Review

Immersive Virtual Reality in Health Care: Systematic Review of Technology and Disease States

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Abstract

Background: Immersive virtual reality (IVR) presents new possibilities for application in health care. Health care professionals can now immerse their patients in environments to achieve exposure to a specific scene or experience, evoke targeted emotional responses, inspire, or distract from an experience occurring in reality.

Objective: This review aimed to identify patient-focused applications for head-mounted IVR for acute treatment of health conditions and determine the technical specifications of the systems used.

Methods: A systematic review was conducted by searching medical and engineering peer-reviewed literature databases in 2018. The databases included PubMed, EMBASE, Cumulative Index to Nursing and Allied Health Literature, Association for Computing Machinery, Institute of Electrical and Electronics Engineers, Scopus, and Web of Science. Search terms relating to health and IVR were used. To be included, studies had to investigate the effectiveness of IVR for acute treatment of a specific health condition. IVR was defined as a head-mounted platform that provides virtual and auditory immersion for the participant and includes a minimum of 3 degrees of orientation tracking. Once identified, data were extracted from articles and aggregated in a narrative review format.

Results: A total of 58 studies were conducted in 19 countries. The studies reported IVR use for 5 main clinical areas: neurological and development (n=10), pain reduction through distraction (n=20), exposure therapy for phobias (n=9), psychological applications (n=14), and others (n=5). Studies were primarily feasibility studies exploring systems and general user acceptance (n=29) and efficacy studies testing clinical effect (n=28).

Conclusions: IVR has a promising future in health care, both in research and commercial realms. As many of the studies examined are still exploring the feasibility of IVR for acute treatment of health conditions, evidence for the effectiveness of IVR is still developing.

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KEYWORDS

virtual reality; health care; telemedicine; systematic review; mHealth

Introduction

Virtual reality (VR) has recently seen a resurgence of interest, both in the general public and academic communities. Technological improvements in processing, graphics, display, and 3D software have led to the release of several new commercially available VR systems since 2010. As a result, VR systems today cost one-sixtieth of the price, have better performance, and require less specialized hardware than systems from 20 years ago [1].

VR systems immerse the user in a virtual environment by completely replacing the visual environment and possibly aural sensation. The aim is to achieve a sense of *presence* such that the user perceives themselves as being part of the virtual environment. Key technical factors that help induce presence are accurate and stable tracking of the user's head and possibly body motions, low-latency updating of the visual image provided to the user, a high display resolution, and a wide field of view.

Although commonly used for entertainment, VR is increasingly being used for so-called *serious* applications. Nonimmersive VR has a long history of use in health care; however, in this study, the more recent trends of immersive virtual reality (IVR) for health-related treatment applications are reviewed. IVR presents interesting possibilities for application in health care. Health care professionals can now immerse their patients in environments to achieve exposure to a specific scene or experience [2], evoke targeted emotional responses [3], inspire [4], or distract from an experience occurring in reality [5]. Relevant previous reviews have focused on specific clinical specialties such as mental health [6] or cognitive and motor rehabilitation [7,8]. This study aimed to summarize research across many clinical specialties. Findings are compared with those of related reviews in the Discussion section.

Terminology varies across different fields and from academia to public vocabulary. In this review, IVR is defined as a VR system that provides at least 3 degrees of freedom (DOF) of head orientation tracking (ie, roll, pitch, and yaw) and uses a head-mounted display (HMD) worn by the user. Traditionally, IVR may also include projection-based virtual environments (sometimes called *CAVE* systems). These systems were excluded to align this review with the recent trend of commercially available low-cost head-mounted devices. In addition to head orientation tracking, IVR systems may further provide head positional tracking or hand, controller, or body tracking in conjunction with various other sensory modalities such as haptic feedback.

Non-IVR systems that display a virtual environment to the user on a personal computer or mobile phone display without head tracking were excluded. Such systems have a long history of successful use in health care, most notably in psychology, with several reviews available [9-12]. Finally, this review did not focus on nontreatment applications of VR in health care such as for training.

The primary research question addressed by this review is as follows: what are the patient-focused applications for IVR in health research? This review examines the technical specifications of the systems being used and collates the health conditions being targeted.

Methods

Search Strategy

This review follows the methods described in a published protocol (PROSPERO 2018 CRD42018105512) [13]. Articles were included if they were published after 2010 when low cost IVR technology became commercially available. Only full-text journal articles available in English were included.

Search terms with appropriate amendments (dependent on medical subject headings) were used to search PubMed, EMBASE, Cumulative Index to Nursing and Allied Health Literature, Association for Computing Machinery, Institute of Electrical and Electronics Engineers, Scopus, and Web of Science for articles. ProQuest Global was additionally searched for theses. Search terms were (health OR rehabilitation OR telere* OR "digital health" OR ehealth OR "virtual care" OR telemedicine OR telehealth) and ("virtual environment" OR "artificial environment" OR "virtual reality") not (surge*). Where possible, results were filtered to human-focused studies.

Article Selection

After duplicates were removed, titles and abstracts were screened for eligibility. The remaining articles were then read in full to confirm eligibility. Owing to the volume of articles returned, rehabilitation applications of IVR were excluded during the abstract and full-text review.

Studies were included if they related to any population receiving acute disease—specific treatment using IVR. Studies were excluded if they described training for health professionals in IVR (generally surgery education), non–earth-based applications (ie, focused, on space exploration), nonacute treatment applications such as rehabilitation, only described a system or hypothetical system without pilot or efficacy results, or were general well-being IVR systems for nondescript clinical purposes such as mood elevation or incentivizing exercise.

The primary search was conducted by one researcher (CS). Abstracts were reviewed by two researchers (CS and AS), with any disagreement discussed to reach consensus.

Data Extraction and Analysis

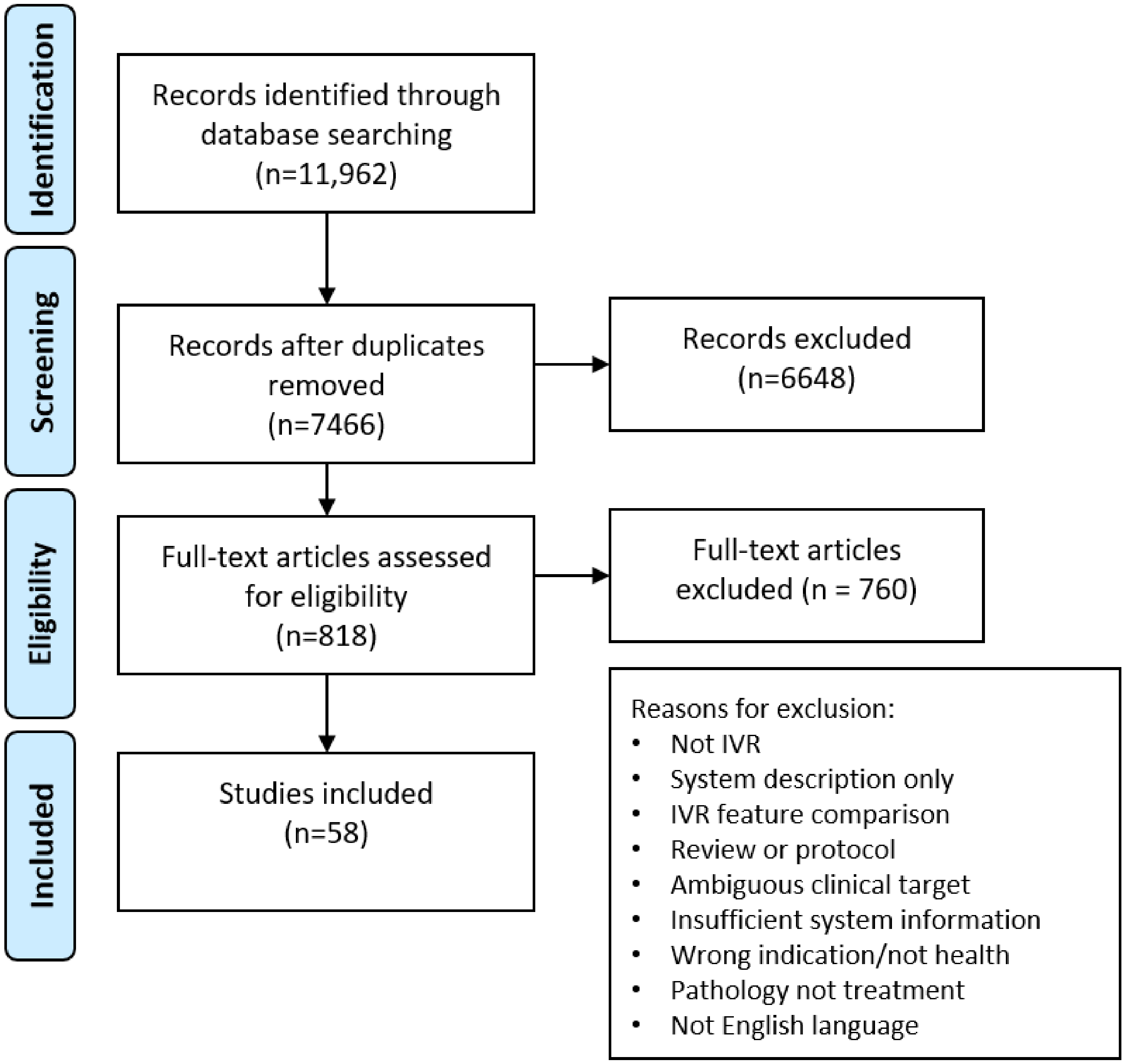
The data extracted included study type (efficacy or feasibility), IVR system, and condition and treatment purpose. Meta-analysis was not completed on the selected studies because of the large variation in identified studies.

Results

Study Selection

Figure 1 shows the article selection process and lists the exclusion criteria. The study extraction and selected results are listed in Tables 1-5.

Figure 1. Article selection process. IVR: immersive virtual reality.



A total of 58 studies were conducted in 19 countries. The studies reported IVR use for 5 main clinical areas: neurological and development (n=10), pain reduction through distraction (n=20), exposure therapy for phobias (n=9), other psychological applications (n=14), and other applications (n=5). Studies were categorized into 3 types: feasibility studies looking at the system and general user acceptance (n=29), efficacy studies testing clinical effect (n=28), and economic analysis (n=1).

What Are the Patient-Focused Applications for Immersive Virtual Reality in Health Research?

Neurological and Development

Ten articles reported that IVR was used for social attention training in children and adults with autism spectrum disorder [14-16]. Owing to the immersive nature of the environment, the individual's attention can be directed in training scenarios [14]. Environments were designed to immerse patients in general social situations [14,17,18] or prepare them for specific social situation such as public bus rides [15]. IVR was used to achieve similar goals for children with intellectual development disabilities [19] and neurodevelopmental disorders [20].

IVR was also used to assist with the treatment of memory and cognitive functioning decline for individuals who had experienced a stroke or Alzheimer disease [21]. These IVR systems enabled individuals to practice undertaking everyday tasks in a simulated environment such as shopping for multiple items [21] or navigating a building structure [22].

Alternatively, IVR was used as a method of cognitive stimulation for patients in a hospital intensive care unit [23]. As these individuals were unable to leave their hospital environment, IVR created an opportunity for them to experience alternate environments to assist with cognitive stimulation [23]. See Table 1 for an overview.

Table 1. Included studies: neurological and development.

Author, year (country)	Immersive virtual reality system	Article type	Condition and treatment purpose	Number of participants	Reported participant age (years)
Gerber et al, 2017 (Switzerland) [23]	Oculus Developer Kit 2	Efficacy	Cognitive stimulation for patients in the intensive care unit	37	20-85
Amaral et al, 2017 (Portugal) [14]	Oculus Developer Kit 2	Feasibility	Social ability in autism spectrum disorder	17	15-26
Bernardes et al, 2015 (Portugal) [15]	Not stated	Feasibility	Social ability in autism spectrum disorder	5	32.2 (4)[a]
Fitzgerald et al, 2018 (Australia) [16]	Oculus Commercial Version 1	Feasibility	Increased learning in autism spectrum disorder	2	25-35
Gelsomini et al, 2016 (Italy) [19]	Google Cardboard	Feasibility	Learn behavioral skills for individuals with intellectual development disabilities	5	Children[b]
Gelsomini et al 2016 (Italy) [20]	Google Cardboard	Feasibility	Functional improvement for individuals with neurodevelopment disorders	10	6-10
Liu et al, 2018 (China) [17]	HTC Vive	Feasibility	Social interaction in autism spectrum disorder	4	5-7
Shahab et al, 2018 (Iran) [18]	HTC Vive	Feasibility	Game therapy for autism spectrum disorder	14	Children[b]
White et al, 2016 (Canada) [22]	Oculus Developer Kit 2	Feasibility	Cognitive changes in Alzheimer disease	1	74
Gamito et al, 2017 (Portugal) [21]	eMagin Z800	Efficacy	Attention and memory after stroke	29	55 (14)[a]

[a]Mean (SD).

[b]Direct quote from article, specific ages for participant/s not reported.

Pain Reduction Through Distraction

In this study, 20 articles reported that IVR was used for patients experiencing pain to distract them by providing alternate sensory input and to treat pain in specific populations with neck pain and phantom limb pain (Table 2).

Table 2. Included studies: pain reduction through distraction.

Author, year (country)	Immersive virtual reality system	Article type	Condition and treatment purpose	Number of participants	Reported participant age (years)
Mosadeghi et al, 2016 (USA) [24]	Samsung Gear VR	Feasibility	Hospitalized patients	30	49.1 (17)[a]
Delshad et al, 2018 (USA) [25]	Samsung Gear VR	Economic analysis	Hospital patients	Not applicable	Not reported
Tashjian et al, 2017 (USA) [26]	Samsung Gear VR	Efficacy	Hospitalized patients	100	54.5 (18)
Ambron et al, 2018 (USA) [27]	Oculus Developer Kit 2	Feasibility	Phantom limb pain	2	Middle aged to late-middle-aged[b]
Amin et al, 2017 (Canada) [5]	Google Cardboard and Oculus Developer Kit 2	Efficacy	Chronic pain	30	23-68
Birnie et al, 2018 (Canada) [28]	Samsung Gear VR	Feasibility	Pediatric cancer	17	8-18
Ebrahimi et al, 2017 (Iran) [29]	Not reported	Efficacy	Dressing changes for burns patients	60	24-40
Faber et al, 2013 (USA) [30]	Cybermind HiRes900	Efficacy	Burns patients	36	8-57
Ford et al, 2018 (USA) [31]	Sunnypeak[c]	Feasibility	Burns patients	10	30-69
Garrett et al, 2017 (Canada) [32]	Oculus Developer Kit 2	Feasibility	Chronic pain	8	31-71
Gold et al, 2018 (USA) [33]	AppliedVR and Samsung Gear VR or Google MergeVR	Efficacy	Phlebotomy	143	15.4 (3)[a]
Henriksen et al, 2017 (France) [34]	Oculus Developer Kit 2	Feasibility	Phantom limb pain	3	45-60
Hoffman et al, 2014 (USA) [1]	Oculus Commercial Version 1	Feasibility	Skin stretching therapy for burns patients	1	11
Jeffs et al, 2014 (USA) [35]	Kaiser Optics SR80a	Efficacy	Dressing changes for burns patients	28	10-17
Nielsen et al, 2017 (Denmark) [36]	HTC Vive	Feasibility	Phantom limb pain	8	21-27
Osumi et al, 2017 (Japan) [37]	Oculus Developer Kit 2	Feasibility	Phantom limb pain	8	43-64
Bahat et al, 2015 (Australia) [38]	Vuzix Wrap 1200VR	Feasibility	Chronic pain and movement	32	40.6 (14)[a]
Bahat et al, 2018 (Australia) [39]	Oculus Developer Kit 1	Efficacy	Chronic pain and movement	90	38.5, 57.5[d]
Scapin et al, 2017 (Brazil) [40]	Samsung Gear VR	Feasibility	Burns patients	2	8-9
Tanja-Dijkstra et al, 2014 (UK) [41]	Vuzix iWear VR920	Efficacy	Dental anxiety related to pain	69	33.1 (13)[a]

[a]Mean (SD).

[b]Direct quote from article, specific ages for participant/s not reported.

[c]These systems are low-cost phone-based head-mounted displays that are not widely commercially available.

[d]Quartile 1, quartile 3.

Distraction

IVR was used to provide patients with sensory information unrelated to their current situation or condition, the immersive nature of the virtual environments being a key factor in this application. Distraction through modified sensory input showed a reduction in pain sensations [5,24,26,32] and has been used to assist with painful procedures or exercises such as phlebotomy [28,33], dental appointments [41], dressing changes [29-31,35,40], and movement therapy for burns patients [1]. IVR has been used in both pediatric and adult populations for this purpose, in the hospital, clinic, and home settings [29-31,35,40].

Treatment

Studies were identified where IVR was used to replicate the treatment method Mirror Box Therapy, where patients use a mirror to create the illusion of an amputated limb still being present [36]. IVR represents a format in which amputated limbs can be simulated and used to complete gamified tasks [27,34,36,37]. IVR was also used to optimize the accuracy with which patients executed neck movement exercises to increase their range of motion and reduce their neck pain symptoms [38,39].

Exposure Therapy for Phobias

Overall, 9 articles reported that IVR has been harnessed to treat phobias, used as a method of either self-guided [42-44] or clinician-led [2,45,46] exposure therapy for patients (Table 3). Phobias included social phobia [2,42] (social anxiety disorder [SAD]), acrophobia [43,46] (fear of heights), agoraphobia [44,45] (fear of entering open or crowded places), aviophobia [47] (fear of flying), arachnophobia [3] (fear of spiders), and claustrophobia [48] (fear of confined spaces). Many of the IVR environments or activities were personalized for the specific patient, highlighting the benefit of using technology such as IVR for exposure therapy [2,3,49,42,44-45,46].

Table 3. Included studies: exposure therapy for phobias.

Author, year (country)	Immersive virtual reality system	Article type	Condition and treatment purpose	Number of participants	Reported participant age (years)
Bouchard et al, 2017 (Canada) [2]	eMagin Z800	Efficacy	Social phobia (SAD[a])	59	34.5 (12)[b]
Freeman et al, 2018 (UK) [49]	HTC Vive	Efficacy	Acrophobia (fear of heights)	100	30-53
Hartanto et al, 2016 (Netherlands) [42]	Custom	Feasibility	Social phobia (SAD[a])	5	38-64
Hong et al, 2017 (Korea) [43]	Samsung Gear VR	Efficacy	Acrophobia (fear of heights)	48	23.2 (2)[b]
Malbos et al, 2013 (Australia) [44]	Virtual Realities HMD42	Efficacy	Agoraphobia	18	24-72
Maples-Keller et al, 2017 (USA) [47]	eMagin Z800	Efficacy	Aviophobia (fear of flying)	89	21-67
Meyerbroeker et al, 2013 (Netherlands) [45]	WorldViz Vizard 3.0	Efficacy	Agoraphobia	55	18-65
Shiban et al, 2015 (Germany) [3]	eMagin Z800	Efficacy	Arachnophobia	41	18-60
Shiban et al, 2016 (Germany) [48]	eMagin Z800	Efficacy	Claustrophobia	48	18-65

[a]Social anxiety disorder.

[b]Mean (SD).

Other Psychological Applications

Overall, 14 articles reported other psychological application for IVR (Table 4), including self-management in depression [50,51], exposure therapy for posttraumatic stress disorder (PTSD) [52-54], reducing delusions and hallucinations [4,46,55,56], improving unhealthy eating habits [57-60], and reducing attention deficits in schizophrenia [61].

Table 4. Included studies: other psychological applications.

Author, year (country)	Immersive virtual reality system	Article type	Condition and treatment purpose	Number of participants	Reported participant age (years)
Atherton et al, 2016 (UK) [55]	nVisor SX111	Efficacy	Persecutory ideation in paranoid individuals	26	43.4 (16)[a]
Cai et al, 2017 (China) [50]	Not reported	Feasibility	Self-guided symptom management for individuals with depression	12	20-35
Cárdenas-López et al, 2014 (Mexico) [57]	Neuro-VR 2.0	Feasibility	Increased weight loss after gastric band surgery for obesity	3	32-44
Cárdenas-López et al, 2015 (Mexico) [58]	Neuro-VR 2.0	Efficacy	Increased weight loss in obese individuals	24	≥18 and ≤50
Dellazizzo et al, 2018 (Canada) [4]	Samsung Gear VR	Feasibility	Reduction of verbal hallucination symptoms	1	Early 50s[b]
Dietrichkeit et al, 2018 (Germany) [56]	Oculus Developer Kit 2	Feasibility	Recall accuracy for individuals who experience delusions	2	36-44
Freeman et al, 2016 (UK) [46]	HTC Vive	Efficacy	Reduced safety-seeking behavior in individuals with persecutory delusions	30	40.6 (14)[a]
Hussain et al, 2018 (USA) [51]	Oculus Commercial Version 1	Feasibility	Increase in positivity generally and toward seeking help for depressed individuals	12	18-26
Keizer et al, 2016 (Netherlands) [59]	Oculus Developer Kit 2	Efficacy	Body size distortion in anorexia nervosa	30	22 (4)[a]
La Paglia et al, 2016 (Italy) [61]	Neuro-VR 2.0	Efficacy	Attention deficits in schizophrenia	15	29 (12)[a]
Marco et al, 2013 (Spain) [60]	Not reported	Feasibility	Eating disorders	34	15-40
McLay et al, 2017 (USA) [52]	Custom	Efficacy	Exposure therapy in posttraumatic stress disorder (PTSD)	88	33 (8)[a]
McLay et al, 2014 (USA) [53]	Custom	Feasibility	Symptoms reduction in PTSD	28	25-49
Reger et al, 2016 (USA) [54]	eMagin Z800	Efficacy	Exposure therapy for PTSD	162	29.5 (6)[a]

[a]Mean (SD).

[b]Direct quote from article, specific ages for participant/s not reported.

Depression

Both depression-focused studies described self-administered VR therapy that could be used at home. In one case, a preprogrammed virtual avatar prompted individuals to share their experiences with depression with the aim of increasing self-help behaviors [51]. A second application featured integrated neurofeedback for self-management of symptoms at home through interaction with preprogrammed environments [41].

Posttraumatic Stress Disorder

IVR was used in two studies to improve the immersion of the experience for exposure therapy in PTSD treatments [52-54]. Exposure therapy using VR is well documented in the literature; however, only two studies were identified as immersive for this review.

Delusions and Hallucinations

IVR for persecutory delusions allowed patients to be immersed in social environments with progressively more avatars present, which enabled a safe situation to practice being in a social environment [46]. Another IVR experience used virtual immersive social environments to build self-confidence as a mechanism to combat paranoia and persecutory delusions [55]. IVR was also used to ameliorate delusions related to memory recall by using IVR to experience environments and practice recalling details accurately [56].

A case study examined using IVR as a mechanism for therapy for individuals experiencing verbal hallucinations. Using an avatar created in IVR, a therapist was able to virtually embody the persona of the verbal hallucination, allowing the patient a new mechanism of interactive therapy, which showed promising results [4].

Unhealthy Eating Habits

Overall, 4 papers described the results of studies using IVR to assist with acute unhealthy eating habits, including obesity, anorexia nervosa, and general eating disorders [57-60]. In all 4 studies, IVR was used to create a full-body illusion aimed at correcting inaccurate patient perceptions of themselves as a supplement to cognitive behavioral therapy [57-60].

Schizophrenia

Individuals living with schizophrenia received IVR-based cognitive behavioral therapy to undertake attention training tasks [61].

Other Applications

A total of 5 articles were identified where IVR was being used for patient-focused clinical application that did not specifically align with the other categories identified (Table 5). These articles demonstrated the use of IVR for vestibular conditions [62,63], tinnitus [64], multiple sclerosis [65], and balance control for fetal alcohol spectrum disorder (FASD) [66]. Of 3 studies, 2 reported using IVR to optimize patient execution of exercises to reduce vestibular conditions [62,63], including vestibular hypofunction and benign paroxysmal positional vertigo. IVR was also used to assist with specialist clinician-guided tinnitus treatment, in place of cognitive behavioral therapy [64]. Multiple sclerosis patients walked on a treadmill with sensors at their feet and used IVR to improve their gait while avoiding or stepping over virtual obstacles [65]. Children with FASD used IVR to enhance task-specific balance practice exercises, improving their overall balance control [66].

Table 5. Included studies: other applications.

Author, year (country)	Immersive virtual reality system	Article type	Condition and treatment purpose	Number of participants	Reported participant age (years)
Malinvaud et al, 2016 (France) [64]	Not reported	Efficacy	Reduced tinnitus symptoms	148	52.5 (13)[a]
Micarelli et al, 2017 (Italy) [62]	Revelation[b]	Efficacy	Vestibulo-ocular reflex gain in vestibular hypofunction	51	50.5 (9)[a]
Peruzzi et al, 2016 (Italy) [65]	eMagin Z800	Feasibility	Gait improvement in multiple sclerosis patients	8	34-60
Tabanfar et al, 2018 (Canada) [63]	HooToo[b]	Efficacy	Epley treatment for paroxysmal positional vertigo	20	26.4 (7)[a]
McCoy et al, 2015 (USA) [66]	Custom	Feasibility	Sensorimotor balance control training for children with FASD[c]	11	11.4 (2)[a]

[a]Mean (SD).

[b]These systems are low-cost phone-based head-mounted displays that are not widely commercially available.

[c]Fetal alcohol spectrum disorder.

What Are the Technical Specifications of These Systems?

Systems from 58 articles were categorized into 3 groups: commercially available integrated systems, commercially available systems that use a smartphone as a display device, and custom-designed systems that are not commercially available. Of 58 articles, 5 did not provide adequate information to identify the IVR system used, however, did provide adequate photos and use language to convince the authors that IVR was used in the study [15,29,50,60,64]. Where a system is reported to have 0 DOF of head tracking, the referenced studies incorporated an additional head tracking system to make the VR system immersive.

Some studies reported the use of IVR software that may support a variety of hardware devices. These studies were included when the authors were convinced that the reported software version supported IVR hardware as a display option. The software systems reported included NeuroVR version 2.0 (Milan, Italy) [61], WorldViz Vizard version 3.0 [45], and AppliedVR RelieVR [33]. In addition, one study reported the use of a modified HMD that included an eye tracking device [23]. Detailed technical specifications are listed in Tables 6-9.

Table 6. Commercially available, integrated immersive virtual reality systems.

Manufacturer	System	Head tracking DOF[a]	Display resolution	Horizontal FOV[b] (degree)	Number of studies	References
HTC	Vive	6	2160×1200	110	5	Liu et al (2018) [17], Shahab et al (2017) [18], Nielsen et al (2017) [36], Freeman et al (2016) [49], and 2018 [46]
Oculus	Rift Commercial Version 1	6	2160×1200	110	3	Hoffman et al (2014) [1], Fitzgerald et al (2018) [16], Hussain et al (2018) [51]
Oculus	Rift Development Kit 2	6	1920×1080	100	10	Amin et al (2017) [5], White et al (2016) [22], Gerber et al (2017) [23], Amaral et al (2017),[14] Ambron et al (2018) [27], Garrett et al (2017) [32], Henriksen et al (2017) [34], Osumi et al (2017) [37], Dietrichkeit et al (2018) [56], Keizer et al (2016) [59]
Oculus	Rift Development Kit 1	3	1280×800	110	1	Bahat et al (2018) [39]
Kaiser Optics	SR80a	0	1280×1024	80	1	Jeffs et al (2014) [35]
Cybermind	HiRes900	0	800×600	approximately 50	1	Faber et al (2013) [30]
eMagin	Z800	3	1600×600	approximately 43	7	Bouchard et al (2017) [2], Shiban et al (2015) [3], and (2016) [21], Gamito et al (2017) [47], Maples-Keller et al (2017) [48], Reger et al (2016) [54], Peruzzi et al 2016 [65]
Virtual Realities	VR1280	0	1280×1024	60	1	Atherton et al (2016) [55]
Virtual Realities	HMD42	3	800×600	42	1	Malbos et al (2013) [44]
nVisor	SX111	0	1280×1024	102	1	Atherton et al (2016) [55]
Vuzix	Wrap 1200VR	3	1280×720	35	1	Bahat et al (2015) [38]
Vuzix	iWear VR920	3	1280×480	32	1	Tanja-Dijkstra et al (2014) [41]

[a]DOF: degrees of freedom.

[b]FOV: field of view.

Table 7. Commercially available, smartphone-based immersive virtual reality systems.

Manufacturer	System	Mobile device	Head tracking DOF[a]	Display resolution	Number of studies	References
Samsung	Gear VR	Samsung Note 4	3	2560×1440	2	Scapin et al (2016) [24], Mosadeghi et al (2016) [40]
Samsung	Gear VR	Samsung Galaxy S7	3	2560×1440	1	Tashjian et al (2017) [26]
Samsung	Gear VR	Samsung Galaxy S6	3	2560×1440	3	Birnie et al (2018) [28], Gold et al (2018) [33], Hong (2017) [43]
Google	MergeVR	Google Pixel (version not reported)	3	—[b]	1	Gold et al (2018) [33]
Google	Cardboard	Samsung Galaxy Note 4	3	2560×1440	1	Amin et al (2017) [5]
Google	Cardboard	Apple iPod Touch (fifth Generation)	3	1136×640	1	Ford et al (2018) [31]
Google	Cardboard	Not reported	3	—[b]	2	Gelsomini et al (2016a) [19] and (2016b) [20]
Not stated	Sunnypeak	Apple iPod (version unstated)	3	—[b]	1	Ford et al (2018) [31]
Not stated	HooToo	Apple iPhone 6	3	1334×750	1	Tabanfar et al (2018) [63]
Not stated	Revelation	Nokia Lumia 930	3	1920×1080	1	Micarelli et al (2017) [62]

[a]DOF: degrees of freedom.

[b]Unknown as mobile device was not reported.

Table 8. Custom immersive virtual reality systems.

System	Head tracking DOF[a]	Display resolution	Horizontal FOV[b] (degree)	Number of studies	References
Memphis	Not reported	Not reported	Not reported	1	Hartanto et al (2015) [42]
STABEL[c]	Not reported	Not reported	Not reported	1	McCoy et al (2015) [66]
VRGET[d]	Not reported	Not reported	Not reported	2	McLay et al (2014) [52] and (2017) [53]

[a]DOF: degrees of freedom.

[b]FOV: field of view.

[c]STABEL: Sensorimotor Training to Affect Balance, Engagement and Learning.

[d]VRGET: Virtual Reality Graded Exposure Therapy.

Table 9. Immersive virtual reality software frameworks.

Manufacturer	System	Number of studies	References
Neuro-VR	Neuro-VR 2.0	3	Cardenas-Lopez et al (2014) [57] and (2015) [58], La Paglia (2016) [61]
WorldViz	Vizard 3.0	1	Meyerbroeker et al (2013) [45]
AppliedVR	RelieVR	1	Gold et al (2018) [33]

Discussion

Principal Findings

This review identified 58 studies from 19 countries that used IVR for acute treatment of conditions. The included studies featured participants ranging in age from 5 to 74 years, with one acceptability study reporting a significant age difference between participants willing to use IVR (younger participants) and those unwilling to use IVR (older participants) [24]. The conditions treated in the included studies were broadly in 5 categories: neurological and neurodevelopment, pain, phobias, psychological applications, and miscellaneous. All the studies used IVR to immerse patients into a virtual environment, but the purposes were different; examples including experience of an environment, exposure therapy, and assistance with accuracy of movement or distraction. The IVR applications presented in the reviewed articles were at different stages of maturity. Approximately half of the reviewed articles tested the feasibility of treatment with IVR, whereas others that were slightly more mature tested the efficacy of IVR compared with conventional treatment methods. This suggests that although nonimmersive

VR has a long history of use in health treatment [67], IVR as a tool in treatment and management of health conditions is still a developing area.

A benefit of IVR systems is that the simulated environment can be easily tailored to the individual patient, such as the clinician controlling a virtual embodiment of an avatar that is relevant to the patient's condition, or designing a specific, patient-relevant environment [46,51]; however, such applications require careful system design that takes the clinician's technical abilities into account. Future generations of commercially available IVR systems will likely have an increasing focus on social and multiuser interactions, further enabling interactive treatment methodologies that are already being employed [14,15,44,45].

Future Directions and Implications for Practice

The data indicate that IVR systems are sometimes extended with other sensors and input modalities such as integrating eye tracking [23] or brain-computer interfaces [14]. Although useful in some health settings, such extensions of IVR may not become commonplace in commercial systems designed for general consumers. However, the budding applications of IVR in health care may inform the future development of commercial IVR technology, including considerations such as water resistance for use in water-based therapy regimes or high-moisture environments [68,69]. Some studies also described the use of weight-assisting arms to support an HMD when the patient may not be able to support the weight of the device themselves [1].

It appears that IVR has a promising future in health care, in research and commercial realms. As many of the studies examined are exploratory, the feasibility of IVR for acute treatment of conditions and the evidence for the effectiveness of IVR is still developing. The studies that did examine efficacy demonstrated preliminary evidence that IVR is either as effective as or more effective than their selected conventional therapy. A majority of the studies had low participant numbers and did not extend their analysis to undertake statistical significance testing of a hypothesis. Future research into the effectiveness of IVR could incorporate more rigorous statistical methods to examine effectiveness.

In the studies, it was reviewed here that commercially available IVR systems are not commonly being used for in-home or self-treatment regimes. This highlights a potential application area that could be investigated in the future: the use of IVR in a telehealth or remote health setting.

The early state of IVR technology adoption highlights another area for future work: the development of policy and procedural guidelines for patient safety and security when interacting with IVR technology. For example, such procedures may consider the need for antibacterial design or treatment of face-touching components for sharing of IVR HMDs and calibration of IVR technology to the individual patient's sensory ability to prevent or reduce simulation sickness. Policies should also consider and address patient data protection issues, and provide adequate guidance on privacy, specifically for biometric or similar data collected when interacting with IVR systems.

Implications for Research

From a research quality perspective, this review highlighted that many studies did not provide adequate detailed technical information about the IVR system being used—this aligns with findings of poor reporting quality from previous reviews [6]. Details such as specific software and hardware versions were not routinely reported in adequate detail for technical systems to be reproducible. Especially in the case of custom IVR systems, it is important for such details to be reported thoroughly to aid research quality, peer-review, evaluation, and reproducibility. This is an area where future studies could improve their reporting. For example, including a photo or diagram of a patient interacting with the IVR system provides a rich source of information for the reader, while adding minimal text to a research manuscript.

Limitations

Owing to the volume of studies, this review had to be limited to acute treatment applications of IVR. IVR has also appeared in health literature as a training tool for health professionals, especially for surgical applications and in rehabilitation to increase compliance with exercise regimes and improve the accuracy of rehabilitation task completion. Any of the several existing reviews can be referred to for more information about the use of IVR in these areas.

Conclusions

Some studies indicate that simulation sickness is still a limiting factor for application of IVR systems in health care [26,70,71]. This is an ongoing area of research in the broader IVR community [71], and future improvements to IVR system design will likely increase the compatibility of IVR technology with the general populace. In the interim, this finding highlights the need for best practice guidelines for IVR system deployment and development. Furthermore, IVR systems are not suitable for all populations—a consideration that is important for health applications. However, IVR technology can be adapted to suit the needs of specific populations such as blind or low-vision patients [72,73]. The emergence of a technical contracting business that specializes in IVR for health applications is a promising step in this direction. To this end, there is a need for close integration of technical and clinical team members to maximize the efficacy of any new or proposed system.

Conflicts of Interest

None declared.

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Abbreviations

DOF: degrees of freedom
FASD: Fetal Alcohol Spectrum Disorder
HMD: head-mounted display
IVR: immersive virtual reality
PTSD: posttraumatic stress disorder
SAD: social anxiety disorder
VR: virtual reality

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