Chapter 13
Usability and Applications of Virtual and Augmented Reality in Older Adults

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ABSTRACT

Virtual reality (VR) and augmented reality (AR) have been explored to be an effective alternative to integrating mental health intervention proposals, particularly in eldercare. The objective is to map the usability and applications of VR and AR technologies in interventions for the elderly population. The main areas of interventions in AR and VR applied to the elderly are stimulation and cognitive rehabilitation, physical rehabilitation, treatment of mental diseases, and promotion of quality of life. Despite the need for further studies, VR and AR have strong adherence among the elderly and demonstrate promising potential in interventions that seek to promote mental health and improve the quality of life.

INTRODUCTION

The growth of the elderly population has been increasingly noticeable due to the increase in life expectancy. The World Health Organization points out in its World Report on Aging and Health (WHO, 2015) that there was a significant increase in population aging, where one out of five people is aged 60 and over. It is necessary, then, to think about new forms of social functioning through actions and

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interventions that promote the health and autonomy of the elderly. Technological resources appear as an effective alternative in optimizing care for the elderly since they can overcome barriers such as cost, durability, and reach. These advantages have been enhanced due to the current global health conjecture, where contact between health professionals and patients has been restricted or drastically reduced (Ferreira-Brito et al., 2020).

Aging is a natural human course characterized by a decline in physical, sensory, and mental capacities (Tuena et al., 2020). In addition to the deficits arising from the normal aging process, some dysfunctions are commonly present among the elderly population, such as Alzheimer's disease, mild cognitive impairment (MCI) and Parkinson's disease. Thus, it is a priority to take care of this population's health and promote actions that keep them healthy and active (WHO, 2015). In this sense, although the idea of the elderly interacting voluntarily and masterfully with technological devices is unthinkable for some (Wiederhold, 2020), many studies have been conducted, and new technologies are being developed to address problems associated with the physical and mental abilities of the elderly, aiming to improve their quality of life (Lee et al., 2019).

New technologies are consolidated as an effective alternative in integrating intervention proposals with the elderly, especially in mental health. Virtual reality (VR) and augmented reality (AR) are technologies characterized by having components of visual, tactile, and kinesthetic perception, very similar to the real world (Malik et al., 2013; Optale et al., 2010). Prata et. al. (2018, p. 203) define VR as "a computer-generated self-contained digital world, consequently, virtual reality in a game is another powerful resource for the game designer to provides a richer and deeper player experience for the player because the entire "world" that the game is taken place is under his/her control. According to Grabowski (2020, p.01), VR technology is a form of illusion, a tool capable of replacing the real world with a virtual world fabricated using an electronic device such as a computer. The author explains that VR is commonly characterized by "Head-Mounted Display goggles equipped with one or two screens that display a computer-generated image. The image is generally stereoscopic, which means that it depicts slightly different images for each eye to simulate the impression of spatial vision". Augmented Reality is defined by Azuma (1997) as a variation of a virtual environment where there is no total immersion. While using an AR resource, the user is able to see the real world in an integrated manner with the virtual environment and virtual objects (or images) are just superimposed or composited with the real world. To be considered an AR system, this technology must combine the real and virtual environments, it must be interactive in real time and provide a 3D registration of virtual and real objects.

Both VR and AR have been widely explored for promoting, through their power of immersion and stimulation, several positive experiences for different audiences, in other contexts, such as the improvement of physical, psychological, and social factors; treatment of symptoms associated with stress and trauma (Dibbets, 2019; Zimmer et al., 2019); cognitive assessment and rehabilitation (Tuena et al., 2020); contribution to the treatment of schizophrenia (Dyck et al., 2010; Macedo et al., 2015); and disaster training with students (Caroca et al., 2016).

Current research indicates that the use of VR and AR to treat disorders such as depression and anxiety among the elderly emerges among the new evidence-based practices, with promising results and strong adherence among this population, going against the stereotype that the elderly are not adapt or are not attracted to technologies (Bhar et al., 2020).

In recent years, a multiplicity of studies on AR and VR interventions and experience have been produced (Mascret et al., 2020; Merriman et al., 2018); focused on increasing confidence and balance to prevent falls (Bakker et al., 2020; Chen et al., 2020); dementia (Sari et al., 2020); well-being and

quality of life applied to the elderly (Barsasella et al., 2021). Therefore, the use of technologies shows promising potential in interventions that seek to promote mental health, rehabilitation, and this population's quality of life improvement.

The main objective of this review is to map and present, in a descriptive way, the available evidence about the usability and applicability of VR and AR technologies in interventions aimed at mental health and psychosocial rehabilitation of the elderly population.

VIRTUAL AND AUGMENTED REALITY AMONG OLDER ADULTS

In the last few years, there has been an increase in virtual reality and augmented reality investigation as an intervention for the elderly population to develop physical and mental health. The results found in this review confirm that technologies have been consolidated as an effective alternative, overcoming the most evident barriers over time, such as the current world situation of physical distance and other contact restrictions. Another contribution to its expansion concerns the constant evolution of technological devices that always prevent the improvement and resolution of everyday problems.

In this sense, the present study reinforces the advantages resulting from the use of technologies, namely for the domain of cognitive and psychosocial rehabilitation, quality of life, and mental health of the elderly in studies divided into five categories that are classified as the areas of greatest expansion in the articles found.

The main themes of the articles included in this review were categorized according to nature and objectives proposed by interventions that used VR and or AR for the elderly population. In this way, the studies were divided into five main categories:

1. Feasibility studies and acceptance of the experience in AR and VR
2. Prevention and contribution in the treatment of dementia, Alzheimer's disease, dementia, Parkinson's disease, depression, and anxiety
3. Evaluation and rehabilitation of cognitive functions such as memory, attention, language, and executive functions.
4. Training in spatial navigation skills, confidence, and balance improvement in the prevention of falls, and performance of daily activities
5. Promoting social engagement, well-being, quality of life, and mental health

Feasibility Studies and Acceptance of the Experience in AR and VR

The feasibility of applying VR arouses great interest from researchers since it presents itself as a strategy that can overcome barriers such as cost and sustainability and cognitive issues treatment (Abichou et al., 2017). Acceptance is a fundamental criterion in technology usability and involves understanding aspects such as effort, expectation and performance, social influence, and facilitating conditions as primary factors for predisposition to use (Tuena et al., 2020). In general, the authors found positive results about the use and acceptance of VR by the elderly (Lin et al., 2018; Syed-Abdul et al., 2019; Tuena et al., 2020; Yeh et al., 2020). Although technical and usage problems use suitable usability design methods, it is possible to obtain viable virtual systems for clinical purposes aimed at the elderly (Tuena et al., 2020).

However, some studies point to important characteristics that influence the acceptance of VR use by the elderly. Data from the study by Roberts et al. (2019) indicate that VR acceptance varies according to the perception of usability and usefulness. Marivan et al. (2016), in turn, found that the acceptance of the elderly also varies according to the motivation and willingness they have to carry out the activities. Syed-Abdul et al. (2019) highlight how the perception of utility, ease, and satisfaction has significant effects on VR acceptance and use. Yeh et al. (2019) reinforce that as a leisure activity, the continuous use of VR is associated with ease of use, utility, safety and flexibility, and fun. Therefore, the elderly can have both positive and negative perceptions about the use of VR. Thus, the approaches must consider the particularities of the users, prioritizing the interest of the elderly with the technologies to maximize their use and the consequent improvement in the quality of life (Marivan et al., 2016). They should also consider that some health problems, such as labyrinthitis and other vision related diseases, can interfere with satisfaction when using VR, so it is essential to consider the barriers in this type of intervention (Syed-Abdul et al., 2019).

The studies brought information that there is a positive response regarding the acceptance of VR use for leisure purposes, with virtual activities being a new entertainment option for the elderly (Yeh et al., 2019). In the research by Lin et al. (2018), the data revealed good acceptance by the elderly for leisure activities of virtual reality that are fun, safe, and easy. They seek an innovative experience that makes them feel physically and mentally healthy, which improves the quality of life, interpersonal relationships, and the feeling of belonging. The articles also point to positive results regarding the feasibility of using VR (Coelho et al., 2020; Park et al., 2020; Ferreira-Brito et al., 2020, Marivan et al., 2016). These data were extracted from studies that aimed to analyze the improvement in cognitive aspects in patients with mild cognitive impairment (Park et al., 2020; Ferreira-Brito et al., 2020) and patients with dementia (Coelho et al., 2020).

Ferreira-Brito et al. (2020) also highlighted, in addition to feasibility, the instrument's ecological advantages, as well as its accessibility and low cost. Marivan et al. (2016), in turn, showed the viability of VR for psychomotor rehabilitation by highlighting a positive response regarding the use of virtual reality training by patients with post-fall syndrome. Thus, we can see that the assessments on the feasibility and acceptance of VR among the elderly show that this technology has brought positive effects on cognitive and motor improvement, and consequently, on the quality of life of the elderly.

Prevention and Contribution in the Treatment of Dementia, Alzheimer's Disease, Parkinson's Disease, Depression, and Anxiety

Among the significant psychological disorders people face in their aging process are dementia, Alzheimer's disease, Parkinson's disease, depression, and anxiety. Studies point out the potential of using VR and AR tools to assess and treat these disorders (Ahmed et al., 2018). Dementia is considered a growing problem in current societies. Although science has not yet indicated an immediate cure for its treatment, it can still be delayed and even stopped under certain conditions. Alzheimer's disease accounts for about 60% to 70% of all dementia cases (WHO, 2015) and is often preceded by mild cognitive impairment (Manera et al., 2016), characterized by a multifaceted impairment of cognitive and executive functions, in addition to difficulty interacting with the physical and social environment (Tarnanas et al., 2013).

García-Betances et al. (2015) presented an overview, criteria, and strategy for developing VR tools in cognitive rehabilitation training to assist medical teams, health professionals, and other caregivers improve daily life activities to people with Alzheimer's disease and MCI. Results showed that cognitive

rehabilitation systems based on VR could achieve the training goals and support procedures to mitigate behavioral and psychological symptoms of patients with Alzheimer's Disease and MCI. Another research, a case study, the potential of training with VR-based learning techniques to increase autonomy in culinary activities for patients with Alzheimer's Disease was evaluated. The results indicated that the patient relearned some culinary activities using virtual reality techniques, transferred to real life, and the improvement in task performance has remained stable over time (Foloppe et al., 2015).

One of the most advanced therapies in this field is cognitive rehabilitation using VR and AR. Studies reported that after rehabilitation with this type of tool, patients with dementia were more attentive and focused, not only on training skills but also on tasks of daily living. In a rehabilitation intervention using a serious game with VRs for 4 to 5 weeks, the performance of patients with mild dementia was assessed before, during, and after the intervention based on neuropsychological tests. The results showed a statistically significant improvement in four cognitive functions: functional memory, memory retention, executive functions, rigid thinking, and marginal changes in two other functions: attention and problem-solving. Although the results seem promising, the researchers pointed out the need for further studies with larger samples to corroborate the findings (Fasilis et al., 2018).

An alternative treatment for people with dementia, admittedly more fragile in terms of physical constitution, as they remain sedentary, would be the use of exergaming. This tool combines physical exercises with cognitive stimulation in a virtual environment. A study with the application of exergaming for two weeks in older adults with dementia showed positive results in their health status, with a higher adherence level than traditional aerobic exercises and reduced frailty in the physical, psychological and social domains. However, this item has no statistically significant difference compared to conventional aerobic training (Karssemeijer et al., 2018).

In a study with 30 participants with dementia undergoing attention activity and other cognitive tasks, comparing the use of VR and paper, it was demonstrated that 70% of the participants were more satisfied with the activities in VR. This number is still curiously higher among apathetic patients than the non-apathetic participants, demonstrating the potential to use VR in cognitive training with these patients (Manera et al., 2016). Another study compared the performance of older adults with mild dementia, impaired memory, and healthy older people through neuropsychological tests in a fire evacuation simulation VR tool, compared to neuropsychological tests in standard questionnaires. Results demonstrated success in diagnosing pre-dementia with the VR tool, overcoming the predictive clinical validity of traditional assessments (Tarnanas et al., 2013).

Depression and anxiety are mental disorders that affect people of all ages but have become increasingly common among the elderly due to changes in the body, mind, and social life. An experimental study evaluated the effect of an immersive sensorimotor rehabilitation program based on virtual reality - including scenarios of urban and natural environments, of free fall, among others - on mental health in the elderly, with pre and post-intervention assessment on the scales of depression, anxiety, and well-being. The tool demonstrated a multidimensional approach, responding appropriately to reducing symptoms associated with mental disorders and reducing all scales used (Brito et al., 2021). A systematic review using exergames to reduce depressive symptoms in the elderly found positive results. Studies that required depressive symptoms as an inclusion criterion for participation reported a significant decrease in depressive symptoms within the group after the exergame intervention. The main criticisms of the studies pointed out in this review were: small samples, exclusion of older adults with disabilities, and poorly standardized definition of exergame (Drazich et al., 2020).

A study using the VR tool with an elderly Thai population was developed to simulate a garden environment to treat depression, including walking in the virtual forest, arm movement, and brain function stimulation. Most older adults presented a high degree of satisfaction concerning the experience. However, adjustments were suggested, such as improved image quality and higher interaction environments (Suwanjatuporn & Chintakovid, 2019).

For Parkinson's Disease, the second most frequent neurodegenerative disease, related to age and resulting in loss of neurons with negative effects on dopamine production and movement regulation, some studies have revealed the successful use of VR-based treatments. However, in a systematic review, it has not been demonstrated that the effectiveness of VR-based systems therapy has been superior to conventional physiotherapy programs in patients with Parkinson's disease on motor balance and psychosocial variables, mainly cognition and quality of life (Morales-Gómez et al., 2018). Scope review found promising results in cognitive and motor rehabilitation, pointing out that VR-assisted cognitive-behavioral therapy can be adapted to suit the subtypes of anxiety disorders with the potential to improve the effectiveness of psychotherapy for patients with illness Parkinson's. However, it was pointed out that none of the researched articles explicitly focused on the treatment of anxiety in Parkinson's Disease, and further studies are needed (Thangavelu et al., 2020).

Evaluation and Rehabilitation of Cognitive Functions such as Memory, Attention, Language, and Executive Functions

The use of VR tools with the elderly has been widely used for four main purposes: assessing and diagnosing cognitive impairment, cognitive training or testing, training of caregivers, and approaches to treat cognitive deficits (Skurla et al., 2019).

Schneider et al. (2020) point out that it has become possible to promote improvements and more effective treatments related to cognitive functions with advancing technology and medicine. Among the various options available, technologies such as virtual reality and augmented reality have stood out for offering good cost-benefit, effectiveness, and a good level of adherence. The authors presented in their review a description and comparison of possible alternatives directed to the improvement and rehabilitation of cognitive processes. They clarified that, as memory depends on the environment, VR becomes a handy tool in the evaluation and even cognitive deficits rehabilitation and recovery.

It is known that cognitive training has positive effects on the cognitive level and can be developed especially through virtual reality, given its characteristic of imitating a real situation (Park et al., 2020). Furthermore, stimulation using virtual reality devices has characteristics similar to the primary mechanism of the human brain, which facilitates cognitive modeling through designs designed to simulate the internal and external environment (Gaggioli et al., 2017).

Chan et al. (2020) reveal that cognitive stimulation through virtual reality has great potential to be used as an alternative to traditional models of cognitive stimulation and show good adherence by the elderly. One of the advantages pointed out by this study concerns the possibility of intervention with VR being self-managed. On the other hand, it is questioned about the engagement of the elderly in virtual activities since they have reduced interpersonal contact compared to traditional interventions. Liao et al. (2019) also compared the effects of physical and cognitive training using VR with traditional physical and cognitive training techniques in older adults with mild cognitive impairment. Their results show an advantage concerning VR training. Although both training sessions develop executive function and verbal memory (immediate recall), only VR training improved performance in global cognition, verbal memory

(delayed recall), and daily instrumental activities. In yet another comparison between interventions with VR and traditional interventions, Park et al. (2019) bring in their studies significantly positive results on an intervention in the elderly with mild cognitive impairment aimed at improving the visuospatial work of memory. When applying the training using mixed reality for six weeks and comparing it with a control group, it was observed that the group that received the mixed reality intervention obtained significantly better performance than the group that received the conventional intervention. Finally, the systematic review carried out by Skurla et al. (2019) shows that interventions with VR as a training tool for cognitive impairment for the elderly provide greater ecological validity than traditional interventions.

Thapa et al. (2020) investigated the effects of an intervention using fully immersive virtual reality on physical, brain, and cognitive functions in older adults with mild cognitive impairment. The 68 participants were randomly divided between the control group and the VR intervention group. The intervention program consisted of 4 sets of games using an Oculus VR headset and two manual controls for the assessment of physical and cognitive aspects, and participants performed 24 cognitive training sessions using VR, lasting 100 minutes each, three times per week for eight weeks, in addition to receiving guidance on the practice of eye stretching exercises and educational training. Participants performed only educational training for general health care in the control group, which consisted of a weekly session lasting 30-50 minutes for eight weeks. This study showed that interventions using VR technology are highly effective, and cognitive training based on this technology has positive effects in improving some physical, executive, and cognition aspects of patients with MCI.

In a literature review, Cherniack (2011) analyzed the published evidence in the medical field on the VR applicability in identifying and rehabilitating cognitive disorders in older adults. The results showed possibilities for using technologies, including neuropsychological assessment, diagnostic tests for deficits in executive functions, Parkinson's treatment and rehabilitation. In conclusion, comparative and more in-depth studies are still needed with a more significant number of participants. However, VR applied to the assessment and rehabilitation of the elderly is seen as an effective and versatile tool capable of meeting the health needs of this population.

Anderson-Hanley et al. (2018) proposed to evaluate the effects of an intervention involving aerobic and cognitive exercises in elderly residents in the community with or without risk of mild cognitive impairment. The study lasted six months, with 111 older adults who were randomly divided into three groups, and consisted of guiding an ergonomic bicycle connected to a screen that displayed the simulation. In group 1 (Exer-tour), the participants took a virtual panoramic bike tour and physical exercises interactively but with a low level of effort and cognitive load. Group 2 (Exer-score) consisted of performing interactive physical exercise, with goals and scores and with a relatively difficult cognitive effort from a video game; and in group 3 (game-only), the participants played the same type of video game, but the virtual bicycle needed to be guided through a joystick. This study showed that in the exer-tour and exer-score groups, there was a significant improvement in one of the three measures of executive function, in verbal memory. After three months of intervention, it was noticed that the exer-tour group had a significant effect on aspects of memory and everyday cognitive function. The authors concluded that the association between interactive physical and cognitive exercises brought significant cognitive benefits to the participants over six months.

Gaggioli et al. (2017) presented a fully immersive virtual reality system for training and rehabilitation with the elderly. The "positive bike" was designed to promote a real bike experience for dual-task intervention training in older adults. The system of this training program consists of an exercise bike arranged in an Automatic Virtual Cave Environment equipped with stereoscopic projectors. In the simu-

lation, the user rides on the exercise bike through a park with animals and plants on the way and has the task of performing dual-task activities (motor and attentional). The authors clarified that the "positive bicycle" program is still in the testing process (pilot study) to determine clinical viability and usability. In the next phase of the research, the program was carried out with a sample of frail older people to evaluate the effectiveness of this population's functional state and well-being.

Studies to evaluate the use of VR-based tools in the characterization of memory profiles are also being developed. In the review by Plancher and Piolino (2017), it was possible to identify that the use of VR to assess episodic memory in normal and pathological aging has grown in recent years. The data also demonstrated that there is an improvement in episodic memory with active exploration of virtual environments. Widmann et al. (2012) used a photorealistic virtual reality model of a city to assess episodic verbal and spatial memory in healthy elderly and with mild Alzheimer's, comparing it with standardized neuropsychological tests of verbal and spatial ability. The results showed that, while healthy participants had an equivalent performance in VR and traditional interventions, participants with Alzheimer's had their capacities impaired in both interventions, especially about free memory, becoming more evident in the context of virtual reality than in standardized neuropsychological tests.

Monteiro-Junior et al. (2017) and Serino et al. (2017) also positively evaluated the VR intervention for memory improvement purposes, indicating the potential feasibility of this VR-based training for the spatial orientation of the elderly population. The study by Plechatá et al. (2019) evaluated and compared the user experience of immersive VR and non-immersive VR between two different age groups. The authors also evaluated immersion level effect on episodic memory performance for diagnostic purposes and tested the memory task validity performed in a virtual environment in both groups. Participants in this study were divided into two groups. The activity consisted of performing The Virtual Supermarket Shopping Task Performance, an exercise in a virtual environment that simulated a grocery store. As a result, the authors cite the significant differences in the participants' age-related performance when performing the task on a desktop vs. performing the same task in VR. Older adults had more errors when using VR, indicating that performing tasks with VR can be more difficult for this population than using a personal computer. However, this study also identified motivation and a good acceptance in using this technology by older adults.

Some state-of-the-art diagnostic methods are being developed to characterize cognitive impairment (Valladares-Rodriguez et al., 2019). Skurla et al. (2019) presented, through a systematic review, that virtual reality tools are helpful not only to detect the presence of MCI and Alzheimer's but also to perform the differential diagnosis between the two. Park et al. (2020) investigated the effectiveness of applying VR training programs based on the culture in patients with mild and amnestic cognitive impairment. The results showed that a 12-week program has no significant effect on patients' cognitive appearance. Still, for diagnostic purposes, Zygouris et al. (2017) evaluated the accuracy of a cognitive VR training application as a screening tool for the diagnosis and remote detection of MCI, indicating that the application is helpful in the detection of MCI.

In a systematic review, Cibeira et al. (2020) explored VR applicability as a therapeutic tool for diagnosing and preventing cognitive impairment in older adults. Most of the studies selected were related to cognitive impairment treatment, five articles aimed at diagnosing cognitive deficits, and only two articles were directed to study the use of VR as a preventive tool to the decline in cognitive functions. The results suggest that the use of technologies effectively improves the cognitive functions of older adults with some level of impairment and can be used in tasks of daily living. However, just a few studies focused on preventing cognitive decline, and more research is needed in this field.

Training in Spatial Navigation Skills, Confidence and Balance Improvement in the Prevention of Falls, and Performance of Daily Activities

With the aging process, it is natural to experience a decline in motor and balance functions in the central and peripheral nervous systems, consequently causing impairments in cognitive functions and a reduction in both sensitivity and the capacity for discrimination and interpretation by sensory receptors (Arlati et al., 2019; Laurence & Michel, 2017). According to Mirelman et al. (2013), recent studies have shown a strong correlation between motor and cognitive deficits with falls among the elderly population. The use of technologies such as VR can be an attractive and more effective alternative in the context of intervention because it can promote a more stimulating and prosperous environment than more traditional rehabilitation options.

Dermody et al. (2020) proposed evaluating the effectiveness of virtual reality applications using VR headsets available in the market to improve mental, physical, or psychosocial health among elderly residents in the community or institutionalized. Seven studies were analyzed, and the results indicate that the use of VR resources promoted significant improvements in the participants' health related to reduced risk of falls, and cognitive functioning in Alzheimer's disease, for instance. Those results indicate that technologies associated with health interventions have great potential.

Laurence and Michel (2017) carried out a literature review to analyze the causes for the occurrence of dizziness and imbalance and about the possible factors related to the high rates of falls among the elderly population, in addition to reviewing the methods for prevention, rehabilitation, and recovering the quality of life of these individuals. Among the possible forms of intervention, the authors clarify that both classical activities such as the use of cognitive stimulation or physical exercise and aerobic training, as well as the use of recent technologies such as virtual reality, video games, or computer training, can reduce the cognitive decline and improve balance and levels of attention and memory, in addition to helping to prevent falls and age-related deficits.

Mirelman et al. (2013) evaluated the effects of treadmill training combined with the use of VR simulating an obstacle course on the risk of falls, and improved mobility and cognitive function in a group of older adults without cognitive impairment, with mild cognitive impairment and diagnosed with Parkinson's disease without cognitive impairment. The intervention group task consisted of walking on a treadmill while a camera captured movements with sensors, and a simulation of paths with obstacles was projected onto a screen. The results and considerations are partial, and the authors conclude that the proposed intervention can maximize motor learning and induce the subject to perform a behavior change. Because it has a standardized protocol, it is a therapy that can be reproduced. This intervention project is favorable to developing and improving new care models that combine mobility training, cognitive stimulation, and technology to prevent and control falls and improve the quality of life of the elderly population with or without chronic diseases.

Monteiro-Júnior et al. (2017) investigated the effect of physical exercises using VR with exergames (PhysEx) on depressive symptoms, physical performance, fear of suffering falls, and the cognitive functions of institutionalized elderly. Participants were allocated between the VR experimental group and the active control group. The results demonstrated significant improvements in mobility and short-term memory among subjects in the VR experimental group, suggesting that the inclusion of physical exercises may contribute to the prevention and reduction of cognitive decline and functional loss in institutionalized elderly.

Davis and Ohman (2016) sought to compare the participants' performance in two wayfinding tasks in a virtual reality environment called Virtual Senior Living. In the tasks, the participants needed to find their way to a location through a VR simulation of a residence for elderly. For the first task, the subjects needed to find their way to a dining room (without signs), and in the second task, the path with multiple signs was directed to a specific door that led to the external environment. The control group included older people without cognitive impairment, and the intervention group included older adults with mild cognitive impairment or an early-stage Alzheimer's diagnosis. This intervention demonstrated that the use of signs in the environment makes it more favorable to orientation and has great potential in helping older adults with Alzheimer's find their way more effectively.

Ijaz et al. (2019) conducted a study to develop and analyze the viability of an immersive VR program to assess memory and spatial navigation capacity in the elderly. Participants were divided into an intervention group using the VR-CogAssesse platform and a control group using a standard screening platform on a personal computer to perform a recall test. The results demonstrated a higher score of recall of reference points, a lower index of navigation errors, and a significantly more significant increase in engagement and levels of presence in the intervention group. The authors concluded that immersive VR is effective, feasible, and compatible for spatial navigation memory assessment.

Lin et al. (2020) evaluated the effects of a combination of 3D virtual reality and horticultural therapy on the mental and physical health of institutionalized elderly. Participants were divided into experimental and control groups, and the intervention lasted for nine consecutive weeks. The results demonstrated that implementing the intervention with institutionalized older adults using 3D virtual reality resources was successful. Therefore, a 9-week program may be sufficient to promote significant improvements in health status, perception of importance, the meaning of life, socialization, improved mood, life quality, and depression levels.

Promoting Social Engagement, Well-Being, Quality of Life, and Mental Health

Emotional experience and its regulation have been associated with protective factors for physical and mental well-being throughout life, even affecting human immune functioning (Diamond & Fagundes, 2012). The use of virtual environments to increase positive experiences through mood inducers, such as exercises to generate positive autobiographical memories, mindfulness, and breathing rhythms, showed significant results in joy and relaxation and a decrease in sadness and anxiety of the elderly (Baños et al., 2012).

Ronquillo et al. (2020) evaluated an AR application to create an intelligent recommendation system for user's emotional state detection. The system shows multimedia content that connects emotionally with the user, selecting videos, images and sounds to improve the well-being of the elderly in their daily activities. The image sequence had a good impact on users, and the results showed good acceptability. The participants also provided important feedback for the development of future apps such as the need for clear instructions on app's use and the importance of having a facilitator to make the experience more pleasant and provide greater service so the users can adapt to the AR lens.

The emotional impacts of watching a 360º video in immersive conditions using VR headsets versus a non-immersive video using smartphones were also evaluated in a comparative study between elderly and young people. The results suggest that the smartphone intervention had a significant impact on the emotional well-being of elderly participants, while the immersive VR intervention generated some divergences regarding acceptability. In both studies, participants contributed important information for

improving these tools, indicating that it is essential to involve and consider the needs of the elderly in the development of VR technologies (Liu et al., 2020).

The importance of involving the elderly and caregivers in the co-design process of new technologies was the focus of the study by Guerrero et al. (2019), which, through a co-participatory design, involved the elderly and caregivers in the development of an intelligent assistive system, which uses augmented reality based on projection with user interface technology to assess the functionality of the technology for daily medication management activity. The study presented a formal structure to understand the level of independence in daily activities and how assistive technology can adapt the support to an individual and be an essential support for carrying out daily activities.

Another determining factor for promoting and maintaining the well-being and mental health of the elderly population is social interaction. Studies indicate that virtual worlds can be an essential resource to provide social engagement, entertainment, and valuable information for the elderly population. Virtual worlds are known as computer-simulated environments in which multiple users can enter simultaneously to interact with the environment and other users. The research carried out by Siriaraya et al. (2014) was based on semi-structured interviews and previous research on healthy aging to explore the role of virtual worlds in personal engagement and characteristics of older adults who participated in virtual worlds simulations. This study had the participation of 15 older people who were already regular users of two virtual environments through the use of computers. The results showed that virtual worlds provide mental stimulation and engagement in productive activities, facilitate social involvement, and empower the elderly to manage their disabilities.

Shaunfield et al. (2014) carried out the project with long-term care residents. They evaluated the impact of face-to-face visits and trips to virtual fields concerning depression, social support, and physical and mental health. The results showed a significant mental health increase of the residents after the intervention, with a decrease in the indicators of depression and an improvement in physical health and social support. These results coincide with the systematic review carried out by Van Houwelingen-Snippe et al. (2021). They sought to understand how implementing interventions using virtual representations of nature to provide greater well-being in older people occurs, concluding that there is preliminary evidence on the effectiveness of virtual (natural) environments to improve well-being among the elderly.

Social support was investigated through a study that used an interactive VR environment to conduct an online support group for elderly widows, compared to a grief education website. The results showed that both interventions showed good acceptability and viability and resulted in significant improvements in grief, anxiety, loneliness, perceived stress, and overall quality of sleep at all times of the study. However, only widows in the VR support group showed a significant improvement in depression level over time (Knowles et al., 2017).

Comorbidities that arise throughout the aging process, such as mild cognitive impairment or dementia, are also associated with depression and negative emotional states that affect the mental health and well-being of the elderly. The literature review carried out by D'Cunha et al. (2019) indicated that virtual, mixed, and augmented reality interventions are becoming more accessible and are an exciting and emerging method to promote life quality, social interaction, and psychological well-being.

Advances in technology, particularly virtual reality, are also being studied in the elderly population suffering from chronic pain or pain to provide analgesia for involvement, distraction and improving these people's quality of life and depressive symptoms. The immersive VR intervention performed by Benham et al. (2019) did not indicate differences in the quality of life or depressive symptoms among the elderly. However, the results showed a significant decrease in pain perception and good acceptability for the use

of this intervention. The authors suggest that the immersive VR intervention showed good applicability and effectiveness in reducing pain intensity for elderly residents in the community. These findings corroborate the systematic review carried out by Mathias et al. (2019), who identified the use of VR in the clinical environment for the elderly population in several domains of mental health, such as cognition, conditions along the spectrum of mood, anxiety, and anxiety disorder, for example. The authors point out that the use of this technology is promising but is necessary for future studies to address the key issues surrounding the use of VR in clinical settings, such as usability, data privacy, and confidentiality.

CONCLUSION

This review mapped the studies found in the literature regarding the usability and applicability of VR and AR technologies in interventions aimed at mental health and psychosocial rehabilitation of the elderly population. It was found that in the last ten years, there has been a growing increase in the number of annual publications on this theme, primarily experimental studies, showing the emerging and innovative character of new technologies. A significant majority of research on the use of VR and AR by the elderly focus on their cognitive and motor improvement, and are aimed at individuals diagnosed with Alzheimer's or Parkinson's. VR was considered an adequate tool for treating disabilities such as spatial memory and other cognitive functions and is characterized as an innovative, interesting, and economical approach to promote social engagement and mental health in elderly populations.

Despite the exponential interest, it is emphasized that it is still a field of study under construction. The studies show excellent acceptability of VR and AR technologies, in addition to positive effects in the most varied domains aimed at promotion, prevention, and intervention for the elderly population. However, they also make evident the importance of considering the specific needs of this population concerning familiarity and the impact of the immersive experience. One solution would be to include this audience in developing interventions through a co-participative design to improve usability, promoting greater accessibility and technological literacy.

It was also observed the lack of standardization of the studies regarding the terminologies used referring to the new technologies and little conceptual framework referring to the elderly population. One of these aspects is the fact that while virtual reality reaches more people and promotes a safe immersion experience, on the other hand, it does not require fundamental physical contact in relationships and may not be accessible to those whose physical, psychological, or social barriers hinder the use of technological devices.

While ethical issues are important when talking about the use of new tools and represent an area in ascending exploration such as RA and RV in mental health interventions with the elderly population, just a few studies address this subject. Davis and Ohman (2016) report that even though some studies with these technologies are conducted with a potentially vulnerable population, it is still a low-risk intervention. Skurla et al. (2019), on the other hand, explains that ethical issues related to the use of these technologies with older people in a severely vulnerable position still need to be addressed and warns of the need to ensure privacy and data confidentiality in the widespread VR use in clinical environments.

Although all studies show the importance of using VR and or AR technologies for the elderly population, many did not present clear information about the methodologies and interventions used and references regarding interventions follow-up. Thus, future studies should address the development, impact, and effects of interventions in a more integrative way and provide long-term follow-up and with larger

samples to maximize the benefits and accessibility of new technologies for mental health and psychosocial rehabilitation for the elderly.

REFERENCES

Ahmed, B., Kim, D. H., Hwang, Y., & Park, S. J. (2018). Treatment of Alzheimer's, Cognitive, Chronic Pain Rehabilitation, Depression and Anxiety disorders. *One System for Elderly Using VR, 15th International Conference on Ubiquitous Robots (UR).* https://ieeexplore.ieee.org/document/8441897

Anderson-Hanley, C., Barcelos, N. M., Zimmerman, E. A., Gillen, R. W., Dunnam, M., Cohen, B. D., Yerokhin, V., Miller, K. E., Hayes, D. J., Arciero, P. J., Maloney, M., & Kramer, A. F. (2018). The Aerobic and Cognitive Exercise Study (ACES) for Community-Dwelling Older Adults with or At-Risk for Mild Cognitive Impairment (MCI): Neuropsychological, Neurobiological and Neuroimaging Outcomes of a Randomized Clinical Trial. *Frontiers in Aging Neuroscience*, *10*, 76. doi:10.3389/fnagi.2018.00076 PMID:29780318

Anderson-Hanley, C., Snyder, A. L., Nimon, J. P., & Arciero, P. J. (2011). Social facilitation in virtual reality-enhanced exercise: Competitiveness moderates exercise effort of older adults. *Clinical Interventions in Aging*, *6*(1), 275–280. doi:10.2147/CIA.S25337 PMID:22087067

Arlati, S., Colombo, V., Spoladore, D., Greci, L., Pedroli, E., Serino, S., Cipresso, P., Goulene, K., Stramba-Badiale, M., Riva, G., Gaggioli, A., Fserrigno, G., & Sacco, M. (2019). A Social Virtual Reality-Based Application for the Physical and Cognitive Training of the Elderly at Home. *Sensors (Basel)*, *19*(2), 261. doi:10.339019020261 PMID:30634719

Azuma, R. T. (1997). A survey of augmented reality. *Presence (Cambridge, Mass.)*, *6*(4), 355–385. doi:10.1162/pres.1997.6.4.355

Bakker, J., Donath, L., & Rein, R. (2020). Balance training monitoring and individual response during unstable vs. stable balance Exergaming in elderly adults: Findings from a randomized controlled trial. *Experimental Gerontology*, *139*(111037). Advance online publication. doi:10.1016/j.exger.2020.111037 PMID:32730797

Baños, R. M., Etchemendy, E., Castilla, D., García-Palacios, A., Quero, S., & Botella, C. (2012). Positive mood induction procedures for virtual environments designed for elderly people. *Interacting with Computers*, *24*(3), 131–138. doi:10.1016/j.intcom.2012.04.002

Barsasella, D., Liu, M. F., Malwade, S., Galvin, C. J., Dhar, E., Chang, C., Li, Y., & Syed-Abdul, S. (2021). Effects of Virtual Reality Sessions on the Quality of Life, Happiness, and Functional Fitness among the Older People: A Randomized Controlled Trial from Taiwan. *Computer Methods and Programs in Biomedicine*, *200*(105892). Advance online publication. doi:10.1016/j.cmpb.2020.105892 PMID:33280934

Benham, S., Kang, M., & Grampurohit, N. (2019). Immersive Virtual Reality for the Management of Pain in Community-Dwelling Older Adults. *OTJR (Thorofare, N.J.)*, *39*(2), 90–96. doi:10.1177/1539449218817291 PMID:30595096

Bhar, S., Koder, D., Davison, T., Kelly, J., Jayaram, H., Silver, M., Linossier, J., & Collins, R. (2020). A clinician's quick guide of evidence-based approaches: Psychological treatments for depression and anxiety with older adults living in residential aged care facilities. *Clinical Psychologist*, *24*(2), 206–207. doi:10.1111/cp.12229

Brito, H., Pham, T., & Vicente, B. (2021). Effect of sensorimotor rehabilitation based on an immersive virtual reality model on mental health. *International Journal of Geriatric Psychiatry*, gps.5541. Advance online publication. doi:10.1002/gps.5541 PMID:33797806

Caroca, J., Bruno, M. A., & Aldunate, R. (2016). Situated learning based on virtual environment for improving disaster risk reduction. *Journal of E-Learning & Knowledge Society*, *12*(4), 81–92. doi:10.20368/1971-8829/1192

Chan, J. Y. C., Chan, T. K., Wong, M. P. F., Cheung, R. S. M., Yiu, K. K. L., & Tsoi, K. K. F. (2020). Effects of virtual reality on moods in community older adults A multicenter randomized controlled trial. *International Journal of Geriatric Psychiatry*, *35*(8), 926–933. doi:10.1002/gps.5314 PMID:32346896

Chen, M., Tang, Q., Xu, S., Leng, P., & Pan, Z. (2020). Design and Evaluation of an Augmented Reality-Based Exergame System to Reduce Fall Risk in the Elderly. *International Journal of Environmental Research and Public Health*, *17*(19), 7208. doi:10.3390/ijerph17197208 PMID:33019759

Cherniack, E. P. (2011). Not just fun and games: Applications of virtual reality in the identification and rehabilitation of cognitive disorders of the elderly. *Disability and Rehabilitation. Assistive Technology*, *6*(4), 283–289. doi:10.3109/17483107.2010.542570 PMID:21158520

Cibeira, N., Lorenzo-López, L., Maseda, A., López-López, R., Moreno-Peral, P., & Millán-Calenti, J. C. (2020). Realidad virtual como herramienta de prevención, diagnóstico y tratamiento del deterioro cognitivo en personas mayores: Revisión sistemática. *Revista de Neurología*, *71*(6), 205–212. doi:10.33588/rn.7106.2020258 PMID:32895903

Coelho, T., Marques, C., Moreira, D., Soares, M., Portugal, P., Marques, A., Ferreira, A. R., Martins, S., & Fernandes, L. (2020). Promoting Reminiscences with Virtual Reality Headsets: A Pilot Study with People with Dementia. *International Journal of Environmental Research and Public Health*, *17*(24), 9301. doi:10.3390/ijerph17249301 PMID:33322679

D'Cunha, N. M., Nguyen, D., Naumovski, N., McKune, A. J., Kellett, J., Georgousopoulou, E. N., Frost, J., & Isbel, S. (2019). A mini-review of virtual reality-based interventions to promote well-being for people living with dementia and mild cognitive impairment. *Gerontology*, *65*(4), 430–440. doi:10.1159/000500040 PMID:31108489

Davis, R., & Ohman, J. (2016). Wayfinding in ageing and Alzheimer's disease within a virtual senior residence: study protocol. *Journal of Advanced Nursing*. https://onlinelibrary.wiley.com/doi/abs/10.1111/jan.12945

Dermody, G., Whitehead, L., Wilson, G., & Glass, C. (2020). The role of virtual reality in improving health outcomes for community-dwelling older adults: Systematic review. *Journal of Medical Internet Research*, *22*(6), e17331. Advance online publication. doi:10.2196/17331 PMID:32478662

Diamond, L. M., & Fagundes, C. P. (2012). *Emotion regulation in close relationships: Implications for social threat and its effects on immunological functioning. Interdisciplinary research on close relationships: The case for integration*. American Psychological Association. doi:10.1037/13486-004

Dibbets, P. (2019). A novel virtual reality paradigm: Predictors for stress-related intrusions and avoidance behavior. *Journal of Behavior Therapy and Experimental Psychiatry*, *67*(101449), 101449. Advance online publication. doi:10.1016/j.jbtep.2019.01.001 PMID:30642531

Drazich, B. F., LaFave, S., Crane, B. M., Szanton, S. L., Carlson, M. C., Budhathoki, C., & Taylor, J. L. (2020). Exergames and Depressive Symptoms in Older Adults: A Systematic Review. *Games for Health Journal*, *9*(5), 339–345. doi:10.1089/g4h.2019.0165 PMID:32551982

Dyck, M., Winbeck, M., Leiberg, S., Chen, Y., & Mathiak, K. (2010). Virtual faces as a tool to study emotion recognition deficits in schizophrenia. *Psychiatry Research*, *179*(3), 247–252. doi:10.1016/j.psychres.2009.11.004 PMID:20483465

Fasilis, T., Patrikelis, P., Siatouni, A., Alexoudi, A., Veretzioti, A., Zachou, L., & Gatzonis, S. S. (2018). A pilot study and a brief overview of rehabilitation via virtual environment in patients suffering from dementia. *Psychiatriki*, *29*(1), 42–51. doi:10.22365/jpsych.2018.291.42 PMID:29754119

Ferreira-Brito, F., Alves, S., Santos, O., Guerreiro, T., Caneiras, C., Carriço, L., & Verdelho, A. (2020). Photo-Realistic Interactive Virtual Environments for Neurorehabilitation in Mild Cognitive Impairment (NeuroVRehab.PT): A Participatory Design and Proof-of-Concept Study. *Journal of Clinical Medicine*, *9*(12), 3821. doi:10.3390/jcm9123821 PMID:33255869

Foloppe, D. A., Richard, P., Yamaguchi, T., Etcharry-Bouyx, F., & Allain, P. (2015). The potential of virtual reality-based training to enhance the functional autonomy of Alzheimer's disease patients in cooking activities: A single case study. *Neuropsychological Rehabilitation*. doi:10.1080/09602011.2015.1094394

Gaggioli, A., Greci, L., Arlati, S., Stramba-Badiale, M., Pedroli, E., Colombo, D., Serino, S., Cipresso, P., & Riva, G. (2017). Positive bike - An immersive biking experience for combined physical and cognitive training of elderly patients. *Annual Review of Cybertherapy and Telemedicine*, *15*, 196–199.

García-Betances, R. I., Jiménez-Mixco, V., Arredondo, M. T., & Cabrera-Umpiérrez, M. F. (2015). Using Virtual Reality for Cognitive Training of the Elderly. *American Journal of Alzheimer's Disease and Other Dementias*, *30*(1), 49–54. doi:10.1177/1533317514545866 PMID:25107931

Grabowski, A. (2020). *Virtual reality and virtual environments: a tool for improving occupational safety and health* (1st ed.). Taylor & Francis Ltd. doi:10.1201/9781003048510

Guerrero, E., Lu, M. H., Yueh, H. P., & Lindgren, H. (2019). Designing and evaluating an intelligent augmented reality system for assisting older adults' medication management. *Cognitive Systems Research*, *58*, 278–291. doi:10.1016/j.cogsys.2019.07.001

Hsiao, K. F., & Rashvand, H. F. (2015). Data modeling mobile augmented reality: Integrated mind and body rehabilitation. *Multimedia Tools and Applications*, *74*(10), 3543–3560. doi:10.100711042-013-1649-8

Ijaz, K., Ahmadpour, N., Naismith, S. L., & Calvo, R. A. (2019). An Immersive Virtual Reality Platform for Assessing Spatial Navigation Memory in Predementia Screening: Feasibility and Usability Study. *JMIR Mental Health*, *6*(9), e13887. doi:10.2196/13887 PMID:31482851

Karssemeijer, E. G. A., Bossers, W. J. R., Aaronson, J. A., Sanders, L. M. J., Kessels, R. P. C., & Olde-Rikkert, M. G. M. (2019). Exergaming as a Physical Exercise Strategy Reduces Frailty in People with Dementia: A Randomized Controlled Trial. *Journal of the American Medical Directors Association*, *20*(12), 1502–1508. doi:10.1016/j.jamda.2019.06.026 PMID:31409559

Knowles, L. M., Stelzer, E. M., Jovel, K. S., & O'Connor, M. F. (2017). A pilot study of virtual support for grief: Feasibility, acceptability, and preliminary outcomes. *Computers in Human Behavior*, *73*, 650–658. doi:10.1016/j.chb.2017.04.005

Laurence, B. D., & Michel, L. (2017). The Fall in Older Adults: Physical and Cognitive Problems. *Current Aging Science*, *10*(3), 185–200. doi:10.2174/1874609809666160630124552 PMID:28874111

Lee, L. N., Kim, M. J., & Hwang, W. J. (2019). Potential of augmented reality and virtual reality technologies to promote well-being in older adults. *Applied Sciences (Switzerland)*, *9*(17), 3556. Advance online publication. doi:10.3390/app9173556

Lee, M., Son, J., Kim, J., & Yoon, B. (2015). Individualized feedback-based virtual reality exercise improves older women's self-perceived health: A randomized controlled trial. *Archives of Gerontology and Geriatrics*, *61*(2), 154–160. doi:10.1016/j.archger.2015.06.010 PMID:26145489

Liao, I. I., Tseng, H. L., Lin, Y. J., Wang, C. J., & Hsu, W. C. (2020). Using virtual reality-based training to improve cognitive function, instrumental activities of daily living, and neural efficiency in older adults with mild cognitive impairment. *Edizioni Minerva Medica*, *56*(1), 47–57. doi:10.23736/S1973-9087.19.05899-4 PMID:31615196

Lin, C. S., Jeng, M. Y., & Yeh, T. M. (2018). The Elderly Perceived Meanings and Values of Virtual Reality Leisure Activities: A Means-End Chain Approach. *International Journal of Environmental Research and Public Health*, *15*(4), 663. doi:10.3390/ijerph15040663 PMID:29614012

Lin, T. Y., Huang, C. M., Hsu, H. P., Liao, J. Y., Cheng, V. Y., Wang, S. W., & Guo, J. L. (2020). Effects of a Combination of Three-Dimensional Virtual Reality and Hands-on Horticultural Therapy on Institutionalized Older Adults' Physical and Mental Health: Quasi-Experimental Design. *Journal of Medical Internet Research*, *22*(11), e19002. doi:10.2196/19002 PMID:33135666

Liu, Q., Wang, Y., Yao, M. Z., Tang, Q., & Yang, Y. (2020). The Effects of Viewing an Uplifting 360-Degree Video on Emotional Well-Being among Elderly Adults and College Students under Immersive Virtual Reality and Smartphone Conditions. *Cyberpsychology, Behavior, and Social Networking*, *23*(3), 157–164. doi:10.1089/cyber.2019.0273 PMID:31663773

Macedo, M., Marques, A., & Queirós, C. (2015). Virtual reality in assessment and treatment of schizophrenia: A systematic review. *Jornal Brasileiro de Psiquiatria*, *64*(1), 70–81. doi:10.1590/0047-2085000000059

Malik, S. A., Abdullah, L. M., Mahmud, M., & Azuddin, M. (2013). Mobile applications using augmented reality to support older people. *International Conference on Research and Innovation in Information Systems, ICRIIS*, 374–379. 10.1109/ICRIIS.2013.6716739

Manera, V., Chapoulie, E., Bourgeois, J., Guerchouche, R., David, R., Ondrej, J., Drettakis, G., & Robert, P. (2016). A Feasibility Study with Image-Based Rendered Virtual Reality in Patients with Mild Cognitive Impairment and Dementia. *PLoS One*, *11*(3), 1–14. doi:10.1371/journal.pone.0151487 PMID:26990298

Marivan, K., Boully, C., Benveniste, S., Reingewirtz, S., Rigaud, A. S., Kemoun, G., & Bloch, F. (2016). Rehabilitation of the psychomotor consequences of falling in an elderly population: A pilot study to evaluate feasibility and tolerability of virtual reality training. *Technology and Health Care*, *24*(2), 169–175. doi:10.3233/THC-151114 PMID:26578283

Mascret, N., Delbes, L., Voron, A., Temprado, J.-J., & Montagne, G. (2020). Acceptance of a Virtual Reality Headset Designed for Fall Prevention in Older Adults: Questionnaire Study. *Journal of Medical Internet Research*, *22*(12), e20691. Advance online publication. doi:10.2196/20691 PMID:33315019

Mathias, L., Rahman, A., Skurla, M., & Vahia, I. (2019). The Application of Virtual Reality in Geriatric Mental Health: The State of the Evidence. *The American Journal of Geriatric Psychiatry*, *27*(3), 174–175. doi:10.1016/j.jagp.2019.01.085

Merriman, N. A., Roudaia, E., Romagnoli, M., Orvieto, I., & Newell, F. N. (2018). Acceptability of a custom-designed game, city quest, aimed at improving balance confidence and spatial cognition in fall-prone and healthy older adults. *Behaviour & Information Technology*, *37*(6), 538–557. doi:10.1080/0144929X.2018.1462402

Miller, K. J., Adair, B. S., Pearce, A. J., Said, C. M., Ozanne, E., & Morris, M. M. (2014). Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: A systematic review. *Age and Ageing*, *43*(2), 188–195. doi:10.1093/ageing/aft194 PMID:24351549

Mirelman, A., Rochester, L., Reelick, M., Nieuwhof, F., Pelosin, E., Abbruzzese, G., Dockx, K., Nieuwboer, A., & Hausdorff, J. M. (2013). V-TIME: a treadmill training program augmented by virtual reality to decrease fall risk in older adults: study design of a randomized controlled trial. *BMC Neurology*, *13-15*(1), 15. Advance online publication. doi:10.1186/1471-2377-13-15 PMID:23388087

Monteiro-Junior, R. S., da Silva Figueiredo, L. F., Maciel-Pinheiro, P., Abud, E. L. R., Braga, A. E. M. M., Barca, M. L., Engedal, K., Nascimento, O. J. M., Deslandes, A. C., & Laks, J. (2017). Acute effects of exergames on cognitive function of institutionalized older persons: A single-blinded, randomized and controlled pilot study. *Aging Clinical and Experimental Research*, *29*(3), 387–394. doi:10.100740520-016-0595-5 PMID:27256080

Monteiro-Junior, R. S., Figueiredo, L. F. D. S., Maciel-Pinheiro, P. T., Abud, E. L. R., Engedal, K., Barca, M. L., Nascimento, O. J. M., Laks, J., & Deslandes, A. C. (2017). Virtual Reality-Based Physical Exercise with Exergames (PhysEx) Improves Mental and Physical Health of Institutionalized Older Adults. *Journal of the American Medical Directors Association*, *18*(5), 454.e1–454.e9. doi:10.1016/j.jamda.2017.01.001 PMID:28238675

Morales-Gómez, S., Elizagaray-García, I., Yepes-Rojas, O., De la Puente-Ranea, L., & Gil-Martínez, A. (2018). Efectividad de los programas de inmersión virtual en los pacientes con enfermedad de Parkinson. Revisión sistemática. *Revista de Neurología*, *66*(03), 69–80. doi:10.33588/rn.6603.2017459 PMID:29368325

Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., Gamberini, L., Capodieci, S., & Bordin, A. (2010). Controlling memory impairment in elderly adults using virtual reality memory training: A randomized controlled pilot study. *Neurorehabilitation and Neural Repair*, *24*(4), 348–357. doi:10.1177/1545968309353328 PMID:19934445

Park, E., Yun, B. J., Min, Y. S., Lee, Y. S., Moon, S. J., Huh, J. W., Cha, H., Chang, Y., & Jung, T. D. (2019). Effects of a Mixed Reality-based Cognitive Training System Compared to a Conventional Computer-assisted Cognitive Training System on Mild Cognitive Impairment: A Pilot Study. *Cognitive and Behavioral Neurology, 32*(3), 172–178. doi:10.1097/WNN.0000000000000197

Park, J., Liao, Y., Kim, D., Song, S., Lim, J. H., Park, H., Lee, Y., & Park, K. W. (2020). Feasibility and Tolerability of a Culture-Based Virtual Reality (VR) Training Program in Patients with Mild Cognitive Impairment: A Randomized Controlled Pilot Study. *International Journal of Environmental Research and Public Health*, *17*(9), 3030. doi:10.3390/ijerph17093030 PMID:32349413

Plancher, G., & Piolino, P. (2017). Virtual Reality for Assessment of Episodic Memory in Normal and Pathological Aging. *The Role of Technology in Clinical Neuropsychology*. doi:10.1093/oso/9780190234737.003.0015

Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., & Piolino, P. (2012). Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment. *Neuropsychologia*, *50*(5), 592–602. doi:10.1016/j.neuropsychologia.2011.12.013 PMID:22261400

Plechatá, A., Sahula, V., Fayette, D., & Fajnerová, I. (2019). Age-Related Differences with Immersive and Non-immersive Virtual Reality in Memory Assessment. *Frontiers in Psychology*, *10*, 1330. doi:10.3389/fpsyg.2019.01330 PMID:31244729

Prata, W., Oliveira, J., & Melo, P. (2018). Walking with Angest: Subjective Measures for Subjective Evaluation in a Walking Simulator Virtual Reality Game. In J. Chen & G. Fragomeni (Eds.), Lecture Notes in Computer Science: Vol. 10910. *Virtual, Augmented and Mixed Reality: Applications in Health, Cultural Heritage, and Industry. VAMR 2018*. Springer. doi:10.1007/978-3-319-91584-5_16

Roberts, A. R., De Schutter, B., Franks, K., & Radina, M. E. (2019). Older adults' experiences with audiovisual virtual reality: Perceived usefulness and other factors influencing technology acceptance. Clinical Gerontologist. *The Journal of Aging and Mental Health*, *42*(1), 27–33. doi:10.1080/07317115.2018.1442380 PMID:29505343

Ronquillo, L., Zamudio, V., Gutierrez-Hernandez, D., Lino, C., Navarro, J., & Doctor, F. (2020). Towards an automatic recommendation system to well-being for the elderly based on augmented reality. *Proceedings of the 2020 16th International Conference on Intelligent Environments, IE 2020*, 126–131. 10.1109/IE49459.2020.9155010

Sari, D. W., Igarashi, A., Takaoka, M., Yamahana, R., Noguchi-Watanabe, M., Teramoto, C., & Yamamoto-Mitani, N. (2020). Virtual reality program to develop dementia-friendly communities in Japan. *Australasian Journal on Ageing*, *39*(3), e352–e359. doi:10.1111/ajag.12797 PMID:32483931

Schneider, F., Horowitz, A., Lesch, K. P., & Dandekar, T. (2020). Delaying memory decline: Different options and emerging solutions. *Translational Psychiatry*, *10*(1), 13. doi:10.103841398-020-0697-x PMID:32066684

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*, 240. doi:10.3389/fnagi.2017.00240 PMID:28798682

Shaunfield, S., Wittenberg-Lyles, E., Oliver, D. P., & Demiris, G. (2014). Virtual Field Trips for Long-Term Care Residents: A Feasibility Study. *Activities, Adaptation and Aging*, *38*(3), 237–247. doi:10.1080/01924788.2014.935911

Siriaraya, P., Ang, C. S., & Bobrowicz, A. (2014). Exploring the potential of virtual worlds in engaging older people and supporting healthy aging. *Behaviour & Information Technology*, *33*(3), 283–294. doi:10.1080/0144929X.2012.691552

Skurla, M. D., Rahman, A. T., Salcone, S., Mathias, L., Shah, B., Forester, B. P., & Vahia, I. V. (2021). Virtual reality and mental health in older adults: A systematic review. *International Psychogeriatrics*. doi:10.1017/S104161022100017X

Suwanjatuporn, A., & Chintakovid, T. (2019). Using a Virtual Reality System to Improve Quality of Life of the Elderly People with Depression. *IEEE International Conference*, 153-156. 10.1109/ICCE-Asia46551.2019.8941607

Syed-Abdul, S., Malwade, S., Nursetyo, A. A., Sood, M., Bhatia, M., Barsasella, D., Liu, M. F., Chang, C. C., Srinivasan, K. M. R., & Li, Y. J. (2019). Virtual reality among the elderly: A usefulness and acceptance study from Taiwan. *BMC Geriatrics*, *19*(1), 223. doi:10.118612877-019-1218-8 PMID:31426766

Tarnanas, I., Schlee, W., Tsolaki, M., Müri, R., Mosimann, U., & Nef, T. (2013). Ecological Validity of Virtual Reality Daily Living Activities Screening for Early Dementia: Longitudinal Study. *Journal of Medical Internet Research*, *15*(8), 1–4. doi:10.2196/games.2778 PMID:25658491

Thangavelu, K., Hayward, J. A., Byrne, G. J., Au, T. R., Dissanayaka, N. N., Pachana, N. A., Mitchell, L. K., & Wallis, G. M. (2020). Designing Virtual Reality Assisted Psychotherapy for Anxiety in Older Adults Living with Parkinson's Disease: Integrating Literature for Scoping. *Clinical Gerontologist*. doi:10.1080/07317115.2019.1709597

Thapa, N., Park, H. J., Yang, J. G., Son, H., Jang, M., Lee, J., Kang, S. W., Park, K. W., & Park, H. (2020). 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. doi:10.3390/jcm9051283 PMID:32365533

Tuena, C., Pedroli, E., Trimarchi, P. D., Gallucci, A., Chiappini, M., Goulene, K., Gaggioli, A., Riva, G., Lattanzio, F., Giunco, F., & Stramba-Badiale, M. (2020). Usability issues of clinical and research applications of virtual reality in older people: A systematic review. *Frontiers in Human Neuroscience*, *14*, 93. Advance online publication. doi:10.3389/fnhum.2020.00093 PMID:32322194

Valladares-Rodriguez, S., Fernández-Iglesias, M. J., Anido-Rifón, L., Facal, D., Rivas-Costa, C., & Pérez-Rodríguez, P. (2019). Touchscreen games to detect cognitive impairment in senior adults. A user interaction pilot study. *International Journal of Medical Informatics*, *127*, 52–62. doi:10.1016/j.ijmedinf.2019.04.012 PMID:31128832

Van Houwelingen-Snippe, J., Ben Allouch, S., & Van Rompay, T. J. L. (2021). Virtual Reality Representations of Nature to Improve Well-Being amongst Older Adults: A Rapid Review. *Journal of Technology in Behavioral Science*, *6*(3), 464–485. Advance online publication. doi:10.100741347-021-00195-6 PMID:33688575

Widmann, C. N., Beinhoff, U., & Riepe, M. W. (2012). Everyday memory deficits in very mild Alzheimer's disease. *Neurobiology of Aging*, *33*(2), 297–303. doi:10.1016/j.neurobiolaging.2010.03.012 PMID:20392540

Wiederhold, B. K. (2020). How Virtual Reality Is Changing the Reality of Aging. *Cyberpsychology, Behavior, and Social Networking*, *23*(3), 141–142. doi:10.1089/cyber.2020.29176.bkw PMID:32150700

World Health Organization - WHO. (2015). *World report on ageing and health.* WHO.

Yeh, T. M., Pai, F. Y., & Jeng, M. Y. (2019). The factors affecting older adults' intention toward ongoing participation in virtual reality leisure activities. *International Journal of Environmental Research and Public Health*, *16*(3), 333. Advance online publication. doi:10.3390/ijerph16030333 PMID:30691062

Zimmer, P., Buttlar, B., Halbeisen, G., Walther, E., & Domes, G. (2019). Virtually stressed? A refined virtual reality adaptation of the Trier Social Stress Test (TSST) induces robust endocrine responses. *Psychoneuroendocrinology*, *101*, 186–192. doi:10.1016/j.psyneuen.2018.11.010 PMID:30469086

Zygouris, S., Ntovas, K., Giakoumis, D., Votis, K., Doumpoulakis, S., Segkouli, S., Karagiannidis, C., Tzovaras, D., & Tsolaki, M. (2017). A Preliminary Study on the Feasibility of Using a Virtual Reality Cognitive Training Application for Remote Detection of Mild Cognitive Impairment. *Journal of Alzheimer's Disease*, *56*(2), 619–627. doi:10.3233/JAD-160518 PMID:28035922