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Review Article

Virtual Reality in Medical Education: Prometheus' Gift or Pandora's Box?

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Virtual reality (VR) is a computer-generated simulation that resembles a real-world environment and allows the user to explore and interact with it. VR increases attention, interest, and motivation in learning, and it can be used anywhere and at any time. Situations that are difficult to simulate with real tools can be easily created by VR technology. VR enables repeatable experiences in a safe learning environment without the risk of harm to the student or patient. However, it can also cause some problems such as digital eye strain, VR sickness, addiction, and altered perceptions of reality. This review defines VR and its associated concepts, highlights the significant stages that VR technology has undergone from past to present, and presents the advantages it offers and the potential risks it brings to medical education. It aims to provide a comprehensive and up-to-date scientific foundation for its appropriate and effective use.

Introduction

In Greek mythology, Prometheus is known for taking fire from the Olympian gods and gifting it to humanity[1]. The event in this myth is similar to a lightning bolt falling from the sky and teaching fire to humans. The ability to reproduce something that exists in nature has been very important for humanity's journey towards civilization. Virtual reality (VR) can be compared to dreams, which are an inherent part of human nature. In dreams, we see a version of the real world, usually believe it to be real, and interact with it. Could VR technology be a Promethean gift that brings dreams into the real world? When talking about Greek mythology and Prometheus, it is impossible not to mention Pandora. People also accepted Pandora's box as a gift from the gods, but it contained nothing but harsh pains and troublesome diseases[1]. VR technology is increasingly being used both as a tool for

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entertainment in daily life and as a learning tool in the field of education. Could virtual reality headsets be a modern Pandora's box, unleashing profound medical and social risks upon society? This review defines VR and its associated concepts, highlights the significant evolutionary stages that VR technology has undergone, and presents the advantages it offers and the potential risks it brings in medical education. It aims to provide a comprehensive and up-to-date scientific foundation for its appropriate and effective use.

Definitions

VR is a computer-generated simulation that resembles a real-world environment and allows the user to explore and interact with it[2][3]. There are many different terms that can be used synonymously with VR, such as virtual world, virtual environment, artificial world, artificial reality, or cyberspace[4]. Augmented reality (AR) is a technology based on the principle of placing computer-generated digital contents into users' real-world field of view[2][5]. Mixed reality (MR), also known as hybrid reality, combines VR and AR technologies[6]. It overlays digital elements onto the real-world environment, as seen in AR, and allows users to interact with digital elements as in VR [2]. Extended reality refers to a departure from reality and is a broad umbrella term covering the concepts of VR, AR, and MR[2] [Figure 1].

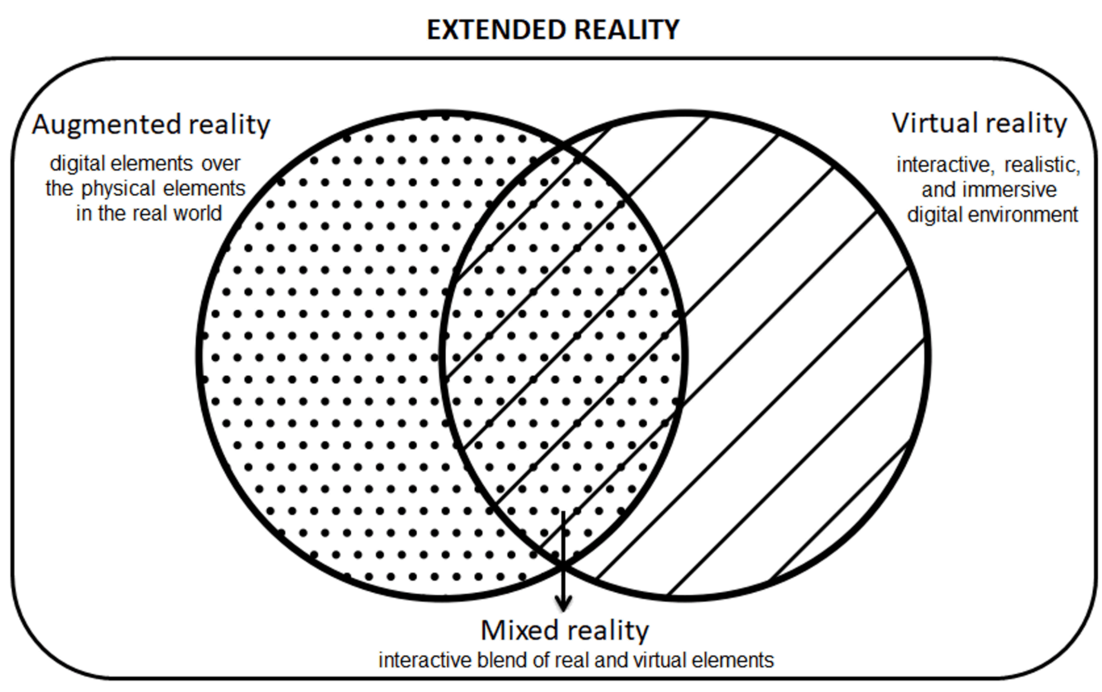

Figure 1. An overview of terms related to extended reality.

The term "metaverse" was first used in a science fiction novel called "Snow Crash" in 1992[7]. The metaverse is a virtual environment that allows people from various locations to interact[8]. Users in the metaverse communicate with each other through avatars, which are digital representations of real people, within a virtual world that parallels the real world[7][9]. Some authors use the term metaverse as a broader concept to refer to the digitized world expressed through digital media[10].

Classification

VR can be divided into monoscopic and stereoscopic categories. In monoscopic VR, a single image is directed to both eyes, and no headset is required as it can be displayed on any device screen; although the realism and immersion are lower compared to stereoscopic VR, it remains a cost-effective option[3]. Stereoscopy is a technique used to create a three-dimensional (3D) effect by inducing an illusion of depth, allowing two-dimensional shapes to be perceived as three-dimensional[11][12]. For this, different images are shown to each eye[13]. That is, the image created for the right eye is not seen by the left eye, and the image created for the left eye is not seen by the right eye[13]. The brain combines the two separate images coming from the two eyes and produces a stereoscopic three-

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dimensional image that creates a sense of depth perception[13]. To understand stereoscopy, you can conduct a simple experiment. Hold your index finger at a certain distance from your eyes and focus on any object behind your finger. The image of your index finger will appear double. Your left eye will see your finger to the right, and your right eye will see it to the left. You can confirm this by closing your eyes alternately. In stereoscopic VR, two separate images (stereoscopic pairs) are presented, one for each eye. Stereoscopic VR offers high immersion because it mimics how we see the real world, evoking a sense of "being there"[3]. There are two commonly used methods to create a 3D perception: either separate images are shown to the right and left eyes with a barrier in between (as in VR headsets), or special glasses are used to allow each eye to see two separate images (as in 3D cinema glasses)[11][12]. VR can also be classified into two main categories: head-mounted or headset-free. In head-mounted VR, the virtual environment is presented directly to the user's eyes through a headset. In head-mounted displays (HMDs), the headset may be connected to a computer (PC-powered VR), it may be self-contained (standalone), or it may be designed to carry a smartphone[14]. In headset-free VR, the user sees the virtual environment by looking at a screen. Examples of headset-free VR technologies include car driving simulators, flight simulators, Cave Automatic Virtual Environment (CAVE), metaverse environments such as Second Life, and 360-degree videos[8][15][16]. Some authors refer to highly immersive applications that use headsets completely blocking out the real world exclusively as VR[17].

VR technologies can also be classified based on their immersiveness into non-immersive and immersive VR. Non-immersive VR systems refer to those composed of a monitor, keyboard, and mouse, while immersive VR refers to technologies that block out information from the physical surroundings through head-mounted displays [18][19][20][21].

History

There can be different perspectives on the historical foundations of virtual reality. With a somewhat exaggerated approach, the quest for realism in images can be traced back to cave paintings where shadows were added to pictures[22]. The second critical stage can be seen as the integration of perspective into the art of painting in Italy in the 15th century[23]. As a result, objects started to be depicted as they appeared and in a way that created a sense of depth perception[23]. The key milestones in the evolution of VR include Charles Wheatstone's (1802-1875) introduction of the stereoscopic method in 1838 and David Brewster's (1781-1868) invention of the stereoscope, the first

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portable 3D viewing device, in 1849[24]. Another significant figure in VR history is Oliver Wendell Holmes (1809-1894). Holmes referred to stereoscopic pictures as stereographs and also developed his own stereoscope[24]. Stanley Grauman Weinbaum (1902-1935), an American science fiction writer, made a prediction far ahead of his time for virtual reality in his novel "Pygmalion's Spectacles," written in 1935, with the following statements: “And when the story is recorded, then I put the solution in my spectacles -my movie projector. I electrolyze the solution, the story, sight, sound, smell, taste all!”[25]. The View-Master, a stereoscopic children's toy considered a precursor to modern VR devices, was introduced in 1939[26]. Morton Leonard Heilig (1926-1997) developed the Sensorama simulator between 1957 and 1962. This device aimed to stimulate the user's senses using various components such as vibrating chairs and smell generators, providing a multi-sensory experience (i.e., vision, motion, sound, aroma, wind, vibration)[27][28]. In 1965, Ivan Edward Sutherland developed the Ultimate Display, pioneering the use of the first computer-generated interface[27]. In 1968, he and his team created the first HMD, sometimes referred to as the Sword of Damocles, marking a significant milestone in the development of modern VR systems[29] [Figure 2].

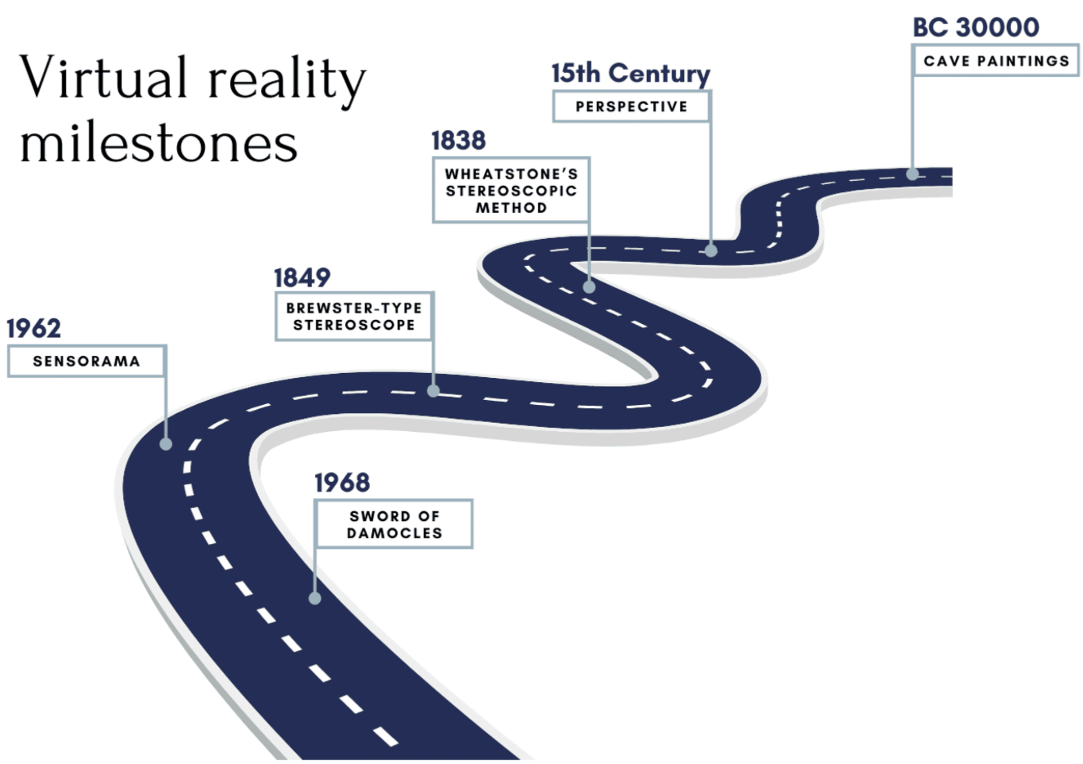

Figure 2. Virtual reality milestones.

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VR in Medical Education

Advantages and disadvantages of using VR in medical education are summarized in Figure 3.

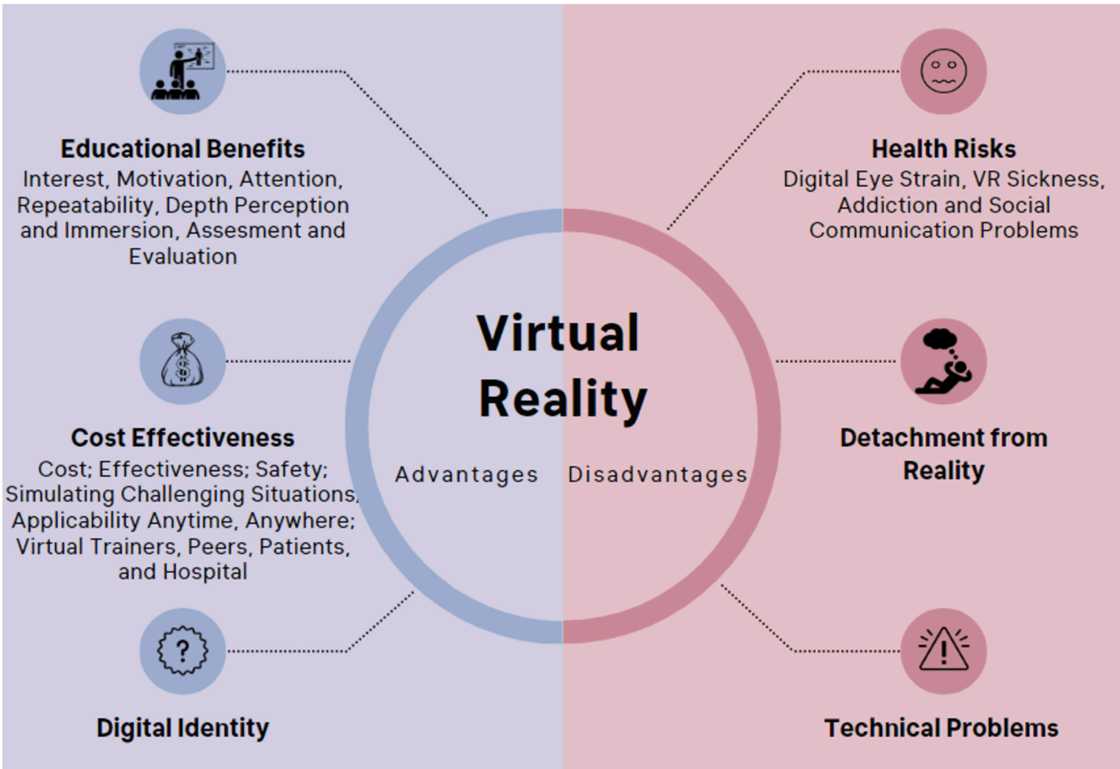

Figure 3. Advantages and disadvantages of using virtual reality in medical education.

Advantages

Interest and Motivation: Interest serves as a primary catalyst driving student engagement in the learning journey[30]. VR makes learning content more engaging, offering an enthralling experience for learners across all age groups[14][31]. Integrating this innovative technology into teaching materials has the potential to heighten students' interest in the subject matter and boost their motivation to actively participate[31][32][33].

Attention: It is widely studied that there is a close relationship between working memory and attention [34]. It is imperative to minimize distractions within learning environments[19]. Utilizing VR headsets to selectively present desired images directly to students' eyes can effectively clear the

doi.org/10.32388/SUZO18.3

learning environment of visual clutter[19]. Studies show that VR positively affects learning by increasing attentiveness[35].

Applicability: With few exceptions, VR headsets are lightweight and highly mobile, allowing users to access VR content from virtually anywhere, at any time[5][31][32]. This versatility renders VR an invaluable tool, particularly in scenarios such as the COVID-19 pandemic, where remote learning is essential[14][32][33]. Through VR technology, remote classes and conferences can closely replicate real-life experiences[6][36].

Simulation: Simulation is valuable in medical education, as in various other domains. Nevertheless, there are circumstances where simulating with tangible objects proves exceedingly challenging or unfeasible[10][37]. For example, replicating a disaster scenario is very expensive and nearly unattainable[6][37]. Likewise, trying to simulate a surgical procedure using physical models presents its own set of difficulties. In such cases, VR technology can offer experiences remarkably close to reality, introducing new ways to teach complex medical content[14][31][32].

Safety: When teaching procedures that are risky to perform on real patients, VR provides a risk-free environment for practice, much like mannequins do[31][32][33][38]. Therefore, VR has occupied a significant place in the field of surgical training, particularly[14][31][32].

Repeatability: Content presented via VR can be repeated unlimitedly. Unlike real patients who may experience fatigue or reluctance, or models that may wear out, such concerns do not apply in VR. Students can repeat procedures as many times as needed until they achieve mastery[14][31][32].

Realism: Head-mounted VR technologies can generate significantly greater depth perception compared to content displayed on a computer, smartphone, or tablet screen, offering users a more immersive experience[32][39]. Increasing realism in simulation contributes to enhanced learning outcomes[32][40].

Digital Identity: In the virtual world, users frequently choose to portray themselves not as they are in reality, but as they wish to be perceived[10]. Through their digital identities, known as avatars, they have the freedom to create representations that are separate from their real-life attributes[10]. Thus, instead of "me as I am", "me I want to show" is created[10]. VR users may identify with or take on attributes of their virtual bodies[41]. This empowerment may allow students to overcome challenges such as physical imperfections, disabilities, stuttering, low self-confidence, self-criticism, shyness, timidity, social anxiety, social phobia, physical bullying, and sexual harassment, which could otherwise hinder their learning[21][41][42].

Virtual Environment: Training educators to meet desired standards in real life poses significant challenges. Virtual trainers offer an alternative by reducing the reliance on real educators[17][36]. In real-world educational settings, students may inadvertently adopt inaccurate information or behaviors from their peers. Virtual reality environments not only provide a more controlled and supervised setting but also offer virtual peers capable of behaving appropriately for educational purposes, fostering conditions for social learning[3]. VR serves as an excellent alternative for simulated patient applications[3][5][6]. Virtual patients can be integrated into various scenarios, facilitating a deeper understanding of specific diseases or conditions[3][6][14]. VR can also be used to teach social skills such as communication with patients[3][14][35]. For example, students can be placed in the role of patients, thus enabling them to develop a high level of empathy towards real patients[3]. Virtual hospital environments, such as outpatient clinics or operating rooms, can be arranged to meet the desired educational objectives, thereby offering numerous alternatives to practitioners in the field of clinical training[5][6].

Assessment and Evaluation: VR allows for documented and unbiased assessments and offers detailed analyses by monitoring every user's inputs and interactions[5][18]. Utilizing objective evaluation methods via VR instead of subjective scoring can strengthen the reliability and validity[17][18]. Through diminishing reliance on human assessors, VR may ensure ease of implementation, scoring, and interpretation, thereby enhancing usability and practicality[17][36]. Receiving feedback and debriefing about their performance from the VR system is a critical component in achieving effective and lasting improvements for the students[3][17].

Usefulness: VR technology can not only be implemented as an additional teaching tool but also offers significant superiorities over traditional methods in certain aspects[31][32]. For instance, in anatomy education, it is impossible to perform dissections from different planes each time using cadavers or models[6]. However, VR enables such dissections virtually, facilitating a better understanding of the body's complex structure[6][14][43]. Surgery education is another domain where the effectiveness of VR is clearly demonstrated[18][35][39][44]. VR consistently proves its capacity to reduce injuries, enhance operation speed, and improve overall patient outcomes[3][17].

Cost Effectiveness: VR has the potential to ease financial, ethical, and supervisory limitations associated with traditional medical learning resources, such as cadavers and other skills lab equipment, offering a potentially more cost-effective approach to education across diverse fields[3][31][32]. Moreover, the versatility of VR headsets allows for their collective use in teaching numerous procedures across various disciplines, thereby enhancing their cost-effectiveness[14]. Although the initial investment for a VR headset may be substantial, the subsequent acquisition of different applications typically demands much less[5]. Consequently, in the long run, VR emerges as a notably advantageous option in terms of cost[31][32].

Risks

Digital Eye Strain: In the modern era, our eyes are under increased strain[45]. Unlike our ancestors, who naturally shifted their gaze between near and far distances and had limited exposure to light-emitting sources, today we find ourselves constantly focusing on nearby objects and enduring prolonged exposure to such sources of light[45]. Both in our daily routines and professional pursuits, we spend extensive hours fixated on the screens of computers, phones, tablets, interactive boards, and VR headsets[45]. Digital eye strain, known by various names including computer vision syndrome, ocular asthenopia secondary to digital devices, eye strain after computer or mobile usage, and visual fatigue, is a condition characterized by both ocular (related to the eye's surface, accommodation, and vergence) and extraocular symptoms (such as headache, neck and shoulder pain, and backache) that arise from extended periods of digital device use[45]. This condition can significantly impair work performance and productivity, with an estimated annual indirect economic cost surpassing $50 billion in the United States[46].

The prolonged focus on nearby objects stresses two sets of muscles: those responsible for moving the eyeball and those that adjust the lens thickness[47]. As we focus on nearby objects, the eyeballs turn inward towards each other, and the ciliary muscles contract, causing the lens to thicken [Figure 4][47]. Prolonged staring at nearby objects intensifies the strain on the muscles coordinating the movement of the eyeballs and the thickness of the lens. The sustained accommodation and convergence may result in symptoms such as difficulty focusing, blurred vision, and double vision (diplopia)[45].

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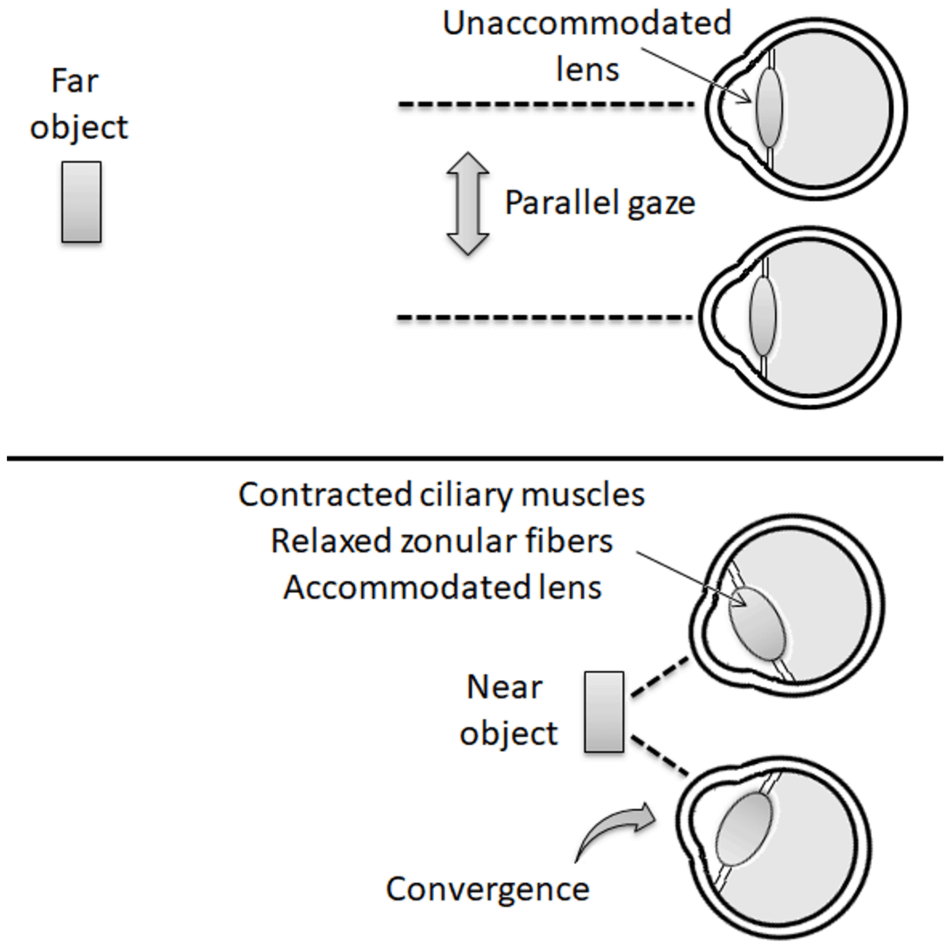

Figure 4. Convergence and accommodation. When the eye focuses on near objects, the eye globes move inward toward each other (convergence) and the lens thickens due to the contraction of the ciliary muscles (accommodation).

Digital screens emit light, which acts as an oxidizing agent[48]. Extended exposure to light from digital screens over time may result in heightened photooxidation and subsequent harm to ocular structures, particularly goblet cells, corneal epithelial cells, and photoreceptor cells[46].

Blinking is essential for maintaining a healthy ocular surface by moistening it with tears[45]. The tear film consists of three main layers: lipid, aqueous, and mucin[46]. The lipid layer, derived from meibomian glands, prevents evaporation and provides lubrication; the aqueous layer, primarily from the lacrimal gland, nourishes, washes, and protects the cornea; and the mucin layer, mainly from conjunctival goblet cells, ensures tear adherence to the cornea[46]. Parasympathetic nerves stimulate

doi.org/10.32388/SUZO18.3

lacrimal gland and goblet cells, while blinking regulates meibomian gland secretion[46]. Screen viewing reduces blink rate and increases the number of incomplete blinks in which the upper eyelid does not cover the entire corneal surface, thereby inhibiting lipid distribution from the meibomian glands and increasing the ocular evaporation area[45][46]. The heightened visual and cognitive demands associated with digital screen use are believed to decrease the frequency of blinking and encourage incomplete blinking[46]. Ultimately, viewing digital screens results in a shorter tear film break-up time, while also prolonging the interblink interval, causing symptoms of dry eye to emerge, such as eye irritation, burning, itching, redness, and sensitivity to light[45][46]. The ocular protection index (OPI) is the ratio between tear film break-up time and the interblink interval. An OPI below 1 indicates that the tear film breaks up before the next blink, leaving the ocular surface unprotected during the blink cycle[46]. When reading a book, our gaze tends to be downward, whereas with digital screens like VR headsets, we look straight ahead, resulting in a wider gap between our eyelids, ultimately increasing the exposed corneal surface area and evaporation [Figure 5]. The increase in palpebral fissure height due to the horizontal gaze at the screen further exacerbates the risk of dry eyes[45]. Persisting dry eye issues over an extended period can lead to damage to relevant anatomical structures, particularly the lacrimal gland, as a result of overuse mechanisms[46].

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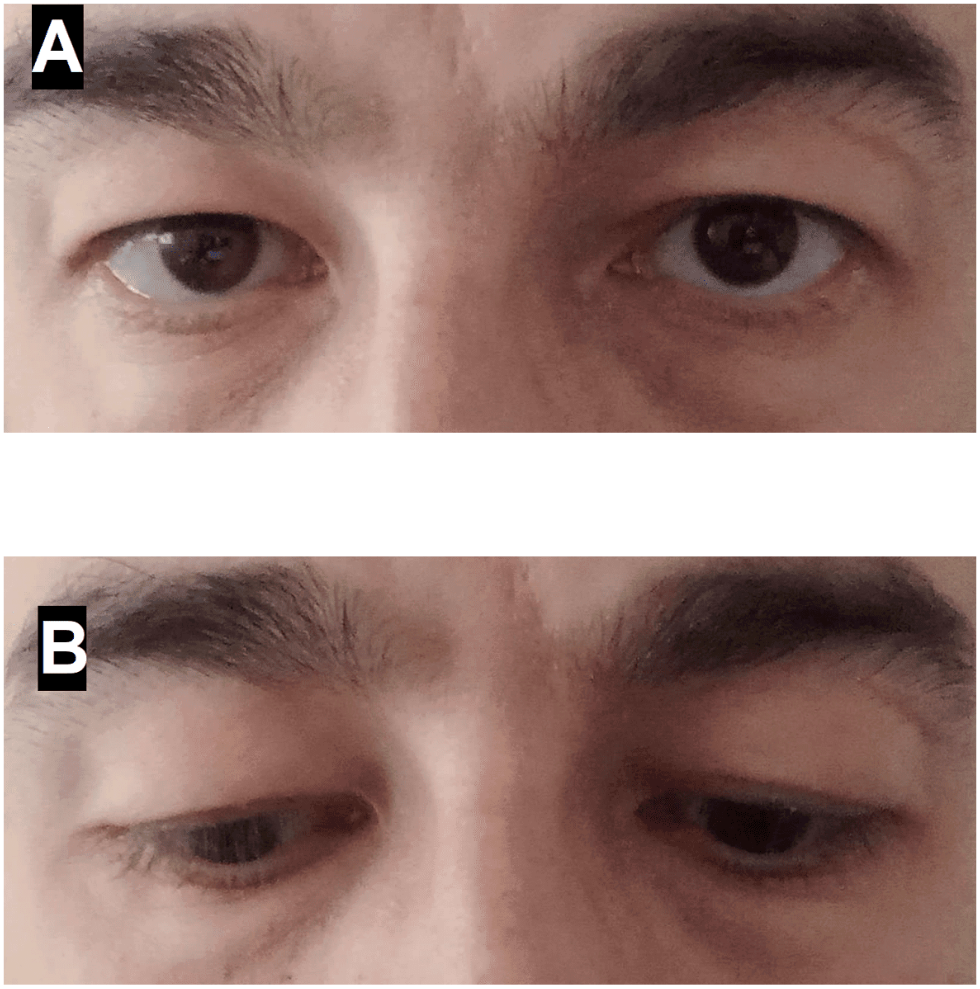

Figure 5. The distances between the eyelids while looking at VR screens and reading books. (A) When maintaining a direct gaze forward, as is the case when looking at VR screens, there is a significant gap between the eyelids, leading to greater exposure of the eye surface to the external environment. (B) In contrast, when the eyes gaze downward, such as during reading a book, the distance between the eyelids diminishes.

VR Sickness: VR sickness, also known as simulator sickness, cybersickness, and virtual reality-induced motion sickness, encompasses symptoms such as nausea, vomiting, sweating, dizziness, and vertigo that arise from using virtual environments[39][49][50]. VR sickness can hinder users' ability to interact smoothly with content or complete tasks effectively, thus discouraging the use of the technology[39][51]. Unclear images, poor resolution, low refresh rate, wider field of view, susceptibility to motion sickness, and content consisting of high amounts of motion such as rollercoaster rides are the main factors associated with VR sickness[49][51]. VR usage has the potential to increase the

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processing load of visual information passing through complex cerebral pathways, resulting in cognitive fatigue[52]. VR sickness is believed to be partly caused by the inconsistency between the user's virtual movements in the simulation environment and their physical movements in real life[39][50]. During VR usage, unlike in real life, conflicting signals arise among the vestibular, visual, and somatosensory senses[39][50]. Another cause closely associated with VR sickness is the conflict between vergence and accommodation (vergence-accommodation conflict)[49]. In the real world, the eyes focus and converge at the same distance, whereas in the virtual environment, they may focus and converge at different distances[53]. The conflict arises when VR systems simulate vergence cues while not providing support for focus cues[54]. In normal conditions, blur and disparity drive accommodation and convergence, respectively, with accurate accommodation eliminating blurred vision and accurate vergence eliminating double vision[53][54]. In VR systems, each eye perceives a slightly different view, creating disparity cues, which influence the vergence as the viewers observe objects of varying depths[54]. However, as the light emitted from the screens lacks depth information and focusing occurs at a fixed distance, the accommodation does not correspond to the depth perception, leading to vergence-accommodation conflict (VAC) [Figure 6][49][52][54]. To address the VAC problem, systems need to adjust the focal lengths in virtual images, with various methods currently being studied[52][53].

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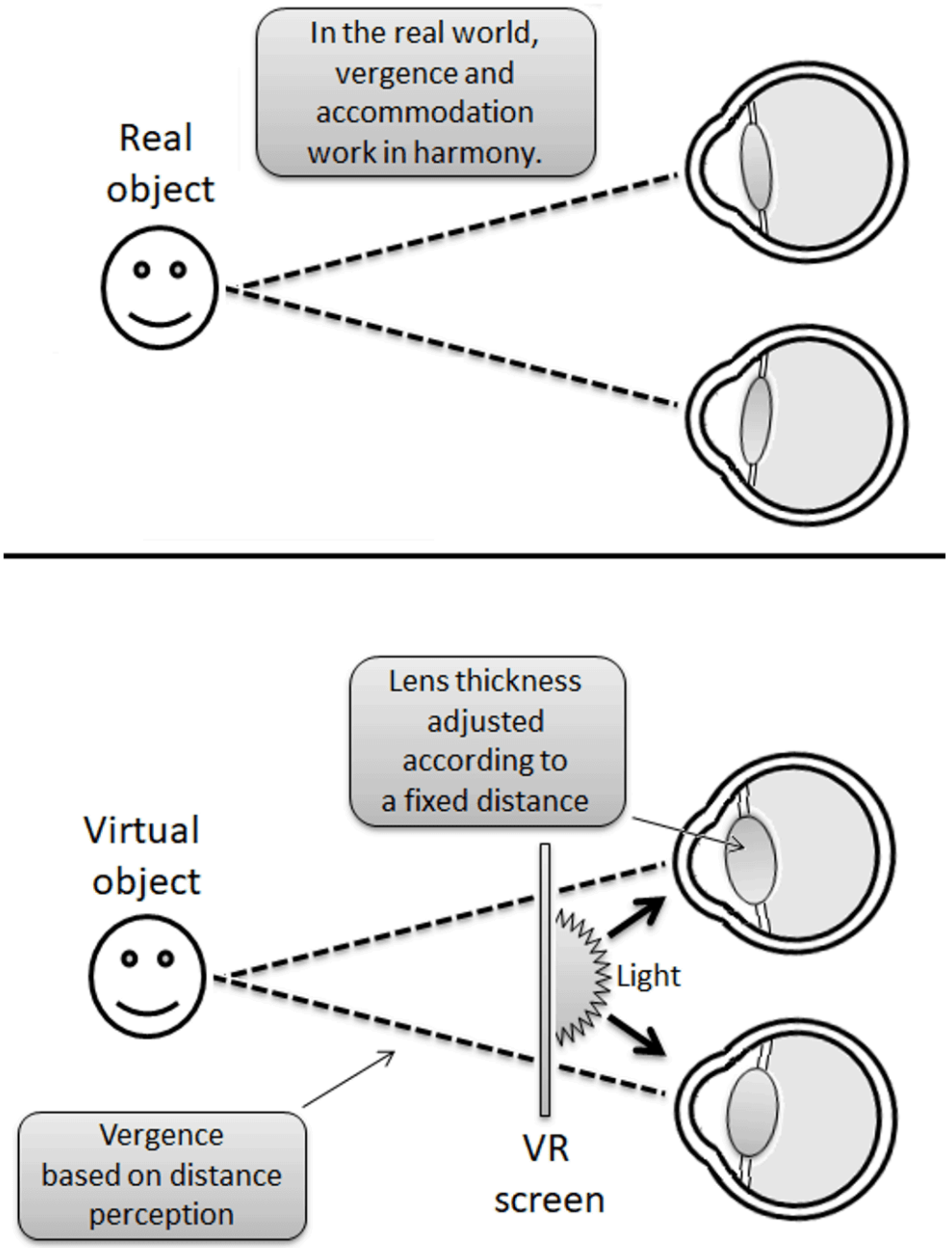

Figure 6. Vergence-accommodation conflict. In the real-world environment, vergence is combined with the accommodation process to see objects (above). VR systems maintain a fixed focus distance while directing vergences to desired distances, leading to vergence-accommodation conflict (below).

Addiction and Social Communication Problems: Various studies have demonstrated addiction to tools such as computer games; therefore, caution should be exercised with VR usage to prevent issues like

doi.org/10.32388/SUZO18.3

excessive use[39]. Over-immersion in virtual human relationships can lead to the neglect of real-world relationships and make it difficult to form new ones[10]. Studies indicate that VR technology, like other similar computer technologies, may be isolating, associated with reduced face-to-face communications, and consequently weaker social connections [10][39][55].

Detachment from Reality: Contextual factors such as sizes, sounds, and functionalities are essential to avoid potential errors in learning and training[31]. While VR can offer a semblance of reality, it forever falls short of the genuine experience[17]. VR offers lower haptic fidelity compared to other simulators[5]. It is clear that certain learning scenarios and objectives, such as performing abdominal palpation, providing chest compressions, or placing a peripheral intravenous catheter, cannot be taught as effectively with VR simulation[3][5][17].

Technical Problems: Technical issues such as internet connectivity problems can disrupt educational activities delivered through VR and may lead to not fully obtaining the expected benefits from VR[6]. Also, the short battery life of VR devices can be a limiting factor for extended use. Some devices offer a power-saving mode, but while this adjustment may extend battery life, it can negatively impact graphic accuracy.

Conclusions

For our eyes, which evolved to function in environments without light-emitting devices and screens used at close distances, VR technology has become one of the growing digital burdens that intensifies day by day. On the other hand, the opportunities offered by VR technology in the field of medical education, such as seeing the complex structures and relationships of organs in three dimensions in anatomy education or repeatedly performing procedures in surgical training without the risk of harming a patient, cannot be ignored. It seems that VR technology is neither Prometheus's gift nor Pandora's box. When incorporating VR into an educational program, careful consideration should be given to how it will contribute to helping students achieve learning objectives. The VR method must align with the teaching strategy. There should be a clear and well-grounded answer to why VR technology is being chosen. If the journey begins solely with interest and enthusiasm for novelty, such tools often end up on dusty shelves. VR should be seen as a technology that offers indispensable opportunities in medical education but should be used with consideration of its risks, and the balance of benefits and harms should be observed when including it in educational programs.

Possible Future Studies

In order for the use of VR in the educational field to become more widespread, new technologies are needed that will create less load on visual structures and alleviate symptoms similar to motion sickness. Undoubtedly, VR presents invaluable opportunities in medical education. However, it is important to remember that its effectiveness will vary depending on the topics, procedures, and the specific VR tools and software employed. Research to date has predominantly focused on teaching anatomy and surgical procedures, areas where VR is believed to offer the greatest benefit. Given the extensive scope of medical education, there is a clear need for numerous specialized studies to evaluate the effectiveness of VR across various domains.

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Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.