DIGITAL HEALTH

Virtual reality for healthcare: A scoping review of commercially available applications for head-mounted displays

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Abstract

Objective: This scoping review aimed to describe the scope of commercially available virtual reality (VR) healthcare applications for mainstream head-mounted displays (HMD)s.

Methods: A search was conducted during late April and early May 2022 over five major VR app stores using "health," "healthcare," "medicine," and "medical" as keywords. Apps were screened based on their title and description sections. Metadata collected included: title, description, release date, price (free or paid), multilingual support, VR app store availability, and HMD support.

Results: The search yielded 1995 apps, out of which 60 met the inclusion criteria. The analysis showed that the number of healthcare VR apps has been steadily increasing since 2016, but no developer has released more than two apps so far. Most of the reviewed apps can run on HTC Vive, Oculus Quest, and Valve Index. Thirty-four (56.7%) apps had a free version, and 12 (20%) apps were multilingual, i.e., supported languages other than English. The reviewed apps fell into eight major themes: life science education (3D anatomy, physiology and pathology, biochemistry, and genetics); rehabilitation (physical, mental, and phobia therapy); public health training (safety, life-saving skills, and management); medical training (surgical and patient simulators); role-playing as a patient; 3D medical imagery viewing; children's health; and online health communities.

Conclusions: Although commercial healthcare VR is still in its early phases, end-users can already access a broad range of healthcare VR apps on mainstream HMDs. Further research is needed to assess the usefulness and usability of existing apps.

Introduction

The earliest Virtual Reality (VR) inventions are commonly attributed to Mort Heilig for his Sensorama machine built in the late 1950s[1] and to Ivan Sutherland for his invention of the head-mounted display (HMD) in the mid-1960s.[2] Since then, multiple definitions and names for VR were proposed[3] such as "virtual worlds"[4] and "virtual environments"[5] and highlighted the essential features of VR experiences: being immersed, feeling present, and interacting within a synthetic environment.[6] In the 1990s, expectations for VR technology were high, but its use was limited to specific scientific communities due to its immaturity and high production costs.[7] By the late 1990s, the VR hype had faded with interest shifting

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towards internet-related technologies which seemed more feasible and promising at the time.[8]

In the last decade, interest in VR has been reinvigorated and large investments have been made in the industry.[9–11] This led to quick advancement in VR HMD technology and a reduction in the cost of headsets. In 2016, consumer versions of HTC Vive and Oculus Rift were released, rendering immersive virtual experiences accessible to a wide audience.[12,13] However, the initial price tags for HTC Vive and Oculus Rift were high and both headsets were PC-tethered, i.e., had to be connected to a powerful computer to function. In 2018, Oculus Go, the first standalone VR headset, was released and could be acquired for less than 200 USD.[14] Two years later, in 2020, Facebook (now Meta) announced that Oculus Go was discontinued in favor of Oculus Quest,[15] another standalone headset offering 6 Degrees of Freedom (DoF) by tracking whole body movement, thereby offering higher levels of immersion and interactivity compared to the Oculus Go. Currently, multiple types of tethered and standalone VR HMDs are available on the market. Tethered HMDs can be PC-tethered like the HTC Vive, Oculus Rift, Valve Index, and Windows MR headsets; gaming console-tethered like PlayStation VR; or smartphone-tethered like Samsung Gear. Standalone HMDs include Oculus Quest and HTC Vive Focus.

Recent advances in HMD VR technology and their newly affordable costs are generating increased interest in VR among researchers and users. Uses of VR have expanded beyond entertainment to include healthcare, education, tourism, and productivity. A particularly promising VR application and research field is healthcare. In fact, research on medical and clinical applications of VR has been increasing rapidly[6,16,17] and researchers have been exploring how VR can support various healthcare activities[18] such as medical education and training,[19–21] communication training,[22–24] physical rehabilitation,[25–28] dementia and memory loss rehabilitation in older patients,[29,30] mental health interventions,[31–33] assessment and treatment of depression and anxiety,[34–39] patient education, drug design, and palliative care. For end-users, VR is mostly used for gaming and watching movies.[40] However, some users have opted to use VR for telemedicine and to care for their mental and physical health during the COVID-19 pandemic, suggesting the entry of commercial VR into the healthcare sphere.[40]

For most researchers and end-users, the only way to explore VR for healthcare purposes is through commercially available applications on mainstream HMDs. However, all reviews of VR in healthcare targeted academic research activities and focused on specific healthcare applications. Therefore, the maturity and scope of commercial healthcare VR is currently unknown.

The goal of this scoping review is to assess the maturity and scope of commercial healthcare VR by (1) examining the release trend, HMD support, price, and language of healthcare VR apps across major VR stores; (2) analyzing the content of existing apps; and (3) discussing their potential uses and limitations.

Methods

This scoping review is reported following the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guideline.[41] During late April and early May 2022, a broad search was conducted for healthcare-related VR apps over five major VR app stores. Searches using "health," "healthcare," "medicine," and "medical" as keywords were performed on the Steam, Viveport, Microsoft, and PlayStation stores. These keywords were chosen to identify the maximum set of apps that are related to any healthcare activity, including but not limited to medical education and provision. Reviewers found discrepancies in keyword-based search results on the Oculus Experiences store. To counter this problem, all of the apps available on the Oculus Experiences store for both Rift and Quest headsets were screened.

Screening and selection of apps

Apps were screened based on their title and description sections. VR apps broadly related to any healthcare activity were included in the review. Fitness and wellness apps were excluded due to their high prevalence and for having similar health benefits as other games where the user engages in body movement or relaxation, rendering the selection process difficult. Two reviewers screened the apps independently and discrepancies were resolved through discussions with a third reviewer.

Data abstraction

The following metadata points were collected for the included apps: title, description, release date, price (free or paid), language support, VR store availability, and HMD support. App ratings and exact prices were not abstracted due to the adoption of different rating systems across stores and variability in pricing across stores and countries. The metadata was added to a Google Sheet document by two reviewers.

Analysis and mapping

Descriptive statistics were conducted to examine the (i) time trend in app releases, (ii) VR app store availability, (iii) HMD support, and (iv) app pricing and language support. In addition, all the authors conducted a content analysis of the apps based on their titles and description sections. Major themes were identified and used to categorize the apps.

Results

Screening and selection of apps

The screening and selection process is shown in Figure 1. In total, 1995 apps were screened by two reviewers separately.

Apps were excluded for being unrelated to healthcare (n = 1726), duplicates (n = 130), fitness apps (n = 11), wellness apps including meditation and relaxation (n = 12), games (n = 9), unavailable apps (n = 7), apps marginally related to healthcare (n = 10), and augmented reality (AR) apps (n = 29). One application was excluded for having an incomplete description. A total of 60 applications were included in the review. The relevant metadata for the reviewed apps is shown in the appendix.

Release trend of commercial VR healthcare apps

The 60 reviewed apps were developed by 56 unique developers. Only four developers released more than one app (Center for Disease Control and Prevention [CDC]: 2 apps; Medis Media: 2 apps; Virtual Medicine: 2 apps; Victory VR: 2 apps). The earliest release date was 2016 with two healthcare VR apps being released that year. Since 2016, there has been an upward trend in healthcare VR app releases with a slowdown in 2019. Figure 2 shows the number of apps released each year and Figure 3 shows the number of apps released for the five mainstream HMDs.

Availability of healthcare VR apps on major VR app stores

Table 1 shows the availability of the reviewed apps on major VR app stores. Out of the 60 reviewed apps, Steam had the largest number of apps (40 apps), whereas no apps were found on the PlayStation store. The Oculus Rift Experiences and the Oculus Quest Experiences stores are accessed separately, therefore their results are presented separately in the table.

HMD support for commercial healthcare VR apps

The Oculus Rift headset was discontinued in 2021. However, Oculus Rift apps can be run on Oculus Quest headsets using Oculus link, which allows users to turn their Quest headsets into PC-tethered VR headsets. Therefore, in our analysis, we considered apps that are supported by Oculus Rift to be available on Oculus Quest as well.

Table 2 shows the number of supported apps on each HMD. HTC Vive supports most VR healthcare apps (44 apps) followed by Oculus Quest (41 apps).

Price and language support

Out of 60 reviewed apps, 34 (56.7%) apps had a free version and 12 (20%) apps were multilingual, i.e., supported languages other than English. Table 3 shows the distribution of free and multilingual apps across HMDs.

HTC Vive and Oculus Quest have the largest number of apps with free versions (24 apps). Similarly, for language support, HTC Vive and Oculus Quest have the largest number of multilingual apps (9 apps). Oculus Quest has the largest number of both free and multilingual apps (4 apps).

Content analysis of the apps

The apps were classified into eight major themes according to their content: life science education (3D anatomy, physiology and pathology, biochemistry, and genetics); rehabilitation (physical, mental, and phobia therapy); public health training (safety, life-saving skills, and management); medical training (surgical and patient simulators); role-playing as a patient; 3D medical imagery viewing; children's health; and online health communities. Fifty-three apps fell under a unique theme and seven apps were classified under two themes. The definition of each theme, its app count, and the HMD support for its apps are shown in Table 4. Figure 4 shows the distribution and overlap of apps across the themes.

Life science education

This theme includes 24 apps: 18 for 3D anatomy, 3 for physiology and pathology, 4 for biochemistry, and 2 for genetics. Some of the anatomy apps aim to teach all body systems[1] while others focus on a specific organ such as the brain (*Brain Anatomy VR*), the skin (*Human Skin VR Experience*), the heart (*Insight Heart VR*), and the eye (*The Physiology of the Eye*). Three of the anatomy apps also teach about physiology and pathology (*Adventure Learning Inside Humans*, *Insight Heart VR,* and *The Physiology of the Eye*). The topics covered by the biochemistry apps include general biochemistry (*Nanome*); cell biology and the sleep-wake cycle (*The Circadian Rhythm*); blood cells (*The Body VR: Journey inside a Cell*), and microbiology (*Kellogg's Gut Bacteria Reef*). Finally, the two apps aiming to teach genetics focus on the role of chromosomes (*Genius Genetics*) and the discoveries of Gregor Mendel, who is commonly considered the father of modern genetics (*Victory VR Comics: Mendel and the Mystery of Genetic Traits*).

Rehabilitation

This theme includes 10 apps, 3 for physical rehabilitation, 4 for mental rehabilitation, and 3 for phobia therapy. Physical rehabilitation apps provide physical and spatial exercises aimed at muscle training and motion analysis for the neck (*PT +*), shoulders (*Reach Shoulder Health*), and eyes (*Vision Therapy*). Of the mental rehabilitation apps, one explains how an anxiety attack unfolds and how to manage it (*Anxiety Treatment with Relaxation Demo*) and another targets obsessive compulsive disorder and allows users to understand compulsive thoughts through gamification
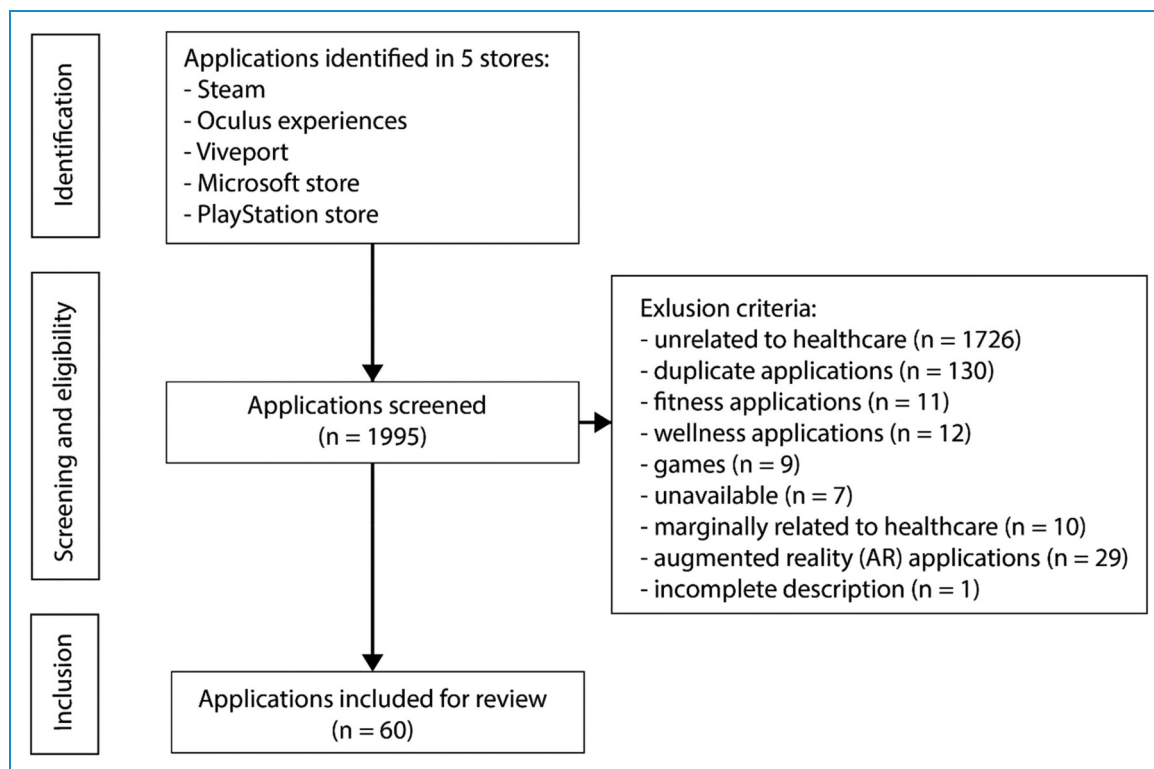
Figure 1. Flow diagram of the app search, screening, and selection process.
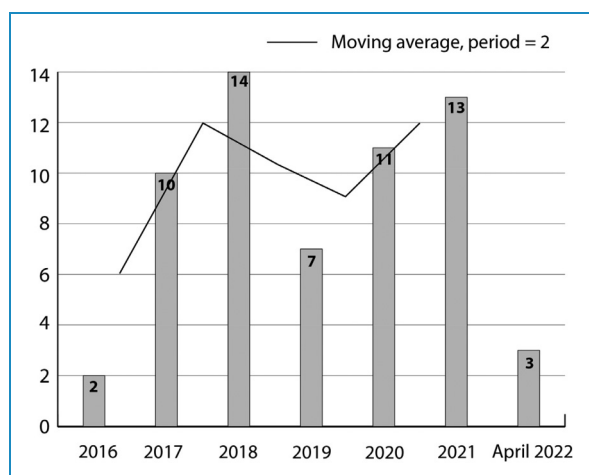
Figure 2. Release trend of healthcare VR apps from 2016 to April 2022.

(*Dichotomy*). A third (*Corona Kombat*) is an experimental game in which the user fights viruses to relieve the stress suffered from mental side effects of the COVID-19 pandemic and lockdowns. The final app in this theme is an extensive music app that contains a therapy guide to support therapists aiming to achieve a wide variety of cognitive, sensory, and emotional therapeutic goals through music-making (*Jam Studio VR - Education & Health Care Edition*). The three phobia therapy apps help users overcome phobias through progressive virtual exposure to the trigger, while learning mechanisms to control them. These apps address arachnophobia, i.e., fear of spiders (*Arachnophobia*), fear of heights (*Bridge Trek*) and several other phobias including open spaces, heights, flying, elevators, speech anxiety, and fruits and vegetables (*Vrerience*).

Public health training

This theme includes 8 apps: 4 for safety, 2 for life-saving skills, and 3 for management.

The four safety apps include *CrashCourse*, which focuses on the prevention of concussions that could occur during a football game; *LabTrainingVR: Biosafety Cabinet Edition*, which offers training on how to set up and manage a biosafety cabinet; *LabTrainingVR: Personal Protective Equipment* Edition, which teaches laboratory scientists how to use PPEs and prevent the transmission of infectious agents; and *Occupational Safety and Health for Electricians*, which provides training for people working with high-risk electrical equipment to develop their ability to avoid electrical safety hazards.

The two apps focusing on life-saving skills provide training in a simulated medical environment on how to perform CPR on patients experiencing cardiac arrests (*VR-CPR Personal Edition*) and other types of medical emergencies (*Valley General Hospital*). Finally, the three apps focusing on public health management offer insights
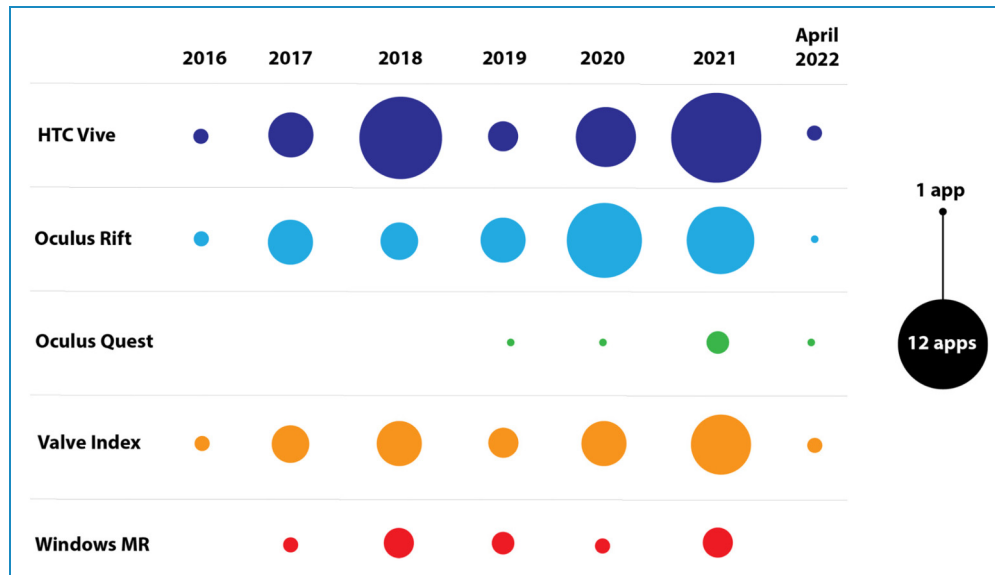
Figure 3. Release trend of healthcare VR apps for major commercial HMDs.

into the spread of the Coronavirus (*SituationCovid*); the situational management and treatment of sport-related concussions (*CrashCourse*, also in the safety theme); public health management skills for nurses (*Public Health Nursing Immersion*).

3D medical imagery viewing

This theme includes four apps that allow users to view and manipulate various types of medical images in 3D. Three apps (*MEDICALHOLODECK*, *MedicalImagingVR*, and *BrainVis*) allow the user to import and view their own MRI and CT scans in 3D. One of these three apps (*BrainVis*) is focused on neuroimaging and supports the viewing of NIfTI images resulting from Functional Magnetic Resonance Imaging (fMRI).

The fourth app (*syGlass View*) allows the visualization of various kinds of large 3D data sets and supports—but is not specifically targeted at—DICOM images.

Medical training

This theme includes two subthemes: surgical simulators and patient simulators. The surgical simulators accounted for 6 apps that provide users with a virtual way to train for surgical procedures. Two applications focus on knee surgery (*Aesculap Orthopilot Elite*, *Wraith VR Total Knee Replacement Surgery Simulation*). Another application teaches suturing and wound care (*PST VR*). The remaining three applications (*Surgera VR*, *Surgical Robot Simulator*, *Medical Realities Platform*) cover a range of surgeries: *Surgera* offers a tracheostomy simulation while the other two offer a range of other surgeries including hernia repair, cholecystectomy, and visceral bleeding.

The patient simulator subtheme included two apps: *Virti* and *VR Patients*. Both apps could be used for medical training as they allow the users to interact with virtual simulated patients with various health conditions. *VR Patients* is a fully computer-generated immersive environment which includes 3 cases in its basic package and allows users to create additional scenarios. *Virti* is an education and training platform that allows for immersive medical training through the use of 360-degree videos or computer-generated immersive environments. It also allows educators to create custom questions and contains a learning dashboard where educators can track their students' progress.

Role-playing as a patient

Five apps allow the user to role-play as a patient with a specific need or illness in order to (1) raise awareness and broaden the understanding of experiences and challenges faced by the patient or (2) prepare patients for their upcoming procedures. Two of these apps use computer-generated imagery (CGI) (*Imercyve: Living with Intellectual Disability*; *Notes on Blindness*) and three use a mix of CGI and live-action videos (*Across the Line*; *Dementia Yn Fy Nwylo I / First Hand*; *Vremedies – CT Procedure Experience*). Experiences covered by awareness-raising apps include: entering a health center to have an abortion (*Across the Line*), living with dementia (*Dementia Yn Fy Nwylo I / First Hand*), intellectual disability (*Imercyve: Living with Intellectual Disability*), and blindness (*Notes on Blindness*). Only one app falls into the patient preparation theme and targets children with upcoming CT scans (*VRemedies - CT Procedure Experience*).

Table 1. Availability of healthcare VR apps on major VR app stores.

Steam	Viveport	Oculus Rift Experiences	Oculus Quest Experiences	Microsoft Store	PlayStation Store
40 (66.7%)	15 (25%)	13 (21.7%)	6 (10%)	6 (10%)	0 (0%)

Table 2. HMD support for healthcare VR apps.

HTC Vive	Oculus Quest (native)	Oculus Quest (via Oculus link)	Valve Index	Windows MR
44 (73.3%)	6 (10%)	35 (58.3%)	33 (55%)	16 (26.6%)

Online health communities

One app (*Innerworld*, previously named *Help Club*) enables users to join peer-led groups focused on mental health support.

Children's health

Three apps are specifically made for children. Two apps focus on educating children on the importance of oral health by allowing them to play the dentist's role and perform dental treatments (*Chicaro Dentistry*), and by teaching them how to brush their teeth through a toothbrushing challenge (*Brush Up VR*). One app helps children and their parents prepare for their upcoming CT scan by going through the experience virtually (*VRemedies - CT Procedure Experience*).

Discussion

App release trend, HMD support, cost, and languages

The number of healthcare VR apps on mainstream HMDs grew from two apps in 2016 to 60 apps in April 2022. Even though the number of apps has been steadily growing, our analysis highlighted the current lack of highly-experienced developers in the field of commercial healthcare VR. In fact, only four developers have released more than one healthcare VR app, with a maximum output of two apps per developer. The number of healthcare VR apps is expected to continue growing as new developers enter the market and existing developers gain experience. This growth seems probable as more investment is being made in the industry to accelerate content creation.[42]

Healthcare VR content is currently available on five of the major stores: Steam, Viveport, Oculus Quest and Oculus Rift experiences, and Microsoft Store. Steam had the majority of reviewed apps (40 apps), which is not surprising as Steam VR content is not targeted at a specific HMD. As for HMD support, HTC Vive supports most of the reviewed apps (44 apps) followed by Oculus Quest (41 apps). However, most apps working on Oculus Quest (35 apps) are not native Quest apps and were originally developed

Table 3. Distribution of free and multilingual apps across HMDs.

	Apps with free versions	Multilingual apps	Multilingual apps with free versions
HTC Vive	24	9	2
Oculus Quest (native and via Oculus link)	24	9	4
Valve Index	20	7	2
Windows MR	10	3	1

for the Oculus Rift. These apps can be run on Quest by tethering the headset to a computer using the Oculus Link cable. There are also workarounds that allow users to run Oculus Rift apps on HTC Vive such as the *Revive* software. However, employing such workarounds does not guarantee an experience with the originally intended quality.

In addition to having the right HMD, the cost of the apps and their language support might be barriers for low-income and non-English speaking users. In this regard, we found that most of the reviewed apps (34 apps) were either completely free or had a free version that allows the users to try its basic functions before signing up for the full paid version. As for language support, only 12 apps could be used in languages other than English with Chinese, French, and Russian being the most supported languages (5 apps each). Interestingly, Oculus Quest has the largest number of multilingual apps with free versions (4 apps) even though it is one of the newest HMDs. These results indicate that users wanting to take full advantage of healthcare VR must pay a premium and engage in a mostly English experience.

App content

We analyzed the content of the reviewed apps and categorized them into eight major themes. The most represented

Table 4. Themes of healthcare VR apps available on mainstream HMDs.

Themes and subthemes	Definition	App Count	HTC Vive	Oculus Quest	Valve index	Windows MR
Life science education						
3D anatomy	Apps that support human anatomy learning through the use of 3D models	18	12	11	8	8
Physiology and pathology	Apps that support learning about physiology and diseases	3	2	1	1	1
Biochemistry	Apps that support learning about biochemistry	4	4	4	3	1
Genetics	Apps that support learning about genetics	2	1	1	0	1
Rehabilitation						
Physical rehabilitation	Apps that aim to promote, maintain, or restore physical health	3	2	3	2	0
Mental rehabilitation	Apps that aim to promote, maintain, or restore mental health	4	3	4	3	2
Phobia therapy	Apps that aim to help people overcome their phobias	3	2	2	2	0
Public health training						
Safety	Apps that allow users to learn about and develop occupational safety skills	4	3	2	1	1
Life-saving skills	Apps that allow users to develop life-saving skills	2	2	1	1	0
Management	Apps that allow users to develop public health management skills	3	2	3	2	1
Medical training						
Surgical simulators	Apps that allow users to train on surgical techniques	6	6	4	5	1
Patient simulators	Apps that allow the users to interact with virtual patients as part of clinical training	2	2	0	1	0
Role-playing as a patient	Apps that allow learning about a specific health issue by being in the affected person's shoes	5	3	4	3	0
3D Medical imagery viewing	Apps that allow the visualization of medical imagery in 3D	4	4	4	4	4
Children's health	Healthcare apps specifically built for children	3	3	0	2	0
Online health communities	Apps that allow patients to form virtual communities to support one another	1	1	1	1	0

theme was life science education (24 apps), covering a wide range of topics related to human and animal anatomy, physiology and pathology, biochemistry, and genetics. The learning experience offered by these apps is more immersive and interactive than traditional screen-based online learning which could increase learners' motivation and engagement.[43,44] However, none of the available apps supports multiplayer mode which would allow for collaborative immersive online learning and majorly transform online health education.[45]
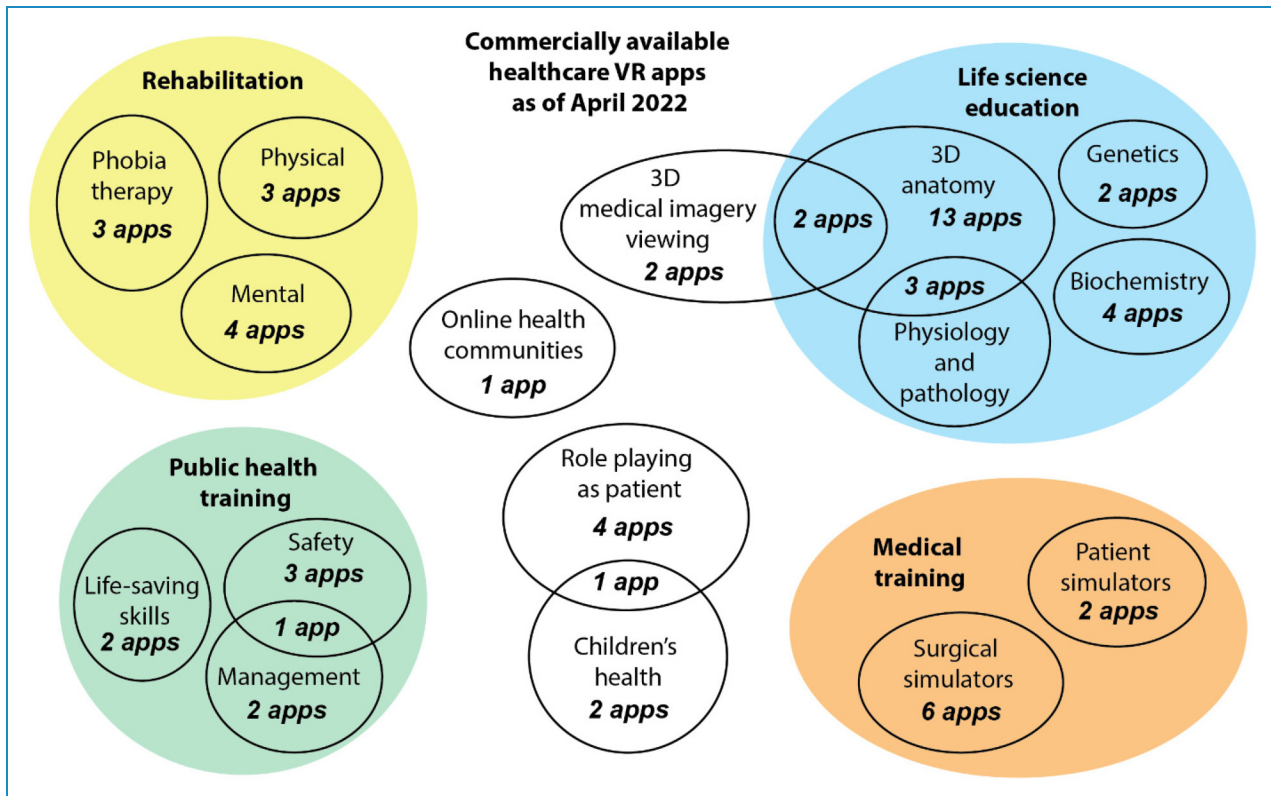
Figure 4. Distribution of commercial healthcare VR apps across themes.

Out of the topics covered by life science education apps, anatomy learning was the most prevalent topic (18 apps). These apps allow users to view and interact with 3D anatomy models, with functions similar to those offered by 3D medical imagery viewing apps. Even though 3D anatomy and 3D medical imagery viewing apps had some overlaps, we chose to consider them as two separate themes. This choice was based on the distinct purpose of the apps and the main activities that they support: learning about anatomy using generic 3D models versus viewing a specific patient's anatomy for diagnosis or surgical planning. With these distinctions in mind, we found that two out of four apps offering 3D medical imagery viewing also offer 3D anatomy learning, indicating some value in having both functionalities combined.

The second most common theme was rehabilitation (10 apps) and included apps that support physical and mental rehabilitation in addition to phobia therapy. Physical rehabilitation apps were limited to the neck, shoulder, and eyes. This may be due to the ease of tracking the movement of these body parts using current HMD technology. Future technology advancements may enable reliable tracking of other body movements which would expand the scope of guided physical rehabilitation. Nevertheless, it is necessary to assess effectiveness of these apps while considering the effect of wearing HMDs on physical workload and joint torque.[46] In other respects, we found four apps that are

meant to support mental rehabilitation through education and relaxation, stress and compulsion-reducing games, and making music. In addition to employing promising methods such as gamification and music-based interventions,[47] these apps could incorporate cognitive behavioral therapy (CBT) components which may be effective when administered in VR.[37] As for phobia treatment, the available apps target various types of phobias and offer the users immersive exposure therapy. These types of apps may prove effective with some phobias when they offer experiences that mimic in vivo exposure.[31,48] However, more research with larger samples is still needed to establish this evidence across all types of phobias.

The third largest theme was public health training and had a total of 8 apps aiming to teach life-saving skills, occupational safety, and public health management. These apps are mainly educational and focus on raising awareness and offering training on how to navigate health or occupational emergencies. Having these apps available on commercial HMDs is essential to increase their reach and impact on public health. However, the low levels of realism offered by these apps makes it necessary to use them in conjunction with real-life training.

Another major theme that emerged was VR apps for medical training. Most of the medical training apps (6 apps) were surgical simulators allowing users to perform a variety of surgical techniques. The high representation

of surgical simulator apps is expected as simulation-based surgical training is a promising venue for VR due to its high repeatability, ease of setup, safety,[49] and the possibility to incorporate metric-based approaches for evaluating the user's proficiency in proficiency-based progression programs.[50] These commercial findings also align with research trends as most of the research examining VR use in medical education focuses on surgical simulators.[51] However, researchers examining VR surgical training mainly use the consoles of surgical-assisting robots[51] rather than multi-purpose HMDs. In this case, using commercial HMDs for surgical training may increase access, reduce cost, and allow for quick upscaling. However, overuse and overreliance on commercial HMD-based training present dangers: surgeons may develop a false sense of confidence while not reaching the level of manual dexterity required to perform real-life surgeries.

In addition to surgical simulators, we found two apps that support clinical training by allowing users to interact with virtual patients with prespecified cases. These apps can be used by educators to create custom cases and automatically track the progress of students, which could prove helpful for scaling up immersive and interactive case-based medical training.

One theme—role-playing as a patient—particularly benefits from the immersive nature of VR to facilitate empathy-building and perspective-taking. Four of the reviewed apps allow users to role-play as a patient with a specific health problem or disability. By putting themselves in the patients' shoes, users can build emotional, cognitive, and compassionate empathy[52] which could eventually lead to fewer antisocial attitudes towards these patients in real life.[53] Role-playing is also used as a method for patient preparation, with the current target being limited to children with an upcoming CT scan. Future developments could target other medical processes such as prehabilitation of surgical patients,[54] preparation of pregnant women for their postpartum periods,[55] or self-management for patients with chronic diseases.[56]

A small but promising theme that emerged from our analysis was the use of VR apps to teach children healthy habits and prepare them for unpleasant medical procedures. Using VR among children and adolescents could prove more effective than traditional methods because the process is more interactive and enjoyable. Currently, the two apps focusing on promoting children's health are limited to oral health but future apps could target other health topics such as nutrition, drug use, bullying, and sexual health.[57] Similarly, the one app focusing on pre-procedure preparation is limited to a hospital visit involving a CT scan but could target other complicated or unpleasant procedures in future developments.

We only found one VR app (*Innerworld*, previously *Help Club*) that supports the formation of Online Health Communities (OHC). Web-based OHCs are virtual places where people with common health concerns can provide each other with support and information. Multiple studies have highlighted the positive impact of patient[58] and physician participation[59,60] in OHCs on patient activation, empowerment, and compliance, while underscoring the risks of unmoderated OHCs.[61] Currently, the activities and sessions that take place in Innerworld are peer-led and do not involve mental health specialists which allows a large number of people to help others but raises concerns over the potential impact of unqualified mental health support.

Limitations and future work

A main limitation of this work is our reliance on the apps' description section when analyzing their content. Since we targeted multiple HMDs in our review, we could not test all the apps and provide first-hand assessment of their content and quality. This limited our ability to ensure the accuracy of the apps' descriptions and led to an equal treatment for all the reviewed apps. Further work is needed to provide objective usefulness and usability assessments of available apps.

Another limitation of this work is the exclusion of wellness and fitness apps from the review. This exclusion was intended to simplify the reviewing process by setting clear inclusion rules. However, during our review, we found a large number of wellness and fitness apps with a wide range of uses including rehabilitation, physical training, meditation, and relaxation. Future work can analyze commercially available fitness and wellness VR apps.

Conclusions

The number of commercial healthcare VR apps has been growing since 2016 and is expected to grow further with larger investments being put in the VR content creation industry and with new developers entering the market and existing developers gaining experience. Our review showed that as of April 2022, there are at least 60 commercial VR applications that could be used by various stakeholders for a broad range of healthcare activities. Most of these apps are supported on HTC Vive, Oculus Quest, and Valve Index, have a free version, but do not support languages other than English.

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Note

1. *3D Organon VR anatomy*, *Adventure learning inside the humans*, *Anatomy Explorer 2020*, *Body Awesome*, *Elementary Anatomy: With Story Mode*, *Everyday Anatomy VR*, *Human Constructor VR*, *Medical Holodeck*, *Medical Imaging VR*, *Sharecare You VR*, and *VEDAVI VR Human Anatomy*

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Appendix − Metadata collected for the reviewed apps

App	Theme	HTC Vive	Oculus Quest	Valve index	Windows MR	Multilingual	Free version	Release year
3D ORGANON VR ANATOMY	3D anatomy	X	X	X	X	X	X	2019
Across The Line	Role-playing as a patient	X	X	X	-	-	X	2017
Adventure Learning Inside Humans	3D anatomy Physiology and pathology	X	-	-	-	-	-	2018
AESCULAP® OrthoPilot®Elite VR Palpation	Surgical simulator	X	-	X	-	-	X	2017
Anatomy Explorer 2020	3D anatomy	-	X	-	-	-	-	2020
Anatomy Labs VR	3D anatomy	-	-	-	X	-	-	2018
Anxiety Treatment with Relaxation Demo	Mental rehabilitation	X	X	X	-	-	X	2022
Arachnophobia	Phobia therapy	X	X	X	-	-	-	2016
Body Awesome	3D anatomy	X	-	-	-	-	-	2018
Brain Anatomy VR	3D anatomy	-	-	-	X	-	X	2018
BrainVis	3D medical imagery viewing	-	X	-	-	-	X	2018
Bridge Trek	Phobia therapy	X	-	X	-	-	X	2018
Brush up VR	Children's health	X	-	X	-	X	-	2017
CHICARO DENTISTRY	Children's health	X	-	-	-	X	-	2021
Circadian Rhythm	Biochemistry	X	X	-	-	-	X	2018
Corona Kombat	Mental rehabilitation	-	X	-	-	X	-	2020
CrashCourse: Concussion Education Reimagined	Public health training - Management Public health training - Safety	X	X	X	X	-	X	2019
Dementia Yn Fy Nwylo I / First Hand	Role-playing as a patient	-	X	-	-	X	X	2019

(continued)

Continued.

App	Theme	HTC Vive	Oculus Quest	Valve index	Windows MR	Multilingual	Free version	Release year
Dichotomy	Mental rehabilitation	X	X	X	X	-	X	2021
Elementary Anatomy: With Story Mode	3D anatomy	X	X	X	X	-	-	2021
Everyday Anatomy VR	3D anatomy	X	X	X	X	X	-	2021
Genius Genetics	Genetics	X	-	-	-	-	-	2018
Ghost Productions: Wraith VR Total Knee Replacement Surgery Simulation	Surgical simulator	X	X	X	X	-	X	2019
Help Club	Online health community	-	X	-	X	-	X	2021
Human Constructor VR	3D anatomy	X	X	-	-	X	-	2020
Human Skin VR Experience English edition	3D anatomy	X	-	-	-	-	-	2017
Imercyve: Living with Intellectual Disability	Role-playing as a patient	X	X	X	-	-	-	2021
INSIGHT HEART VR	3D anatomy Physiology and pathology	-	-	-	X	-	-	2017
Jam Studio VR - Education & Health Care Edition	Mental rehabilitation	X	X	X	X	-	-	2018
Kellogg's Gut Bacteria Reef	Biochemistry	X	X	X	-	-	X	2021
LabTrainingVR: Biosafety Cabinet Edition	Public health training - Safety	X	-	-	-	-	X	2020
LabTrainingVR: Personal Protective Equipment Edition	Public health training - Safety	X	-	X	-	-	X	2021
MEDICAL REALITIES PLATFORM	Surgical simulator	X	-	-	-	-	X	2018
MEDICALHOLODECK. The DICOM Viewer and Human Anatomy Lab in Virtual Reality. For Surgery Preparation and Medical Education in Teams.	3D anatomy 3D medical imagery viewing	X	X	X	X	-	X	2020
MedicalImagingVR	3D anatomy 3D medical	X	X	X	-	-	X	2020

(continued)

Continued.

App	Theme	HTC Vive	Oculus Quest	Valve index	Windows MR	Multilingual	Free version	Release year
	imagery viewing							
Nanome	Biochemistry	X	X	X	X	-	X	2018
NOTES ON BLINDNESS VR	Role-playing as a patient	-	X	-	-	X	X	2019
Occupational Safety and Health for Electricians	Public health training - Safety	-	X	-	-	-	X	2021
PST VR (Primary Surgical Treatment)	Surgical simulator	X	X	X	-	-	X	2020
	Physical rehabilitation	X	X	X	-	-	-	2020
Public Health Nursing Immersion	Public health training - Management	-	X	-	-	-	X	2022
Reach Shoulder Health	Physical rehabilitation	-	X	-	-	-	X	2020
SHARECARE YOU VR	3D anatomy	X	X	X	X	X	-	2020
SituationCovid	Public health training - Management	X	X	X	-	-	-	2020
Surgera VR	Surgical simulator	X	X	X	-	-	X	2018
Surgical Robot Simulator	Surgical simulator	X	X	X	-	-	X	2021
syGlass View	3D medical imagery viewing	X	X	X	X	-	X	2021
The Body VR: Journey inside a Cell	Biochemistry	X	X	X	-	X	X	2016
The Physiology of the Eye	3D anatomy Physiology and pathology	X	X	X	-	X	-	2017
Valley General Hospital: NiVR	Public health training - Life saving skills	X	X	-	-	-	-	2021
VEDAVI VR Human Anatomy	3D anatomy	-	X	-	-	-	-	2017
	Genetics	-	X	-	X	-	X	2017

Continued.

App	Theme	HTC Vive	Oculus Quest	Valve index	Windows MR	Multilingual	Free version	Release year
Victory VR comics :Mendel and the mystery of genetic traits								
Virti	Patient simulator	X	-	-	-	-	X	2021
VISION THERAPY	Physical rehabilitation	X	X	X	-	-	-	2017
VR Anatomy	3D anatomy	X	-	X	-	-	X	2018
VR Patients	Patient simulator	X	-	X	-	-	X	2022
VR-CPR Personal Edition	Public health training - Life saving skills	X	-	X	-	X	-	2019
VRemedies - CT Procedure Experience	Role-playing as a patient Children's health	X	-	X	-	-	-	2018
Vrerience	Phobia therapy	-	X	-	-	-	-	2019
Wonderful You	3D anatomy	-	X	-	-	-	X	2017