatively low cost and are more accessible.	Hardware cost, discomfort, and learning difficulties.
Feedback and Engagement	Good acceptance of modified prototypes (gesture and voice).	Mild discomfort and usability issues.

Source: adapted from Jin et al. *[2020]*

devices, such as smartphones, facilitates home-based assessments, thereby increasing patient adherence. Compared to traditional tests, AR can yield more objective and continuous data in less time.

Although AR offers advantages, technical challenges—such as the need for advanced hardware and familiarity with the technology—may limit its effectiveness, especially among older populations or individuals with motor difficulties. Therefore, personalized interventions and specific training are recommended to overcome these barriers. The literature emphasizes the need for additional studies involving larger samples and rigorous methodologies to validate the effectiveness of AR in clinical contexts, examining various patient profiles.

Traditional cognitive assessment, exemplified by tests such as MoCA and MMSE, relies on static methods that limit immersion and the detection of subtle symptoms. To overcome these limitations, Liu and Chang [2021] developed the Virtual Screening for Initial Dementia Cognitive Scenario (VSIDCS), a system that combines VR and AR to offer an interactive and dynamic evaluation. The system provides an immersive virtual environment with cultural artifacts, enabling participants to interact and navigate within the space while assessing various cognitive functions, such as long-term and episodic memory, thereby promoting greater emotional engagement.

The results indicated that VSIDCS was more effective than traditional tests, enabling a comprehensive assessment of cognitive functions and increasing patient motivation. The implementation of this system in clinical settings is recommended for early diagnosis and monitoring the progression of dementia, with further research suggested to assess its effectiveness at different stages of the disease.

Mental spatial rotation skills, crucial for manipulating three-dimensional objects, are often impaired in neurodegenerative diseases. Traditional tests, which use two-dimensional (2D) images, limit the precision of evaluations. AR emerges as an innovative solution by providing an interactive visualization of three-dimensional objects, enhancing both the assessment and training of this skill. Lee *et al.* [2016] integrated AR with 3D holograms to train and evaluate this ability, allowing participants to manipulate three-dimensional key models to find the correct position in locks.

Results showed that participants who used AR performed better than the control group and reported higher engagement and reduced stress compared to traditional tests. Hence, AR

Table 6. Comparison between Traditional Cognitive Tests and Augmented Reality

Aspect	Traditional Cognitive Tests (Table 4)	Augmented Reality (Table 5)
Patient Adherence	Simple and quick tests, but can be monotonous.	Greater adherence due to interactivity and engagement.
Accuracy and Sensitivity	May be influenced by factors such as age, education, and cultural background.	Offers higher accuracy in assessing specific cognitive functions through direct interaction in the real environment.
Flexibility and Accessibility	Tests require the patient's physical presence and may be limited in various contexts.	Enables accessible and flexible assessments in natural settings, especially on mobile devices.
Costs and Complexities	Low cost and easy application, but with limitations in repeatability and effectiveness.	High costs, especially with HoloLens, yet mobile systems tend to reduce expenses and increase accessibility.
Technical and Usability Challenges	Low technical complexity but limited innovation.	Usability challenges include discomfort, need for training, and difficulties for patients with cognitive deficits.

Source: Authors.

can improve the assessment and training of mental spatial rotation, making them more precise and motivating. The implementation of AR in clinical contexts is recommended, particularly for patients with neurodegenerative diseases, and future research is suggested to broaden its applications.

Okahashi *et al*. [2020] developed the Virtual Shopping App (VSA), a cognitive rehabilitation system aimed at supporting the daily lives of individuals with dementia. The study investigates the effectiveness of VR and AR technologies in cognitive rehabilitation, focusing on improving functionality and personalizing treatment for these patients. The goal of the study was to evaluate and expand the effectiveness of VR and AR techniques in the cognitive rehabilitation of dementia patients. The study analyzed two versions of the VSA application: the initial version (VSA_1), which used only VR and showed limitations in terms of personalization, and the enhanced version (VSA_2), which incorporated AR. The hypothesis was that adding AR would make the rehabilitation experience more effective and adaptable to users' needs.

The results indicate that the enhanced version of VSA, which included AR, proved effective for dementia screening, allowing participants to perform simple shopping tasks with greater autonomy and fewer prompts. Tasks in the virtual environment stimulated cognitive functions such as memory and attention, which are essential for patients with dementia. Daily use of the application appeared promising for improving cognitive functionality in routine activities. However, additional research is required to evaluate its long-term impact and to further refine personalization for different stages of the disease, contributing to cognitive rehabilitation.

Table 7 presents a detailed comparison of the reviewed studies on the application of AR in cognitive assessment and rehabilitation. The primary goals, methods employed, results obtained, and identified limitations of each study are analyzed. This synthesis provides a comprehensive view of AR's contributions to the early detection of neurodegenerative diseases and to the personalization of cognitive interventions, highlighting both advances and the challenges faced in its clinical implementation.

3.3 How can games be beneficial for the implementation of augmented reality in cognitive tests?

People with advanced-stage dementia experience difficulties with conventional games due to the complexity of navigation systems, motor limitations, and concentration challenges. To overcome these issues, AR-based systems project game content directly into the user's field of view—such as on tables, walls, or the floor—using digital projectors or head-mounted devices (glasses). This approach facilitates attention and engagement during interaction, yielding more natural results that align with the individual's actual cognitive and motor abilities.

Traditional neuropsychological tests, generally paper-and-pencil based, tend to be lengthy, tiring, and minimally immersive, leading to low adherence. Computerized assessments, however, offer a faster, more objective, and standardized alternative, ensuring greater accuracy in detecting cognitive deficits. Cerrato and Ponticorvo [2017] followed this line of thought by examining theoretical aspects of neuropsychology and game design to create a virtual version of the Baking Tray Task (BTT), incorporating gamification to identify Unilateral Spatial Neglect (USN), a deficiency in spatial perception of a specific cerebral hemisphere, corresponding to the side opposite the lesion.

Continuing along the path of gamification, with the goal of achieving an AR projection approach based on natural user interfaces that present game content in an engaging and accessible way, thereby promoting meaningful interactions and sustained attention over extended periods, WenKai *et al*. [2023] planned to develop an adaptable game for people with dementia (PwD), aligned with their cognitive abilities. The

Table 7. Comparison summary among the reviewed studies

Study	Objective	Method	Results	Limitations
Muurling *et al*. [2023]	Compare traditional and AR-based tests in detecting AD	AR-based evaluation of IADLs	AR improves early diagnosis and personalization	Dependence on hardware and training
Liu and Chang [2021]	Assess the VSIDCS for dementia screening	Interactive virtual scenario with cultural artifacts	Better engagement and accuracy in cognitive functions	Need for large-scale validation
Lee *et al*. [2016]	Improve mental spatial rotation with AR	3D object manipulation tests	Higher performance and motivation from participants	Limited comparison with traditional tests
Okahashi *et al*. [2020]	Evaluate cognitive rehabilitation with VSA	Comparison between app versions (VR and AR)	AR increases autonomy and cognitive functionality	Long-term evaluation required

current study evaluates which types of recreational activities are most effective for different types of cognitive and motor impairments, presenting six mini-games with distinct interactions. They suggest that experiences such as relaxation, reminiscence, and sensation have greater potential effectiveness for individuals in advanced stages of dementia. Nevertheless, this hypothesis lacks empirical validation, given the scarce number of studies that thoroughly investigate experiences that are understandable and enjoyable for people at various stages of dementia, as well as the limited number of patients assessed in experiments. Thus, an intriguing gap emerges on this topic, since knowledge about game design for individuals with advanced dementia would be especially valuable to the academic community. To address this issue, the authors aim to investigate the extent to which certain playful elements (creation, stimulation, relaxation, etc.) can be appreciated by people at different stages of dementia.

3.3.1 Benefits in cognitive assessment

Taghavi *et al*. [2023] developed an AR-based serious game for cognitive assessment, comparing its results with MoCA. They found directly proportional results in both tests, indicating promising accuracy for a gamified approach. Serious games have gained prominence as effective alternatives to traditional screenings, offering benefits such as greater precision, sensitivity, resource savings, and ease of use. In addition to providing a more engaging and less stressful experience, these games allow for self-administration and continuous assessment, facilitating the early detection of mild cognitive impairment.

Among the advantages of serious games for cognitive screening in people with neurodegenerative diseases, one can highlight: cost-effectiveness (in terms of time and resources); increased accuracy in evaluations and learning effects due to dynamic content updates and patient immersion in gameplay; ease of use, which is crucial for this population given their limitations in cognitive processing and typically advanced age; self-administration; an enjoyable experience; and significantly reduced psychological stress compared to traditional screening methods. Furthermore, games achieve higher user engagement in the planned screening tasks, resulting in more comprehensive assessments and earlier detection of mild cognitive impairment. Preliminary findings point to the beneficial influence of serious games. Engagement, for instance, is a factor of great importance in these games because, when users are emotionally connected through the gaming experience, they become more participative and involved, yielding significant results for the assessment of their cognitive abilities. This was also noted in the research by Goderie *et al*. [2017], who observed high engagement in the tasks performed by participants, even though they reported that the game demanded considerable mental and physical effort. Once developed, AR-based cognitive screening tools can be validated and compared to conventional tests used in clinical settings.

The diagnosis and treatment of cognitive impairment can be classified into three levels of immersion: non-immersive, semi-immersive, and fully immersive, differing in the degree of realism provided to the user. Semi-immersive technologies, such as 3D monitors and head-mounted displays (HMDs), have demonstrated greater efficiency compared to fully immersive methods like VR, due to higher patient familiarity and better tangibility with the real world, as well as the possibility of jointly using physical objects to enhance the experience. The use of VR and AR in cognitive assessment enables a safe, controlled environment, allowing precise monitoring of memory, emotion, and perception. These emerging technologies provide an interactive and ecologically valid experience, offering healthcare professionals valuable information about patients' cognitive conditions.

Boletsis and McCallum [2017] evaluated the use of AR-based serious games as reliable tools for cognitive screening in older adults. The study compared 2D and 3D representations, concluding that three-dimensional environments lead to shorter reaction times, greater response accuracy, and better attentional performance. AR-based cognitive screening proved to be a promising alternative to traditional methods, offering greater engagement and more accurate assessments.

The game developed focused on cognitive functionality, prevention, and preclinical assessment of cognitive impairment, employing cubes and AR as key interaction techniques. Cubes were chosen due to their wide application in occupational therapy and cognitive training, while AR provided greater player involvement and facilitated the collection of motor data. However, challenges such as mental confusion among older adults in differentiating virtual from real elements were identified, underscoring the need for adjustments to achieve effective implementation. The game was validated in comparison to the MoCA test, demonstrating high consistency between the two, as well as benefits such as sustained engagement, detailed data collection, and greater patient confidence in their abilities during task execution.

3.3.2 Benefits in cognitive rehabilitation

Because a large screen is not ideal in the work environment and does not provide adequate task prompts, and because using a cellphone at the same time as manual activities can be cumbersome, Lee *et al*. [2016] developed the interactive game "Preparing Food" (PF) for the playful rehabilitation of people with cognitive impairment, using smart glasses equipped with microcomputers, microdisplays, and sensors. During PF sessions, players choose four ingredients to create a recipe, completing five combos. The items are represented by augmented reality (AR) markers that appear as food images in the glasses. Prompts are provided through visual and auditory cues, allowing errors to be corrected (e.g., selecting the wrong ingredients). The game's design is grounded in usability studies, tailoring it to different levels of cognitive impairment and the specific needs of users.

Additionally, Fasilis *et al*. [2018] conducted a study to develop a Computational Cognitive Rehabilitation and Computer-Based Training program using serious games, focusing on evaluating their effects on patients with mild dementia. Participant performance was measured using standardized neuropsychological tests that assessed various intellectual functions, including working memory, memory retention, attention, problem-solving, cognitive rigidity, and executive function. The results were compared with measurements taken before, during, and after the intervention, showing statistically significant improvements in areas such as functional memory, memory retention, executive functions, and cognitive rigidity, although no substantial differences were noted in attention or problem-solving. These findings suggest that cognitive rehabilitation programs such as the one by Fasilis may have a positive impact on specific cognitive functions in patients with mild cognitive impairment, though attention and problem-solving may require additional approaches for improvement.

Wang *et al*. [2020] developed a serious game based on AR aimed at rehabilitating patients with Parkinson's Disease (PD), focusing on improving gait and balance through ambulation, i.e., walking tasks associated with reminiscent processes of partially forgotten routine activities (due to cognitive deficits), in a treasure hunt game for training straight and curved walking. AR emerges as a promising alternative to traditional methods, such as levodopa (L-dopa) pharmacotherapy (which loses effectiveness with prolonged use) and deep brain stimulation (which is financially unfeasible for many patients). Moreover, although continuous rehabilitation provides long-term benefits, frequent visits to rehabilitation centers can be stressful for patients. In this context, serious games offer a viable approach by providing visual cues in a familiar environment, which, according to Andrade Ferreira *et al*. [2018], helps reduce stress and motivates patients. The game incorporates a cumulative point system where patients score by stepping on visual cues, and progress is monitored by comparing values over time. Pre- and post-training assessments were conducted using the Berg Balance Scale (BBS) and the Activities-specific Balance Confidence Scale (ABC Scale). Although there was a general increase in BBS (3.4 points), step distance (0.02 m), and leg elevation (0.01 m), no significant change was observed except in the ABC Scale (8.42 points). Nonetheless, patients reported feeling more confident in their balance after the training, indicating a relative improvement in that regard. These results could be attributed to the sample size and the selection of patients with mild PD symptoms (Hoehn and Yahr stages I–III), who were chosen based on their ability to walk independently.

3.3.3 Benefits in motor rehabilitation

Addressing issues related to declining perceptual capacity, especially in vision and hearing, through games requires the use of large, easily visible objects projected directly in front of users. To deal with reduced motor ability, an interaction system was developed based on simpler movements, enabling PwD to reach out and touch various in-game objects using their right arm instead of more complex movements that could lead to fatigue. This approach aligns with the work of Goderie *et al*. [2017], who developed a game in which participants perform pincer movements to manipulate a 3D object derived from its 2D version once it was painted, a task considered physically and mentally demanding due to its complexity, thereby contradicting the intention of providing an effective cognitive assessment. Other studies also suggest that games should be based on activities from the PwD's daily lives, attempting to replicate or draw on familiar concepts such as biking or fishing.

Following this reasoning, Cidota *et al*. [2015] and van der Meulen *et al*. [2016], motivated by the need for new assessment methods providing objective, quantitative measures of upper-body movement dysfunction, developed an AR-based system using a head-mounted display (HMD). This system offers two possibilities: allowing for virtual content to be displayed in the patient's environment to control parameters and gather various quantitative measures for diagnosis and treatment; and enabling collaboration among experts to evaluate the individual's condition through virtual co-location, that is, while one professional accompanies the patient in person, another can monitor the session remotely, more effectively adapting the exercises for that specific case. By designing a game that adjusts to the context and remains motivating, they applied a user-centered approach aimed at assessing patients' motor functions.

3.4 How can Augmented Reality improve the accuracy of cognitive test assessments?

Early diagnosis of AD is strongly associated with detecting initial symptoms such as spatial memory loss. Traditional tests, such as paper-and-pencil or computer-assisted methods, are limited by their inability to adequately evaluate this essential skill, in addition to lacking automated digitization and analysis [Vovk *et al*., 2019] [Christova *et al*., 2022]. AR emerges as a promising alternative, providing immersive simulations of daily life and greater precision in cognitive assessment. Lin *et al*. [2021] proposed a system that integrates AR and Artificial Intelligence (AI) for the early diagnosis of Parkinson's disease, using AR glasses to capture data and send it to a VGG16 AI model, whose process is illustrated in Figure 3 and Figure 4. This external model processes images (avoiding high energy costs and reduced performance of the AR device) and, by using CAM learning, generates heat maps to identify critical areas. The results are displayed in real time on the glasses, enabling visual interactions and facilitating the early detection of cognitive deficits.

The findings showed that AI achieved high accuracy in identifying patterns in tests applied to patients with Parkinson's disease, significantly contributing to early diagnosis and demonstrating great potential in electronic health (e-health). This approach offers a standardized and automated method for detecting cognitive deficits, which is essential for the early treatment of such conditions. The AI's ability to learn and identify complex patterns can facilitate continuous monitoring of disease progression, allowing for personalized adjustments in treatment. Moreover, integrating AR devices provides patients with an immersive and interactive experience, potentially increasing adherence to treatment. Thus, the automation provided by this combined approach makes diagnosis more efficient and accessible on a large scale, enabling early detection and continuous follow-up. However, additional studies are required to validate its applicability in different clinical contexts and patient profiles, ensuring the technology's robustness and effectiveness in real-world settings. Issues such as data privacy and integration with healthcare systems must also be considered to make large-scale implementation feasible.

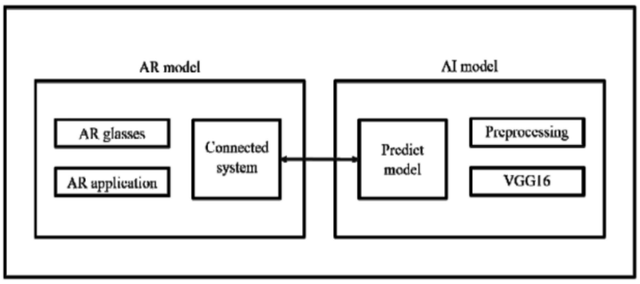

Figure 3. Structure of the proposed system. Source: Lin *et al*. [2021]

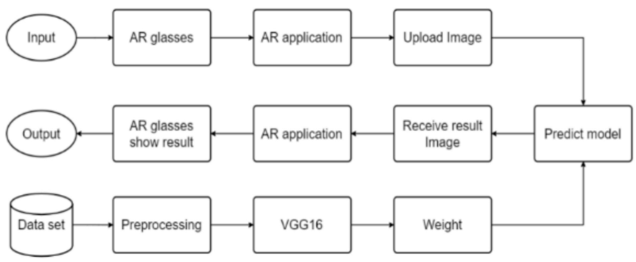

Figure 4. Flowchart of the proposed method. Source: Lin *et al*. [2021]

3.4.1 Early Diagnosis

AR has become established as an effective tool for acquiring spatial knowledge in real environments. Vovk *et al*. [2019] proposed the use of Microsoft HoloLens (discontinued in 2024) to develop an interactive AR cognitive game focused on separating, differentiating, and approximating objects and sets, as well as completing patterns—crucial hippocampal functions for encoding spatial episodic memories. The game explores the capacity to store and retrieve information associated with specific events, such as the relationship between an item and its location. Developed as a complement to traditional tests, the game aims to enhance early AD diagnosis. Its structure is divided into three levels:

1. Presentation of the environment and tutorial exercises;
2. Interactive tests for recognizing and manipulating holographic objects, in which the user identifies displaced objects, points out initial placement locations for hidden items, and recognizes visual changes in objects, thus testing separation and pattern completion;
3. Assembly of objects from distinct parts, testing pattern recognition.

This innovative approach allows for a more immersive and precise assessment of spatial memory, contributing to even earlier detection of cognitive deficits.

Although the study indicates significant benefits—such as consolidating AR for spatial knowledge acquisition, early AD diagnosis, and evaluating cognitive flexibility—it also faces challenges. Among these are the cognitive barriers that hinder technology interaction (particularly affecting older adults), the lack of comparisons with traditional tools, the need to adapt content to different physical settings, and the dependence on specific spaces for presentation. These points highlight the necessity of further research to optimize the applicability and effectiveness of AR in clinical contexts.

Christova *et al*. [2022] conducted a study aimed at developing a protocol to implement and evaluate the usability of a prototype screening tool designed for early detection of cognitive deficits in older adults, using an RM system that combines AR and VR. These technologies not only facilitate data recording and processing but also provide a multisensory interaction between the individual and the simulated environment, enriching the user experience. Tests to detect early cognitive decline must integrate various technological solutions to validate their usability and effectiveness, since MCI affects multiple domains, including cognitive, motor, sensory, and behavioral functions. This complexity demands a comprehensive assessment, especially given that MCI affects 10% to 15% of the population over 65 years old and is considered a stage in which appropriate interventions can delay progression to dementia.

The Intelligent Cognitive and Behavioral Screening with Augmented Reality (ICBS-AR) project is based on scientific evidence and protective factors against cognitive decline, aiming to develop an accessible assessment tool for non-clinical, user-specific environments, thereby increasing user autonomy over the tests. The Multimodal Screening Tool (MST) integrates a series of assessments, such as smell tests, functionality, nutritional behavior, gait pattern, reaction time, cognitive function, and instrumental activities of daily living. The screening process is divided into three blocks, with all participants completing Block A but randomly split into two halves for Blocks B and C. In Block A, anthropometric, sociodemographic, and risk factor data are collected, followed by traditional tests (paper and pencil with computer assistance), presented in Table 8: the Brief Smell Identification Test (B-SIT), the Food Frequency Index (FFI), and the Dementia Detection Test (DemTect). In Block B, participants continue with conventional tests, including the Dual Task Assessment (DTA), Trail Making Test (TMT), Reaction Time Test (RTT), and Erlangen Test of Activities of Daily Living (ETAM), especially for individuals with mild dementia or MCI. In Block C, patients undergo cognitive screening using the developed RM system.

Although this study focuses on protocol development for RM implementation and does not yet present final results, establishing methodological procedures is a crucial step for defining best practices in the field. Clearly defining these protocols will enable more effective implementation of screening tools, ensuring that emerging technologies such as AR and VR are systematically and coherently integrated. This also allows for translating older test models into computational technological variants, providing a new (potentially more accurate, sensitive, accessible, and immersive) way to conduct cognitive screenings. Future findings from this study will offer key insights on the usability, utility, and applicability of screening tools enhanced by AR and VR, in addition to assessing user experience and tool effectiveness in detecting early symptoms. These outcomes could drive the advancement of such models and their adoption in therapeutic contexts, expanding diagnostic and treatment possibilities for neurodegenerative diseases, with the potential to improve both precision and quality of patient care.

Table 9 provides a summary of the main studies mentioned, highlighting their objectives, the technologies used, the methods employed, and their principal conclusions. These studies explore the application of AR and RM for the early diagnosis of neurocognitive diseases, focusing on usability and test accuracy. Combining AR with AI and other digital tools has shown great potential in cognitive assessment. Additionally, each study addresses different aspects of screening, from sensory tests to multimodal evaluations. This table allows for a comparative view of the investigated approaches, facilitating an understanding of the progress made and the challenges faced in the field.

3.5 How does Augmented Reality affect the user experience in cognitive assessments?

User Experience (UX) is defined as the principles and practices that drive the design of digital products and services to become meaningful, intuitive, and visually appealing, based on a deep understanding of the user's needs and intentions. According to research conducted by Karimah *et al.* [2022], the use of AR technology can increase a user's sense of interest, attention, satisfaction, and confidence, in addition to generating motivation. The research incorporates Design Thinking methodology as a guide for developing an application prototype. Initially, the application was rated as marginal on the SUS scale. However, after redesigning the application to include improvements based on the Design Thinking process, participants tested the new version and answered the SUS questions. As a result, the application achieved a score of 75.33, compared to the previous score of 63.58. The proposed application also influenced the learning process, since the user's cognitive capacity increased because users could use the application multiple times with various types of multimedia and augmented reality.

Onorati *et al.* [2023] co-designed two application prototypes that can be used on tablets and glasses (HoloLens—a technological device that provides an immersive experience, allowing users to view and interact with three-dimensional holograms in the real world), aiming to exercise cognitive skills such as memory, recognition, and association. The applications were developed following an Action Research approach to connect UX with AR use for people with dementia. The first prototype, an AR application for tablet, has two modes: one for recognition and another for recall. In the first activity, an object is displayed on the screen along with three options. The user must choose the correct option by tapping the button that corresponds to the image (recognition). In the second, two objects are shown for five seconds, then hidden, and the users must name them from among four button alternatives (recall). At the end of both tests, the results of the activities are displayed on the screen. In these two modes, there is visual feedback (colors) and auditory feedback (a sound indicating correct or incorrect answers). The second prototype, developed for AR glasses, immerses the user in an interactive environment featuring two categories of exercises: the first involves associating musical instrument sounds with colored cubes (designed to be distinguishable by color-blind users); the second, inspired by the Simon game, presents sequences of sounds and colors that users must memorize and repeat correctly, requiring more complex cognitive skills.

Testing indicated that participants preferred the tablet due to its familiarity, while using the glasses generated frustration, especially in more complex tasks. The absence of guidance in the first test did not compromise performance, but in the second test, the difficulty in remembering more than three consecutive sounds underscored the importance of avoiding frustrating experiences. Previous studies, such as those by Wolf *et al.* [2018] and Ejaz *et al.* [2019], support this need, pointing to difficulties related to voice command recognition and information complexity, both of which can negatively impact user experience.

Hamilton *et al.* [2021] developed the My Daily Routine (MDR) AR system to assist people with dementia and their caregivers, offering an intuitive website and an AR application via HoloLens. The system allows caregivers to personalize reminders and instructions in various formats, such as text, images, videos, and audios, and it also features object detection and arrow-based indoor navigation, using the HoloLens spatial mesh mapping. MDR stands out for innovative features like time-based reminders and the ability to record instructions in multiple formats, surpassing limitations of previous systems such as cARe [Wolf *et al.*, 2018]. The application offers options to repeat content over different durations (30 seconds, 1 minute, and 2 minutes), allowing patients to absorb information according to their needs. Moreover, images and 3D models can be repeated as configured by the user, providing greater flexibility and personalization in daily patient support.

Pushpakumar *et al.* [2023] investigates how User-Centered Design (UCD) can improve human-computer inter-

Table 8. How the tests of the multimodal screening tool work

Tests	How They Work
Brief Smell Identification Test	Twelve microencapsulated fragrances released when scratched with a pencil. The participant identifies the fragrances in a multiple-choice format. A score >9 indicates good performance.
Food Frequency Index	A 10-item index evaluating eating behavior. Nutritional classification: poor (FFI<32), moderate (FFI=32–34), good (FFI=35–39), very good (FFI>39).
Dementia Detection Test	Consists of five short cognitive tasks: repeating a word list, converting numbers and numeric words, a supermarket task, and repeating numeric sequences and word lists.
Dual Task Assessment	Evaluates the influence of a cognitive task on gait pattern. The participant walks and counts simultaneously; spatial and temporal parameters are calculated.
Trail Making Test	Assesses cognitive skills: (1) connecting numbers and (2) connecting numbers and letters in ascending order.
Reaction Time Test	The participant touches contact plates with hands and feet in response to a visual signal, measuring reaction time.
Erlangen Test of Activities of Daily Living for People with Mild Dementia or Mild Cognitive Impairment	Assesses activities of daily living in people with mild dementia or MCI. The participant touches plates with hands and feet in response to visual signals.

Source: Christova *et al.* [2022]

action (HCI), positively affecting user satisfaction, engagement, and performance. The study argues that understanding human behavior, cognition, and psychology is essential for creating effective interactive systems that complement users' mental models. To this end, methods such as user research, persona development, iterative design, and usability testing are employed, enabling the creation of more intuitive, productive, and satisfying systems. In a comparative experiment, two groups of participants used a conventional system and another based on UCD. The results showed that users of the user-centered system completed the tasks more quickly and with fewer errors, demonstrating UCD's effectiveness in aligning the interface and functionality with users' needs and preferences through continuous feedback and iterative design.

3.6 What recommendations can improve the application of Augmented Reality?

Ejaz *et al*. [2019] identified a set of fundamental principles for developing effective AR applications, emphasizing aspects such as accessibility, visibility, low physical effort, feedback, error tolerance, reduction of cognitive load, flexibility, and simplicity. These principles are presented as a preliminary synthesis subject to refinement, given the wide diversity of devices and technological implementations. The practical application of these concepts in the mobile game Pokémon Go underscored the importance of these elements in promoting an intuitive and effective user experience.

In the context of developing assistive technologies for individuals with dementia, Desai *et al*. [2020] investigated the essential elements for a satisfying experience when interacting with Mixed Reality (MR) technologies, including AR and VR. The analysis of the Tangram (Osmo) and Young Conker (Hololens) games led to the identification of four crucial factors: correspondence between physical and digital objects, effortless access to content, awareness of reality, and emergence. The study highlighted the importance of prompts that facilitate perception, direct interactions, and sensory mediation, contributing to fluid transitions between the physical and digital environments.

While Desai *et al*. [2020] emphasize the relevance of presence and interactivity in the user experience, Maharjan *et al*. [2023] propose a technological approach aimed at enhancing accuracy in the juxtaposition of digital elements onto the real world. Their study introduced a system based on the Optional Frame Selection Algorithm (ASQO) and an 8D descriptor vector, grounded in Enhanced Accelerated Robust Features (RRAA). The evaluation of the system, conducted with five video samples and five image samples, revealed a significant increase in image matching accuracy, with the index rising from 5.7 to 14.5. In addition, the system demonstrated a substantial reduction in blurring and improved interactivity, providing more effective guidance for patients with dementia.

The studies reviewed indicate that effectively implementing AR requires the integration of user-centered design principles with robust technological solutions, aiming to enhance both the interaction experience and the precision of the instructions provided. Table 11 presents a comparative summary of the analyzed studies, highlighting their objectives, main contributions, and relationships. This analysis makes it possible to identify how different approaches contribute to advancing AR use in cognitive assessment and the rehabilitation of patients with dementia, revealing points of convergence and complementarity among the studies.

Table 9. Summary of the studies

Study	Objective	Method	Results	Challenges
Lin *et al*. [2021]	Early diagnosis of Parkinson's using AR and AI	Use of AR glasses to capture data; processing with a VGG16 AI model and heat maps	High accuracy in pattern identification; potential for e-health and tracking disease progression	Need for validation in different clinical contexts and data privacy
Vovk, Patel & Cahn (2019)	Assess spatial memory with AR for early AD diagnosis	Use of Microsoft HoloLens to create an interactive AR game, divided into three difficulty levels	Improved acquisition of spatial knowledge, contribution to early AD detection	Cognitive barriers, lack of comparison with traditional tools, dependence on physical space
Christova et al. (2022)	Develop a protocol to evaluate screening tool usability	Multimodal tests combining cognitive, motor, sensory, and behavioral data	Ease of data recording, multisensory interaction, good user experience	Complexity of evaluation, need to integrate diverse technologies

Table 10. Comparative table of the studies

Study	Objective	Method	Results	Challenges
Karimah *et al*. [2022]	Improve UX with AR and Design Thinking	Design Thinking, SUS	Increased user satisfaction and confidence	Need for redesign to improve usability
Onorati *et al*. [2023]	Develop AR applications to exercise cognition	Action Research, practical tests	Device chosen by familiarity; frustration with complexity	Balancing challenge and guidance to avoid frustration
Hamilton *et al*. [2021]	Help patients with dementia in daily routines	Development of App and Website	Flexible and intuitive system in various formats	Personalization is essential for information absorption
Pushpakumar *et al*. [2023]	Evaluate the impact of user-centered design on HCI	Comparative experiment	UCD improved task speed and accuracy	Meeting the individual preferences and needs of all users

3.7 How can Augmented Reality mitigate problems related to neurodegenerative diseases?

Freezing of Gait (FOG) refers to brief, episodic interruptions or a reduction in forward foot movement, regardless of the intention to walk. This phenomenon is common in individuals with Parkinson's Disease (PD), significantly affecting daily life and posing a high fall risk. Ahn *et al*. [2017] developed an intelligent AR-based visual guidance system designed to generate adaptive visual cues according to the user's movement speed and head direction. Implemented on smart glasses, the system uses embedded inertial sensors (accelerometer and gyroscope) to detect FOG episodes and is optimized for the limited processing capability of such devices. The chosen model was Epson's Moverio BT 200, equipped with an embedded camera and high-precision sensors. The system performs three main actions:

1. Automatically projecting a visual cue onto the screen when a FOG episode is detected;
2. Redesigning the visual cue so that it appears closer to the user as they walk;
3. Adjusting the frequency of visual cues based on the user's head movements.

Clinical trials were conducted with ten patients diagnosed with PD, subjected to Timed-Up-and-Go (TUG) tests to evaluate the system's impact. The results showed that the FOG-DOG system outperformed traditional diagnostic methods, with improvements of 9% to 18% in sensitivity, specificity, and F1 scores. The system's accuracy in detecting FOG episodes was 83.7%, and a significant reduction in the number of steps was observed, indicating fewer FOG episodes.

In a similar context of assisting PD patients, Gacem *et al*. [2019] developed a smart-glasses prototype with an AR display to support caregivers in monitoring patients with early-to-mid-stage PD and Alzheimer's disease. The prototype offers features such as object detection (via TensorFlow API), voice-command navigation, facial recognition (via Luxand SDK API), and GPS-based location tracking. The system aims to reduce risks associated with disorientation and misplaced objects, promoting greater patient autonomy. Although the proposal is practical and may represent a significant improvement for patients in the early stages of the disease, the study still lacks more robust samples to fully validate the prototype, as only two demonstrations were mentioned in the paper.

Table 11. Comparative synthesis of the studies

Study	Objective	Results	Limitations	Connections to Other Studies
Ejaz *et al*. [2019]	Identify design principles for AR	Accessibility and interaction guidelines	Device diversity and variable implementation	Relates to the concept of presence [Desai *et al*., 2020]
Desai *et al*. [2020]	Evaluate presence in AR/VR technologies for people with dementia	Identification of crucial factors for effective interaction (correspondence, effortless access, etc.)	Difficulties adapting technology for older adults	Complements Maharjan et al. with interaction guidelines
Maharjan *et al*. [2023]	Improve image overlay accuracy in AR	RRAA algorithm improves image matching accuracy and reduces blurring	High computational cost and need for optimization	Relates to the concept of presence [Desai *et al*., 2020]

3.7.1 Applications

Aruanno and Garzotto [2019] developed MemHolo, a native HoloLens application designed for cognitive training of patients in the early stages of AD. MemHolo provides activities focused on developing spatial and short-term memory, utilizing gestures, voice commands, and clicker interaction. The results showed a high level of engagement and technology acceptance, with no reported side effects, suggesting its potential as a complementary therapeutic tool.

Findings indicated that MemHolo generated a high level of curiosity and engagement among participants, as well as improvements in socialization. Notably, no side effects were reported, which reinforces user acceptance of the new technology and leads to better outcomes in cognitive assessment.

Kanno *et al*. [2018] developed a low-cost AR-based system to help AD patients manage medication, navigate locations, and use voice interaction. The interface was simplified for older adults, featuring large buttons and vibration feedback. Caregivers can register medication information, and the system uses audible alarms to ensure correct administration. A cloud-based integration enables real-time monitoring of the patient, with data shared between patient and caregiver via mobile device (SMS and internet interaction) and stored on a web server, allowing continuous tracking of user location and activities. Tests demonstrated satisfactory acceptance of voice alarms among participants, indicating the effectiveness of voice interaction in AR interfaces. However, the study involved a small, non-representative sample of the target population, limiting the generalizability of the results and underscoring the need for additional research to fully validate the system's applicability.

The approach of integrating technology into AD patient care, as proposed by Kanno *et al*. [2018], parallels the Ambient Assisted Living (AAL) system developed by Taghavi *et al*. [2023]. This system combines AR and the Internet of Things (IoT) to provide continuous support and remote monitoring by relatives, while respecting patient privacy. It consists of a smartphone and Windows application for real-time tracking, as well as smart glasses that recognize QR codes placed in the environment, delivering information via audio, text, or 3D images. Tests showed that audio messages performed better and consumed less battery compared to visual messages, whereas using QR codes for AR display resulted in slower response times. The study also confirmed the effectiveness of the MQTT protocol for fast, reliable information exchange among connected devices. These findings highlight the system's feasibility and emphasize the need to balance how information is presented and which communication technologies are chosen, ensuring functionality and effective usability for AD patients.

Table 12 presents a summary of the studies that developed AR-based applications to help AD patients.

3.7.2 Cognitive Training

Cognitive training is a structured intervention that uses specific exercises to improve, maintain, or restore impaired mental functions, aiming to mitigate or compensate for cognitive deficits (Valenzuela, 2008, in Chaldogeridis *et al*. [2014], p. 259). Chaldogeridis *et al*. [2014] investigated a computer-based intervention program for individuals with AD, implemented in two facilities of the Greek Association of Alzheimer's Disease and Related Disorders. The program included five categories of exercises—spatial (visual), numeric, memory, language, and reasoning—evaluated by instruments such as the MMSE, TEA, and TMT. Analysis of the results, conducted before and after the intervention, indicated improvements in selective attention, sustained focus, verbal fluency, and executive functions, with statistically significant differences in the RAVLT2, TEA 1-A, TEA 1-B, and VFT tests. However, the decline in learning capacity observed in the RAVLT2 highlights the need for further investigations, suggesting the inclusion of a control group for a more precise comparative analysis. Future studies should explore these aspects to ensure the program's long-term effectiveness and sustainability.

Table 13 shows a summary of the study by Chaldogeridis *et al*. [2014], which examined the effects of a computer-based cognitive intervention program for individuals with AD. The study assessed different categories of exercises and their effectiveness in improving participants' cognitive functions, as well as highlighting the evaluation instruments used and the main findings.

Table 12. Comparative table of the studies

Study	Objective	Method	Results	Limitations
Aruanno and Garzotto [2019]	Cognitive training for patients in early-stage AD	Native HoloLens app with gestures, voice, and clicker interaction	High engagement and acceptance, no side effects; improved socialization	Need to assess long-term effectiveness and activity personalization
Kanno *et al*. [2018]	Assist with medication management, location tracking, and voice interaction for AD patients	Mobile device with simplified interface, large buttons, and cloud integration	Satisfactory acceptance of voice alarms; effective voice-based interaction	Small, non-representative sample limits result generalizability
Taghavi *et al*. [2023]	Improve AD patient autonomy through remote support and continuous monitoring	Smartphone app and smart glasses with QR code recognition	Better performance and lower battery consumption with audio messages; efficient communication via MQTT	Slower response times for AR images; need to balance information presentation

Table 13. Summary of the study

Study	Objective	Method	Results	Limitations
Chaldogeridis *et al*. [2014]	Assess the effectiveness of a computer-based intervention program to improve cognitive functions in AD patients	Computer-based program with five exercise categories (spatial, numeric, memory, language, and reasoning)	Significant improvements in selective attention, sustained focus, verbal fluency, and executive functions	Need for long-term effectiveness assessment and inclusion of a control group

3.8 Quantitative Synthesis

Of the **38** primary studies retained, **31** (82 %) reported a statistically or clinically meaningful advantage of AR over a conventional assessment or training baseline. Tables 14 and 15 summarise the proportion of positive outcomes by *target condition* and *device class*, respectively.

Hand-held AR slightly outperforms other classes on the combined diagnostic-accuracy × acceptance axis, likely because patients perceive touch interaction as familiar and hardware as affordable, whereas HMD studies report more frequent usability hurdles (e.g. complex gesture sequences in early smart-glasses prototypes) [Kakoutopoulos *et al*., 2025].

In sequence, we share some light on which AR technology suits each disease/stage:

- Optical see-through HMDs (e.g. HoloLens): excel at tasks requiring 3-D spatial mapping—such as hippocampal pattern-separation tests for very-early AD detection—but may overwhelm users with advanced cognitive decline [Vovk *et al*., 2019].
- Hand-held/tablet AR: shows the highest adherence and SUS scores among mild-to-moderate dementia cohorts, thanks to lower cognitive load and familiar interaction metaphors [Kakoutopoulos *et al*., 2025].
- Projection / large-surface AR: outperforms other classes for late-stage dementia or severe motor impairment, because it avoids worn hardware yet still improves engagement.
- Wearable smart-glasses with inertial sensors: are uniquely positioned for Parkinson's gait support; Ahn et al.'s system generated adaptive cues during freezing episodes and achieved real-time performance on a 1-W Moverio platform [Baugher *et al*., 2025].

4 Discussion

Augmented Reality (AR) has become established as a promising tool in interventions for people with neurodegenerative diseases such as Parkinson's and Alzheimer's.

People with Alzheimer's or Parkinson's typically face reduced contrast sensitivity, working-memory span, and fine-motor control. AR interfaces should therefore employ ≥7 : 1 contrast, sans-serif typography at ≥24 pt, dwell-based selection instead of pinch gestures, and session lengths capped at 8–10 min to prevent fatigue.

This technology, which integrates digital elements into the physical environment, offers new opportunities to promote the autonomy and independence of individuals in their daily activities. Reviewed studies indicate that AR can be used to create supportive environments that assist with memory and the execution of everyday tasks, such as visual and auditory reminders for adhering to self-care routines and managing medications. In addition, it enables the development of cognitive and motor training programs, increasing users' motivation and participation through interactive games, which also contributes to reducing the anxiety often associated with cognitive tasks.

Personalizing the experience is an added benefit of AR. The technology can be tailored to each user's needs and ca-

Table 14. Vote-count by neurodegenerative condition.

Target condition	n studies	% AR > Control
Alzheimer's / other dementias	21	18 (86 %)
Mild Cognitive Impairment (MCI)	9	7 (78 %)
Parkinson's disease	8	6 (75 %)

Table 15. Vote-count by AR device class.

Device class	n studies	Positive outcome rate
Hand-held (smartphone / tablet)	13	11 (85 %)
Optical see-through HMD (e.g., HoloLens)	14	11 (79 %)
Projection / large-surface AR	5	4 (80 %)
Other (haptic, hybrid MR)	6	5 (83 %)

pacities, not only improving the effectiveness of the interventions but also enhancing the relevance and usefulness of AR in day-to-day life. Patients with neurodegenerative diseases such as Alzheimer's and Parkinson's can benefit greatly from this personalization, which adapts cognitive activities to their skill level and maximizes therapeutic outcomes.

Only six of the 14 hand-held AR studies were trialled with the target demographic; the remainder recruited healthy students, masking the socioeconomic mismatch that can make 3K USD smart-glasses unattainable for retirees in LMIC contexts. We therefore recommend prioritising smartphone-based AR (median cost 200 USD) for large-scale screening.

Regarding the cost of AI-AR integration, local inference on a Snapdragon XR2 consumes 350 mW; at 60 fps this reduces battery life to ≈75 min. Offloading to an edge-GPU (NVIDIA T4) costs 0.002 USD per inference and adds 40–60 ms latency. A hybrid strategy—local pre-filtering and cloud classification—meets the 100 ms UX budget while keeping CAPEX low for clinics.

4.1 Impacts of Augmented Reality on Cognitive Assessments: Benefits and Limitations

The use of AR in cognitive assessments offers significant advantages, transforming traditional evaluation practices. By integrating digital elements into the physical environment, AR creates interactive, immersive experiences that facilitate the collection of more accurate data on cognitive abilities such as memory, attention, and spatial perception. Studies suggest that these dynamic, interactive environments increase participant engagement, providing more contextual and detailed assessments. Additionally, AR allows tests to be personalized, adapting to the user's skill level and offering real-time feedback, which improves the evaluation experience and strengthens cognitive development. This approach opens up new possibilities not only for assessments but also for clinical and educational interventions.

However, implementing AR in cognitive assessments involves challenges, such as the need for controlled environments, the high cost of technological devices, and the learning curve for patients unfamiliar with such tools—factors that can affect acceptance and effectiveness. Furthermore, accessibility issues, such as those faced by patients with motor impairments, may limit interaction with AR devices. Despite these difficulties, literature indicates that AR can overcome many limitations of traditional tests. The latter, often standardized and decontextualized, may fail to reflect patients' true cognitive abilities, whereas AR provides assessments in more natural and integrated settings, allowing a more comprehensive view of cognitive functioning and also considering emotional and social factors that influence cognition.

4.2 Traditional Assessment vs. AR-based Assessment

Traditional cognitive assessments present substantial limitations, such as interference from external factors and reliance on task recall, which can lead to inaccurate results. Although instruments like the MMSE are widely used, they exhibit shortcomings, such as insufficient sensitivity for detecting visuospatial skills, which are crucial in neurodegenerative diseases like Alzheimer's. In contrast, AR enables the analysis of visuospatial reasoning in three-dimensional environments, addressing the limitations of traditional tests. With the growing accessibility of AR, VR, and MR technologies, their use in clinical and home settings is increasingly feasible, helping patients become more familiar with tests and engage more effectively.

AR not only provides more accurate assessments but can also be used to encourage adherence to cognitive maintenance activities—essential for patients with cognitive impairment. Studies indicate that AR-based games and activities may encourage patients to carry out cognitive tasks in a more engaging way, thereby contributing to the preservation of cognitive abilities. As such, AR serves as a valuable tool for both diagnosis and early intervention.

Table 16 below compares traditional assessment with AR-based assessment across essential criteria such as accuracy, interactivity, and cost. The observed differences highlight AR's advantages in improving accuracy and user engagement, as well as reducing administration time. However, challenges related to familiarity with technology and the initial investment required for large-scale implementation are also noted. While AR offers an innovative and potentially more effective approach, adaptations are needed for different audiences and environments. Thus, it is crucial to weigh the benefits and limitations of each method to ensure an effective adoption of the technology.

4.3 Early Detection and the Importance of Technology in Identifying Cognitive Changes

Early detection of neurodegenerative diseases is essential for developing effective interventions. AR, with its ability to simultaneously integrate various types of data, provides a more sensitive and precise approach for detecting early cognitive changes compared to traditional tests. AR applications have proved particularly effective in identifying early signs of Alzheimer's disease, capturing behavioral and cognitive changes that traditional tests may fail to detect. By allowing physical, motor, and sensory aspects to be analyzed comprehensively, AR offers a broader understanding of cognitive impairment, which is crucial for early detection and for tailoring interventions.

5 Conclusion

This systematic review investigated the use of Augmented Reality (AR) in the evaluation of cognitive tests, with a focus on neurodegenerative diseases and user experience. The results suggest that AR can enhance accuracy and interactivity in assessments, facilitating the early detection of cognitive changes and contributing to more effective interventions, especially in contexts such as Alzheimer's and Parkinson's. This potential is significant, given the rising prevalence of cognitive diseases in an aging population.

However, the usability of AR technologies still presents challenges, including the need for improvements in simplicity and accessibility, aimed at reducing the physical and mental effort required of patients. User experience must be prioritized in the development of these technologies to ensure effective and comfortable assessments.

Future research should focus on optimizing usability, emphasizing intuitive design, clinical integration, and evaluating AR across different stages of neurodegenerative diseases. Continued investigation is essential for maximizing AR's potential and improving care and treatment for patients with neurocognitive conditions.

The practical implications are important for healthcare professionals, technology developers, and researchers. For healthcare professionals, adopting AR can enhance diagnoses and personalize assessments, requiring appropriate training. For developers, the creation of more intuitive and accessible interfaces is necessary. Lastly, researchers should explore the applicability of AR at different stages of neurodegenerative diseases and its impact on patients' quality of life.

Declarations

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Authors' Contribution

L. Nascimento, W. Correia, F. Campos and M. van Gisbergen contributed to the conception of this study. M. Barros, A. Lins, J. Teixeira contributed to the revision of the manuscript. L. Nascimento and W. Correia are the main contributors and writers of this manuscript.

All authors read and approved the final version of the manuscript.

Conflicts of Interest

The authors declare that they have no competing interests.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon request.

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Table 16. Differences between Traditional Assessment and AR-based Assessment

Criterion	Traditional Assessment	AR-based Assessment	Observed Difference
Accuracy	Moderate	High	Significant improvement
Interactivity	Low	High	Greater engagement
Administration Time	Long	Reduced	Considerable reduction
Ease of Use	High	Medium (learning required)	Depends on familiarity with technology
Cost	Low	High	Investment in devices

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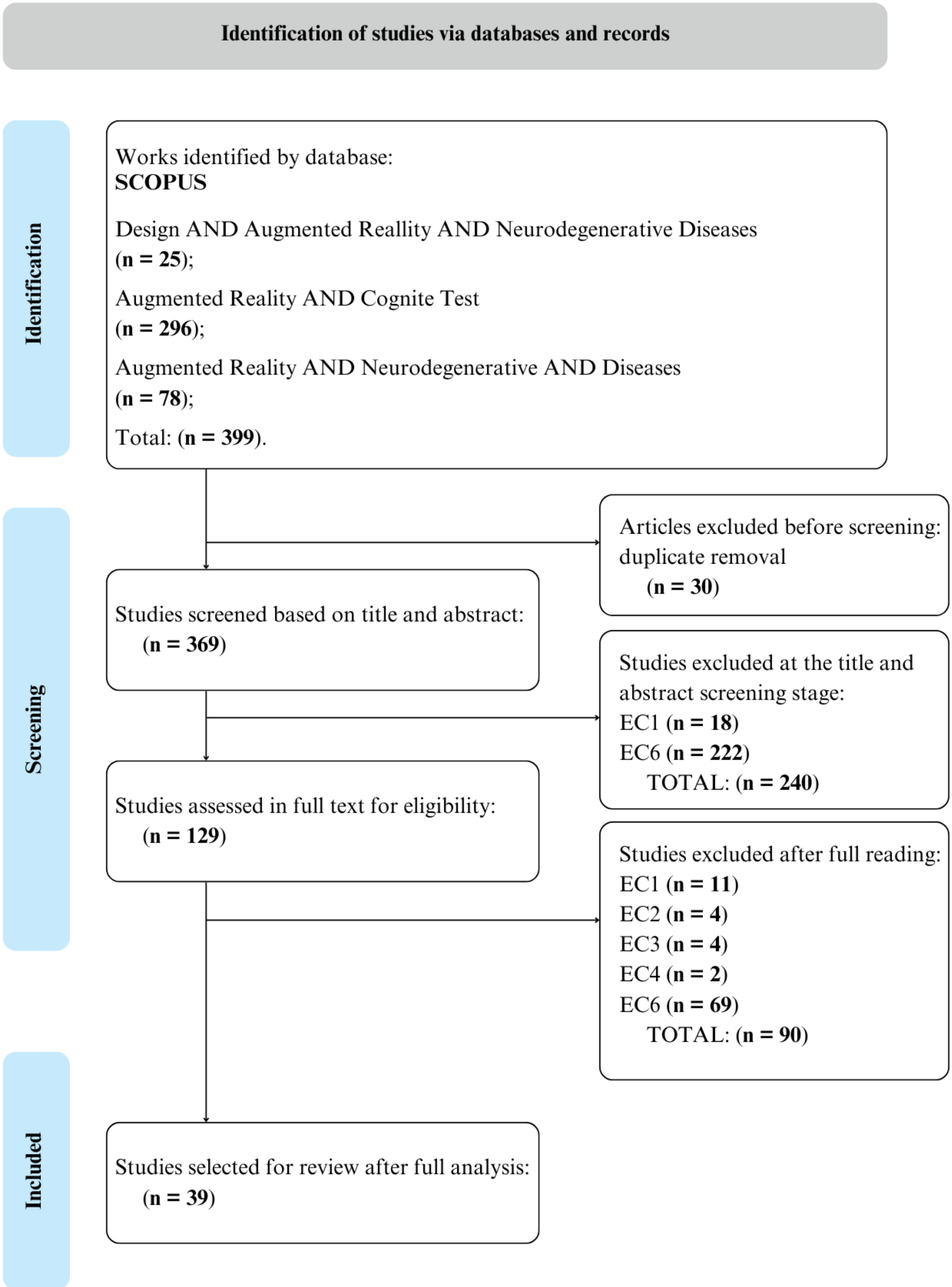

Figure 1. PRISMA Flow Diagram