# Neuropsychology, Augmented Reality and Virtual Reality in the context of ERPI - Innovative approaches to the well-being of the elderly

https://doi.org/10.56238/sevened2024.012-031

Carolinne Oliveira[1], Diamantino Ribeiro[2], Maiara Praça[3], Paula Rocha[4] and Paulo Jerónimo[5]


## ABSTRACT

This research is about the potential of augmented reality and virtual reality technology to improve the cognitive well-being of patients with diagnosed pathologies living in residential care facilities for the elderly. The study aims to review the existing literature on the use of virtual and augmented reality in neuropsychology, particularly in relation to cognitive functions, and to identify successful case studies or pilot projects in similar contexts.

This research also aims to provide a theoretical anchor for the implementation of augmented reality and virtual reality projects in a real-life context, and to contribute to the growing body of knowledge on the potential applications of augmented reality technology in promoting cognitive well-being and quality of life in older people.

Methodologically, the work was supported by the techniques of literature review, content analysis, observation and case study.

The results provided an overview of the effectiveness of activities using augmented reality and virtual reality in improving cognitive function, mood and quality of life in older people, as well as a perspective on best practices for the design and implementation of augmented reality and virtual reality experiences in care environments for older people.


**Keywords:** Cognitive well-being, Neuropsychology, Augmented Reality, Extended Reality, Virtual Reality.

[1] Lusófona University, Porto, Portugal
E-mail: carollinestefanyoli@gmail.com
[2] Lusófona University, Porto, Portugal
E-mail: diamantinojtribeiro@gmail.com
ORCID: https://orcid.org/0000-0002-7168-8821
[3] Lusófona University, Porto, Portugal
E-mail: maiarapracapsicologia@gmail.com
ORCID: https://orcid.org/0000-0002-4901-3983
[4] Lusófona University, Porto, Portugal
E-mail: paularocha@keepcorporate.com
ORCID: https://orcid.org/0009-0000-4080-2161
[5] Lusófona University, Porto, Portugal
E-mail: paulo350jeronimo@gmail.com

## INTRODUCTION

Extended Reality (XR) is an umbrella term used to encompass all immersive technologies, including augmented reality (AR), virtual reality (VR), and mixed reality (MR). XR pushes the boundaries of traditional reality, integrating digital elements into the user's perception of the physical world, thus creating immersive and interactive experiences.

The term "Extended Reality" or "Extended Reality" (XR) has come to be used to encompass the wider spectrum of immersive technologies beyond virtual reality. While the exact origin of the term is not attributed to a single individual, it has gained greater prominence as the development of immersive technology has expanded to include a variety of digital experiences that extend, augment, or alter reality. Leading authors and researchers in the field of XR include:

> Jeremy Bailenson: Founding Director of the *Virtual Human Interaction Lab* (VHIL) at Stanford University. Bawenson's research focuses on the psychology of virtual and augmented reality.
> Steve Aukstakalnis: Author of "*Practical Augmented Reality: A Guide to the Technologies, Applications, and Human Factors for AR and VR*," Aukstakalnis is an expert in augmented and virtual reality technologies.
> Tom Furness: Known as the "Grandfather of Virtual Reality", Furness has made significant contributions to the field of XR through his research and development of VR and AR systems.
> Jason Jerald: Author of "*The VR Book: Human-Centered Design for Virtual Reality*," Jerald is considered an authority on VR technology and its applications in various domains.

The convergence of technology and healthcare brings about a paradigm shift in the way we approach the well-being of older populations, particularly those living in senior or assisted living homes. In this new context of innovation, augmented reality (AR) and virtual reality (VR) stand out as two important branches of immersive technology, presenting new options to address the complex challenges associated with the cognitive health of older people.

While virtual reality allows users to enter or immerse themselves in fully computer-generated environments, Augmented Reality overlays digital information onto the real world, seamlessly integrating virtual elements with the physical environment, as we mentioned. This unique feature of AR has profound implications for therapeutic interventions, especially in the context of elderly care. By augmenting the lived environment with digital enhancements, AR sessions provide a dynamic and interactive platform to engage older patients in therapeutic activities tailored to their cognitive abilities and individual needs.

In this study, we look at the potential of augmented reality and virtual reality technology to enhance the cognitive well-being of elderly patients in the context of senior residence. Specifically, we explore the intersection of these XR's and neuropsychology, seeking to understand how the experiences of both XR's can address and improve cognitive functions affected by age-related pathologies. Through a literature review and consultation of successful case studies and pilot projects, this study seeks to present scientific evidence on the efficacy and feasibility of integrating AR and VR activities in an elderly care setting.

In addition, this study aims to constitute itself as one of the theoretical bases for the practical implementation of AR and VR projects, presenting information on the best practices of design and implementation in real-world contexts. It is also intended to understand the effectiveness of AR and VR therapy sessions in improving cognitive function, mood and overall quality of life of the elderly, as well as the potential positive impact of technology.

The methodology applied in this study includes literature review, observation and analysis of case studies. The sources consulted are essentially open *source* sources available on the Internet.

## VIRTUAL REALITY AND AUGMENTED REALITY IN NEUROPSYCHOLOGY

In the realm of immersive technologies, augmented reality (AR) and virtual reality (VR) represent two distinct but complementary approaches, each of which presents specific ways to change and improve our perception of reality.

Thus, conceptually, AR is a technology that superimposes digital information or virtual objects onto the real-world environment, improving the user's perception and interaction with their surroundings. AR systems typically use devices such as smartphones, tablets, or AR glasses to overlay digital content onto the physical world. As defined by Milgram and Kishino (1994), AR sits on a continuous line between the virtual environment and the real environment, offering users a mixed experience that enriches their sensory input without completely replacing it (Milgram & Kishino, 1994; Skarbez et al., 2021).

Augmented reality has emerged as a promising tool in neuropsychology, providing innovative ways to assess and rehabilitate cognitive functions in individuals with neurological disorders. By overlaying digital stimuli onto the real-world environment, the use of AR can create ecologically valid assessments and therapeutic experiences tailored to the specific needs of patients. This personalized use allows clinicians to encompass cognitive domains such as attention, memory, executive function, and spatial awareness in contexts that closely resemble real-life scenarios. (Rose et al., 2000)

Virtual reality, on the other hand, allows users to be transported to fully computer-generated environments, simulating a sense of presence and immersion in a synthetic reality. VR technologies often involve *head-mounted displays* (HMD) and specialized devices to create a fully immersive experience that takes users into virtual worlds. According to Steuer (1992), VR is a unique form of mediated reality, in which users feel present in the virtual environment, thus allowing for rich and immersive interactions. (Steuer, 1992)

Therefore, extended reality (XR), which as we have seen, encompasses AR, VR, and mixed reality (MR), extends the capabilities of traditional neuropsychological assessments and interventions, providing immersive and interactive experiences.

In the field of neuropsychology, XR technologies have the potential to simulate complex environments and activities, facilitating thorough assessments of cognitive function and allowing rehabilitation-oriented sessions to be (Parsons et al., 2007) conducted.

## REVIEW OF THE LITERATURE ON COGNITIVE FUNCTIONS WORKED ON IN AUGMENTED REALITY AND VIRTUAL REALITY THERAPIES

First of all, it is necessary to understand what neuropsychological rehabilitation consists of.

It is a set of interventions designed to optimize functionality and reduce the inability of people with health problems to interact with their environment. It is an essential part of health care, along with health promotion, disease prevention, treatments, and palliative care (WHO, 2024).

The goal of neuropsychological rehabilitation is to help the person be as independent as possible in their activities of daily living, and to allow participation in education, work, leisure, and important life roles, such as taking care of the family. It may include individual or group therapies, cognitive rehabilitation, psychotherapy, psychoeducation, and psychosocial interventions. (WHO, 2024)

There are three main approaches in neuropsychological rehabilitation, according to the studies of Clare et al. (2003):

1. Cognitive stimulation: Involvement in activities and discussions aimed at the general improvement of cognitive and social functioning, usually in a group context.
2. Cognitive training: Repeated practice on specific tasks that reflect underlying cognitive processes, such as memory and attention. It can be individual or group, face-to-face or remote.
3. Cognitive rehabilitation: An individualized approach that builds on the person's strengths and compensates for the most deficient areas, based on a comprehensive assessment of cognitive, functional, social, and emotional functioning. It uses tasks, psychoeducation, and compensatory strategies.

These approaches have widely documented efficacy, for example in people with mild cognitive impairment and neurocognitive disorders. In Lazar et. al (2014) a review is observed on new technology programs implemented in cognitive stimulation and training, with the clear objective of promoting an improvement in the cognitive functioning of individuals, and with success in all cases analyzed in the review. (Clare & Woods, 2003) (Lazar et al., 2014)

Neurological rehabilitation was, then, the starting point for us to deepen the specific cognitive functions worked on in therapies with AR and VR.

## COGNITIVE FUNCTIONS WORKED ON IN AUGMENTED REALITY THERAPIES

Augmented reality has aroused a great deal of interest due to its potential to influence attention-related processes, including selective attention and sustained attention.

Selective attention refers to the ability to focus cognitive resources on relevant stimuli while filtering out irrelevant distractions. AR interventions have been shown to improve selective attention by directing users' attention to specific digital stimuli overlaid on the real-world environment. The study led by Josef Buchner in 2022 demonstrated that AR-based training tasks improved participants' ability to selectively arrange target objects in a cluttered visual scene, leading to improved task performance and reduced distraction. In addition, AR technologies can dynamically adjust digital stimuli based on the user's preferences and task demands, further facilitating selective attention processes. This adaptive feature of AR systems makes it possible to implement techniques related to personalized attention, adapted to individual needs and cognitive goals (Buchner et al., 2022) (Marougkas et al., 2023b) .

Sustained attention, also known as vigilance, refers to the ability to maintain concentration and alertness over an extended period. Therapies that use AR have shown promise for improving vigilance, providing dynamic and interactive experiences that maintain users' interest and engagement over time. Research by Ngeemasara Thapa's team, for example, showed that AR-based cognitive training tasks led to improvements in vigilance performance among the elderly, with participants exhibiting increased vigilance and reduced attention lapses during task completion. (Thapa et al., 2020a)

It is observed, then, that the immersive nature of AR experiences can promote vigilance, minimizing external distractions and keeping users engaged with stimuli relevant to the task. Therefore, by integrating interactive elements and branching techniques, AR therapies or interventions can contribute to maintaining users' attention and motivation, facilitating a more immersive and rewarding cognitive training environment (Marougkas et al., 2023a) .

It has also been possible to verify that activities using AR have emerged as promising tools to improve various aspects of memory, including spatial memory and episodic memory. Research in this area has been deepening the effectiveness of AR in facilitating the processes of memory encoding, retrieval and consolidation, giving a perspective of its potential as a memory improvement technique.

Spatial memory refers to the ability to recall and navigate spatial environments. AR therapies take advantage of the immersive and interactive nature of technology to provide enriched spatial experiences that stimulate spatial memory processes. The studies led by José Manuel Cimadevilla demonstrated that AR-based navigation devices improved the performance of users' spatial memory, allowing them to recall spatial information more accurately and efficiently. (Cimadevilla et al., 2023)

It's interesting to note that AR applications can overlay digital markers or cues on real-world environments, providing users with additional contextual information to support spatial memory retrieval. According to some authors, this spatial increase improves the scenarios, facilitating memory retrieval and the tasks involved in therapy (Hoe et al., 2019; Keil et al., 2020).

Episodic memory, on the other hand, involves the recollection of specific events and experiences linked to a particular time and place. AR therapies offer immersive storytelling experiences that engage users in interactive narratives, facilitating the encoding and retrieval of episodic memory. The research carried out by Dingler *et. al.* (2019) demonstrated that AR-based storytelling applications improved participants' episodic memory, leading to improved recall accuracy and vividness of memories. (Dingler et al., 2021)

In parallel, AR technology can create personalized memory cues or 'triggers' embedded in real-world contexts, eliciting episodic memories associated with specific locations or objects. These memory cues serve as retrieval stimuli, facilitating the recall of autobiographical memories and increasing the richness of episodic memory experiences (Sheldon et al., 2020).

In summary, it is observed that scientific studies regarding memory improvement through therapies that use augmented reality (AR) highlight the potential of AR technology to improve both spatial memory and episodic memory processes.

Let's now look at the role of AR in improving executive functions. Augmented reality has also sparked interest as a potential tool for improving executive functions, including planning, problem-solving, and decision-making. Research in this area has explored the efficacy of AR therapies in improving cognitive processes associated with executive function, showing a perspective of their potential as a cognitive enhancement technique.

As far as planning is concerned, activities involve the ability to set goals, develop strategies, and organize tasks to achieve desired outcomes. Interactive planning environments are created that engage users in goal-oriented behaviors and decision-making processes. They defend Han et. al (2021) that AR-based planning tools improve users' ability to create and execute plans in real-world contexts, leading to more efficient task completion and goal achievement. (Han et al., 2021)

Additionally, AR technologies can provide users with real-time feedback and visual representations of their plans, facilitating self-monitoring and adaptive planning strategies. This real-time *feedback* mechanism increases users' awareness of their planning process and allows them to adjust their plans in response to changing circumstances or constraints (Geisen & Klatt, 2022; Liu et al., 2012).

As for problem solving, an activity that involves the ability to identify, analyze and implement solutions to complex problems, AR therapies have the advantage of designing immersive problem-solving environments that present users with challenges and interactive scenarios. AR-based problem-solving tasks improve participants' ability to generate creative solutions and overcome obstacles, promoting flexible thinking and innovation. (Alzahrani, 2020; Chang et al., 2013)

Regarding decision-making, the process involves evaluating alternatives in making choices based on available information and preferences, activities that use AR include decision-making simulations, placing users in realistic decision-making scenarios. Studies show that AR-based decision-making tasks can improve participants' ability to make informed decisions in situations of uncertainty, leading to more accurate and confident choices. (Guntur et al., 2020; Hoppenstedt et al., 2021)

It is now important to verify the effects of AR on spatial cognition and navigation skills.

Spatial cognition encompasses the mental processes involved in perceiving, understanding, and manipulating spatial information. AR therapies provide interactive spatial learning environments that engage users in space-oriented tasks, such as map reading, pathing, and spatial memory tasks. Some work has shown that AR-based spatial therapy sessions improved spatial reasoning and mental rotation skills in participants of various age groups, including the elderly, leading to improved spatial cognition performance. It has been observed that AR technologies can provide users with dynamic visualizations and interactive simulations of spatial concepts, facilitating active exploration and experimentation of spatial relationships. This interactive aspect of AR interventions promotes experiential learning and deepens users' understanding of spatial concepts and principles (Lee et al., 2016).

Regarding navigation capabilities, these involve the ability to navigate through physical environments and space-oriented tasks such as route planning, landmark recognition and orientation. AR therapies provide interactive navigational aids that overlay digital information onto real-world environments, showing users cues and guidance to enhance the experience. AR-based navigation systems have improved the efficiency and accuracy of users' navigation, allowing them to navigate unfamiliar environments with greater ease and confidence. (Fick et al., 2021)

It is therefore observed that AR technologies can improve users' spatial awareness by producing contextually relevant information and visualizations that facilitate spatial orientation and updating. Overlaying digital markers or clues on real-world imagery improves users' situational awareness and supports effective navigation strategies such as landmark-based navigation and route planning (Jiang & Subakti, 2023; Khan et al., 2022).

In summary, the different studies related to the cognitive functions used in AR therapy sessions provide valuable information about the potential of AR technology as a tool for cognitive improvement. Based on the perspectives of the referenced authors, there are several key points that highlight the various benefits of using AR for cognitive function:

- **Increased engagement and immersion**
  AR interventions provide immersive and interactive experiences that engage users in cognitive tasks and activities, fostering active participation and engagement in spatial, memory, executive function, and attention processes.
- **Personalized learning and adaptation**
  AR technologies provide personalized learning experiences tailored to individual cognitive needs and preferences, allowing for adaptive *feedback* and personalization based on users' cognitive profiles and learning goals.
- **Real-world contextualization**
  AR activities contextualize cognitive tasks in real-world environments, providing users with more relevant learning experiences that bridge the gap between abstract concepts and practical applications.
- **Collaborative and social learning**
  AR technologies facilitate collaborative and social learning experiences by allowing users to interact with virtual objects and collaborate with others in real time, fostering teamwork, communication, and collective problem-solving skills.
- **Transferability to real-world contexts**
  AR interventions promote the transfer of cognitive skills and knowledge to real-world contexts, allowing users to apply the concepts and strategies learned in everyday life situations, such as orientation, decision-making, and problem-solving tasks.

Therefore, the integration of augmented reality (AR) activities into cognitive therapy and rehabilitation programs holds great promise for improving cognitive functions in diverse populations and contexts. In this way, by taking advantage of the interactive and immersive nature of AR technologies, researchers and practitioners can develop innovative therapies aimed at improving, inter alia, attention, memory, executive function, and spatial awareness.

## COGNITIVE FUNCTIONS WORKED ON IN VIRTUAL REALITY INTERVENTIONS

Virtual Reality (VR) has emerged as a versatile tool for cognitive enhancement. Researchers have been delving into its potential to improve attention, memory, executive function, and spatial awareness through immersive and interactive therapies, such as AR.

In the field of neuropsychology, VR has emerged as a promising tool to improve attention control and concentration by creating immersive and interactive environments that engage users in tasks and activities that require attention.

Attention control refers to the ability to selectively assign cognitive resources to stimuli while inhibiting distractions and irrelevant information. Therapies that use VR allow for the creation of immersive, attention-training programs that lead users to challenge their ability to control in dynamic and realistic environments. To Freeman *et. al.* (2017) VR-based attention-grabbing tasks improved participants' ability to stay focused and resist distractions, leading to greater control of attention and concentration. Other authors, such as the team of Iriarte et. al. (2016), report that VR technologies allow simulating attention-demanding scenarios and environments that closely mimic real-world situations, creating opportunities for the user to practice and refine their attention control skills in ecologically valid contexts (Freeman et al., 2017) (Iriarte et al., 2016).

Concentration involves the sustained focus and mental effort required to maintain attention on a task or stimulus over time. VR platforms offer engaging and immersive concentration training exercises that challenge users' ability to maintain attention and resist mental fatigue. Several authors, among them Moulai et. al. (2024) demonstrated that VR-based concentration practice tasks improved participants' ability to maintain attention and maintain optimal performance levels during prolonged cognitive tasks, which led to improved concentration and task performance. We then see that VR technologies can dynamically adjust the difficulty and complexity of tasks based on users' performance and attention, through adaptive regimes that optimize concentration levels and cognitive engagement (Moulaei et al., 2024) (Ishibashi et al., 2023; Plancher et al., 2012).

Regarding the impact on memory, virtual reality (VR) has shown promise as a tool to improve memory retention and recall through immersive and interactive experiences that engage users in memory-related tasks and activities. Research in this area has sought to understand the effectiveness of VR therapies in improving various aspects of memory, showing a perspective of their potential as a cognitive improvement technique.

Memory retention involves the ability to store and maintain information over time. VR activities can feature immersive memory-encoding environments that engage multiple sensory modalities to enhance memory consolidation processes. The work of Riva *et. al.* (2012) demonstrated that VR-based memory encoding tasks improved participants' memory retention for spatial and episodic information, leading to an increase in recall accuracy and vividness of memories. (Riva et al., 2012)

In addition, VR technologies can provide contextual indicators and spatial contexts that facilitate memory encoding and retrieval processes by increasing the salience and accessibility of encoded memories (Maples-Keller et al., 2017).

In terms of memory retrieval, i.e. the ability to recall information stored in memory when needed, VR interventions make it possible to apply interactive memory retrieval exercises that challenge users' retrieval abilities in realistic and dynamic environments. In this field, the study carried out by Rose et. al. (2023) demonstrated that VR-based memory retrieval tasks improved participants' ability to retrieve autobiographical memories and factual information, leading to greater retrieval accuracy and temporal coherence. (Betts et al., 2023)

It should also be noted that, in this context, VR technologies can perform memory retrieval simulations that facilitate these processes, supporting the retrieval of associated memories and reinforcing memory traces (Freeman et al., 2017).

In the field of executive function, virtual reality (VR) therapies have been developed to work on areas such as cognitive flexibility, inhibition and working memory. These interventions offer immersive and interactive experiences that challenge users' executive function skills in dynamic and realistic environments. Research in this area has focused on the effectiveness of various aspects of executive function, offering a perspective of its potential as a cognitive enhancement technique.

In the field of cognitive flexibility, for example, which concerns the ability to adapt and switch between different tasks or mental sets, VR has made it possible to create programs to train cognitive flexibility that show users variable and unpredictable scenarios, requiring them to adjust their behavior and strategies accordingly. Studies have shown that VR-based tasks to practice cognitive flexibility improved participants' ability to switch between tasks and mental sets, leading to greater cognitive flexibility and adaptive behavior. (Ibrahim et al., 2016; Sadeghi et al., 2021)

In addition, other authors have been arguing that VR technologies can simulate complex and dynamic environments that challenge users' cognitive flexibility in realistic and ecologically valid scenarios, providing the transfer of the effects of simulations to real-world situations (Tortora et al., 2024; Zulueta et al., 2018).

With regard to inhibition (which involves the ability to suppress irrelevant or interfering stimuli and responses), VR therapies allow you to perform inhibition training exercises that challenge users' inhibitory control abilities in distracting and challenging environments. VR technologies can provide users with interactive (Manasse et al., 2023; Yu et al., 2023) *feedback* and reinforcement to strengthen inhibitory control processes, facilitating self-regulation and impulse control (Oei & Patterson, 2013; Oh et al., 2022).

In relation to working memory, i.e. memory related to the ability to retain and manipulate information in the mind for short periods, VR therapies allow the creation of training tasks that involve users in processes of encoding, maintenance and retrieval of memory in immersive environments. Studies have shown that VR-based working memory training tasks improved participants' working memory capacity and performance on working memory tasks, leading to improved cognitive functioning and task performance. (Ansado et al., 2018; De Luca et al., 2023; He et al., 2022; H. Kim et al., 2022; Prats-Bisbe et al., 2024)

Other studies also report that VR technologies can provide users with adaptive and personalized working memory training environments that adjust the difficulty and complexity of tasks based on individual cognitive abilities and performance levels, optimizing practical outcomes. (Caglio et al., 2012)

Let's now look at the impact of VR therapies on spatial cognitive abilities. Therapies to train space navigation involve the acquisition and improvement of navigation skills, including route planning, landmark recognition, and spatial orientation. VR therapies allow you to create immersive navigation environments that simulate real-world scenarios and challenges, requiring users to navigate through landscapes and virtual environments. Serino et. al (2018) were able to demonstrate that VR-based spatial navigation training tasks improved participants' spatial orientation skills and navigation performance, leading to improved cognitive spatial abilities and navigation skills. (Serino et al., 2017)

In addition, VR technologies can provide users with interactive *feedback* and guidance to support navigation learning and skill development, facilitating spatial learning and memory consolidation processes (Coughlan et al., 2018).

Regarding the impact of therapies aimed at training cognitive spatial skills (which encompass a range of skills related to spatial perception, mind mapping and environmental awareness), VR has been demonstrating a high potential to improve cognitive spatial skills, creating conditions to improve spatial reasoning and navigation skills in realistic environments. Several authors argue that spatial navigation training based on the use of VR improved participants' cognitive spatial abilities, including mental rotation, spatial memory, and spatial reasoning, leading to better performance on spatial cognitive tasks and assessments. (Liao et al., 2019; Ren et al., 2024; Thapa et al., 2020b; Zhu et al., 2022)

Studies also report that VR technologies can provide users with multisensory feedback and spatial cues that improve spatial awareness and facilitate spatial learning processes, promoting the transfer of the effects of training to real-world navigation tasks. (D.-R. Kim et al., 2023; Park, 2022)

In summary, the approach and implementation of virtual reality (VR) tools for cognitive enhancement reveals great potential to improve various aspects of cognitive function, including attention, memory, executive function, and spatial awareness. We can then highlight the following added value:

— **Integration of *multi-sensory* feedback**

VR technologies provide users with multi-sensory feedback and immersive environments that engage multiple sensory modalities, improving the relevance and realism of cognitive training tasks. By integrating visual, auditory, and tactile media, VR therapies provide enriched learning experiences that promote engagement and retention of cognitive skills.

- **Personalized and adaptive training**
  VR activities can be tailored to individual cognitive needs and preferences through personalized, tailored training programs or therapies that adjust the difficulty and complexity of tasks based on users' performance and progress. This tailored approach optimizes outcomes and promotes the transfer of skills to real-world contexts, increasing the efficacy and relevance of these therapies.
- **Real-world application and transfer of training effects**
  The realistic and ecologically valid nature of VR environments makes it easy to transfer the effects of training to real-world tasks and activities. By simulating everyday situations and challenges, VR activities prepare users for navigation, decision-making, and problem-solving tasks in the real world, making it easier to generalize and apply the skills learned in a variety of contexts.

While VR shows promise as a cognitive enhancement tool, more research is needed to explore its long-term effects and possible limitations. Future studies should explore optimal training protocols, dosage, and duration of VR sessions, as well as factors influencing individual differences in response to cognitive training. In addition, addressing the technical and usage challenges of VR technology can improve the accessibility and scalability of cognitive training programs.

In summary, the integration of virtual reality (VR) activities in cognitive training and rehabilitation shows great promise for improving cognitive function in diverse populations and contexts. By creating immersive and interactive training environments, therapies using VR provide innovative approaches to improving cognitive skills and promoting cognitive well-being, with implications for healthcare, especially for the senior population.

## BENCHMARKING

In the field of cognitive rehabilitation and improvement, augmented reality (AR) and virtual reality (VR) have emerged as transformative technologies that offer unique avenues of intervention. A comparative analysis of their effects on cognitive functions, as seen in 3.1 and 3.2, reveals important information about their strengths and limitations, as highlighted below:

### Effects on cognitive functions:

- **Attention**

VR activities often provide immersive, visually stimulating environments that can effectively capture and hold the attention of seniors.

AR activities, on the other hand, overlay digital information onto the real world, potentially improving selective attention by directing users' focus to relevant stimuli.

- **Memory**

  VR technology can create vivid and immersive memory encoding and retrieval contexts, promoting memory consolidation and recall.

  AR can facilitate memory encoding by creating contextual cues and spatial associations in real-world environments.

- **Executive Function**

  VR experiences provide dynamic and interactive environments that challenge cognitive flexibility, inhibition, and working memory through immersive tasks and simulations.

  AR experiences can provide  real-time feedback and guidance, to support decision-making and problem-solving in real-world contexts, potentially improving executive function skills.

- **Spatial awareness**

  VR sessions provide immersive spatial navigation training environments that challenge users' spatial cognition and navigation skills, while AR sessions overlay digital spatial cues on real-world environments, potentially improving spatial awareness and navigation in familiar environments.

## Strengths and limitations:

- **Strengths of AR**

  AR experiences integrate seamlessly into real-world environments, providing contextually relevant information and improving situational awareness.

  AR technologies are often more affordable and easier to use, requiring minimal equipment and setup compared to VR systems.

- **Limitations of AR**

  AR sessions may be limited by the availability and accuracy of real-world spatial data, which may affect the effectiveness of spatial augmentation.

  AR technologies can struggle to create immersive and engaging experiences compared to VR, eventually limiting their effectiveness in certain cognitive training tasks.

- **Strengths of VR**

  VR experiences allow for full control over the virtual environment, allowing for tailored and customizable training scenarios.

VR technologies can provide immersive and realistic simulations of complex scenarios and environments, promoting the transfer of the effects of training to real-world tasks.

— **Limitations of VR**

The use of VR may require specialized equipment and configuration, limiting accessibility and scalability, particularly for the elderly or individuals with mobility issues.

VR technologies can induce discomfort in some users, potentially impacting their engagement and adherence to training programs.

We can infer that both AR and VR sessions are unique opportunities for cognitive rehabilitation and improvement, with different advantages and challenges. By understanding this context, coaches and therapists can make more informed decisions about the selection and implementation of AR and VR technologies in cognitive training programs.

While augmented reality and virtual reality experiences have distinct advantages and challenges, their complementary nature foresees great opportunities for the future of cognitive rehabilitation and improvement. By harnessing the strengths of AR and VR technologies, researchers and practitioners can continue to innovate and improve cognitive training programmes in general, and in particular in the context of older people living in specialised units.

## SUCCESSFUL CASE STUDIES AND PILOTS

In recent years, augmented reality (AR) and virtual reality (VR) technologies have emerged as promising tools to improve the well-being and quality of life of the elderly, as we have been demonstrating. From cognitive rehabilitation to the promotion of physical activity and social involvement, therapies with AR and VR are innovative solutions to respond to the diverse needs of a part of the senior population in the context of assisted care or senior residences.

In this chapter, we present an overview of successful case studies and pilot projects using AR and VR technologies in older adults, highlighting their applications, results, and implications for practice and research.

Through the observation of concrete projects, we obtain additional information, which we consider very relevant, about the transformative potential of AR and VR in promoting health, independence and better quality of life of the elderly.

Fig. 1 - Using Augmented Reality for Dementia Diagnostics and Therapeutics[6]

Source: Neelem Sheikh (2022)

The following is a summary of some of the projects consulted (which are already significant in number and focus on a wide variety of approaches):

- **Effectiveness of an Exercise Program for Older Adults Using an Augmented Reality Exercise Platform: A Pilot Study[7]**

  *Effectiveness of an Exercise Program for Older Adults Using an Augmented Reality Exercise Platform: A Pilot Study*

  Autores: Park, TS & Shin, MJ.

  **Main results:** The results of this study confirmed changes in the physical and cognitive functions of elderly women who participated in an AR-based exercise program for 6 weeks. The exercise program was confirmed to be effective (even with the short intervention period of 6 weeks. In the future, more community-based exercise programs for older adults should be conducted, based on the AR exercise equipment used in this study. It is important to keep older adults living in the community interested in participating in exercise programs to manage their health.
- **Effect of virtual reality exercises on balance and fall in elderly people with fall risk: a randomized controlled trial[8]**

  *Effect of Virtual Reality Exercises on Balance and Falls in Older Adults at Risk of Falling: A Randomized Controlled Trial*

  Authors: Zahedian-Nasab, N., Jaberi, A., Shirazi, F., & Kavousipor, S.

[6] Source: https://altoida.com/blog/using-augmented-reality-for-dementia-diagnostics-and-therapeutics/

[7] Bibliografia: Park TS, Shin MJ. Effectiveness of an Exercise Program for Older Adults Using an Augmented Reality Exercise Platform: A Pilot Study. Ann Geriatr Med Res. 2023 Mar; 27(1):73-79. doi: 10.4235/agmr.23.0016. Epub 2023 Mar 22. PMID: 36945873; PMCID: PMC10073971.

[8] Bibliografia: Zahedian-Nasab, N., Jaberi, A., Shirazi, F., & Kavousipor, S. (2021). Effect of virtual reality exercises on balance and fall in elderly people with fall risk: a randomized controlled trial. BMC geriatrics, 21(1), 509. https://doi.org/10.1186/s12877-021-02462-w.

**Main results:** According to research findings, 6 weeks of balance exercises with VR can improve balance and fear of falling among seniors living in nursing homes.

— **The Effect of Reminiscence Therapy Using Virtual Reality on Apathy in Residential Aged Care: Multisite Nonrandomized Controlled Trial**[9]

*The Effect of Reminiscence Therapy Using Virtual Reality on Apathy in Residential Care for the Elderly: Multi-Site Non-Randomized Controlled Trial*

Authors: Saredakis D, Keage HA, Corlis M, Ghezzi ES, Loffler H, Loetscher T.

**Main results:** Although no statistically significant difference was found between the VR group and the active control group, the study demonstrates that VR can be implemented in an elderly care setting using correct protocols and that residents in elderly care facilities enjoy the recall process. The use of VR allows access to a wide range of content, which is always increasing, and aged care facilities may be able to use VR in other contexts, for example in lifestyle activities, music or travel.

— **NavMarkAR: A Landmark-based Augmented Reality (AR) Wayfinding System for Enhancing Spatial Learning of Older Adults**[10]

*NavMarkAR: A landmark-based Augmented Reality (AR) guidance system to improve spatial learning for older adults*

Autores: Qiu, Z., Ashour, M., Zhou, X., & Kalantari, S.

**Main results:** The results of the study made three major contributions to this domain. Firstly, they demonstrated that multimodal navigation guidance in AR can be highly effective in helping older adults reach their destination; secondly, the landmark-based design was effective in helping them acquire allocentric knowledge in indoor environments; finally, surveys and interviews revealed important information about the perspectives and needs of older people in the context of using the system, leading to a set of specific *design* recommendations for AR navigation tools.

— **Immersive Virtual Reality-Based Cognitive Intervention for the Improvement of Cognitive Function, Depression, and Perceived Stress in Older Adults With Mild Cognitive Impairment and Mild Dementia: Pilot Pre-Post Study**[11]

[9] Bibliografia: Saredakis D, Keage HA, Corlis M, Ghezzi ES, Loffler H, Loetscher T., The Effect of Reminiscence Therapy Using Virtual Reality on Apathy in Residential Aged Care: Multisite Nonrandomized Controlled Trial J Med Internet Res 2021; 23(9):e29210, doi: 10.2196/29210

[10] Bibliografia: Qiu, Z., Ashour, M., Zhou, X., & Kalantari, S. (2023). NavMarkAR: A Landmark-based Augmented Reality (AR) Wayfinding System for Enhancing Spatial Learning of Older Adults. ArXiv, abs/2311.12220.

[11] Bibliografia: Zhu, K., Zhang, Q., He, B., Huang, M., Lin, R., & Li, H. (2022). Immersive Virtual Reality-Based Cognitive Intervention for the Improvement of Cognitive Function, Depression, and Perceived Stress in Older Adults With Mild Cognitive Impairment and Mild Dementia: Pilot Pre-Post Study. JMIR serious games, 10(1), e32117. https://doi.org/10.2196/32117.

Virtual Reality-Based Immersive Cognitive Intervention for the Improvement of Cognitive Function, Depression and Perceived Stress in Older Adults with Mild Cognitive Impairment and Mild Dementia: Pilot Study.

Autores: Zhu, K., Zhang, Q., He, B., Huang, M., Lin, R., & Li, H.

**Main results:** The use of the CVSM system may be effective in improving the cognitive function of patients with MCI and DM, including general cognitive function, memory, executive function, and attention. IVR technology enriches cognitive intervention approaches and provides acceptable, professional, personalized, and engaging cognitive training for older adults with cognitive impairment.

— **Impact of Virtual Reality–Based Group Activities on Activity Level and Well-Being Among Older Adults in Nursing Homes: Longitudinal Exploratory Study**[12]

Impact of Virtual Reality-Based Group Activities on the Level of Activity and Well-Being of Older Adults in Nursing Homes: Longitudinal Exploratory Study.

Autores: Li Y, Wilke C, Shiyanov I, Muschalla B.

**Main results:** This study presents a new and original perspective, producing new knowledge about the use of VR in nursing homes. The use of VR has been well accepted and has fulfilled the goal of increasing capacity and well-being. It can be a very important group activity, for seniors in senior residence units, to improve group social interaction. To obtain more solid evidence, randomized controlled trials are needed.

— **Fully Immersive Virtual Reality Using 360° Videos to Manage Well-Being in Older Adults: A Scoping Review**[13]

Fully Immersive Virtual Reality Using 360° Videos to Manage Well-Being in the Elderly: An Overall Review

Authors: J. Restout, I. Bernache-Assollant, C. Morizio, A. Boujut, L. Angelini, A. Tchalla, A. Perrochon,

**Main results:** The use of 360° VR videos seems feasible in older adults living in the community or in residential elderly care facilities, as they are safe and provide enjoyment. It is an emerging and promising therapeutic tool for managing psychosocial disorders. This review gathered key considerations for the design and implementation of interventions using 360° VR videos in clinical practice.

[12] Bibliografia: Li Y, Wilke C, Shiyanov I, Muschalla B, Impact of Virtual Reality–Based Group Activities on Activity Level and Well-Being Among Older Adults in Nursing Homes: Longitudinal Exploratory Study. JMIR Serious Games 2024; 12:e50796. doi: 10.2196/50796

[13] Bibliografia: J. Restout, I. Bernache-Assollant, C. Morizio, A. Boujut, L. Angelini, A. Tchalla, A. Perrochon, (2023)Fully Immersive Virtual Reality Using 360° Videos to Manage Well-Being in Older Adults: A Scoping Review, Journal of the American Medical Directors Association, Volume 24, Issue 4, Pages 564-572, https://doi.org/10.1016/j.jamda.2022.12.026.

- **Using a Nature-Based Virtual Reality Environment for Improving Mood States and Cognitive Engagement in Older Adults: A Mixed-Method Feasibility Study**[14]

  Using a Nature-Based Virtual Reality Environment to Improve Mood States and Cognitive Impairment in the Elderly: A Mixed-Method Feasibility Study

  Autors: Saleh Kalantri, Tong Bill Su, Armin Mostafawi, Angela Lee, Ruth Barankevich, Walter Ro Boot, Sarah J. Cizza

  **Main results:** The results indicated significant improvements in the "good mood" and "calm" dimensions after exposure to VR, as well as improvements in attitudes towards technology. Positive outcomes were significantly higher for participants with physical disabilities, compared to those without disabilities. The *feedback* interviews provided a variety of useful suggestions on ways to improve the *design* and content of VR equipment, to meet the needs of an older population.

- **Using Virtual Reality for Cognitive Training of the Elderly**[15]

  Use of virtual reality for cognitive training of the elderly

  Authors: García-Betances RI, Jiménez-Mixco V, Arredondo MT, Cabrera-Umpiérrez MF.

  **Main results:** Cognitive training systems based on virtual reality are able to achieve the expected goals in people affected by age-related cognitive impairments. They support procedures for alleviating the behavioural and psychological symptoms of patients with early-stage MCI and AD to better meet the specific rehabilitation needs of these patients, as well as the requirements for caregivers to conduct sessions. In addition to the general relevance of contributions to the current state of the art on cognitive training, a feature that is evident in the implementation of VR CT training systems is the reliance on intense multidisciplinary collaboration during the innovation and design phases of the system, as well as the high level of patient involvement. medical researchers, technical experts and caregivers.

- **A Review of Extended Reality Exercise Games for Elderly** [16]

  A Review of Extended Reality Exercise Games for Seniors

[14] Bibliografia: Saleh Kalantari, Tong Bill Xu, Armin Mostafavi, Angella Lee, Ruth Barankevich, Walter R Boot, Sara J Czaja, Using a Nature-Based Virtual Reality Environment for Improving Mood States and Cognitive Engagement in Older Adults: A Mixed-Method Feasibility Study, Innovation in Aging, Volume 6, Issue 3, 2022, igac015, https://doi.org/10.1093/geroni/igac015

[15] Bibliografia: García-Betances RI, Jiménez-Mixco V, Arredondo MT, Cabrera-Umpiérrez MF. (2015) Using Virtual Reality for Cognitive Training of the Elderly. American Journal of Alzheimer's Disease & Other Dementias®.; 30(1):49-54. doi:10.1177/1533317514545866

[16] Bibliografia: Fu, Y.; Hu, Y.; Sundstedt, V. and Forsell, Y. (2022). A Review of Extended Reality Exercise Games for Elderly. In Proceedings of the 15th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2022) - HEALTHINF; ISBN 978-989-758-552-4; ISSN 2184-4305, SciTePress, pages 201-210. DOI: 10.5220/0010907800003123

Autores: Fu, Y.; Hu, Y.; Sundstedt, V. and Forsell, Y.

**Main results:** The positive effect of these games was common in the research results. Even if there are issues, such as simulator sickness, security risks, device issues, and cost, there are still opportunities and room for research and development in the future. The overall positive attitude towards XR exercise games for seniors can be seen by researchers as well as developers and users. However, these gaming apps also have some issues and future improvements are needed. The analysis presented is beneficial for researchers and developers to develop or improve future XR applications by learning from existing work.

— **Cognitive training on stroke patients via virtual reality-based serious games**[17]

*Cognitive training in stroke patients through virtual reality-based games*

Authors: Pedro Gamito, Jorge Oliveira, Carla Coelho, Diogo Morais, Paulo Lopes, José Pacheco, Rodrigo Brito, Fábio Soares, Nuno Santos, and Ana Filipa Barata

**Main results:** The overall results point to the need for more support for the use of VR cognitive training applications in neuropsychological rehabilitation.

— **PTSD Elderly War Veterans: A Clinical Controlled Pilot Study**[18]

*PTSD in Elderly War Veterans: A Controlled Clinical Pilot Study*

Authors: Pedro Gamito, Jorge Oliveira, Pedro Rosa, Diogo Morais, Nuno Duarte, Susana Oliveira, and Tomaz Saraiva.

**Main results:** Patients enrolled in the VG group showed a statistically reduced reduction in disorders associated with PTSD, such as depression and anxiety. Far from conclusive, this pilot study nevertheless presents some promising data on the use of VR in veteran populations.

— **Relaxing in virtual reality: one synthetic agent relaxes all**[19]

*Relaxation in Virtual Reality: A Synthetic Agent Relaxes Everyone*

Authors: Pedro Gamito, Teresa Souto, Ana Rita Conde, Ágata Salvador, Maria José Ferreira, João Alves de Sousa, Marco Ferreira, Fábio Dias, Shivani Atul, Rita Pereira, Edna Távora, Inês Maia, Jorge Oliveira.

**Main results:** The results suggest that the presence of an unfamiliar humanoid character was not perceived as a dissonant element in the environment and did not negatively influence the outcome of relaxation. This study lays the groundwork for future studies

[17] Bibliografia: Gamito et. al. (2015). Cognitive training on stroke patients via virtual reality-based serious games. Disabil Rehabil, Early Online: 1-4.

[18] Bibliografia: Gamito et. al. (2010). PTSD Elderly War Veterans: A Clinical Controlled Pilot Study. Cyberpsychology, Behavior, and Social Networking, Volume 13, Number 1, 43-48.

[19] Bibliografia: Gamito et. al. (2010). PTSD Elderly War Veterans: A Clinical Controlled Pilot Study. Cyberpsychology, Behavior, and Social Networking, Volume 13, Number 1, 43-48.

that can present insight into the optimal characteristics of a SyA, contributing to the development of accessible and beneficial digital applications for a wide range of individuals in clinical and non-clinical settings.

— **Virtual Reality-Based Cognitive Stimulation on People with Mild to Moderate Dementia due to Alzheimer's Disease: A Pilot Randomized Controlled Trial**[20]

  *Virtual Reality-Based Cognitive Stimulation in People With Mild to Moderate Dementia Due to Alzheimer's Disease: A Pilot Randomized Controlled Trial*

  Authors: Jorge Oliveira, Pedro Gamito, Teresa Souto, Rita Conde, Maria Ferreira, Tatiana Corotnean, Adriano Fernandes, Henrique Silva and Teresa Neto

  **Main results:** Preliminary results suggest an improvement in global cognitive function in the experimental group, with an effect size corresponding to a large effect on global cognition, which suggests that this approach is effective for neurocognitive stimulation in older adults with dementia, contributing to the maintenance of cognitive function in AD.

These successful studies and pilots highlight the transformative potential of augmented reality (AR) and virtual reality (VR) technologies in improving the well-being and quality of life of older adults in residential care settings. From cognitive rehabilitation and the promotion of physical activity to social engagement and emotional well-being, AR and VR technology has made it possible to create versatile solutions to meet the diverse needs of the elderly, with the aim of creating greater independence, autonomy and a better quality of life.

Projects implemented in the real world demonstrate the feasibility, acceptability, and effectiveness of AR and VR technologies in supporting various aspects of senior living[21], from everyday activities to specialized sessions targeted at specific health conditions.

The positive results observed in different studies highlight the importance of personalized, person-centred approaches to AR and VR exercises, taking into account the unique preferences, abilities and goals of older adults.

In terms of future prospects, we believe that this is an area of research in full development, and that it will be possible to harness much of the potential of AR and VR technologies in elderly care settings. This includes developing new applications, refining intervention protocols, and addressing technical and usage challenges to improve accessibility and scalability. Similarly, we advocate that collaboration between researchers, practitioners, industry stakeholders and older adults themselves, are essential to co-create and implement AR and VR solutions that truly meet the needs and aspirations of older adults living in residential care facilities.

---

[20] Bibliografia: Oliveira et. al. (2010). Virtual Reality-Based Cognitive Stimulation on People with Mild to Moderate Dementia due to Alzheimer's Disease: A Pilot Randomized Controlled Trial. Int. J. Environ. Res. Public Health 2021, 18, 5290. https://doi.org/10.3390/ijerph18105290.
[21] See Annex 1.

In our view, the successful case studies and pilot projects highlighted at this point serve as inspiring examples of how AR and VR technologies can empower older people to live fulfilling and meaningful lives, particularly in a senior housing setting. By embracing innovation and leveraging the implementation of solutions with AR and VR, we can continue to advance the field of aged care and promote health, well-being, and dignity for all older adults.

## MAIN CHALLENGES FOR IMPLEMENTATION

To complete this study, it is important to understand the main challenges currently faced in the implementation of AR and VR technologies in the elderly population.

Augmented reality (AR) and virtual reality (VR) technologies hold immense promise for improving various aspects of elderly care, from cognitive rehabilitation to social engagement and the promotion of physical activity, as demonstrated in the literature consulted. However, the successful implementation of AR and VR therapies in the elderly faces several challenges. In this chapter, we list some of the main obstacles and considerations that hinder the widespread adoption and use of AR and VR technologies among older adults:

— **Device rejection**

One of the main challenges to the implementation of AR and VR technologies in elderly care is the potential resistance or rejection of these devices. Seniors may perceive AR and VR devices as unfamiliar or intimidating, leading to a reluctance to use them (Czaja et al., 2018) . Concerns about complexity, use, and discomfort may further contribute to device rejection among older adults, impacting the efficacy and acceptance of AR and VR interventions (Creed et al., 2023).

— **Health Issues**

Health problems, including visual impairments, vestibular disorders, and motion sickness, may pose significant barriers to the use of AR and VR technologies in the elderly population. Visual impairments, such as reduced acuity and contrast sensitivity, can affect the ability of older adults to perceive and interact effectively with AR and VR content. Similarly, vestibular disorders and motion sickness can exacerbate discomfort and disorientation when using VR headsets, limiting the feasibility and acceptance of VR sessions (Bennett et al., 2019) (Doré et al., 2023).

— **Technical Challenges**

Technical challenges related to hardware limitations, software compatibility, and connectivity issues can hinder the implementation of AR and VR technologies in aged care settings. Older adults may encounter difficulties in setting up and calibrating AR and VR devices, requiring additional support and assistance from caregivers or technical staff

In addition, compatibility issues between AR and VR platforms, applications, and operating systems can hinder seamless integration and interoperability, complicating the implementation of AR and VR interventions (Torous et al., 2019). (Nazar & Subash, 2024; Tusher et al., 2024).

— **Cost and accessibility**

Cost considerations and accessibility barriers pose important challenges to the implementation of AR and VR technologies in aged care facilities. The high cost of AR and VR devices, software licenses, and technical support services can limit their accessibility and availability, especially for smaller or resource-poor organizations (Chirico et al., 2023) . On the other hand, accessibility concerns related to physical disabilities, cognitive impairments, and language barriers may further restrict older adults' access to AR and VR therapies, exacerbating disparities in technology adoption and health outcomes (Hung et al., 2023).

— **Ethical issues**

Ethical considerations surrounding the use of AR and VR technologies in elder care should also be addressed. These considerations include issues related to privacy, data security, informed consent, and potential unintended psychological effects or manipulation. Careful attention should be paid to ensure that the use of AR and VR follows ethical principles, respects the autonomy and dignity of older adults, and prioritizes their well-being (Creed et al., 2023b; Parsons, 2021; Zhou et al., 2023).

Another fundamental aspect is related to health issues beyond those described above. Several health problems, such as vestibular disorders and motion sickness, may represent important barriers to the use of AR and VR technologies among the senior population. These and other medical conditions can affect the feasibility, safety, and efficacy of AR and VR therapies, requiring careful consideration and adaptation of technology-based solutions. Among the most relevant physical conditions, we highlight: epilepsy and migraines, heart disease and other similar diseases and conditions. (Doré et al., 2023; Wang et al., 2023)

People with epilepsy or migraines may be sensitive to certain visual stimuli, such as flashing lights or rapid movements, which can trigger seizures or headaches. Therefore, AR and VR content should avoid elements that may cause adverse reactions in susceptible individuals. Individuals with epilepsy should also be closely monitored during VR experiences to ensure their safety and well-being. (Brinciotti et al., 2021; D’Agnano et al., 2023; Fisher et al., 2022; Gray et al., 2023)

On the other hand, seniors with heart conditions, such as arrhythmias or cardiovascular disease, may be at risk of experiencing adverse cardiovascular events during immersive VR experiences. Prolonged exposure to VR environments with intense physical activity or emotional stress can exacerbate underlying heart problems and should be avoided or carefully monitored (Bouraghi et al., 2023; Micheluzzi et al., 2024; Szczepańska-Gieracha et al., 2021) . Hence, healthcare professionals should assess the cardiac health of older adults before recommending VR interventions and providing appropriate guidance and supervision.

Cognitive impairments, such as dementia or Alzheimer's disease, can affect users' ability to navigate AR and VR interfaces or understand complex instructions (Cushman et al., 2008; Matsangidou et al., 2023; Wenk et al., 2023) . Interventions and adaptations should be made according to the specific needs and challenges of individuals with these disabilities. Hence, despite the immense potential of AR and VR technologies in aged care, several challenges must be addressed to facilitate their successful implementation and widespread adoption. By understanding and addressing issues related to device rejection, health considerations, technical challenges, and cost and accessibility barriers, investigators, practitioners, and policymakers, can work together to overcome these obstacles and harness the transformative power of AR and VR technologies. (Babalola et al., 2023; Creed et al., 2023a; Hung et al., 2023)

## FINAL THOUGHTS

From the literature consulted, we can infer that the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies in the context of senior care holds great promise for improving the well-being and quality of life of the elderly.

Regarding the benefits of AR and VR, the use of these technologies allows the development of innovative solutions to work on various aspects of elderly care, including cognitive rehabilitation, the promotion of physical activity, social engagement and emotional well-being. These technologies have been shown to be effective in improving cognitive function, reducing incidents of falls, improving social interaction, and promoting relaxation among the elderly.

Through the successful case studies and pilot projects, it was possible to highlight several key ideas about the potential benefits and considerations of AR and VR exercises in elderly care.

From the point of view of challenges, it is observed that despite the benefits evidenced, the implementation of AR and VR technologies faces several obstacles, such as device rejection, health problems, technical challenges, and cost and accessibility barriers. Resolving these obstacles, especially those external to the elderly, is crucial to ensure the successful adoption and use of AR and VR sessions in an aged care setting.

From our point of view, another very relevant aspect in this context is the future trends of Extended or Extended Reality (XR) for elderly patients. This field, which as we have seen, encompasses AR, VR and mixed reality (MR), is poised to advance further into the field of elderly care. Future trends in XR for elderly patients may include:

- **Personalized workouts:** Using advanced data analytics and machine learning algorithms to tailor AR and VR sessions to individual preferences, abilities, and health needs.
- **Immersive experiences:** Improving the realism and engagement of AR and VR experiences through the development of immersive technologies such as haptic feedback, spatial audio, and 'photorealistic' graphics.
- **Remote monitoring and telehealth**: Integration of AR and VR technologies into telehealth platforms to enable remote monitoring, assessment, and care for elderly patients in their homes or residential care facilities.
- **Therapeutic applications:** Development of novel therapeutic applications of AR and VR in elderly care, including pain management, stress reduction, reminiscence therapy, and mindfulness training.
- **Social Relationships:** Leverage AR and VR to facilitate social relationships and community engagement among isolated or homebound older adults through virtual socialization, group activities, and shared experiences.

At the same time, it is expected that future studies will focus on investigating the long-term effects and sustainability of AR and VR therapies on health outcomes and quality of life of older adults, such as understanding the mechanisms underlying the therapeutic benefits of AR and VR technologies, including neurobiological, psychological, and social factors; address disparities in access to and uptake of AR and VR therapies among diverse older adult populations, including those with physical disabilities, cognitive impairments, and socioeconomic disadvantages; develop evidence-based guidelines and best practices for the design, implementation, and evaluation of AR and VR exercises in aged care settings.

At the same time, the successful implementation of extended reality therapies in elderly care requires the expertise of appropriately trained therapists who can tailor interventions to the needs and cognitive abilities of each patient, collaborating closely with neurologists to ensure alignment between clinical goals and neurological considerations.

Finally, it should be noted that this state-of-the-art study and literature review was carried out in the context of a proposal for the implementation of the initiative 'MindScape – Augmented Reality and Virtual Reality Project' in a senior residence located in the city of Porto, Portugal. The main objective of the initiative is to harness the power of augmented reality and virtual reality technology to improve the cognitive well-being of hospitalized seniors. After the pilot test, to be carried out in the second half of 2024, it is intended to extend the experience to other Portuguese senior residences, through the implementation of properly structured and monitored programs. The pilot project of the 'MindScape' initiative will have the collaboration of psychologists, therapists and university students on *a pro bono basis,* and with the financial sponsorship of the Positive Life Association. In the future, an application will be submitted for funds made available by the European Union, within the scope of *Digital Health* or Social Economy programs, which will allow the project to be scaled in order to replicate it in as many Portuguese senior institutions as possible.

## REFERENCES


1. Alzahrani, N. M. (2020). Augmented Reality: A Systematic Review of Its Benefits and Challenges in E-learning Contexts. *Applied Sciences, 10*(16), 5660. https://doi.org/10.3390/app10165660

2. Ansado, J., Chasen, C., Northoff, G., Bouchard, S., & Brulé, J. (2018). The Virtual Reality Working-Memory-Training Program (VR WORK M): Description of an individualized, integrated program. *Annual Review of CyberTherapy and Telemedicine, 16*, 101–108.

3. Babalola, A., Manu, P., Cheung, C., Yunusa-Kaltungo, A., & Bartolo, P. (2023). A systematic review of the application of immersive technologies for safety and health management in the construction sector. *Journal of Safety Research, 85*, 66–85. https://doi.org/10.1016/j.jsr.2023.01.007

4. Bennett, C. R., Bex, P. J., Bauer, C. M., & Merabet, L. B. (2019). The Assessment of Visual Function and Functional Vision. *Seminars in Pediatric Neurology, 31*, 30–40. https://doi.org/10.1016/j.spen.2019.05.006

5. Betts, K., Reddy, P., Galoyan, T., Delaney, B., McEachron, D. L., Izzetoglu, K., & Shewokis, P. A. (2023). An Examination of the Effects of Virtual Reality Training on Spatial Visualization and Transfer of Learning. *Brain Sciences, 13*(6), 890. https://doi.org/10.3390/brainsci13060890

6. Bouraghi, H., Mohammadpour, A., Khodaveisi, T., Ghazisaeedi, M., Saeedi, S., & Familgarosian, S. (2023). Virtual Reality and Cardiac Diseases: A Systematic Review of Applications and Effects. *Journal of Healthcare Engineering, 2023*, 1–20. https://doi.org/10.1155/2023/8171057

7. Brinciotti, M., Wilkins, A. J., Penacchio, O., & Matricardi, M. (2021). Pattern-sensitive patients with epilepsy use uncomfortable visual stimuli to self-induce seizures. *Epilepsy & Behavior, 122*, 108189. https://doi.org/10.1016/j.yebeh.2021.108189

8. Buchner, J., Buntins, K., & Kerres, M. (2022). The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning, 38*(1), 285–303. https://doi.org/10.1111/jcal.12617

9. Caglio, M., Latini-Corazzini, L., D'Agata, F., Cauda, F., Sacco, K., Monteverdi, S., Zettin, M., Duca, S., & Geminiani, G. (2012). Virtual navigation for memory rehabilitation in a traumatic brain injured patient. *Neurocase, 18*(2), 123–131. https://doi.org/10.1080/13554794.2011.568499

10. Chang, Y.-J., Kang, Y.-S., & Huang, P.-C. (2013). An augmented reality (AR)-based vocational task prompting system for people with cognitive impairments. *Research in Developmental Disabilities, 34*(10), 3049–3056. https://doi.org/10.1016/j.ridd.2013.06.026

11. Chirico, A., Avellone, M., Palombi, T., Alivernini, F., Alessandri, G., Filosa, L., Pistella, J., Baiocco, R., & Lucidi, F. (2023). Exploring the Psychological Nexus of Virtual and Augmented Reality on Physical Activity in Older Adults: A Rapid Review. *Behavioral Sciences, 14*(1), 31. https://doi.org/10.3390/bs14010031

12. Cimadevilla, J. M., Nori, R., & Piccardi, L. (2023). Application of Virtual Reality in Spatial Memory. *Brain Sciences, 13*(12), 1621. https://doi.org/10.3390/brainsci13121621

13. Clare, L., & Woods, B. (2003). Cognitive rehabilitation and cognitive training for early-stage Alzheimer's disease and vascular dementia. In L. Clare (Ed.), *Cochrane Database of Systematic Reviews*. John Wiley & Sons, Ltd. https://doi.org/10.1002/14651858.CD003260

14. Coughlan, G., Laczó, J., Hort, J., Minihane, A.-M., & Hornberger, M. (2018). Spatial navigation deficits — overlooked cognitive marker for preclinical Alzheimer disease? *Nature Reviews Neurology, 14*(8), 496–506. https://doi.org/10.1038/s41582-018-0031-x

15. Creed, C., Al-Kalbani, M., Theil, A., Sarcar, S., & Williams, I. (2023a). Inclusive Augmented and Virtual Reality: A Research Agenda. *International Journal of Human–Computer Interaction*, 1–20. https://doi.org/10.1080/10447318.2023.2247614

16. Creed, C., Al-Kalbani, M., Theil, A., Sarcar, S., & Williams, I. (2023b). Inclusive Augmented and Virtual Reality: A Research Agenda. *International Journal of Human–Computer Interaction*, 1–20. https://doi.org/10.1080/10447318.2023.2247614

17. Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*(12), 888–895. https://doi.org/10.1212/01.wnl.0000326262.67613.fe

18. Czaja, S. J., Boot, W. R., Charness, N., Rogers, W. A., & Sharit, J. (2018). Improving Social Support for Older Adults Through Technology: Findings From the PRISM Randomized Controlled Trial. *The Gerontologist, 58*(3), 467–477. https://doi.org/10.1093/geront/gnw249

19. D'Agnano, D., Lo Cascio, S., Correnti, E., Raieli, V., & Sciruicchio, V. (2023). A Narrative Review of Visual Hallucinations in Migraine and Epilepsy: Similarities and Differences in Children and Adolescents. *Brain Sciences, 13*(4), 643. https://doi.org/10.3390/brainsci13040643

20. De Luca, R., Bonanno, M., Marra, A., Rifici, C., Pollicino, P., Caminiti, A., Castorina, M. V., Santamato, A., Quartarone, A., & Calabrò, R. S. (2023). Can Virtual Reality Cognitive Rehabilitation Improve Executive Functioning and Coping Strategies in Traumatic Brain Injury? A Pilot Study. *Brain Sciences, 13*(4), 578. https://doi.org/10.3390/brainsci13040578

21. Dingler, T., Agroudy, P. El, Rzayev, R., Lischke, L., Machulla, T., & Schmidt, A. (2021). Memory Augmentation Through Lifelogging: Opportunities and Challenges (pp. 47–69). https://doi.org/10.1007/978-3-030-30457-7_3

22. Doré, B., Gaudreault, A., Everard, G., Ayena, J. C., Abboud, A., Robitaille, N., & Batcho, C. S. (2023). Acceptability, Feasibility, and Effectiveness of Immersive Virtual Technologies to Promote Exercise in Older Adults: A Systematic Review and Meta-Analysis. *Sensors, 23*(5), 2506. https://doi.org/10.3390/s23052506

23. Fick, T., van Doormaal, J. A. M., Hoving, E. W., Willems, P. W. A., & van Doormaal, T. P. C. (2021). Current Accuracy of Augmented Reality Neuronavigation Systems: Systematic Review and Meta-Analysis. *World Neurosurgery, 146*, 179–188. https://doi.org/10.1016/j.wneu.2020.11.029

24. Fisher, R. S., Acharya, J. N., Baumer, F. M., French, J. A., Parisi, P., Solodar, J. H., Szaflarski, J. P., Thio, L. L., Tolchin, B., Wilkins, A. J., & Kasteleijn-Nolst Trenité, D. (2022). Visually sensitive seizures: An updated review by the Epilepsy Foundation. *Epilepsia, 63*(4), 739–768. https://doi.org/10.1111/epi.17175

25. Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., & Slater, M. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine, 47*(14), 2393–2400. https://doi.org/10.1017/S003329171700040X

26. Geisen, M., & Klatt, S. (2022). Real-time feedback using extended reality: A current overview and further integration into sports. *International Journal of Sports Science & Coaching, 17*(5), 1178–1194. https://doi.org/10.1177/17479541211051006

27. Gray, H. G., Tchao, D., Lewis-Fung, S., Pardini, S., Harris, L. R., & Appel, L. (2023). Virtual Reality Therapy for People With Epilepsy and Related Anxiety: Protocol for a 3-Phase Pilot Clinical Trial. *JMIR Research Protocols, 12*, e41523. https://doi.org/10.2196/41523

28. Guntur, M. I. S., Setyaningrum, W., Retnawati, H., & Marsigit. (2020). Can augmented reality improve problem-solving and spatial skill? *Journal of Physics: Conference Series, 1581*(1), 012063. https://doi.org/10.1088/1742-6596/1581/1/012063

29. Han, K., Park, K., Choi, K.-H., & Lee, J. (2021). Mobile Augmented Reality Serious Game for Improving Old Adults' Working Memory. *Applied Sciences, 11*(17), 7843. https://doi.org/10.3390/app11177843

30. He, D., Cao, S., Le, Y., Wang, M., Chen, Y., & Qian, B. (2022). Virtual Reality Technology in Cognitive Rehabilitation Application: Bibliometric Analysis. *JMIR Serious Games, 10*(4), e38315. https://doi.org/10.2196/38315

31. Hoe, Z.-Y., Lee, I.-J., Chen, C.-H., & Chang, K.-P. (2019). Using an augmented reality-based training system to promote spatial visualization ability for the elderly. *Universal Access in the Information Society, 18*(2), 327–342. https://doi.org/10.1007/s10209-017-0597-x

32. Hoppenstedt, E., Radu, I., Schneider, B., & Joy, T. (2021). Augmented Reality in Collaborative Problem Solving: A Qualitative Study of Challenges and Solutions. *CSCL 2021 Proceedings*.

33. Hung, L., Mann, J., Wallsworth, C., Upreti, M., Kan, W., Temirova, A., Wong, K. L. Y., Ren, H., To-Miles, F., Wong, J., Lee, C., Kar Lai So, D., & Hardern, S. (2023). Facilitators and Barriers to Using Virtual Reality and its Impact on Social Engagement in Aged Care Settings: A Scoping Review. *Gerontology and Geriatric Medicine, 9*, 233372142311663. https://doi.org/10.1177/23337214231166355

34. Ibrahim, M. S., Mattar, A. G., & Elhafez, S. M. (2016). Efficacy of virtual reality-based balance training versus the Biodex balance system training on the body balance of adults. *Journal of Physical Therapy Science, 28*(1), 20–26. https://doi.org/10.1589/jpts.28.20

35. Iriarte, Y., Diaz-Orueta, U., Cueto, E., Irazustabarrena, P., Banterla, F., & Climent, G. (2016). AULA—Advanced Virtual Reality Tool for the Assessment of Attention. *Journal of Attention Disorders, 20*(6), 542–568. https://doi.org/10.1177/1087054712465335

36. Ishibashi, G. A., Santos, G. dos, Moreira, A. P. B., Verga, C. E. R., Silva, G. A. da, Ordonez, T. N., Moraes, L. C. de, Lessa, P. P., Brucki, S. M. D., & Silva, T. B. L. da. (2023). Effects of cognitive interventions with video games on cognition in healthy elderly people: a systematic review. *Arquivos de Neuro-Psiquiatria, 81*(05), 484–491. https://doi.org/10.1055/s-0043-1764413

37. Jiang, J.-R., & Subakti, H. (2023). An Indoor Location-Based Augmented Reality Framework. *Sensors, 23*(3), 1370. https://doi.org/10.3390/s23031370

38. Keil, J., Korte, A., Ratmer, A., Edler, D., & Dickmann, F. (2020). Augmented Reality (AR) and Spatial Cognition: Effects of Holographic Grids on Distance Estimation and Location Memory in a 3D Indoor Scenario. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, 88*(2), 165–172. https://doi.org/10.1007/s41064-020-00104-1

39. Khan, D., Cheng, Z., Uchiyama, H., Ali, S., Asshad, M., & Kiyokawa, K. (2022). Recent advances in vision-based indoor navigation: A systematic literature review. *Computers & Graphics, 104*, 24–45. https://doi.org/10.1016/j.cag.2022.03.005

40. Kim, D.-R., Moon, E., Shin, M.-J., Yang, Y.-A., & Park, J.-H. (2023). Effect of Individual Virtual Reality Cognitive Training Programs on Cognitive Function and Depression in Middle-Aged Women: Randomized Controlled Trial. *JMIR Mental Health, 10*, e48912. https://doi.org/10.2196/48912

41. Kim, H., Jung, J., & Lee, S. (2022). Therapeutic Application of Virtual Reality in the Rehabilitation of Mild Cognitive Impairment: A Systematic Review and Meta-Analysis. *Vision, 6*(4), 68. https://doi.org/10.3390/vision6040068

42. Lazar, A., Thompson, H., & Demiris, G. (2014). A Systematic Review of the Use of Technology for Reminiscence Therapy. *Health Education & Behavior, 41*(1_suppl), 51S-61S. https://doi.org/10.1177/1090198114537067

43. Lee, I.-J., Chen, C.-H., & Chang, K.-P. (2016). Augmented reality technology combined with three-dimensional holography to train the mental rotation ability of older adults. *Computers in Human Behavior, 65*, 488–500. https://doi.org/10.1016/j.chb.2016.09.014

44. Liao, Y.-Y., Chen, I.-H., Lin, Y.-J., Chen, Y., & Hsu, W.-C. (2019). Effects of Virtual Reality-Based Physical and Cognitive Training on Executive Function and Dual-Task Gait Performance in Older Adults With Mild Cognitive Impairment: A Randomized Control Trial. *Frontiers in Aging Neuroscience, 11*. https://doi.org/10.3389/fnagi.2019.00162

45. Liu, C., Huot, S., Diehl, J., Mackay, W., & Beaudouin-Lafon, M. (2012). Evaluating the benefits of real-time feedback in mobile augmented reality with hand-held devices. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2973–2976. https://doi.org/10.1145/2207676.2208706

46. Manasse, S. M., Trainor, C., Payne-Reichert, A., Abber, S. R., Lampe, E. W., Gillikin, L. M., Juarascio, A. S., & Forman, E. M. (2023). Does virtual reality enhance the effects of inhibitory control training for loss-of-control eating? A pilot factorial experiment. *Eating Behaviors, 50*, 101749. https://doi.org/10.1016/j.eatbeh.2023.101749

47. Maples-Keller, J. L., Bunnell, B. E., Kim, S.-J., & Rothbaum, B. O. (2017). The Use of Virtual Reality Technology in the Treatment of Anxiety and Other Psychiatric Disorders. *Harvard Review of Psychiatry, 25*(3), 103–113. https://doi.org/10.1097/HRP.0000000000000138

48. Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023a). Crafting Immersive Experiences: A Multi-Layered Conceptual Framework for Personalized and Gamified Virtual Reality Applications in Education (pp. 230–241). https://doi.org/10.1007/978-3-031-44097-7_25

49. Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023b). How personalized and effective is immersive virtual reality in education? A systematic literature review for the last

decade. *Multimedia Tools and Applications, 83*(6), 18185–18233. https://doi.org/10.1007/s11042-023-15986-7

50. Matsangidou, M., Solomou, T., Frangoudes, F., Ioannou, K., Theofanous, P., Papayianni, E., & Pattichis, C. S. (2023). Affective Out-World Experience via Virtual Reality for Older Adults Living with Mild Cognitive Impairments or Mild Dementia. *International Journal of Environmental Research and Public Health, 20*(4), 2919. https://doi.org/10.3390/ijerph20042919

51. Micheluzzi, V., Navarese, E. P., Merella, P., Talanas, G., Viola, G., Bandino, S., Idini, C., Burrai, F., & Casu, G. (2024). Clinical application of virtual reality in patients with cardiovascular disease: state of the art. *Frontiers in Cardiovascular Medicine, 11*. https://doi.org/10.3389/fcvm.2024.1356361

52. Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems, E77*(D), 1321–1329. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.102.4646

53. Moulaei, K., Sharifi, H., Bahaadinbeigy, K., & Dinari, F. (2024). Efficacy of virtual reality-based training programs and games on the improvement of cognitive disorders in patients: a systematic review and meta-analysis. *BMC Psychiatry, 24*(1), 116. https://doi.org/10.1186/s12888-024-05563-z

54. Nazar, N., & Subash, Dr. T. D. (2024). Navigating Augmented Realities: A Review Of Advancements, Applications, And Future Prospects Article. *Educational Administration: Theory and Practice, 4182–4182–4186*. https://doi.org/10.53555/kuey.v30i4.2173

55. Oei, A. C., & Patterson, M. D. (2013). Enhancing Cognition with Video Games: A Multiple Game Training Study. *PLoS ONE, 8*(3), e58546. https://doi.org/10.1371/journal.pone.0058546

56. Oh, S. H., Park, J. W., & Cho, S.-J. (2022). Effectiveness of the VR Cognitive Training for Symptom Relief in Patients with ADHD. *Journal of Web Engineering*. https://doi.org/10.13052/jwe1540-9589.21310

57. Park, J.-H. (2022). Effects of virtual reality-based spatial cognitive training on hippocampal function of older adults with mild cognitive impairment. *International Psychogeriatrics, 34*(2), 157–163. https://doi.org/10.1017/S1041610220001131

58. Parsons, T. D. (2021). Ethical Challenges of Using Virtual Environments in the Assessment and Treatment of Psychopathological Disorders. *Journal of Clinical Medicine, 10*(3), 378. https://doi.org/10.3390/jcm10030378

59. Parsons, T. D., Bowerly, T., Buckwalter, J. G., & Rizzo, A. A. (2007). A Controlled Clinical Comparison of Attention Performance in Children with ADHD in a Virtual Reality Classroom Compared to Standard Neuropsychological Methods. *Child Neuropsychology, 13*(4), 363–381. https://doi.org/10.1080/13825580600943473

60. Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., & Piolino, P. (2012). Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. *Neuropsychologia, 50*(5), 592–602. https://doi.org/10.1016/j.neuropsychologia.2011.12.013

61. Prats-Bisbe, A., López-Carballo, J., García-Molina, A., Leno-Colorado, D., García-Rudolph, A., Opisso, E., & Jané, R. (2024). Virtual Reality–Based Neurorehabilitation Support Tool for People With Cognitive Impairments Resulting From an Acquired Brain Injury: Usability and Feasibility Study. *JMIR Neurotechnology, 3*, e50538. https://doi.org/10.2196/50538

62. Ren, Y., Wang, Q., Liu, H., Wang, G., & Lu, A. (2024). Effects of immersive and non-immersive virtual reality-based rehabilitation training on cognition, motor function, and daily functioning in patients with mild cognitive impairment or dementia: A systematic review and meta-analysis. *Clinical Rehabilitation, 38*(3), 305–321. https://doi.org/10.1177/02692155231213476

63. Riva, G., Baños, R. M., Botella, C., Wiederhold, B. K., & Gaggioli, A. (2012). Positive Technology: Using Interactive Technologies to Promote Positive Functioning. *Cyberpsychology, Behavior, and Social Networking, 15*(2), 69–77. https://doi.org/10.1089/cyber.2011.0139

64. Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., & Penn, P. R. (2000). Training in virtual environments: transfer to real world tasks and equivalence to real task training. *Ergonomics, 43*(4), 494–511. https://doi.org/10.1080/001401300184378

65. Sadeghi, H., Jehu, D. A., Daneshjoo, A., Shakoor, E., Razeghi, M., Amani, A., Hakim, M. N., & Yusof, A. (2021). Effects of 8 Weeks of Balance Training, Virtual Reality Training, and Combined Exercise on Lower Limb Muscle Strength, Balance, and Functional Mobility Among Older Men: A Randomized Controlled Trial. *Sports Health: A Multidisciplinary Approach, 13*(6), 606–612. https://doi.org/10.1177/1941738120986803

66. Serino, S., Pedroli, E., Tuena, C., De Leo, G., Stramba-Badiale, M., Goulene, K., Mariotti, N. G., & Riva, G. (2017). A Novel Virtual Reality-Based Training Protocol for the Enhancement of the "Mental Frame Syncing" in Individuals with Alzheimer's Disease: A Development-of-Concept Trial. *Frontiers in Aging Neuroscience, 9*. https://doi.org/10.3389/fnagi.2017.00240

67. Sheldon, S., Williams, K., Harrington, S., & Otto, A. R. (2020). Emotional cue effects on accessing and elaborating upon autobiographical memories. *Cognition, 198*, 104217. https://doi.org/10.1016/j.cognition.2020.104217

68. Skarbez, R., Smith, M., & Whitton, M. C. (2021). Revisiting Milgram and Kishino's Reality-Virtuality Continuum. *Frontiers in Virtual Reality, 2*. https://doi.org/10.3389/frvir.2021.647997

69. Steuer, J. (1992). Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication, 42*(4), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x

70. Szczepańska-Gieracha, J., Jóźwik, S., Cieślik, B., Mazurek, J., & Gajda, R. (2021). Immersive Virtual Reality Therapy as a Support for Cardiac Rehabilitation: A Pilot Randomized-Controlled Trial. *Cyberpsychology, Behavior, and Social Networking, 24*(8), 543–549. https://doi.org/10.1089/cyber.2020.0297

72. Thapa, N., Park, H. J., Yang, J.-G., Son, H., Jang, M., Lee, J., Kang, S. W., Park, K. W., & Park, H. (2020a). The Effect of a Virtual Reality-Based Intervention Program on Cognition in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial. *Journal of Clinical Medicine, 9*(5), 1283. https://doi.org/10.3390/jcm9051283

73. Thapa, N., Park, H. J., Yang, J.-G., Son, H., Jang, M., Lee, J., Kang, S. W., Park, K. W., & Park, H. (2020b). The Effect of a Virtual Reality-Based Intervention Program on Cognition in Older

Adults with Mild Cognitive Impairment: A Randomized Control Trial. *Journal of Clinical Medicine, 9*(5), 1283. https://doi.org/10.3390/jcm9051283

74. Torous, J., Wisniewski, H., Bird, B., Carpenter, E., David, G., Elejalde, E., Fulford, D., Guimond, S., Hays, R., Henson, P., Hoffman, L., Lim, C., Menon, M., Noel, V., Pearson, J., Peterson, R., Susheela, A., Troy, H., Vaidyam, A., … Keshavan, M. (2019). Creating a Digital Health Smartphone App and Digital Phenotyping Platform for Mental Health and Diverse Healthcare Needs: an Interdisciplinary and Collaborative Approach. *Journal of Technology in Behavioral Science, 4*(2), 73–85. https://doi.org/10.1007/s41347-019-00095-w

75. Tortora, C., Di Crosta, A., La Malva, P., Prete, G., Ceccato, I., Mammarella, N., Di Domenico, A., & Palumbo, R. (2024). Virtual reality and cognitive rehabilitation for older adults with mild cognitive impairment: A systematic review. *Ageing Research Reviews, 93*, 102146. https://doi.org/10.1016/j.arr.2023.102146

76. Tusher, H. M., Mallam, S., & Nazir, S. (2024). A Systematic Review of Virtual Reality Features for Skill Training. *Technology, Knowledge and Learning*. https://doi.org/10.1007/s10758-023-09713-2

77. Wang, C., Kong, J., & Qi, H. (2023). Areas of Research Focus and Trends in the Research on the Application of VR in Rehabilitation Medicine. *Healthcare, 11*(14), 2056. https://doi.org/10.3390/healthcare11142056

78. Wenk, N., Penalver-Andres, J., Buetler, K. A., Nef, T., Müri, R. M., & Marchal-Crespo, L. (2023). Effect of immersive visualization technologies on cognitive load, motivation, usability, and embodiment. *Virtual Reality, 27*(1), 307–331. https://doi.org/10.1007/s10055-021-00565-8

79. WHO. (2024, March 3). Rehabilitation 2030 initiative. https://www.who.int/initiatives/rehabilitation-2030

80. Yu, D., Li, X., & Lai, F. H. (2023). The effect of virtual reality on executive function in older adults with mild cognitive impairment: a systematic review and meta-analysis. *Aging & Mental Health, 27*(4), 663–673. https://doi.org/10.1080/13607863.2022.2076202

81. Zhou, S., Gromala, D., & Wang, L. (2023). Ethical Challenges of Virtual Reality Technology Interventions for the Vulnerabilities of Patients With Chronic Pain: Exploration of Technician Responsibility. *Journal of Medical Internet Research, 25*, e49237. https://doi.org/10.2196/49237

82. Zhu, K., Lin, R., & Li, H. (2022). Study of virtual reality for mild cognitive impairment: A bibliometric analysis using CiteSpace. *International Journal of Nursing Sciences, 9*(1), 129–136. https://doi.org/10.1016/j.ijnss.2021.12.007

83. Zulueta, A., Díaz-Orueta, U., Crespo-Eguilaz, N., & Torrano, F. (2018). Virtual Reality-based Assessment and Rating Scales in ADHD Diagnosis. *Psicología Educativa, 25*(1), 13–22. https://doi.org/10.5093/psed2018a18