Virtual Reality for elderly – status quo and perspectives

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Abstract: The last decade has witnessed the exponential growth of Virtual Reality (VR) as an affordable, powerful, and disruptive technology in a variety of fields, among which, notably, are healthcare and well-being. Particularly for the elderly people, VR has already been demonstrated, by a plethora of experiments and studies, as extremely effective in supporting a multitude of therapeutical interventions, from neuromotor and cognitive recovery and maintenance to mental health and wellbeing and socialisation. However, due to the novelty of the technology, the scientific and industry communities are missing both an overarching perspective covering all these intervention areas, as well as a common understanding of the results, challenges, limitations, possibilities, specificity, best practices, design approaches, and integration with traditional therapies, for each area. This hinders the development of commercial-level solutions and widespread adoption in clinical guidelines. This paper aims to cover these gaps, by identifying and analysing five of the most relevant VR intervention areas for elderlies, providing an overview and examples, for each area, and concluding with cross-area perspectives and pinpoints of the most needed research topics, to support the widespread adoption of VR-based interventions for elderly healthcare and wellbeing.

Keywords: Virtual Reality, Elderly people, Neuromotor Rehabilitation, Cognitive Rehabilitation.

Realitatea virtuală pentru vârstnici – stadiul actual și perspective

Rezumat: Ultimul deceniu a fost martorul creșterii exponențiale a realității virtuale (VR) ca tehnologie accesibilă, puternică și disruptivă într-o varietate de domenii, printre care medicina este unul dintre cele mai reprezentative. În special pentru persoanele în vârstă, VR a fost deja dovedită, prin numeroase experimente și studii, ca fiind extrem de eficientă în susținerea unei multitudini de intervenții terapeutice, de la recuperarea și întreținerea neuromotorie și cognitivă până la sănătatea mintală, bunăstarea și socializarea. Cu toate acestea, din cauza noutății tehnologiei, comunităților științifice și industriale le lipsește atât o perspectivă generală care să acopere toate aceste domenii de intervenție, cât și o înțelegere aprofundată a rezultatelor, provocărilor, limitărilor, posibilităților, specificității, celor mai bune practici, abordărilor de proiectare și integrării cu terapiile tradiționale, pentru fiecare zonă. Acest lucru îngreunează tranferul soluțiilor de către exploatarea comercială și adoptarea pe scară largă în ghidurile clinice. Această lucrare își propune să acopere aceste lacune, prin identificarea și analizarea a cinci dintre cele mai relevante domenii de intervenție ale VR pentru vârstnici, oferind pentru fiecare domeniu o imagine de ansamblu și exemple, și încheind cu perspective generale comune și identificarea celor mai necesare subiecte de cercetare, pentru a sprijini adoptarea pe scară largă a intervențiilor bazate pe VR pentru sănătatea și bunăstarea vârstnicilor.

Cuvinte cheie: Realitate virtuală, Vârstnici, Reabilitare neuromotorie, Reabilitare cognitivă.

1. Introduction

Virtual Reality (VR) is a mix of technology and concepts that lead to immersive computer-generated experiences, allowing people to feel transported to computer-generated realistic, interactive, and safe digital environments, with current applicability in almost all fields. VR has developed spectacularly in the last ten years, evolving from a technology with limited, niche applicability – due to costs (equipment of thousands or tens of thousands of dollars) and limited performance (resolution, refresh rate, field of view, latency, hand and body tracking, etc.) – to the current stage where it is extremely affordable in terms of cost (VR headsets available at only a few hundred Euros) and high performance, with hundreds of millions of users and applications in almost all fields (health, education, culture, tourism, training, industries, art and creativity, and entertainment).

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VR currently offers remarkable potential to improve the quality of life for the elderly. Numerous studies have already experimented with the use of VR for older people, with promising results, in areas such as neuromotor rehabilitation, social interaction and reducing isolation, entertainment and leisure, improving mental and emotional health, fall prevention, maintaining cognitive abilities, which will be the focus of this paper, as most relevant use-cases areas.

The industry is already looking to adopt and grow many of the early research results. However, in the scientific literature, there is a lack of synthetic understanding of both overarching aspects covering all uses of VR for the elderly, as well as the specific aspects for each intervention area.

In this context, this article has the following objectives:

- Give an insight into the recent market explosion of VR and why it has become so relevant for health and wellbeing;
- Identify the main VR-based intervention areas for the elderly that have already shown promising research results;
- Examine each selected intervention area in terms of results, challenges, limitations, possibilities, specificity, best practices, design approaches, and integration with traditional therapies; also look at aspects of particular importance to the elderly, such as accessibility, ease of use, and motivation;
- Conclude with overarching perspectives covering the field as a whole.

The structure of the paper is the following: Section 2 gives a brief overview of the recent growth of the VR market, userbase, devices and development environments; Section 3 summarises the VR usage in neuromotor recovery, presenting the typical structure of such systems, the unique benefits and potential, and discussing several relevant studies; Section 4 explores an area of high importance for elderly people – VR exercises addressing mobility, balance and fall prevention; Section 5 investigates the use of VR for maintaining or improving mental and emotional health, specifically for elderly; Section 6 delves further, into how VR can be leveraged towards creating new forms of social interaction for the elderly, and thus reducing isolation; the concluding section summarises the main identified results, trends, and necessities to enable further scientific evolution and market adoption of the results.

2. The recent expansion of Virtual Reality

While the concepts and early VR prototypes emerged in the late '60s', for decades, the evolution of VR was slow due to significant limitations in headset technologies and computing power. However, this changed fundamentally in the last decade, when VR experienced explosive growth, transforming from a niche technology into a global phenomenon with disruptive applications in most fields. This evolution can be seen in several key aspects: the decrease in the cost of VR devices by an order of magnitude, the remarkable increase in their performance and ergonomics, the expansion of VR applications in different fields, the growth of the market, and the userbase.

The market for VR technology has grown significantly in recent years with the rapid development of technology. According to Fortune Business Insights, the global VR market will grow nearly 20 times between 2020-2028 (from $4.4 billion in 2020 to $84 billion in 2028), (Fortune Business Insights, 2024). Other sources, such as National Research Group (2022), indicate an even higher projected growth, reaching $227.34 billion by 2029.

Since 2019, the number of virtual reality users has continuously increased. In 2019, it was estimated that there were about 100 million users globally. According to National Research Group (2022), there were already 171 million VR users globally, with a user penetration rate projected at 52.8%, and in the USA, 13% of households already own a VR headset.

According to statistical data, the age ranges of users are 34% users aged 16 to 24, 35% users aged 25 to 34, 26% users aged 35 to 44, 12% users aged 45 to 54 and 6% users over 55 years old (Blagojević, 2023). While the data shows wider adoption in the young segments – more familiar with the video games, there is an already significant, and growing adoption rate in all age segments.

Eventually, by 2028, the number of AR & VR users worldwide is expected to reach 3,674 billion, with a remarkable adoption in all countries and demographics (Blagojević, 2023).

The main factors driving this remarkable growth are the evolution of VR devices and software development environments, interest in the metaverse, training apps for numerous industries, health and education solutions, and VR gaming.

Growth has been spurred by major investments in VR hardware from companies such as Oculus, Meta, Sony, and HTC.

Affordable standalone devices such as the Oculus Quest series have played a key role in this growth. Released in 2020, the Oculus Quest 2 has quickly become one of the most popular VR devices, with sales increasing from 3 million units in 2020 to 10 million units in 2023. The current version, Oculus Quest 3, brings remarkable quality improvements, keeping the cost affordable, in the conditions of fierce competition in the VR device market, with numerous other solutions already offering outstanding performance at affordable prices, such as the HTV Vive Pro 2, Pico VR, Sony PlayStation VR and many others.

From the point of view of creating VR applications, last decade witnessed a spectacular evolution of specialised development environments, such as Unity 3D or Unreal Engine, with VR support existing in most popular game engines, and also the emergence of generic XR APIs such as WebXR.

Unity 3D is one of the most popular development environments used for VR. It offers a wide range of functionality that allows developers to create high-quality VR experiences for a variety of platforms, including PC, consoles, and mobile devices. Unity 3D is praised for its ease of use and fast learning curve, making it accessible to both experienced developers and those just starting out (Hussain et al., 2020).

Unreal Engine, developed by Epic Games, is another leading game engine used in VR app development. Unreal Engine is known for its superior graphics capabilities, making it preferred for projects that require great visual detail. This engine is especially used in high-end games, complex simulations, architecture, and the film industry, where visual realism is essential.

WebXR is a Web API that allows the creation of VR experiences that can be accessed directly from a web browser. WebXR is an ideal solution for typically lightweight VR projects that want to reach a wide audience but without requiring additional software installation. This API is frequently used in marketing projects, virtual tours, and education, where accessibility and ease of sharing are essential. WebXR combines the power of modern web technologies with VR capabilities, allowing developers to create applications that can be accessed from any device compatible with a modern browser.

Regarding the market, a significant portion is consumer software, especially video games, including ports of traditional desktop and console games, but also a large number of brand-new VR game genres, which make full use of the new interaction modalities uniquely offered by VR. Industrial applications are also becoming increasingly numerous, with recent statistics indicating an impressive degree of adoption – notably, about 75% of companies rated by Forbes as "most valuable brands" are already using VR/AR technologies (Sparapani, 2017). Most significant for this paper (Coie, 2020), forecasts indicate health and education as the areas that will be most impacted by VR.

3. Neuromotor recovery

Neuromotor recovery is the process of restoring functionality and mobility after an accident or illness that has affected the neuro-musculoskeletal system. The most common recovery situations are after a stroke or various accidents. Recovery can involve different approaches depending on the nature and severity of the condition: physiotherapy, aerobic activities, cognitive (such as speech) recovery, and psychology.

According to the WSO (2020), stroke affects about 13.7 million people annually, being the third leading cause of long-term disability (Johnson et al., 2016). Research over the last 15 years highlights the fact that intense, repeated, and focused training, started as soon as possible after a stroke, supports the relearning of lost functions, based on neuroplasticity (Thomas et al., 2017). However, currently, about 60% of survivors remain with dysfunctional sequelae, especially in the upper limbs and with reduced mobility – due to insufficient number of therapists, limitations of traditional recovery techniques, and scarce access to modern technologies (Stroke Statistics, 2021)

VR has become a promising tool in neuromotor recovery. Studies conducted in recent years have proven distinct advantages of using VR technology for the recovery of people who have suffered a stroke.

Neuromotor recovery is a training/learning cycle with the following components carried out quasi-parallel: 1) the patient attempts/performs the motor act (without help, or with physical help from a therapist or device); 2) the patient observes (consciously and subconsciously), through visual, haptic, and proprioceptive senses, whether and how the motor act was performed; 3) patient's cortex associates movement attempts with observations and perfects motor control. All these three elements: trying/performing the act, observation and association/improvement at the cortical level are essential in recovery. Unfortunately, most often, the 2nd element, which is the patient's observation of the act of movement, is affected or cancelled by various factors, such as low or no degree of movement, low visual perception in the peripheral vision area, proprioception affected by the mental state of numbness in the paralysed limb. Therefore, the learning cycle cannot be closed and sustained, the patient is thus unable to relearn the movement. This is a remarkable point where VR can intervene in recovery, by presenting the movement on a real-time, easy-to-perceive avatar of the patient, which offers an excellent virtual substitute for element 2 of the learning cycle.

Typically, in VR-centred neuromotor recovery, the patient wears VR equipment (headset) and tries to perform certain recovery exercises/movements, reflected in the VR environment, sometimes in a gamified form. The system uses motion tracking technologies and sometimes other technologies, such as EEG, EMG, FES, robotic gloves, etc. This typical structure and advantages of such an extended VR-centred neuromotor recovery system are presented in Moldoveanu et al. (2019). This research highlights the unique possibilities of support for patients, starting from the first stages of recovery, by being able to represent in VR either movements actually performed by the patient, but also movement intentions detected by EEG or very low amplitude movements represented amplified in VR, techniques called augmented feedback.

VR brings unique advantages and perspectives for post-stroke neuromotor recovery:

- Recovery requires sustained exercise, several hours a day. Unfortunately, due to a large number of patients and limited number of specialised therapists, most patients cannot be assisted enough to exercise as much as is necessary for optimal recovery, and insufficient exercise dramatically reduces the degree of recovery, leading to lifelong disabilities (Ward & Gutenbrunner, 2016). However, this can be supplemented by VR practice, which requires a much lower degree of supervision from a therapist. Furthermore, recent research develops possibilities for semi-autonomous or even autonomous VR training;
- It is a safe environment without risks for the patient;
- It is realistic, naturalistic, intuitive, and easy for patients to use. Furthermore, the

patient can be guided through information embedded in the VR environment, indicating to him what movement to perform, what virtual object to touch, etc., and even accompanied by a virtual therapist in the form of an NPC;

- Classical approaches can be affected by monotony and loss of motivation. VR can effectively address these issues by gamification of the neuromotor exercises. The exercises can be presented in the form of mini-games in a pleasant, exciting manner, increasing the degree of involvement and long-term motivation;
- Classical approaches can also be affected by distraction and loss of focus. In VR, the patient is implicitly isolated from most external stimuli that can affect focus on the exercise;
- Furthermore, by disconnecting from the hospital environment and immersion in a relaxing and pleasant VR environment, the patient can be offered significant psychological boots and motivation;
- The exercises can be adapted to the degree of mobility of each patient. Furthermore, the speed, intensity, and other parameters of the exercise can easily be adapted to challenge or support the patient;
- In simulated virtual reality, the patient's avatar does not present any dysfunction so that the patient, without realising the existing disabilities, can perform complex tasks, which allows the appearance of conditioning and new neural connections, favouring neuroplasticity. Thus, VR is a unique environment for specific brain training techniques for recovery, whether EEG-based or not, such as visual motion augmentation (Caraiman et al., 2015; Ferche et al., 2018; Moldoveanu et al., 2019; Lupu et al., 2020).
- It can support the continuation of home treatment, which is extremely important for the patient's long-term evolution.

Further, the current state of the field is illustrated by analysing selected significant studies.

Almost two decades ago, Holden (2005) showed that VR technology provides real-time feedback in an intuitive form, allowing patients to see and mimic the movements of a "virtual teacher." In contrast to traditional training, where patients can be distracted by the environment, being affected by it by slowing down learning, virtual environments allow therapeutic tasks to be personalised and simplified in the early stages of learning, focusing attention on the essential elements of the task. Furthermore, it extrapolated that even if future studies would show that VR does not offer performance advantages over real-world practice, the technology remains a powerful tool for testing different motor training methods and types of feedback, being useful for automatically configuring training programs and recording participants' motor responses.

Costa et al. (2019) performed a comparative analysis of upper limbs neuromotor recovery of stroke patients that trained in real vs. a virtual environment. The study group included 11 patients (51 ± 7 years old) who performed 15 training sessions in each of the real and virtual setups. The virtual setup used Kinect 360 and a commercial darts game, while the real setup used a professional dartboard and darts. Video-based kinematic analysis was performed in both cases, including paired Student's t-test and Classification Regression Trees. The results showed a remarkable similarity in the percentage of patients achieving sufficient elbow extension and suitable movement velocities in both the real and virtual setup. Subtle but noteworthy statistical differences were recorded in terms of extension angles (higher in real), velocity (higher in real), throwing time (lower in real) and accuracy (higher in virtual). However, it is hard to generalise these findings, considering the specificity of the task and the small group size.

Shahmoradi et al. (2012) focused on both the design aspects of specialised VR games for post-stroke rehab, as well as their systematic evaluation in terms of medical efficacy. The game's design was built based on the results of a questionnaire filled in by 9 physiotherapists and 11 game designers. We consider a noteworthy perspective the combination of input from both relevant

categories of specialists; however, patients' input should have also been considered. 5 VR neuromotor recovery games were then developed and evaluated with 10 patients, which played performed 12 play sessions of 45 minutes each, scheduled 3 times per week for 4 weeks. Efficacy was evaluated on all upper limb parts (shoulder, elbow, wrists) with specific medical scales, including Modified Motor Assessment and Brunnstrom. The results proved positive effects on several relevant indicators: horizontal shoulder abduction and adduction, elbow flexion, and wrist flexion. No effects were observed on other indicators, such as shoulder flexion, elbow extension and wrist extension. This can be explained based on the specific movements and mechanics from the developed games used in the intervention and hints that a wider range of games is required in the recovery process.

Luo et al. (2021) introduce a highly specialised and innovative device, similar to a musical instrument, flexible to provide six types of musical and play interactions, which can be used as an input-output modality for a variety of neuromotor recovery games. Eighteen participants participated in its evaluation (out of which seven retreated from the study), each performing six training sessions of 15 minutes each. The training involved playing a horse racing game, and a table tennis game using the specialised musical device. Results show significant improvements in self-perceived indicators such as level of performance and satisfaction. Furthermore, passive joint motion scores on neuromotor scales such as FMA-EU and COPM were improved by the intervention. Additionally, questionnaires indicated significant appreciation for the novelty of the device and interactions.

Several studies, such as Holden (2005), have also demonstrated that people with disabilities can learn complex motor skills in virtual environments and that these skills are transferable to equivalent real-world tasks. This way, patients can recover daily functions such as lifting objects from the house, cutlery to eat or lifting a cup of water to drink.

It can be clearly concluded that numerous experimental systems and clinical trials have proven the effectiveness of VR in neuromotor recovery, highlighting the advantages and tremendous potential of VR in this field. It is expected that in the coming period, some of them will progress towards commercial solutions. The specific challenges are related to the possibility of adapting to the wide diversity of patients, accessibility, autonomous use, lack of a domain-specific gamification experience, costs, and validation of larger groups of patients.

4. Mobility, balance and fall prevention

Age-related decreased mobility, muscular strength, and balance may create challenges to perform daily activities. Furthermore, falls are a major problem among the elderly population, leading to physical, psychological, and social damage.

Regular exercises have the effect of preventing a decrease in mobility, improving balance and leading to increased muscle strength. They also contribute to other functional challenges that are associated with this ageing phenomenon and lead to a significant increase in scores to relevant tests or indicators, such as the up-and-go test with shorter time (TUG), Berg balance scale (BBS) and improved fall effectiveness scale (FES-I) (Liu et al., 2022).

A plethora of studies proved the effectiveness of VR as a medium to sustain regular physical exercises for the elderly. In this section, a summary of some of the most relevant ones is presented.

Zhao et al. (2023) is a noteworthy result, proving VR effectiveness in increasing bone density, as well as cutting down the risk of falls in older people.

Ren et al. (2023) review 23 studies, extracting remarkable conclusions regarding VR benefits for the elderly: significant TUG and BBS improvements, balance improvements (more efficient with VR compared to traditional methods), and minimising falls.

Zahedian-Nasab et al. (2021) explores the use of virtual reality (VR) exercises to improve balance and reduce fear of falling in older people who are at increased risk of falling. The research included 60 elderly participants, randomly divided into intervention and control groups.

The intervention group participated in VR exercise sessions using Xbox Kinect twice a week for six weeks. Selected games, such as Kinect Sports 1 and 2, included activities such as skiing, darts, and goalkeepers, designed to improve balance through upper and lower extremity movements. Balance was assessed using the Berg Balance Scale (BBS), and fear of falling was measured using the Falling Efficacy Scale (FES). The Timed Up and Go (TUG) test was used to evaluate physical performance. After six weeks of the intervention, the control group, which continued the routine activities of the asylum, showed no such improvements, While the VR intervention group showed a significant improvement in BBS and TUG scores, indicating better balance and reduced fear of falling.

Piech & Czernicki (2021) systematically review 21 randomised control trials focused on VR and exergames efficacy towards fall prevention for the elderly. The conclusions sustain that elderlies' VR training, especially in the form of exergames, should be regarded as a valuable complement to traditional training methods, with a particular value in the possibility to continue/perform training at home, not only at specialised centres. The review also points out a need for larger studies (with more patients on longer periods of time) to support the promotion of VR interventions as a standard therapeutic/prevention approach.

Babadi & Daneshmandi (2021) explores the use of virtual reality (VR) exercises to improve balance and reduce fear of falling in older people who are at increased risk of falling. The research compares the effects of conventional balance training with those of VR-based balance training. The 36 elderly people (65-70 years) were divided into three groups of 12 participants each, with good gender and age balance: VR training group conventional balance training group, and control group. Training sessions (VR or conventional) were performed once a week, for six weeks. VR interventions involve a variety of VR games or activities, stimulating full-body mobility and balance. Assessments on functional reach, balance, and fall prevention scales indicate significant as well as statistically similar improvements in both VR and the conventional groups versus the control one.

In conclusion, there is already clear, systematic proof that VR can be leveraged as medium for physical exergames for elderly people, standalone or in addition to traditional therapy. Distinct advantages are the possibility of home use, increased engagement through games and gamification, and affordability. Results show significant improvements in mobility and balance through VR interventions compared to control groups.

5. Improving mental and emotional health

In addition to motor skills, the use of VR also helps cognitive maintenance or recovery by making a connection between physical activity and physical activity. There is a correlation between physical and cognitive recovery (Bian et al., 2022).

Most stroke patients are over 45 years old, and for people below this number, a stroke might indicate an unhealthy lifestyle (either food abuse, lack of exercise, or a combination of both). This group of older people are more susceptible to stroke due to old age and the general breakdown of blood vessels. Some of the people who have suffered a stroke suffer from short-term and potentially long-term health problems, which include precise motor functions such as lifting a spoon to eat or walking in a straight line, cognitive and rational impairment such as the inability to speak properly, memory loss, or lack of good decision. These initial problems could leave a person with permanent disabilities if left unaddressed or if the treatment method proves ineffective. It should be noted that in all cases, it is statistically better to have even a "bad" form of rehabilitation than nothing at all. Rehabilitation varies from individual to individual and usually depends on severity and symptoms, but in most cases, cognitive exercises will be necessary for a full recovery.

Aderinto et al., (2023) highlights that from the point of view of systems that address recovery (physical or cognitive), interactions and forms of involvement must be created to provide a positive feedback loop that continues to push patients to continue playing.

Liu et al. (2023) Investigates the application of VR puzzles on post-stroke cognitively impaired elderly patients. VR is used as a rehabilitation tool to improve cognitive functions, especially executive function, and visual-spatial attention, compared to traditional cognitive training methods. Thirty patients (average age of 74.16 ± 7.08 years old) with mild post-stroke cognitive impairment were equally divided into a traditional cognitive therapy group and a VR puzzle group. Assessments included the Montreal Cognitive Assessment (MOCA), Trail Making Test-A (TMT-A), Digit Symbol Substitution Test (DSST), and other cognitive tests. Following the intervention, significant DSST improvements for the VR group. While most patients reported a positive experience in terms of ergonomics and content, mild adverse reactions have been reported in a few individuals. While this pilot study is encouraging, further studies are needed to confirm the effectiveness and explore in more detail the long-term effects of VR in post-stroke cognitive rehabilitation.

Wojciechowski et al. (2021) Looked at the impact of immersive virtual environments on motor and cognitive training for older people. This type of training is becoming increasingly relevant as the global population ages and maintaining cognitive and motor abilities becomes crucial for a high quality of life. The research evaluated the existing literature to understand the effectiveness and applicability of different virtual reality (VR) solutions in this area. The use of immersive VR environments has shown promise in motor and cognitive training for the elderly. These environments provide a safe and controlled setting where participants can practice various exercises that improve balance, coordination, and memory. Studies included in the literature review show that VR interventions can have a positive impact on cognitive and motor functions. VR environments have been effective in maintaining and even improving cognitive functions such as working memory and attention. Studies have indicated that older people are willing to use VR technology and find training experiences enjoyable and motivating. This is essential for the long-term success of these interventions.

Many elderly patients can be bedridden, and for this reason, more attention should be paid to their mental state. The systematic review (Clemente et al., 2024) analysed 97 articles, from which seven articles were selected, published between 2019 and 2022, based on VR-based therapy in forested environments for people over 65 years of age. The study concluded that VR forest therapy improves subjects' mental and physical health. A particular note was that such VR forest experiences may have greater effects on introverted individuals, such as in Yuan et al. (2022). Noteworthy, Brimelow et al. (2020) concluded that such forest VR interventions actively reduce depression by improving participants' mood during sessions. The study highlights the need to standardise effective procedures to reduce social costs and support mental health.

Thus, similar with neuromotor, VR interventions were already proven as beneficial in cognitive recovery or maintenance. Especially for this class of applications, the design of VR applications must include interactions that support positive feedback loops and be easy to understand and use, considering the psychological, physical, and cognitive limitations of elderly users. It is also necessary to establish a set of specific design principles based on successful experimental results, as well as the standardisation of VR-based treatment plans.

6. Social interaction and reducing isolation

The Covid pandemic had a significant negative impact on the mental and physical health of the global population. Physical inactivity due to the reduction of going out of the house, closure of workplaces, socialising or sports led to increased risks of weight gain, cardiovascular diseases, muscle atrophy, loss of bone mass or onset of metabolic disorders. Similarly, social isolation had increased risks for mental and cognitive disorders. These aspects have affected the elderly population to a greater extent, being, in fact, a magnification of the general aspects that can affect this category of population.

Siani & Marley (2021) conducted an anonymous, online survey (16 questions) on 646 participants. The survey results show that VR use has increased significantly during the pandemic, helping to occupy time, sustain and maintain mental and physical well-being, and socialisation,

having a significant impact on the implementation and development of VR-based strategies. The participants reported to be using VR predominantly for video games (98.7%), fitness (75.7%), socialising (55.2%), watching movies (47.8%) and meditation (37.2%).

For healthy ageing, people need physical activity. Schlomann et al. (2019) presents the willingness of older adults to use augmented reality (AR) games on mobile devices in their daily lives for health promotion.

VR and AR can promote healthy lifestyles with health-related games and sustain VR social contact Seifert & Schlomann (2021).

Santos et al. (2019) demonstrate that older adults can develop and sustain social interactions through VR or AR games.

VR games adapted for older adults provide entertainment and cognitive stimulation. These can range from simple puzzle games to more complex simulations such as virtual fishing or travel experiences Seifert & Schlomann (2021). VR can be used for lifelong learning and educational activities, making learning more interactive and engaging.

Miller et al. (2019) present three studies in the context of VR and AR social interaction, which indicate that task performance, nonverbal behaviour and social connection are significantly affected by the presence or absence of specific virtual content such as avatars or embedded agents.

Bortkiewicz et al. (2023) developed a questionnaire with 26 questions and conducted qualitative interviews with elderly people (60-86 years old). Case studies based on interviews with the elderly were used to create educational VR scenarios. Thus, three types of scenarios were drawn up (in the bathroom, in the supermarket, on a trip to the city). The scenarios were used to support the design of VR games, including mechanics that stimulate movements and physical actions that are important for the elderly. Such games and scenarios can create awareness and be used to educate young people, or students (medical, engineering, design, sociology, etc.) about the problems of the elderly by simulating their daily experiences and difficulties.

The use of VR and AR has been proven to stimulate social contact through digital interfaces and reduce social isolation for the elderly. The potential of such VR/AR social tools and experiences is remarkable, especially for older adults with mobility limitations.

7. Conclusions

As summarized in this paper, studies performed in the last decade, and especially during the last years, following the wide adoption of VR, have clearly proven the efficacy of VR-based intervention in the selected investigated areas, of utmost importance for the elderly: neuromotor and cognitive recovery (after stroke or accidents) and maintenance (including specific attributes such as mobility and balance), mental health and wellbeing, social interaction and reducing isolation.

In all these areas, numerous studies have demonstrated positive medical outcomes and high levels of motivation for the patients/users.

While user-friendly accessibility and ease of use, especially important to enable autonomous usage by elderly people/ patients, have been traditionally a big challenge, remarkable progress was achieved in recent years, and it should not be considered a major issue anymore. The same perspective covers the costs for end-users, with such specialised hardware-software solutions becoming easily affordable in most developed countries.

However, two major obstacles remain, which can be briefly summarised as a lack of established domain knowledge (regarding both systems' design and therapeutic integration) and a lack of large-scale trials/validations.

Thus, to complete the way to widespread adoption of VR-based therapies and support programs for the elderly:

- Future research should focus on the identification, description and refinement of best practices, development of design guidelines for VR applications, high degrees of adaptation to users, and specific gamification approaches suitable for elderly people and patients;
- In addition to standalone VR interventions, optimal integration into multipronged therapy plans should also be systematically studied, leading to established clinical guidelines;
- Eventually, long-term studies on large cohorts are needed for clear quantitative evaluations of the benefits, costs, and effects, completing the way to widespread adoption of VR-based therapies and support programmes for the elderly.

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