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Applications of virtual and augmented reality in infectious disease epidemics with a focus on the COVID-19 outbreak

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ABSTRACT

The pandemics of major infectious diseases often cause public health, economic, and social problems. Virtual reality (VR) and augmented reality (AR), as two novel technologies, have been used in many fields for emergency management of disasters. The objective of this paper was to review VR and AR applications in the emergency management of infectious outbreaks with an emphasis on the COVID-19 outbreak. A search was conducted in MEDLINE (PubMed), Embase, IEEE, Cochrane Library, Google Scholar, and related websites for papers published up to May 2, 2020. The VR technology has been used for preventing or responding to infections by simulating human behaviors, infection transmission, and pathogen structure as a means for improving skills management and safety protection. Telehealth, telecommunication, and drug discovery have been among the other applications of VR during this pandemic. Moreover, AR has also been used in various industries, including healthcare, marketing, universities, and schools. Providing high-resolution audio and video communication, facilitating remote collaboration, and allowing the visualization of invisible concepts are some of the advantages of using this technology. However, VR has been used more frequently than AR in the emergency management of previous infectious diseases with a greater focus on education and training. The potential applications of these technologies for COVID-19 can be categorized into four groups, i.e., 1) entertainment, 2) clinical context, 3) business and industry, and 4) education and training. The results of this study indicate that VR and AR have the potential to be used for emergency management of infectious diseases. Further research into employing these technologies will have a substantial impact on mitigating the destructive effects of infectious diseases. Making use of all the potential applications of these technologies should be considered for the emergency management of the current pandemic and mitigating its negative impacts.

1. Introduction

Infectious diseases can rapidly spread worldwide [1]. In the 21st century, infectious diseases, such as influenza, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), and Coronavirus Disease 2019 (COVID-19), have been considered sources of international concern [2–5]. Recently, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has emerged as a novel virus in Wuhan, China, and it has spread to the whole of China and the world. In a short time, this virus has led to a high rate of new cases and mortality [6]. Currently, there is no validated approach to treat COVID-19 cases or a double-blind randomized clinical trial to confirm some significant factors. Therefore, under the current conditions, various infection prevention methods, such as shut-down of countries, quarantine, screening, informing, and smart social distancing, play vital roles in preventing further spreading of the infection [7–9]. Response and preparedness against the COVID-19 disease, particularly in low middle-income countries, constitute a challenging issue [6]. Infectious disease outbreaks may have short-term (e.g., affecting the livelihood of individuals and the country's economy) and long-term effects (e.g., neurological consequences) for individuals [10,11]. In China, outbreaks of SARS and H7N9 had significant negative effects on public health and the economy [12]. Moreover, Jaakkimainen et al. have shown that community-based general practitioners (GPs) and family physicians (FPs) were considerably affected by H1N1 and SARS infectious disease pandemics both on a personal level and in their clinical practice. In other words, they had significant concerns about how an infectious disease pandemic might affect their family members' health, and they tried to change their office

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practice to control and deal with the infected patients [13].

Understanding the factors contributing to the emergency management of infectious pandemics can help facilitate and deal with the effects of an outbreak. The emergency management of infectious outbreaks needs proper planning for the protection of health security against threats [1,14,15]. Moreover, during the COVID 19 pandemic, many healthcare systems had to use virtual methods as an alternative to traditional methods to treat and control patients [16]. For the emergency management of infectious diseases, virtual reality (VR) and augmented reality (AR) can be great options for preventing or responding to pandemic situations [17–21]. VR is a new form of the human-computer interface in which a user can interact with and immerse into a three-dimensional environment using electronic devices, such as headsets and sensors [22]. Mixed reality is another emerging technology that was developed to address the separation of the virtual and real worlds, the most popular of which is AR [23,24]. AR is defined as the combination of the real and virtual worlds in which computer-generated information is presented or added to the real-world experience that users can interact with in an augmented world [25,26].

By simulating the real world, VR has the potential to be used in any infectious outbreaks or disaster situations for improving preparedness against pandemics by considering various aspects, such as human behaviors, disaster consequences, and experiences [27,28]. In disaster medicine, VR has more applications in education, professional skills training, popularization of disaster medical knowledge, and post-disaster psychotherapy [29]. Additionally, disaster can result in a stressful situation in the healthcare system. Education and training have an important role in the preparation of healthcare providers to manage or respond to these situations, and VR can address these challenges by providing an educational environment for various complications, such as crush injuries, infectious diseases, and even disasters [30]. For example, Nakasone et al. introduced a virtual world-based biosafety training application for medical students called "Open Bio-Safety Lab". Twenty-four students participated in a preliminary test study to evaluate the usability of the system, which indicated a high degree of usability for the system [31]. Moreover, this technology can provide an innovative solution to study the behavior of healthcare providers in a controlled virtual environment for training infection prevention [32]. Furthermore, AR can be used in emergency medicine for clinical management using haptic devices, telemedicine, and prehospital care to help on-time care and control through remote location and education of procedural training and clinical decision making for medical students through user-environment interfaces [33]. Additionally, the AR-based training system can be used as a beneficial system to enhance geographic information visualization, communication of the social network, representing a user's position in the map mode, increasing trainee's experience, crowd mapping systems, and so on [34,35].

Recent concerns about the COVID-19 epidemic have led to the development of effective prevention, response, and control approaches or tools to overcome the spread of the virus. The development of many strategies requires evaluating the social interactions that contribute to controlling or overcoming the current pandemic. Given the emerging information technology applications, VR and AR can be used in various aspects of disaster conditions, such as the COVID-19 pandemic. Currently, there is no review study focusing on the applicability of these technologies for infectious disease management. Therefore, this study aimed to review the literature on infectious disease outbreaks, including the COVID-19 pandemic, to determine the applications of VR and AR in the emergency management of epidemics or pandemics.

2. Materials and methods

2.1. Databases and search strategy

A detailed review of the literature was performed on the VR/AR applications in pandemic infectious diseases with an emphasis on the COVID-19 disease. Databases including MEDLINE (PubMed), Embase, IEEE, Cochrane library, WHO, Google Scholar, and reliable websites (gray documents) were searched on May 2, 2020 to identify possible related evidence. Pandemic or epidemic infectious diseases were determined according to the WHO portals [36]. The search strategy of this review is shown in Table 1.

2.2. Inclusion criteria

Studies and website contents were eligible for inclusion if they were defined as applicable to emergency management of infectious pandemics, they were relevant to the practice within the field of infectious diseases, or they indicated the potential applications of these technologies in the COVID-19 epidemic. The papers that were not directly relevant to emergency management, those that were not studying VR/AR, or those that were not primarily published in English were excluded.

2.3. Study selection and data extraction

The papers identified from the information sources were imported to an EndNote X8 library, and the duplicates were removed. Two authors screened the papers according to the eligibility criteria in three steps, i.e., 1) title screening, 2) screening of abstract/website descriptions, and 3) full-text screening. Disagreements were discussed and resolved in an online group based on consensus or through consulting with a third author. After selecting the related papers, the following data was extracted: tool (VR/AR/MR), emergency management phase (prevention/mitigation, preparedness, response, or recovery), infection type, and applications or advantages of the above-mentioned technologies for the management of the COVID-19 pandemic. Finally, the results were classified into sub-themes based on the VR and AR applications.

3. Results

Table 2 lists the capabilities of AR and VR for the emergency management of infectious diseases. A brief description of each study is presented in four sections as follows: **(1)** VR applications in emergency management of a) any infectious disease epidemics [17,19,21,37,38], b) the Ebola pandemic [39,40], c) the SARS pandemic [41,42], and d) the influenza epidemic [43,44]; **(2)** AR applications presented in four subgroups, including the emergency management of a) any infectious disease epidemics [45–47], b) influenza [20,48], and c) dengue [18]; **(3)** AR and VR applications for the COVID-19 disease presented in four sections, i.e., a) potential applications [49–51], b) clinical context [52–56], c) Teleservices [57–60], and d) education [54,61,62]. Finally, a taxonomy of the potential applications of VR and AR in the COVID-19 outbreak was generated in Section 4.

Table 1
Search strategy.

Search	Details
#1	"emergency management" OR "Viral disease" OR "outbreak" OR "infectious diseases" OR "epidemic disaster" OR "pandemic disease" OR "COVID-19" OR "COVID 19" OR "coronavirus" OR "Severe Acute Respiratory Syndrome" OR "SARS" OR "Ebola" OR "Middle East Respiratory Syndrome" OR "MERS" OR "Avian influenza A" OR "H7N9" OR "Pandemic Influenza A″ OR "H1N1" OR "Malaria" OR "Zika virus" OR "Influenza" OR "Cholera" OR "Smallpox" OR "Tularaemia" OR "Yellow fever" OR "H5N1" OR "Avian Flu" OR "Rift Valley fever" OR "Plague" OR "Nipah virus infection" OR "Monkeypox" OR "Marburg virus disease" OR "Lassa fever" OR "Hendra virus infection" OR "Crimean-Congo haemorrhagic fever" OR "Chikungunya" OR "communicable disease"
#2	"Virtual reality" OR "VR" OR "Augmented reality" OR "AR" OR "Mixed reality" OR "MR"
#3	#1 AND #2 Limits: English language

Table 2
Applications of VR and AR in infectious diseases.

Tool	Emergency management	Infection type	Technology applications/advantages	References
VR (Virtual Reality)	Preparedness and response	Infections	Realizing training objectives by simulating human behavior and visual warning of the predicted spread of infection.	[37]
	Preparedness	Infections and microorganisms	Prevention of the transmission of the infection by teaching hand hygiene.	[17]
	Preparedness	Respiratory system pathogenic agents	Providing a tool for learning about infectious diseases.	[38]
	Preparedness	H1N1 and others	Realizing training objectives at universities under quarantine.	[21]
	Preparedness	Emergency pandemic (flu to bioterrorism)	Teaching public health preparedness exercises.	[19]
	Response	Ebola	Improving and controlling basic health and safety factors.	[39]
	Preparedness	Ebola and others	Preparation against disease-related disasters by training for improving safety, collaboration, and management.	[40]
	Response	SARS	Controlling the spread of the outbreak by simulating human behaviors and interactions.	[41]
	Preparedness and response	SARS	Teaching methods for controlling transmission.	[42]
	Preparedness	Influenza	Increasing beliefs and perceptions of individuals about the role of vaccination against transmission of the virus.	[43]
	Preparedness	Influenza	Improving communication skills of residents under influenza vaccine hesitancy conditions.	[44]
	Response	COVID-19	Video calls (potential applications).	[50]
			Simulation of the real-togetherness (potential applications).	[50]
			Reduction of the negative effects of the outbreak (potential applications).	[50]
			Palliative care (potential applications).	[51]
			Providing good death in the last days for patients (potential applications).	[51]
			Recording patients for their families (potential applications).	[51]
			Educating and learning about the COVID-19 virus.	[54,61]
			Seeing into the patient's lungs.	[55]
			Telehealth VR system for many disorders.	[52,53]
			Tele-communication to share patient experiences.	[52,53]
			Academic teleconferences within the VR environment.	[57,58,60]
			Training and collaboration.	[58,60]
			Helping the discovery of potential molecular targets for the inhibition of COVID-19 proteins.	[54]
			Utility in any industry during quarantine.	[52,53, 58–60]
AR (Augmented Reality)	Preparedness	Hospital infections	Training cleanup.	[45]
	Preparedness and Response	Viral diseases	Providing education on virus transmission and spreading.	[47]
	Preparedness	Infectious diseases	Improving hand hygiene and preventing infectious disease transmission.	[46]
	Response	Avian influenza	Realizing prevention and training objectives by providing location information and transmission patterns.	[20]
	Preparedness	Influenza	Being used as an educational tool for increasing the elements of the Attention, Relevance, Confidence, Satisfaction (ARCS) model when faced with the negative effects of influenza.	[48]
	Preparedness	Dengue virus	Education and epidemiological surveillance.	[18]
	Response	COVID-19	Providing high-resolution audio and video communication.	[56]
			Directly sending patient data to the healthcare system.	[56]
			In any industry during quarantine.	[59]
			Visualization of invisible concepts.	[49]
			Annotation.	[49]
			Storytelling for training.	[49]
			Encouraging people to donate.	[62]

3.1. VR applications in infectious disease pandemics

3.1.1. General emergency management applications in infectious diseases

In a recent study, a VR system was proposed to develop improved infection control solutions. This study described the capabilities of a VR system in a variety of healthcare environments. The first capability involved utilizing VR as an improved training system for modifying human behaviors (e.g., hand washing or other infection control behaviors), and providing information about pathogens and transmission ways, and visual warnings of the predicted spread of the infection. The second capability involved improved systems for assessing the effectiveness of a recommended infection control solution. Finally, the third capability involved the application by a producer/seller of antimicrobial products to show the advantages of one product or proposed solution over another [37]. Moreover, a VR environment system was designed for teaching safe behaviors and highlighting the serious role of hand hygiene among healthcare providers to reduce and prevent the transmission of infections and microorganisms by providing visual feedback, visualization of infections or microorganisms, trying to create a better perception among users about critical care positions, and capturing user interactions and the integration of stressors within the VR environment [17]. VR-based simulation has been used as a successful system to educate medical students about the respiratory system by focusing on anatomical and microbial pathogenesis concepts. This system has provided an opportunity for infectious disease education through the simulation of a real-world context [38]. During any pandemic outbreak, such as H1N1, people have to stay at home; hence, face-to-face teaching for students is not possible at universities or schools. The National University of Singapore (NUS) designed a 3D virtual environment, called Second Life, for realizing teaching objectives of the university during quarantine. As a case study, they used the above-mentioned VR system to teach a cybercrime course [21]. A training VR system was developed in the form of a Second Life scenario for emergency conditions (e.g., influenza pandemic to bio-terrorism) with various scenarios, such as "morgue during mass fatalities", "mass dispensing of antiviral medications", and "managing push packs at the Receipt, Staging, and Storage (RSS) area" to provide public health preparedness exercises during the flu outbreak [19].

3.1.2. Emergency management in the Ebola pandemic

One of the efforts of the US Centers for Disease Control and Prevention (CDC) against Ebola was using VR to evaluate and improve health, stress, and anxiety management; skills management; suitable referral protocols; safety basics; and the resilience of non-clinical practitioners through a collaboration with the Center for the Study of Traumatic Stress (CSTS) in three days. This VR training program was called the "Deployment Safety Resiliency Team" (DSRT). Some realistic scenarios were incorporated in this highly-interactive training approach. Participants in this educational system were immersed in a VR-based environment that simulated deployment to one of the following types of settings: "a rural African village", "a city devastated by a hurricane", "a town rocked by an earthquake", "a community hit by a radiological dispersal device", "a location dealing with a pandemic", "a deliberate release of a toxic substance", or "a food-borne infectious disease outbreak" [39]. A VR environment, as a cost-effective tool, has been used for the more realistic simulation of the Ebola outbreak for pre-deployment education and training. This system can improve the problem-solving skills of healthcare providers and other humanitarian workers by boosting critical thinking, increasing teamwork cooperation, and improving worker safety. This VR system was used by the Ebola Treatment Center (ETC) for training. The VR environment had various applications, i.e., describing or recognizing the ETC, different zones, the patient and staff flow, the important role of personal protective equipment (PPE) in different areas inside the ETC, and showing the PPE donning and doffing procedures and the skills necessary to use the protocols in place in the ETC setting [40].

3.1.3. Emergency management in the SARS pandemic

VR was used for modeling epidemic transmission by focusing on the SARS outbreak through crowd contact by simulating pedestrian paths, human daily behaviors, and person-to-person interactions. This is a useful tool to recognize transmission factors by extracting human daily behaviors, and it plays a beneficial role in controlling the spread of the outbreak [41]. A combination of multi-agent simulation and virtual geographic environments was applied for displaying SARS transmission. This approach was designed by determining the conceptual framework of SARS transmission and control, agent attributes, knowledge-based rules, and the physical model of multi-agent interactions. Using this system, the control methods of transmission could be learned [42].

3.1.4. Emergency management in the influenza epidemic

A VR platform was used to improve the perception and beliefs of 18 to 49-year old individuals (N = 49) about the positive role of influenza vaccination in reducing flu transmission, increasing safety, and making people responsible for vaccination. By providing a high perception of presence, VR was able to improve the beliefs and concerns of the participants about the essential role of vaccination against the flu [43]. Moreover, VR was applied for communication training to improve the healthcare providers' relational skills by focusing on resolving the influenza vaccine hesitancy. VR is a beneficial tool to learn communication skills in busy outpatient settings because it is more effective than other platforms, such as online learning [44].

3.2. AR applications in infectious diseases

3.2.1. Emergency management applicable in any infectious disease epidemic

Development of an AR system can be useful in minimizing dangerous contamination spills, or in the event of the sudden emergence of a contagion by allowing the quick training of users and the optimization of learning retention. Accordingly, an AR training system was designed for simulating the cleanup of infected spills in the hospital to control the prevalence of contagious and infectious diseases. This system educates the staff to prepare for cleanup tasks by providing an immersive environment in the real-world through Microsoft's HoloLens equipment [45]. The AR-based serious game, known as Pathomon, was developed by a combination of location information and knowledge about the virus for educating the users about virus transmission and spreading. In this game, users have to fight and overcome the virus by creating the right antiviral and sharing knowledge about viruses through the game. The use of this game can be a good method for improving knowledge about viruses during outbreaks [47]. Through projection mapping, a mixed reality space was used to teach hand hygiene as an important way to improve hand hygiene and prevent the transmission of infectious diseases. In this system, using an alcohol-based hand rub was detected by using the pressure sensor to display the virtual virus in the PC. Then, this was represented in the real world using a projector to control and improve hand hygiene. Results indicated that by applying this MR space, the rate of hand hygiene increased by 8.4% on average [46].

3.2.2. Emergency management in influenza

An AR-based game, called "Outbreak @ The Institute", was designed for a number of training purposes, such as collecting information and overcoming the avian influenza outbreak, as one of the dangerous viruses for humans and birds. This is a handheld technology that provides location information for tracking the position of the building where players are located, and it includes a disease model for showing the transmission patterns of the emerging infection (e.g., by showing the antigen count through health level), and the current health status of the players. In this game, three roles are defined, i.e., medical doctors, field technicians, and public health officials. In order to evaluate this game, 21 students used it. The results indicated that the students experienced and learned about the threat and dangers of outbreak conditions to prevent the speared of the outbreak [20]. An AR system was developed as a learning tool for increasing students' motivation according to the 'Attention, Relevance, Confidence, Satisfaction' (ARCS) model with regard to the negative effects of influenza. The AR system increased the Attention element in the form of games and animated 3D web-based programs, improved the Relevance factor through equilibrium between students' demands and AR contents, promoted the Confidence component with a positive role in interaction and confidence, and finally increased the Satisfaction using various applications of AR, such as getting new information about the flu and self-learning. The use of AR can be a great method for achieving an effective learning tool [48].

3.2.3. Emergency management in dengue

Another serious game was developed to educate and facilitate epidemiological surveillance through awareness and controlling the dynamic transmission of the dengue virus. Dengue is spread between mosquitoes and people, and it is known as a dangerous disease of global concern. This game consists of four modules, including 1) fighting against the dengue and understanding the effective and ineffective activities against the virus at home, 2) learning preventive actions against the spread of the virus among new cases at home, 3) covering one's neighborhood, and 4) performing response action at the city scale. Two versions of this game have been released in the form of VR and AR platforms, and the users can use them through Google Cardboard [18].

3.3. VR and AR applications in COVID-19

The applications related to this section are described in four categories, as shown in Fig. 1. Furthermore, each step is briefly explained.

3.3.1. Potential applications

During the COVID-19 outbreak, VR can be useful for Industry 4.0 (i.e., a smart system that is supported by various technologies, such as

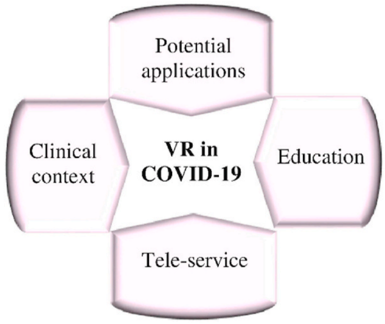

Fig. 1. Classification of VR and AR applications in COVID-19.

Internet of things, artificial intelligence, and VR) by providing different applications, such as video calls, simulation of the real-togetherness feel of people without traveling, reduction of the negative effects of the outbreak, and so on [50]. Additionally, VR is an effective technology in palliative care because face-to-face interactions are strictly prohibited during the pandemic. In other words, VR can provide a good death for COVID-19 cases by providing a simulation of physical worlds and enabling patients to feel experiences on their bucket list, such as visiting Japan during the cherry blossom season. Moreover, VR provides an opportunity for the patients to choose their favorite location to spend their time and be comfortable in their last days. It can also be applied to record patients for their family to treasure their last memorable moments [51].

AR can be used as a beneficial tool in the COVID-19 epidemic due to its features, such as the visualization of invisible concepts, annotation by navigation in the virtual world, and storytelling for training purposes [49].

3.3.2. Clinical aspects

XRHealth developed a telehealth VR system for supporting patients with various diseases, including multiple sclerosis, Parkinson's, breast cancer, menopause, an injury that affected motor function, anxiety, chronic pain, fibromyalgia, substance abuse, post-stroke rehabilitation, brain injury, and a general support group for the elderly population at home. Therefore, the use of this system can help people in the COVID-19 quarantine. Using this system, patients can control their stress and anxiety, engage in physical activity, and perform cognitive exercises. It also provides an opportunity for the interaction of people with various aims, such as exchanging experiences, performing meditation, and so on [52,53]. Furthermore, VR was used by medical providers in the George Washington University Hospital to see the patient's lung to assess the SARS-CoV-2 progress [55]. Researchers were immersed in the "Protein World" created in the VR environment to visualize the details of the SARS-CoV-2. In other words, they wanted to discover potential molecular targets for the inhibition of SARS-CoV-2 proteins; hence, using VR tools can create an extra method for drug discovery [54].

In China, AR was used to provide high-resolution audio and video communication so that when doctors wore HMD in isolation areas, they could do patient rounds and communicate or consult with many doctors at the same time. Moreover, this system provided an automatic recording of the patient's details by sending patient data to the medical system without any contact or paperwork in triage [56].

3.3.3. Telecommunication

The Immersive VR Education Company developed the Engage Platform as a VR training and collaboration platform. The Virtual VIVE Ecosystem Conference (V^2EC) is usually held in Shenzhen, China. However, this year, it was held inside the Engage platform because of the COVID-19 pandemic [58,60]. Additionally, a VR environment was used for holding and organizing the IEEE Conference on VR and 3D User Interfaces (IEEE VR) using Mozilla's VR platform, i.e., Hubs, during the COVID-19 pandemic [57].

Moreover, EON Reality developed a VR and AR-based platform to be used in the current quarantine conditions at home to help many industries, businesses, schools, and governments. Through mobile phones or other immersive devices, users can make use of this platform [59].

3.3.4. Educating

A VR environment was created to better teach the geometry and the structure of the COVID-19 virus through immersive or non-immersive presentation of its basic molecular dynamics at the University of London [61]. Moreover, Laurentian University's Stefan Siemann used VR for studying the enzymes and proteins of SARS-CoV-2 [54].

Snap's AR lens was designed to indicate how monetary donations can help during the COVID-19 pandemic. In this way, this lens teaches people how they can play a useful role by donating resources, while it also highlights the WHO messages about the role of donations against pandemics [62].

3.4. Taxonomy of potential VR and AR applications in the COVID-19 pandemic

According to the results of Sections 1-3, the potential applications of VR and AR in the COVID-19 outbreak are summarized and classified into a number of core topics, i.e., 1) entertainment, 2) healthcare context, 3) business and industry, and 4) education and training objectives. These topics and their subgroup applications are presented in the following taxonomy (Fig. 2).

4. Discussion

It is evident that information technology is progressing rapidly. Accordingly, VR and AR have also developed rapidly, becoming one of the most significant technologies. In this paper, we have tried to show VR and AR applications for infectious diseases; however, it will take time to release other new information about the applications of these technologies against the COVID-19 outbreak. A majority of the studies conducted about VR and AR applications in infectious diseases can be classified into one of four distinct themes, i.e., entertainment, clinical care, business and industry, and education and training.

Various pieces of evidence indicate that VR and AR have the potential to be used in any industry. In the clinical care context, these technologies are a useful tool for providing telehealth services, visualizations, and communication, as well as helping healthcare providers in education, diagnosis, and drug discovery [20,46,50–56]. Beyond the COVID-19 pandemic, there have been numerous studies about VR and AR applications in telemedicine, indicating the capability of these technologies in telehealth services [63,64]. VR capabilities, such as the representation of 3D models, the accurate visualization of the molecular structure, and the interactions of the target ligand, can provide a good method for novel drug discovery, visualization for molecular docking, presenting interactive drug design, and interactive molecular dynamics simulation. In this regard, various apps have been developed for the above-mentioned applications [65]. For example, RealityConvert in both AR and VR forms was developed for converting molecular structures to 3D models. It is a useful tool in the field of bioinformatics and cheminformatics [66]. These technologies should be considered an effective tool during infectious epidemics. They play an effective role in treatment, telehealth, assessment of patients, bioinformatics, and education by presenting various features, such as immersion, interactivity, and virtual worlds. In pharmaceutical fields, the key to drug design is finding the right shape for the molecule to fit inside the targeted protein pocket. Accordingly, VR and AR are more significantly helping scientists discover new drugs by visualizing molecules and identifying new drug-like ligands than the traditional approaches. Therefore, during the COVID-19 outbreak, these technologies can be used for drug discovery. Additionally, the applications of VR and AR in telehealth can provide an

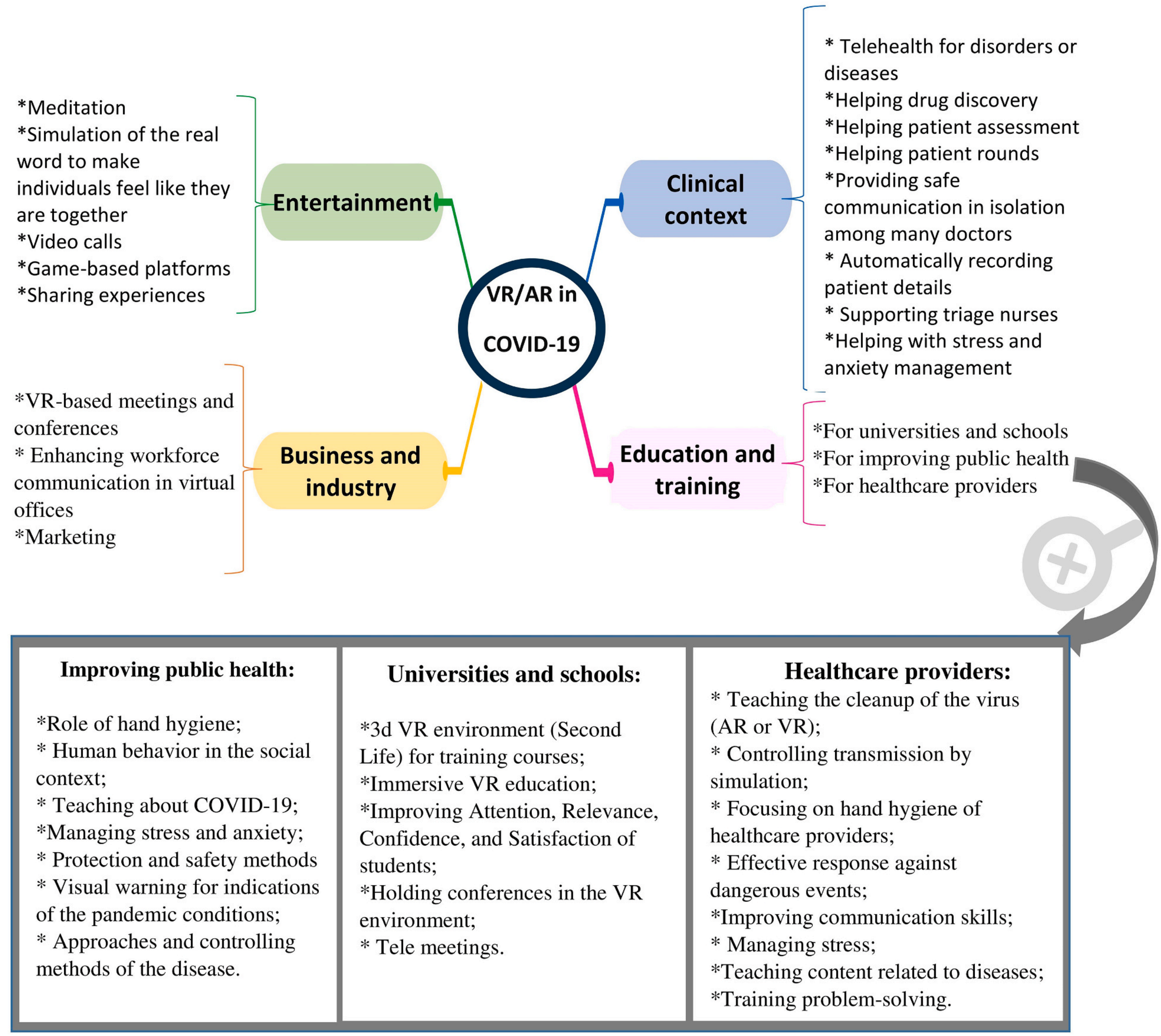

Fig. 2. Overview of VR and AR applications in the COVID-19 outbreak.

opportunity for patients and healthcare providers to deal with the negative impacts of epidemics through the remote delivery of healthcare services. In other words, VR-based telepresence systems can play a beneficial role in reducing face-to-face communication. Therefore, the use of this capability can affect the further spread of infection diseases, increasing the safety protection of the public and the hospital staff. Moreover, VR-based telemedicine can help physicians in the assessment of patients by allowing remote information visualization. Thus, in the clinical context, making use of all the potentials of AR/VR requires examining their applications for the emergency management of infectious disease outbreaks.

Moreover, VR can address the destructive effects of quarantine conditions by offering a simulation of the real world, creating a sense of presence in the real world. In this regard, VR and AR technologies have been used in pursuit of various objectives related to the COVID-19 disease, such as holding VR-based conferences, telecommunication and telemeetings in business, and traveling through the VR world [54,57–62]. In addition to pandemic issues, VR and AR have generally been applied in entertainment [67,68], tourism [69,70], virtual reality teleconferencing [71,72], business [73–75], online education [76,77], and so on. The literature on infectious diseases also indicated applications of these technologies in different diseases, such as SARS, influenza, and Ebola, for education, teleservices, and clinical purposes [18,20,39–44,48].

Education and training play an important role in the emergency management of disasters, and responders need to be cross-trained in multiple roles for preparedness against disaster conditions [19,40]. Our literature review revealed that most of the previous studies on infectious diseases were designed for educating and teaching prevention or preparedness strategies to manage disaster conditions. It should be noted that VR capabilities play an important role before the pandemics in terms of reducing the negative effects of infectious diseases. In other words, individuals can experience a pandemic situation in a simulated environment to learn how they should respond to infectious diseases. Additionally, the COVID-19 disease has forced health authorities and government officials to urge people into quarantine; hence, the use of information technologies, such as VR and AR, as digital solutions, can help us in many areas, including the healthcare system, sharing information, communication, business, education, entertainment, and so on. Therefore, these technologies have the potential to be used in any industry, especially during the quarantine conditions of the COVID-19 epidemic. In general, our results indicate that VR applications were more extensively considered than AR applications for the emergency management of infectious disease pandemics.

5. Conclusion

It appears that VR and AR technologies can play a positive role during infectious disease outbreaks. VR and AR have been widely used in the prevention and response phases of emergency management during infectious disease pandemics, such as SARS and Ebola pandemics, especially for educating and training purposes for the public. During the COVID-19 outbreak, these technologies have the potential to be used in various fields, including 1) clinical context (e.g., telehealth, drug discovery, patient assessment, mental health management), 2) entertainment (e.g., video call, meditation, gaming), 3) business and industry (e.g., holding meetings and conferences, marketing), and 4) education (e.g., in schools and universities, for healthcare providers, and VR-based content for improving public health). These technologies can be used in the above-mentioned fields by providing their different features for facilitating the challenges of COVID-19. However, to respond to COVID-19, all applications of VR and AR should be considered as a supportive approach alongside other information technologies. We believe that VR and AR have a substantial potential to impact the emergency management of COVID-19 or any infectious disease pandemics; however, these potentials need to be studied in a more robust manner.

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Author contribution

Afsoon Asadzadeh: Conceptualization, Verification, Investigation, Data collection, Writing - Original Draft, Review & Editing, Visualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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