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THE ROLE OF VIRTUAL REALITY IN NEURODEGENERATIVE DISEASE MANAGEMENT: ASSESSING COGNITIVE PERFORMANCE AND PROMOTING DAILY FUNCTIONING

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ABSTRACT

Introduction: Virtual reality (VR) has revolutionized the assessment and training of cognitive abilities by providing simulated environments mirroring daily life situations. This research paper discusses the potential of VR in enhancing cognitive performance, particularly in patients with neurodegenerative diseases or who are at risk.

Methods: Studies evaluating cognitive interventions in VR for patients with neurodegenerative diseases or at risk were reviewed. The focus was on assessing cognitive performance improvements and exploring the role of presence and immersion in modulating training effects.

Results: Research indicates that VR interventions enhance cognitive performance in patients with neurodegenerative diseases or at risk. The feeling of presence and immersion significantly influence the effectiveness of training. However, translating these effects into functional benefits in patients' daily lives remains challenging.

Discussion: One of the significant challenges is translating the cognitive benefits gained from VR training into meaningful improvements in daily functioning. VR can potentially promote and measure the transfer of mental benefits by simulating activities close to everyday life. Future development prospects include leveraging neuroimaging tools to enhance cognitive interventions in VR.

Conclusion: Virtual reality presents promising opportunities for improving cognitive abilities in patients with neurodegenerative diseases or who are at risk. However, further research and development requires addressing the challenge of translating training effects into functional benefits.

Integration of neuroimaging tools can advance cognitive interventions in VR, paving the way for more effective therapeutic approaches.

Keywords: Virtual Reality, Intervention Cognitive, Cognitive Training, Alzheimer's Disease, Mild Cognitive Impairment

INTRODUCTION

With the advent of new technologies in recent years, assessment and intervention activities in neuropsychology have been considerably enriched. Among these technologies, virtual reality, by facilitating the creation of simulated environments close to daily life, has made the evaluation and training of cognitive abilities in ecological situations possible. Notably, this technology is of interest for cognitive assessment and intervention due to its ability to simulate natural environments while allowing conditions to be controlled experimentally. Currently, the available tools for assessing mental and support capacities make it difficult to infer the individual's daily functioning or train them to improve their functioning in daily life activities, which would have become problematic. Cognitive interventions are generally far from everyday situations, carried out during individual training sessions in a calm, non-distracting environment. As a result, the transfer of the effects of training to situations in daily life remains limited. Virtual reality is a technology that could help increase the ecological validity of cognitive assessments and interventions (Anghel, Ciubară et al., 2023).

By immersing the user in a dynamic virtual environment, this technology makes it possible to carry out cognitive and sensorimotor activities and interact with a considerable diversity of virtual stimuli. Virtual reality offers the opportunity to create environments that replicate the sensory characteristics of the real world while integrating the cognitive and physical demands of situations that individuals face in their daily lives. Thus, this technology offers new opportunities to assess the integrity of cognitive functioning, particularly using contexts more representative of everyday life and has great potential to determine whether cognitive interventions affect cognitive functioning in daily life, which today represents a major challenge for interventional studies. Given the prevalence of mental disorders in neurodegenerative diseases, the progressive nature of the alteration of cognitive abilities and the repercussions on the functional autonomy of the person in daily life, patients suffering from these diseases, and in particular those suffering from the disease Alzheimer's patients represent a population ideally suited to benefit from the integration of virtual reality into intervention programs (Bernini, Panzarasa et al. 2023).

In the first part, we will present the challenges of using virtual reality in neuropsychology. We will provide an overview of tasks developed to assess cognitive abilities using virtual reality. We will continue by presenting studies that have applied this technology to cognitive intervention programs. Then, we will discuss the methodological issues to highlight the transfer of benefits observed after an intervention on daily cognitive functioning. We will end with a discussion on future development prospects, including, in particular, the contribution of neuroimaging to cognitive interventions in virtual reality (Catania, Rundo et al., 2023).

The challenges of using virtual reality

The development of cognitive assessment and training tasks in virtual environments is relatively recent. Numerous technological constraints limited the feasibility and ecological validity of the first tools developed. One of the major challenges in developing virtual reality tools is promoting the user's feeling of presence in the virtual environment. This phenomenon is called the feeling of presence. It is defined as the subjective experience of being in one place while physically being in another. It is measured using questionnaires assessing the quality of interaction with the environment, the ease of interacting with the interface and the coherence between the experience lived in the virtual environment and that experienced in real life. Several factors modulate this feeling of presence. Some are linked to the characteristics of the virtual environment, such as the quality of the interface (flat screens immersive headset), the type of interaction (response on a computer keyboard ergonomic

controller visible in the virtual environment) or navigation mode in the environment (moving in the virtual environment using a controller *vs* movement of the user in the virtual environment while walking in the real environment). Other factors relate to the user's perception of the degree of realism, their level of control over the virtual environment, and their ability to examine and interact with elements of the climate (Davenport, Gallacher et al., 2023).

A second major issue in the development of these tools is the need to limit the occurrence of cybersickness. These cybersickness manifest in nausea, headaches or spatial disorientation and occur when the user is immersed in the virtual environment. With the recent development of fully immersive, high-performance headsets equipped with stereoscopic glasses allowing a 360-degree view in the virtual environment, the occurrence of cybersickness is less frequent, which favours the extension of the immersion time in virtual reality users, a particularly promising element for the development of clinical applications in cognitive interventions. Recent research has highlighted the possibility of a close link between the feeling of presence in the virtual environment and the occurrence of cybersickness (for a review, see [1]). These two factors would be dependent on sensory integration processes. The immersive dimension of the virtual environment would also play a role in modulating the feeling of presence and the occurrence of cybersickness. If current technological advances make it possible to limit the risks of cybersickness, increase the sense of immersion in the virtual environment and reinforce the feeling of presence, new constraints have emerged, such as the need to prevent falls and risk of collisions in the real environment when people are immersed in the virtual environment (Kim, Moon et al. 2023).

We are assessing cognitive abilities using virtual reality.

A key issue in developing tools for assessing cognitive abilities in virtual reality is whether these tools reflect the concept they are intended to measure. In other words, the aim here is to verify whether the performance obtained on these tools is correlated with the performance of tasks that measure similar theoretical concepts. Several studies have reported significant correlations between virtual reality tasks and traditional tasks assessing cognitive functions. Other studies focusing on the ecological validity of these assessment tools using virtual reality have reported positive correlations between performance in virtual reality and that obtained in daily life tasks (Li et al., 2023).

More recently, a fully immersive task called the "virtual store" has been developed to assess memory more ecologically than traditional neuropsychological tools. This task was designed with an immersive virtual reality system using a natural navigation mode, walking, and simulating a common daily situation: shopping in a grocery store. The task was to memorize a list of common items and then find and retrieve them in the virtual environment. The virtual reality task demonstrated good feasibility in young and older people. Moving around the environment was easy, selecting products within the atmosphere was simple, and very few symptoms associated with cybersickness were reported. Concerning validity, performance on the virtual store task was positively correlated with that obtained on traditional episodic memory tests in young and older individuals. These results are particularly interesting in light of the difficulties encountered by more senior people suffering from neurodegenerative diseases who gradually find themselves losing their autonomy. Using this type of task in virtual reality offers the possibility of assessing the repercussions of cognitive impairment on the person's functioning in an activity close to those carried out in daily life (Muurling, de Boer et al., 2023).

Another study looked at the contribution of virtual reality to an intervention targeting the training of selective and sustained attention skills in patients with Alzheimer's disease or mild cognitive impairment. Results showed that patients reported being very satisfied and interested in the attention task and preferred the virtual reality condition over the paper condition, even though the task was more difficult. Interestingly, apathetic patients preferred the VR condition more strongly than non-apathetic patients. These results suggest that virtual reality-based training can be considered an interesting tool to improve adherence to cognitive training in patients with Alzheimer's disease or at risk (Newton, 2023).

Interestingly, a study explored the effect of cognitive training in virtual reality on the ability of a patient in the early stages of Alzheimer's disease to orient themselves in a virtual building. To promote immersion, the patient was seated in a wheelchair, himself represented in the virtual environment. It is by maneuvering the chair in the real environment that the patient moves in the virtual environment. The training consisted of going to a window, designated pseudo-randomly, in a virtual three-story building. To reach the selected window, the participant had to enter the building, find the elevator, stop on the corresponding floor and navigate to the correct window. In the first sessions, the passage in the elevator was a source of disorientation for the participant. This could be attributed to the rotation necessary to enter and exit the elevator and the loss of bearings. However, after seven weeks of training, with three 45-minute sessions per week, the patient managed to orient himself in the virtual environment without making any errors and to go to the designated windows. The patient's partner reported an improvement in her partner's orientation during car journeys. These results suggest an improvement in spatial orientation abilities following a virtual reality intervention and present future clinical applications of virtual reality intervention programs to strengthen the spatial orientation abilities of patients in the clinical phase of Alzheimer's disease to prevent loss of autonomy (Padovani & Pilotto, 2023).

Also targeting spatial orientation abilities, which appear to be early impaired in patients with Alzheimer's, another study evaluated the effectiveness of virtual reality training to improve these abilities. Patients with Alzheimer's disease was invited to participate in searching for virtual objects in a virtual environment reproducing a small town. Then secondly, the participants had to find the location of the objects previously found starting from a different starting point in the virtual city. The results showed improved long-term spatial memory in patients trained in virtual reality. Two recent studies examined the effects of semi-immersive virtual reality training with the BTS Nirvana system in patients suffering from other neurodegenerative diseases. In the first study, patients with Parkinson's disease were randomized into two groups: virtual reality training and traditional (face-to-face) training.

Each workout consisted of 24 sessions of 60 minutes, three sessions per week for eight weeks. The virtual reality training included different cognitive tasks, and patients were invited to respond using their upper limbs. The images were projected onto a large screen, and an infrared camera recorded the response movements. The results showed a greater improvement in cognitive functioning at the executive and visuospatial abilities levels in the group of patients trained in virtual reality. In a second study, applying the same experimental design, similar results were found in patients with multiple sclerosis (Tortora, Di Crosta et al., 2023).

Interestingly, a recent study explored the question of the influence of the level of cognitive reserve of participants on the ability to improve mental training in immersive virtual reality. The training consisted of purchasing necessities in a virtual supermarket, and the difficulty was modulated by manipulating the number of products to buy. Participants were trained in eight sessions over four weeks. The results showed, after training, an improvement in overall cognitive functioning in patients with mild cognitive impairment and cognitively healthy older people. Furthermore, among the latter, only those with a high level of education showed greater improvement than those with a lower level of education. This relationship was not found in patients with mild cognitive impairment (Anghel, Ciubară et al., 2023).

These results suggest that cognitive reserve may modulate cognitive gains following cognitive interventions in virtual reality in older adults without cognitive impairment. These results are consistent with those reported by other interventional studies in older adults, showing greater improvement in cognitive performance in those with higher levels of reserve. These results suggest that the advantage provided by a high cognitive reserve would decrease when the neuropathological damage associated with the progression of neurodegenerative diseases becomes more significant. The characteristics of the individual, such as their level of cognitive reserve, would play a modulating role in improving cognitive performance following interventions as long as the level of neuropathological damage remains low. These interpretations agree with the interactive model, which predicts that the

characteristics of the individual, defined in particular by their level of cognitive reserve, size, location, and the amount of brain damage, will modulate the neurofunctional and behavioral response to a cognitive intervention (Bernini, Panzarasa et al. 2023).

Currently, we are working on adapting a working memory training program for older people in a situation close to daily life using virtual reality and an immersive headset. This program, called *virtual reality Working memory Training* (VR-WORK-M), recreates a restaurant environment in which participants perform a *business speech*, which consists of memorizing and then repeating a series of verbal elements presented auditorily. The scenario suggests that the participant discusses a business project with a virtual protagonist with whom he is seated in a restaurant. The working memory task used in this program is based on the Brown-Peterson paradigm and requires storing and manipulating information in a short time interval. In this task, participants are asked to recall several short sentences aloud after varying delays, during which participants are asked to perform interfering tasks by manipulating verbal material. Preliminary results show high feasibility, equally high levels of immersion and sense of presence and very low frequencies of cybersickness (Catania, Rundo et al., 2023).

These studies show that cognitive intervention in virtual reality in patients with neurodegenerative diseases or who are at risk is likely to generate cognitive gains observable in terms of performance in experimental cognitive tasks or cognitive tests used classically in the clinic. The question that arises is the transferability of these gains in the daily cognitive functioning of trained patients. In other words, does improving the ability to recall an additional work after virtual reality memory training translate into fewer forgetting when the patient goes shopping?

Virtual reality to measure and promote transfer effects

The question of the transfer of the effects of the intervention to the activities of daily life is central to neuropsychological treatment. Beyond improving cognitive performance on certain tests after a cognitive intervention, the objective of any neuropsychology clinician who provides an intervention is to generate a direct functional benefit in the patient's daily life. A major challenge for virtual reality to be adopted clinically in cognitive interventions lies in its ability to generate cognitive gains that are transferable to the performance of daily life activities. Very few studies have demonstrated that the performance improvement observed in tasks trained in virtual reality is transferred in the form of cognitive gains in real life. In addition, using virtual reality in interventions offers a new, particularly relevant approach to solving the problem of generalizing the effects of cognitive training and their transfer to real, everyday situations. Virtual reality could be used to measure the impact of mental training on daily life activities (Davenport, Gallacher et al., 2023).

For example, a study examined the effects of attention training on elderly participants. It showed that the performance of these participants improved after training on an untrained, life-like task. Real-life simulation of a "virtual car journey". In this task, participants were passengers in a moving car and had to detect road signs to guide the driver while performing a verbal working memory task. Interestingly, the virtual reality task was more sensitive for measuring training effects than classically used self-reported transfer measures (Davenport, Gallacher et al. 2023).

In a recent study, we evaluated the potential of immersive virtual reality to measure transfer after strategic cognitive training targeting memory skills and whether the effectiveness and transfer effects were increased when practice sessions supplemented cognitive training in virtual reality. Forty older people with subjective cognitive decline were trained in the loci method, a memory strategy based on mental imagery and recall tables. They were randomized to either a condition where they practiced the strategy in virtual reality or a control condition where they became familiar with virtual reality without being able to practice the strategy (Kim, Moon et al., 2023).

Training effectiveness was measured using a word recall task, and training transfer effects were measured using two virtual reality recall tasks and a self-assessment memory questionnaire. All participants improved their word recall scores and performance on both VR recall tasks but not on the self-report memory questionnaire. However, no evidence supporting an increase in transfer effects

was found when enriching training with memory exercises practiced in virtual reality. Our results suggest that VR has potential as a transfer measure. This is consistent with previous studies showing that VR assessments can predict real-world performance (for example, see [9]). A few cognitive training studies have relied on virtual reality and reported beneficial effects on real-life measures. For instance, brain-damaged patients who received mental training in a virtual supermarket improved their performance in real-life situations [28]. These results suggest that cognitive gains generated following training in a virtual environment can be transferred to similar real-world situations (Li et al., 2023).

Interestingly, the results of the ACTOP intervention study (*Attentional Control Training in Older People*) that we recently conducted on older people suggest that the nature of the training plays a role in the transferability of the cognitive gains generated by the intervention in the performance of daily life tasks. Ninety older people were divided into three intervention conditions: training of updating skills (N-back type exercises), training of inhibition skills (Stroop test type exercises), and an active control intervention (general knowledge game). All participants used a tablet during the intervention and followed 12 sessions lasting 30 minutes. Results showed a rapid improvement in performance during training for both updating and inhibition training and improved performance on all measures of proximal transfer. Still, these improvements did not differ from the control group. Active. Results suggest that attentional control training improves updating and inhibition performance on training tasks (Muurling, de Boer et al., 2023).

Despite an overall improvement of older people on all transfer tasks, neither updating training nor inhibition training was able to generate additional improvements compared to the active control condition. This suggests that the effectiveness of process-based cognitive training does not directly affect transfer tasks, unlike mental training based on explicit strategy learning, which would be more likely to lead to effects transfer. For example, another interventional study in patients with mild cognitive impairment showed that only patients trained to use mental strategies (MEMO program) had improved their memory performance at the level of delayed recall. This improvement was associated with better use of methods in daily life. These few results suggest that cognitive interventions based on learning mental strategy would be more likely to lead to transfers into everyday life, information that is particularly relevant for the development of future virtual reality intervention programs likely to generate functional benefits in daily living activities (Newton, 2023).

Furthermore, the degree of immersion generated by the virtual environment could constitute an issue for cognitive interventions likely to limit the observation of the transfer of benefits in activities close to daily life. A study that we are currently carrying out aims to determine whether the transfer effect for the same intervention is more advantageous when this intervention is carried out in immersive virtual reality rather than on a digital tablet. In this study, older people are trained, during six 30-minute sessions, to prioritize their attention in a dual-tasking situation in a virtual kitchen. A third of the participants are trained in immersive virtual reality, another third is prepared using a digital tablet displaying the virtual environment, and a final third carries out a control intervention (Padovani & Pilotto, 2023).

One of the tasks in the virtual kitchen is to prepare individual coffees, and the other is to take inventory by memorizing the grocery items to be purchased. The transfer is evaluated in real conditions in a kitchen at the Research Center of the University Institute of Geriatrics of Montreal using the task used during training, in a real version this time. Suppose the degree of immersion in the virtual environment and the resemblance between the trained task and the task to be carried out in real life are likely to favour transfer effects. In that case, only older people trained in immersive virtual reality should improve more than the control group in real conditions. A high degree of immersion would also be associated with a greater feeling of presence in the environment. It would provide better adherence to interventions by increasing motivation and pleasure and promoting transfer into daily life (Tortora, Di Crosta et al., 2023).

The contribution of neuroimaging to cognitive interventions in virtual reality

Functional brain imaging is particularly relevant for studying the neural mechanisms by which training improves cognitive functioning. Cognitive training in patients with neurodegenerative disease or at risk suggests that both compensatory and restorative effects occur. For example, a functional magnetic resonance imaging study in patients with mild cognitive impairment showed that memory training using strategy learning increased brain activation in regions involved in memory encoding before training and induced new activations after training in areas that were not active before training. These results suggest that strategic cognitive training facilitates the recruitment of an intact alternative brain network to compensate for the impaired primary network in these patients. By combining functional neuroimaging with cognitive interventions in virtual reality, these new tools, electroencephalography and near-infrared spectroscopy, are likely to be used more and more at the clinical level as the information they provide is valuable for improving the effects of interventions (Davenport, Gallacher et al. 2023).

Conclusion

In conclusion, virtual reality offers considerable potential for measuring and training cognitive abilities in conditions close to everyday life. The development of realistic virtual environments, simulating everyday life situations, coupled with recent technological advances in ergonomics and realism, makes virtual reality a very promising technology for the development of effective cognitive interventions in patients suffering from neurodegenerative diseases as well as to measure the transfer effects in situations close to daily life. The low cost of immersive virtual reality equipment today and the availability of several cognitive intervention programs adapted to this technology offer favourable conditions for greater use of this type of technology in managing mental disorders patients with neurodegenerative disease (Bernini, Panzarasa et al. 2023).

The current trend should reinforce the enthusiasm for developing virtual reality interventions to favour telehealth and home care and the possibility of offering services through virtual reality networks (for example, the metaverse) shortly. In addition, with the progress made in recent years in the screening of cognitive disorders, it is now possible to provide early care for people likely to progress towards Alzheimer's disease or a related disease. Patients with mild cognitive impairment are good candidates for virtual reality interventions because the ability to acquire new knowledge and skills remains, at this stage, still relatively preserved. It is, therefore, possible that, shortly, these patients will be able to follow cognitive training sessions in virtual reality at home with complete autonomy. The main limit to these possible developments lies in the difficulty of demonstrating the transfer of the effects of the intervention into functional benefits in daily life. The development of virtual environments close to everyday environments to promote and measure these transfers is certainly one of the keys to future advances in treating cognitive disorders (Anghel, Ciubară et al., 2023).

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