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# Virtual reality – an increasingly accessible diagnostic and therapeutic tool

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## Abstract:
Virtual reality is a tool used in education, entertainment and medicine. The key aspect is the degree of immersion in the virtual environment and the complexity of interaction with objects placed around the user. Nowadays, thanks to image recognition technology, interaction with the virtual environment is also done with the user's hands, without additional controllers. This publication presents the benefits of virtual reality in medicine, discusses the complexity of interaction with virtual world objects and the problem of intolerance to virtual reality.

Key words: medical simulation, virtual reality, diagnostic tool, therapeutic tool, post-traumatic stress disorder (PTSD)

## Historical background
The history of Virtual Reality (VR) begins in the 1950s, when the first simulators were developed for pilot training purposes. Images were displayed on external screens, synchronized with the simulator's instrument systems and controls. The reality thus created made it possible to recreate impressions, train and study the reactions of pilots. The concept of VR evolved rapidly and, as early as 1962, Morton Heilig presented a prototype of the first device (or, more accurately, a system of devices) designed for individual entertainment on a new, hitherto unprecedented level. Heilig's machine, aptly named Sensorama, allowed for the display of images in a wide field of view, while also providing stereo sound, olfactory experiences (sprayed scents) and motion sensations (generated air movement and a moving seat; Figure 1)[1]. In the presented simulation of riding a motorbike on city streets, the user was able to experience sensations on a previously unavailable level of multimodality (multi-sensoriality). This first 'individual 4D cinema' outlined the future direction of VR tools – the immersion of the individual user in a world of created reality. As can be seen, from its inception VR has almost inherently been associated with entertainment.

In the initial phase of VR development, devices that resembled contemporary goggles (helmets, goggles, headsets – the nomenclature here is broad and often used interchangeably) required an entire back-end in the form of an extensive and expensive IT infrastructure. The cost of manufacturing and operating the simulation was so high that the first devices were only available in specialized research laboratories. One example is the 'Virtual Reality Lab' project launched by NASA in the 1990s at the Langley Research Center [2]. The project focused on the use of VR for spaceflight simulation, space vehicle design research and analysis of spacecraft behavior in the atmosphere and in space. The widespread use of VR in entertainment was yet to explode. At the turn of the 20th century, the cost of hardware remained an insurmountable barrier to the spread of VR technology. This only began to change in the following decade. With the advent of hardware that did not require a powerful VR computer setup, the availability of hardware increased exponentially, and the emergence of a wide audience stimulated the development of a huge variety of content spanning entertainment, education, healthcare, and industry.

## Virtual environment

Virtual reality is now utilized across numerous fields. The common denominator that allows VR to be used so widely is its ability to recreate virtually any situation in any environment. A virtual environment is not merely a space; it is also an entire situation constituted by interactions between the virtual world and the user.

The virtual environment can be utilized to facilitate almost any process: training an employee, conducting behavioral surveys, assessing competences and analyzing human reactions. This is made possible by the following universal principles:

1. Increasing the involvement of process participants: Interactive elements of the virtual environment, 3D simulations, and gamification features serve to capture users' attention and increase their engagement with the process [3].
2. Experiential learning: Virtual environments allow the exploration and experience of various phenomena and situations in a secure and controlled setting, enabling the safe exploration of phenomena and the development of practical skills in a simulated environment, whereas the same process/experiment conducted in real-world conditions would put the user at risk [4].
3. Accessibility of materials and content: With virtual technology, educational, diagnostic, therapeutic or entertainment resources can be easily accessed from anywhere and at any time via computers, tablets or VR goggles [5].
4. Individualization and personalization: Virtual environments can be tailored to the individual needs, mental state, health status and abilities of users, enabling a more personalized approach to the process [6].
5. Developing practical skills: Virtual simulations can involve the repetition of practical skills and the building of complex competences that are difficult to acquire safely in the real world (e.g. piloting an aircraft, performing a surgical operation) [7].
6. Stimulating creativity: The limitless nature of the virtual world removes barriers to the imagination of creators [8].
7. Reducing costs and opportunity costs: The use of virtual environments allows the process to be replicated multiple times, reducing the costs associated with training, therapy or experimentation compared to traditional methods; lowering transport costs, reducing the risk of damage to components or equipment, and shortening the time required for process preparation [9].

Currently, the virtual environment consists of a number of functionalities (modalities), including:

1. Three-dimensional image, film or 360-degree animation;
2. Stereo sound;
3. Vibrating controllers with buttons that can perform different functions; the controllers themselves can imitate other tools.
4. The user's hands (upper limbs), which are faithfully reproduced in the animation by analyzing the position and movement of the hands in space in real time (cameras placed on the goggles);
5. The user's facial expressions (on selected devices).

Currently available solutions make it possible to transfer selected elements of the real world into a virtual reality environment. The simplest solution, especially for small objects, is to use multidirectional images to copy the object into the virtual world. More sophisticated devices use 3D scanners to achieve greater accuracy by capturing all the details of the objects. Finally, cameras built into VR goggles can be used to recognize real objects around the user. This allows the zone of interaction with the virtual environment to be limited to an area in which the user can move safely.

## Scope of interaction in a virtual environment

Today's technology enables a much wider range of interactions in the virtual environment than was possible even a dozen years ago. It is standard for users to manipulate virtual objects that have been generated and placed in a virtual environment. Such interaction can consist solely of moving an object in space or it can generate a whole sequence of events. Scenarios allow the user to influence a complex environment, e.g. move an object, block the movement of another object, initiate a conversation, interact to remove a hazard, etc. Linear scenarios take the user from point A (start/action) to point B (finish/reaction). Non-linearity allows sequences of actions/events/activities to be generated according to the user's preferences.

A revolutionary level of interaction is the simultaneous interaction between several real people in a given virtual environment. Each user sees the others as avatars (representations of real people). Users can interact by following a planned scenario. This is extremely experiential and at the same time offers enormous potential for activities in the fields of education, cooperation and work organization. Situations that until recently were the domain of science fiction are now becoming widely available, including teleconferences and workshops in a virtual environment, or training courses in a virtual world supervised by people located thousands of kilometers away.

Interaction has also become more accessible and intuitive thanks to developments in technology. An open standard for analyzing images from cameras on VR goggles allows for the accurate reconstruction of the upper limbs in a virtual environment: the movement and position of the arms, forearms, hands and fingers. Instead of clumsy remote controls (tracers), the user manipulates the environment with his or her own hands, which are copied into the virtual world. Appropriate algorithms can also reproduce the movement of the rest of the body in the virtual environment in real time, based on input from sensors located in the goggles and the movement of the upper limbs. Freeing the hands from the need to hold additional maneuvering devices offers possibilities that can be compared to our ancestors freeing their hands when they started to move on two legs on the savannah. This has literally opened up countless possibilities for new applications, including therapeutic ones. Some of these will be presented later in this publication.

Currently, the least appreciated way of interacting with the virtual environment is through the use of position and acceleration sensors built into the goggles. These sensors can be particularly useful from a medical point of view to analyze gait, head movements, tremors, etc.

## Accessibility and tolerance

Until recently, the professional use of virtual reality required computer hardware with relatively high computing power. Separate VR laboratories with dedicated workstations for individual users were created at universities or corporations. Today, VR goggles have the computing power to run a virtual environment without additional hardware. This significantly reduces the cost of using VR and increases the accessibility of the tool, especially in education. The cost of the goggles themselves has also come down significantly in recent years, probably due to the growing number of competing solutions.

At this point, the issue of VR tolerance (or rather intolerance) should be raised. The problem of intolerance to VR has been reported in the literature, mainly in the form of dizziness, nausea, fatigue and anxiety [10]. The symptoms are due to the inconsistency of the sensations received by the brain during the simulation – vision registers movement and interactions with the environment that the senses of touch and balance do not. Interestingly, it seems that the greater the degree of immersion expected from the simulation, the higher the proportion of people with symptoms [11].

Observational evidence indicates a highly variable prevalence of VR intolerance symptoms, ranging from several per cent to up to half of users [12]. It seems that the reported frequency depends on a variety of factors. First and foremost, it depends on the quality of the viewing equipment – as image quality and refresh rates improve, the proportion of people experiencing symptoms decreases. The incidence of symptoms may also be influenced by the age and experience of the user – children and adolescents are more open to virtual experiences than seniors, for whom the virtual environment can evoke feelings of anxiety.

The incidence of symptoms is significantly reduced by using dedicated stations (treadmills) that allow the user to move naturally and safely in the simulation. Using modern haptic tools, such as gloves or other items of clothing, is revolutionary in improving tolerance. The sensation of touch or pressure correlated with the visual and auditory sensations reduces the feeling that the situation is unreal, decreasing the incidence of anxiety, nausea and dizziness. Due to the cost of these solutions, they are most often used in professional studios providing training or entertainment in a virtual environment.

An alternative solution is the use of VR goggles for mixed reality presentations/simulations. Three-dimensional animations (characteristic of augmented reality) are placed in an environment composed of virtual (objects, avatars of other users) and real elements.

When discussing VR tolerance, it is important to emphasize the importance of hygiene when using a virtual environment for work and entertainment. The amount of time spent in the virtual environment should be carefully dosed, with initial sessions no longer than 10 minutes if the user has no experience with this technology. Gradually increasing the length of individual sessions and taking sufficiently long breaks between sessions will allow tolerance to develop. Breathing exercises are helpful and are standard practice for reducing stress and anxiety [14]. The presence of a trusted person in the immediate vicinity significantly improves VR tolerance, although interaction with the user while in the virtual world should be avoided, as this can be an additional source of anxiety. VR goggles should be properly adjusted for head size. Users new to VR should reduce the brightness of the image and try to limit the intensity of particularly bright, unexpected and cyclical lighting effects. The type of animation and the extent of interaction should be suitable for the user, their experience and individual tolerance.

## Virtual reality for children with adjustment difficulties and suspected PTSD

In 2023, the Centre for Medical Simulation and Innovation at the Medical University of Warsaw implemented a project aimed at the early detection of adjustment difficulties and symptoms indicative of possible post-traumatic stress disorder in refugee children from Ukraine. Since the beginning of the Russian-Ukrainian conflict, hundreds of thousands of children have found refuge within the borders of the European Union, the majority in Poland. Many of them have participated and continue to participate in educational activities in Polish schools, despite obvious cultural and language barriers. School educators are faced with the extremely demanding task of supporting Ukrainian children in the process of adaptation, assessing each child's individual needs and the risk of dangerous behaviors (such as isolation, aggression, self-harm) resulting from the lack of adequate processing of emotions.

Post-Traumatic Stress Disorder (PTSD) is a severe mental health condition that can develop after an individual has been exposed to a traumatic event. While PTSD is often discussed in relation to adults, young children are also at risk of developing the disorder following traumatic experiences. The long-term consequences of PTSD in young children are profound, impacting their psychological, social, and physical development.

Children with PTSD often experience ongoing long-term anxiety, depression, and other mood disorders. These children may also exhibit a heightened state of arousal or hypervigilance, which can make them easily startled and excessively cautious. This constant state of anxiety can lead to difficulties in concentrating and learning, impacting their academic performance. The cognitive development of children with PTSD can also be severely affected. PTSD can impair a child's ability to process information, leading to difficulties with learning and memory. Additionally, the stress associated with PTSD can disrupt normal brain development, particularly in areas related to emotion regulation, impulse control, and executive functioning. This can result in long-term difficulties with decision making, problem solving, and sustaining attention. Over time, these psychological issues can evolve into more severe mental health disorders, such as chronic depression or anxiety disorders, which may persist into adulthood.

Social development can also be severely impacted in children with PTSD. They may struggle with forming and maintaining relationships due to trust issues, social withdrawal, and difficulty understanding social cues. They may also exhibit aggressive or oppositional behaviors as a result of their trauma, which can further alienate them from their peers and lead to social isolation. Over time, these social difficulties can result in a lack of social support, which is critical for healthy development and well-being.

An expert team comprising school educators, psychologists, psychotraumatologists, a psychiatrist, and experts in communication and new technologies in medicine have worked together to develop an information platform to support educators in working with children who have fled war and with their families. It uses software for screening symptoms of post-traumatic stress disorder and keeping records of work done with children and their parents. A special feature of the platform is a virtual reality based relaxation application. An adequate level of calmness and a sense of safety are essential for dialogue and for developing the ability to talk about one's feelings.

The application consists of modules designed for different age groups. Each module allows for a relatively simple interaction between the user and the environment. The aim of the app is to calm the user and build mindfulness skills, not to stimulate them further. The app uses sound and calming music to facilitate breathing exercises and relaxation and introduce a sense of safety. Importantly, the app does not have a strict script, and the amount of time the user spends in the virtual environment is determined by the educator.

It should be noted that many schools have the appropriate hardware infrastructure to use VR in the work of school educators. According to the authors of the article, the most important barriers to the use of VR in working with a wide population of children with adjustment problems are the lack of dedicated applications developed together with psychologists/psychotraumatologists and the insufficient knowledge of educators.

## Other practical examples of medical applications

Attempts to apply VR in many fields of medicine, whether for diagnosis, therapy or rehabilitation, have been reported in the literature, especially in recent years. Successful attempts deserve special attention. Unfortunately, VR is still underused in medicine, and it is worth highlighting the potential of this tool, if only for therapy and rehabilitation in the patient's home.

Rmadi H. et al. evaluated the use of VR in cognitive therapy and relaxation for seniors in nursing homes [12]. It should be noted that, despite the residents' initial apprehension, tolerance of the tool improved with subsequent VR sessions – users became more confident with VR. For the growing elderly population, a virtual environment may be the answer to communicating with loved ones or caregivers in the case of chronic immobilization or the need for regular psychological/cognitive therapies. It is to be suspected that, in the future, communication in a virtual environment will be associated with a lower cost and greater availability of therapy (also provided by artificial intelligence avatars).

The use of VR for relaxation is not limited to healthy people. Research suggests that relaxation is also highly effective and well tolerated by people with psychiatric disorders, including schizophrenia [15]. One challenge is the use of VR in the diagnosis and treatment of Alzheimer's disease [16]. The results of using VR with intensive care unit patients are encouraging – bedridden patients respond well to relaxation in a virtual environment [17].

An analysis of the available literature reveals many publications in which the authors argue for the use of VR in rehabilitation. In addition to general rehabilitation, especially for the elderly, reports on the use of VR in the treatment of Parkinson's disease are of particular interest. Parkinson's disease affects multiple domains of human functioning. In addition to tremor, there is slowness of movement, impaired eye-hand coordination, depression and dementia. Each of these domains can be rehabilitated using VR [13]. Virtually the only limitation to the use of this therapy is the lack of available applications – one can easily imagine the whole spectrum of exercises that could be performed by a person with various post-stroke dysfunctions.

## Summary

Virtual reality is a valuable diagnostic, therapeutic and rehabilitation tool that can be used either in the treatment facility, care center or in the patient's home. The potential for using VR in medicine is currently the subject of extensive research – the results of early reports are promising and suggest that as accessibility and tolerability improve, VR will become more widely used. The project implemented by the Center for Medical Simulation and Innovation at the Medical University of Warsaw is part of this trend, introducing an information platform to Polish schools to help educators screen for adjustment disorders and post-traumatic stress symptoms in refugee children from Ukraine. An important element of the platform is a VR application designed to facilitate relaxation in children and young people.

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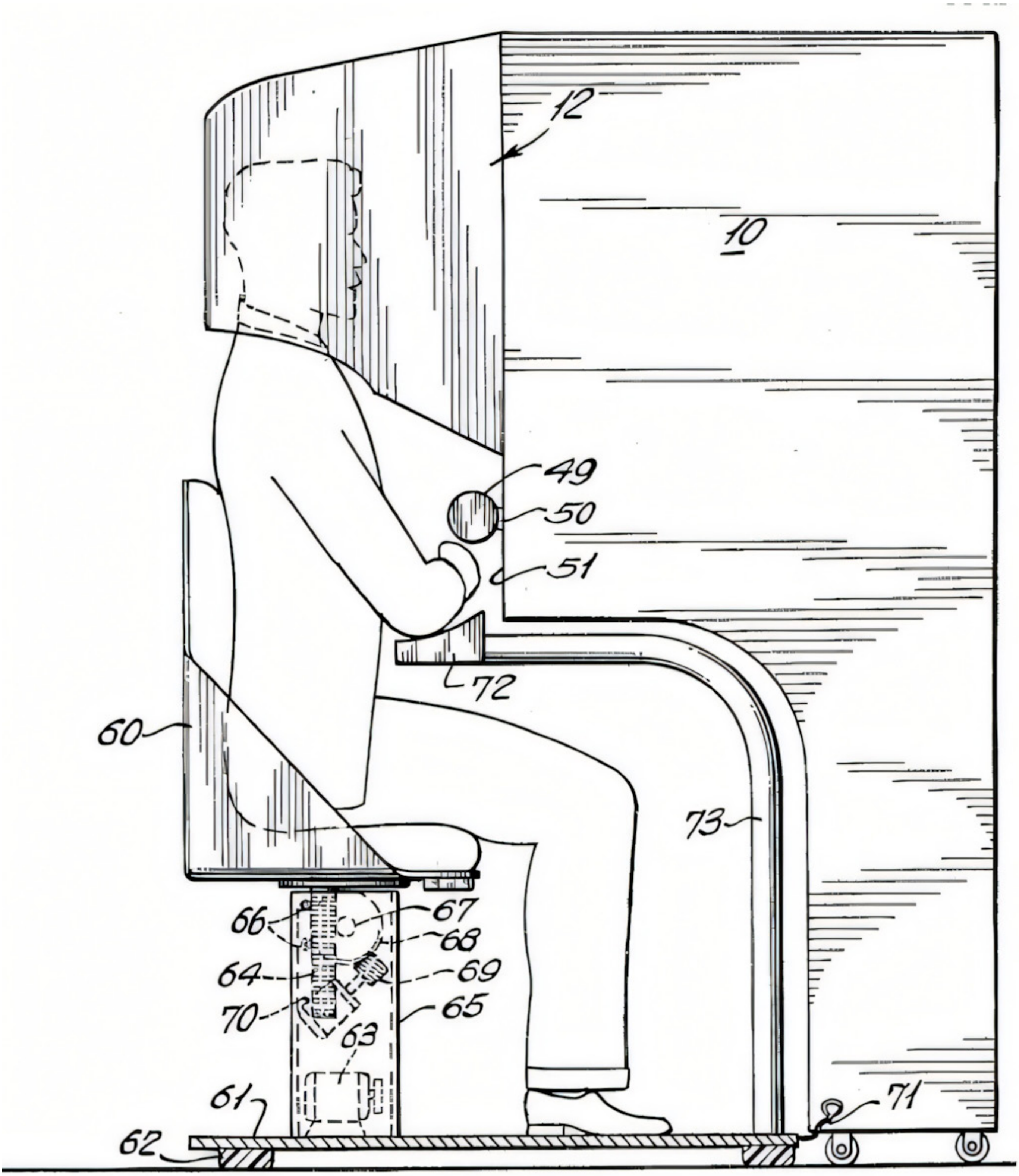


**FIG. 1.** Sensorama – the first system to provide multimodal experiences, the protoplast of both virtual reality systems and 4D cinema; figure from the patent description of Morton Heilig, US3050870

**FIG. 2.** Fragments of a virtual reality relaxation animation for refugee children from Ukraine.