The Report committee for Mary Roland Myers

Certifies that this is the approved version of the following report

Trends in Virtual Reality Technologies for the Learning Patient

APPROVED BY SUPERVISING COMMITTEE

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Joan E. Hughes, Supervisor

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John Bedolla

Trends in Virtual Reality Technologies for the Learning Patient

Mary Roland Myers, B.S.

Report

Presented to the Faculty of the Graduate School
of the University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of

Master of Arts

The University of Texas at Austin.
May, 2017

Trends in Virtual Reality Technologies for the Learning Patient

by

Mary Roland Myers, M.A.
The University of Texas at Austin, 2017
SUPERVISOR: Joan E. Hughes

NextMed convened the Medicine Meets Virtual Reality 22 (MMVR 22) conference in 2016. Since 1992, the conference has brought together a diverse group of researchers to share creative solutions for the evolving challenge of integrating virtual reality tools into medical education. Virtual reality (VR) and its enabling technologies utilize hardware and software to simulate environments and encounters where users can interact and learn. The MMVR 22 symposium proceedings contain projects that support a variety of learners: medical students, practitioners, soldiers, and patients. This report will contemplate the trends in virtual reality technologies for patients navigating their medical and healthcare learning. The learning patient seeks more than intervention; they seek prevention. From virtual humans and environments to motion sensors and haptic devices, patients are surrounded by increasingly rich and transformative data-driven tools. Applied data enables VR applications to simulate experience, predict health outcomes, and motivate new behavior. The MMVR 22 presents investigations into the usability of wearable devices, the efficacy of avatar inclusion, and the viability of multi-player gaming. With increasing need for individualized and scalable programming, only committed open source efforts will align instructional designers, technology integrators, trainers, and clinicians.

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Introduction

NextMed / Medicine Meets Virtual Reality (MMVR) is a long-standing organization of multidisciplinary researchers, designers, educators, and practitioners that develop visual applications to support healthcare learning. They creatively confront challenges in patient care and medical education. The Medicine Meets Virtual Reality 22 conference met in Los Angeles, California in April 2016. The conference attracted education, industry, and military professionals interested in intelligent healthcare tools. Topics covered included patient and public health monitoring and education, data and decision networks in artificial intelligence (AI), wearable and implantable devices, and surgical guidance.

Researchers who presented a lecture paper or formal poster at the conference could submit a paper for publication in the NextMed / MMVR 22 proceedings. The symposia proceedings have been published in the Studies in Health Technology and Informatics series by IOS Press since 1996. Submitting a paper for publication was optional and not required for presentation. About 80% of the papers and posters submitted by lecturers were featured in the 2016 publication. This literature review covers the 82 peer-reviewed papers found in *Studies in Health Technology and Informatics : Medicine Meets Virtual Reality 22 : NextMed / MMVR22*.

In the Preface, Editor J. D. Westwood (2016) promises, "devices that patients, clinicians, and students can use gracefully and intuitively… a vision of medicine transformed by the ability to immerse oneself in data" (pp. *v*). Increasingly rich data-driven tools transform patient statistics into patient learning. Refinements in data algorithms and growing data sets steadily improve the perceived realism and predictive capabilities of virtual reality (VR) applications. Leaps in computer data processing power and rendering speed make users feel more comfortable and immersed in VR. Since its inception in the 90s, VR has advanced in commercially viable ways, making interactive learning imaginable for users in a classroom, clinic, or combat setting. This report will focus on trends in virtual reality technologies for patients navigating their healthcare learning.

Virtual Reality Technology

Virtual reality (VR) and its enabling technologies utilize hardware and software to simulate environments in which users interact and learn. These simulators offer real world scenarios that contain real time communication and feedback. They allow humans to interact with remote and virtual personas, observe virtual consequences, and repeat again when necessary for practice and proficiency. Some simulations run on complex hardware configurations limited to laboratory and clinic use. Broecker, Ponto, Tredinnick, Casper, and Brennan (2016) created the SafeHOME simulator to train patients in virtual environments (VEs) modeled after their actual homes. Their design included large visualization delivery platforms like an immersive VR cave and an advanced visualization space (AVS). The Wheelchair Rift simulator that Headleand, Day, Pop, Ritsos, and John (2016) produced for powered wheelchair users incorporated a head mounted display (HMD) with hand tracking sensors. They also promised to include a real powered wheelchair in future simulation design. Correa-Agudelo, Ferrin, Velez, and Gomez (2016) used live motion capture, color keying, compositing effects, and an immersive video wall to create a mirror image of therapy patients for their training sessions.

Other VR technologies are so small and mobile they could be used almost anywhere. Mierzwa, Huang, Nguyen, Culjat, and Singh (2016) developed ultrasound devices that were so small they could easily be taped to patients for unobtrusive monitoring or therapy. Nguyen et al. (2016) created an asthma monitoring system that combined a smartphone with a low-cost, pocket-sized spirometer to measure patients' airflow anytime. Personal device like smartphones and tablets are often appropriated by VR designers as learning devices. Nehme, Bahsoun and Chow (2016) created a smartphone VR application that mapped surgical procedures into component steps in order to teach better decision making, and Wang, Wu, Bilici, and Tenney-Soeiro (2016) designed augmented reality (AR) material that can broadcast through any iOS enabled mobile device.

VR tools are devices, displays, and data rendering techniques that allow for virtual, multimodal interactions. They can contain visual, auditory, kinesthetic, or tactile multimedia. They do not need to have three-dimensional (3D) graphics or be fully immersive to be included in the Medicine Meets Virtual Reality (MMVR) literature. Instead, they are qualified by their ability to construct a learning space where virtual and real gestures interweave to advance healthcare knowledge. Virtual reality technologies use computer modeling and simulation to build artificial assets that create realistic and lasting sensory impressions. VR models are duplicated and adjusted to serve individual and changing user requirements and needs. VR-based simulations offer controlled learning environments that can be safely visited time and time again. Repeated simulations improve both user and system performance. Broecker, Ponto, Tredinnick, Casper, and Brennan, (2016) say good simulations are context focused, provide effective cues and challenges, facilitate multiple users; and have tailored strategies that designers and users outline together.

MMVR 22 Learners

The learning patient is one of a few types of learners targeted in the studies of the MMVR 22. Trends in surgical technique simulation continue to dominate the literature (e.g., Ahn, Dorozhkin, Schwaitzberg, Jones and De, 2016; Dindar, Nguyen, & Peters, 2016; Marutani et al., 2016; Mekuria et al., 2016; Unger, Tordon, Pisa & Hochman, 2016). These simulations help learners (i.e., developing surgeons) gain expertise and support better outcomes for patients. Their target clients are medical students and continuing education practitioners. Doctors continuously seek expert training on new and updated products and processes, while students seek a safe environment in which to learn without fear of making novice mistakes. VR technologies allow educators and learners to repeatedly experiment in a virtual setting with virtual consequences. Simulations can instantly freeze and rewind to provide learners with review and analysis of simultaneous learning moments.

Soldiers are another distinct group of learners represented in MMVR 22 literature. Improved artificial intelligence (AI) and communication tools support soldiers working together in teams challenged with chaos and crisis in a field setting (Amber & Kunkler, 2016). Soldiers must learn to plan for and react to sudden action far from home base. Huguet, Lourdeaux, Sabouret, and Ferrer (2016) use advanced AI language tools to improve communications between medical team leaders within a virtual environment. Repeated simulations better prepare them for real events.

The Learning Patient

For this report, I was most interested in exploring the unique learning characteristics and needs of patients were addressed in the MMVR 22 literature. Learning patients are trying to maintain independence while they get ready for the unknown. Despite feeling vulnerable and afraid, learning patients desire control. They strive to make informed decisions regarding rehabilitation and pain management (e.g., Barmpoutis et al., 2016; Correa-Agudelo, Ferrin, Velez, & Gomez, 2016; Jin, Choo, Gromala, Shaw, & Squire, 2016). Just as important as medical interventions, they seek preventative healthcare (e.g., Nguyen et al., 2016; Riva et al., 2016; Ruiz et al., 2016). Patients play a vital role in maintaining their own health and independence (e.g., Broecker, Ponto, Tredinnick, Casper, & Brennan, 2016; Correa-Agudelo, Ferrin, Velez, and Gomez, 2016; Headleand, Day, Pop, Ritsos, & John, 2016; Taylor, Taylor, Gamboa, Vlaev, & Darzi, 2016). They should be integral members of their healthcare team. VR-based learning empowers patients to participate in their healthcare curriculum design. A sense of involvement encourages adherence and promotes follow through, improving patient outcomes.

Many patients are wary of technology interventions, especially when their health is involved. However, there is an emerging group of users who are comfortable on gaming systems with avatars and team-based play. They are familiar with advanced communication tools like teleconferencing and multimedia messaging. Application enabled smartphones monitor their daily activity, morph into 3D-capable head mounted displays (HMDs) and behave like personalized, virtual assistants. Yet, no matter their technical inclinations, all patients can feel immersed in haphazard personal and consumer health data. They see health statistics in the news, hear them at the doctor's office, and from friends. Patients try to combine these varied and sometimes contrary narratives into personalized and comprehensive goals for healthcare maintenance and education.

VR designers can help patients and practitioners turn indiscriminate medical and data expressions into learning experiences. Riva et al., (2016) see a future where VR helps people achieve more healthy and active aging through tele-therapy, body motion and health monitoring, and other transformative applications. They describe transformative technologies as "technologically-mediated experiences that support positive, enduring transformation of the self-world" (pp. 308). Transformative VR therapies can augment existing treatments making for healthy living and active ageing.

VR technologies move patients beyond ingesting passive therapies and toward enacting transformative learning. Jin et al. designed a virtual reality game to aid clients in chronic pain management. The Cryoslide game was more than just pain distraction. It helped patients learn better mechanisms for coping with the disease entity, pain. VR learning technologies trigger multisensory processes that alter patient perceptions of self and the world. The Correa-Agudelo, Ferrin, Velez, and Gomez (2016) sensorimotor training for stroke patients attempted to trick their brains into believing the virtual limb they saw on the screen was actually their own. Though their actual limb was paralyzed, they could spend a VR session cognitively reconnecting with their lost limb in a virtual environment (VE). The tele-therapy prototype Barmpoutis et al. (2016) designed used motion sensors to monitor and guide patients during home-based physical therapy sessions. Test subjects were taught new gestures and body motions through positively reinforcing haptic feedback. Active cognitive engagement is what differentiates transformative learning designs from passive VR therapies. Transformative VR experiences help patients see, hear, say, touch, and feel things that elicit emotional and cognitive involvement.

VR Devices

VR technologies involve patients in learning environments using a range of devices. Multimodal encounters can occur on a variety of delivery platforms, and each one is capable of producing transformative learning experiences. High fidelity VR experiences with heightened realism are better remembered and more fun to repeat. MMVR 22 researchers prototyped and created an array of VR learning solutions aimed at improving patients’ health outcomes.

Mobility Training

Headleand, Day, Pop, Ritsos, and John (2016) attempted to simulate powered wheelchair operation as realistically as possible in their Wheelchair-Rift training prototype. Using an Oculus Rift HMD and Leap Motion hand tracking sensor, Wheelchair-Rift faithfully expressed patient head and hand gestures within an immersive 3D VE. The VR devices became an extension of the users’ body, aiding them in learning non-intuitive wheelchair functions. The training environments allowed for safe and repeated practice maneuvers around virtual obstacles, but they lacked personalization, such as practicing wheelchair guidance within one’s own home. Advances in image capture and render mean VR design no longer needs to be limited to generic virtual locations. VE’s can replicate patient-specific settings like home, workplace, or a daily commute.

Broecker, Ponto, Tredinnick, Casper, and Brennan (2016) presented another simulator built with a 3D model of the patient’s home environment, making the content highly customized. Their SafeHOME project presents a dynamic range of contextually charged learning activities for patients discharged from the hospital with new limitations and challenges. Patients are better prepared by training that is specific to the tasks and environments that lay ahead for them after discharge. Broeker et al. tested the SafeHOME simulator on four different visualization platforms: tablet computer, HMD, immersive VR CAVE, and an advanced visualization space (AVS). Their research goal was not to select the best visual delivery platform, but to determine the features of each platform that make it the best device for the individualized patient plan. Each device had its unique benefits and drawbacks according to user situation and condition. A wide variety of patient characteristics must be considered when choosing the right VR device. In addition to their learning goals, a patient's age, health condition, and motor abilities can have a significant impact on their VR experience.

Pain Management

VR devices are often utilized in pain management therapy. VR's success treating chronic pain is attributed to a combination of patient immersion, interaction, emotional engagement, and cognitive distraction. Patients must feel physically immersed in an interactive experience that is both comforting and challenging. Jin, Choo, Gromala, Shaw, and Squire (2016) studied the effect of their Cryoslide VR game on chronic pain management. Cryoslide immersed users in a tranquil and icy VE where they slid around interacting with animated creatures. Patients earned points by recognizing visual patterns and throwing snowballs accordingly. The pattern recognition task provided cognitive distraction while the HMD created a sense of bodily immersion. But some users with pain conditions may have a hard time using an HMD. They may become anxious or nauseous in a VR environment.

Gromala and Squire went on to further explore the usability of an HMD compared to a stereoscopic desktop display. After citing their previous research on Cryoslide in which patients reported negative side effects to the VR therapy game, Tong, Gromala, Gupta, and Squire (2016) compared the feasibility of using differing visual display devices when treating pain patients. Tong et al. deemed patient comfort and simulator sickness effect as more important metrics than sense of presence and immersion. In order to better outfit the learning environment for these at-risk patients, they compared the usability of an Oculus Rift HMD with a DeepStream3D immersive desktop display. Tong et al. invited pain patients to demo the Virtual Meditative Walk they designed to teach users how to manage their chronic pain. Users reported feeling less encumbered while using the HMD, and they also reported a better field of view (FOV) over the desktop screen display. Yet, users experienced less panic and anxiety when they used the desktop display. Patients who may not be good candidates for wearable HMD’s can still have a fruitful VR experience on other visual display devices.

Physical Activity

Taylor, Taylor, Gamboa, Vlaev, and Darzi (2016) designed sensorimotor VR gaming to encourage physical activity in intellectually disabled adults who did not regularly exercise. Given their limited gross motor skills, an HMD was not the optimal device for the visual display. Instead, clients played a weekly VR game with laptops that projected onto a screen about the size of a 70” TV. The laptops were outfitted with webcams that captured patient activity and composited their image into the 2D game display. The games were intended to get users up and moving, so the screen ran the risk of keeping them in a sedentary viewing position. The patients were so engaged with their projected image and in the physical prompts of the game; they did feel immersed in the experience. The VR games proved useful and enjoyable to the participating clients. Interviewed day-center staff also reported related improvements in clients’ overall mood and engagement. Staff did suggest a larger display might improve client experience. A bigger screen could mean broader user movements or multi-player gaming.

Physical Therapy

Correa-Agudelo, Ferrin, Velez, and Gomez (2016) imagined a VR visualization therapy designed for a 32 screen curved visualization wall. The patient mirroring activity prototype displays a virtually rendered limb to stroke patients learning to reengage a paralyzed limb. Motion sensors and a keyable green screen sock helped capture and render technologies insert a new limb in place of the paralyzed limb in real-time. The curved video wall immerses patients in a motor activity while brain computer interfaces (BCIs) monitor them for improved cerebral reorganization. Researchers predict that the presence of the virtual limb speeds up motor learning and the return to motor function.

Sensors and other wearable devices are getting smaller and more sensitive. They can capture multi-gesture motions and report logged data to off-site devices and telepractitioners. Advances like these are utilized in the Barmpoutis et al. (2016) home-based, unsupervised physical therapy sessions. Patient gestures were monitored by a Microsoft Kinect sensor using an Xbox One video gaming system. Haptic feedback delivered through a wearable device signaled the patient when they performed an exercise correctly. The wearable device was a small elastic band with eight vibration motors worn on the patient's limb. A WiFi receiver attached to the elastic band sent sensor data. A desktop computer and a battery powered Arduino chip wirelessly controlled the haptic motors. The haptic device helped subjects learn to perform more consistent movement patterns with less deviation. The guiding hand of haptic intervention allows for repeated practice outside of a clinic environment, without a clinician. Haptic signaling can help fill treatment gaps when only basic guidance is needed, and the patient can be seen remotely. Sometimes haptic touch is not prescriptive or personalized enough to deliver healthcare information, and patients seek a human representation to help with guidance and connection.

Representations in VR

Modern VR learning activities are filled with increasingly realistic representations of humans and environments. Broecker et al. stressed the importance of a personalized virtual environment for powered wheelchair simulation training. Tong et al. attributed their VR's efficacy to its ability to engross a pain patient in a realistic virtual environment. Creating a sense of familiarity with people and place provides important contextual grounding for the learning patient. It can also give users an increased sense of comfort. Healthcare is a very personal activity, and human interaction is a crucial component to patient success. Patients create emotional bonds to the places and people within their healthcare networks. Together they build relationships by sharing stories and passing health information back and forth. These personal narratives can help them more fully engage and participate in real-world and virtual interactions.

The ability to render high fidelity human features and motion in real-time means avatars have become increasingly complex and adaptive representations of patients and practitioners. But increased realism does not always have a positive impact on user experience. As avatars become increasingly realistic representations of humans, they edge viewers closer to what robotics professor Masahiro Mori (1970) first called the "uncanny valley". The uncanny valley hypothesis describes a dramatic decrease in viewer comfort when interacting with human-like representations they perceive as inadequate humans. Andrade, Idrees, Karanam, Anam, and Ruiz (2016) created a smoking cessation game that could be played either with or without an avatar. The avatars were modeled from the likeness of the patients in the study cohort and were intended to increase user engagement in the game. Andrade et al. found the avatar did not improve readiness, confidence, or intentions to quit smoking. Is it possible that the human-like avatar could have created some undocumented discomfort or distraction for the interacting user?

Soldiers returning from active duty that may have difficulty interacting with people in interpersonal settings are shown to have improved interactions with virtual humans. Virtual reality technology trains them to be better communicators with others in the field (Huguet, Lourdeaux, Sabouret, & Ferrer, 2016). Consequently, their field experiences can then cause them to have difficulty communicating with people back home. Rizzo et al. (2016) compared the behavior of soldiers during a clinical interview with real human practitioners and virtual human (VH) practitioners. When reporting symptoms of PTSD, returning soldiers had less automatic nervous behaviors when reporting their condition to a virtual human. Their answers were more honest; their demeanor was less guarded. VH’s create a non-judgmental exchange dynamic where patients feel they can safely engage and learn.

MMVR 22 researchers investigated the use of VH’s to disseminate health-related instructions that are sensitive or stigmatized. Ruiz et al. (2016) experimented with reporting cardiovascular risk to patients using an avatar. Patients were presented with pre-recorded text regarding their cardiovascular risk factors. The text was delivered as either voice alone, or voice with a lip-synching avatar. Patients reported increased willingness to learn and apply content heard from the lip-synching avatar, but it remained unclear if avatars inspired client lifestyle changes and follow-up medical interventions.

Employing avatars may be a practical way to communicate standardized health care information, but it does not replace the need for human caregiver involvement. Instead, it reminds researchers of the importance of persuasive effects gained through human involvement. Though an avatar did not increase the Ruiz et al. subjects' confidence that they could actually change their risk factors, the next avatar could be programmed to deliver more empathetic and encouraging text. An avatar could become a client's greatest health educator and ally as well as a clinician's most consistent aide. With increased exposure, future users may become more comfortable with human representations. VR designers will help instructional designers and clinicians to better integrate VH's into patients' health narratives. Increased knowledge and data sets on human communication patterns continue to make virtual human representations more welcoming and trust-worthy. Avatars could be ideal health aides for motivated learners who have self-reported their health problems and seek to improve their outcomes.

VR Gamification

Gaming technology and VR technology have advanced together, and many MMVR 22 projects are built on commercially available gaming system platforms. Since its inception, VR-based learning has adopted gamification techniques to increase engagement with simulators and aide scaffolding. It abstracts skills training as play and builds up players' ability levels by presenting them with increasingly complicated tasks. Healthcare simulators quickly become games with escalating levels of difficulty, obstacles, goals, and point-based assessments. Games rely on the competitive nature of the players and motivate them by measuring performance. Multiplayer modes increase user interaction by using on-screen video, voice, and chat communication tools. MMVR 22 researchers utilize some elements of these gamification strategies, but could find ways to awaken even more features for better patient outcomes.

Headleand et al.'s Wheelchair-Rift simulation teaches people facing new limitations to adopt a foreign technology with assistive capabilities. Players could navigate through geometric obstacles while mastering chair control. The virtual game space interactions offer no adverse bodily consequences, allowing users to rise to more difficult levels, crash, and repeat. This VR learning experience was designed around solitary play, but multiple player gaming might have increased opportunities for patient learning. The ability to co-play with a trainer or other Wheelchair-Rift users could help clients find supportive reference points with more experienced people.

The Broecker et al. SafeHOME training simulator was modeled after specifications from the patients' own home environment. Their very life became gamified as they practiced completing VR tasks created to help them thrive at home after hospital discharge. The simulation was customized around an individual patient environment, but that does not mean they have to train alone either. Clients would additionally benefit from the live video and voice conferencing features VR gaming systems provide in multi-user mode. Patients could engage with the clinicians and caregivers who make up their healthcare support community. They could regularly meet in virtual space to review the status and success of the discharge plan. Games can unite communities by amplifying multiple voices and storylines. VR technology aides these connections by creating a boundless, virtual space for learners to interact.

When M. J. Taylor et al. tested their motion-sensor game system at a day-center for disabled adults, clients who were typically sedentary during activity sessions were suddenly interacting with technology and getting exercise. This new motivation could have been used to inspire additional interactions with other activity session clients. Staff at the day-center thought a larger gaming screen and a wider view from the laptop webcam would allow multiple users a chance to play together. Multiple player games may foster interpersonal relationship building between people who might otherwise have difficulty interacting outside of gameplay. In addition to inspiring increased physical activity, multi-player sessions may transform how clients understand themselves and the people around them.

VR games are now increasingly accessible from personal and powerful mobile devices. Today's VR designers prioritize delivering responsive content on smartphones and tablets when possible (e.g., Nehme, Bahsoun, & Chow, 2016; Nguyen et al., 2016; D. Taylor et al., 2016). The smoking cessation game that Andrade et al. designed was played from a desktop computer on a monitor with headphones. A touchscreen-enabled smartphone might have been a viable alternative for game delivery. People are more likely to play a game they can easily pull out of their pocket than one further from reach. Games take root during downtime, when we seek distraction and respite from daily obligations. Mobile gaming opens new and plentiful opportunities for healthcare learning that improves through repetition and rewards longitudinal investment. Nguyen et al. built a portable self-management system for asthmatic patients around a smartphone application. The inexpensive prototype produced real time measurements just like the ones specialists use to diagnose, monitor, and manage respiratory conditions. D. Taylor et al. discreetly monitored bariatric surgery patients' daily activity through an application on their smartphones. Both applications collected useful data that could be utilized in push notifications or text invitations challenging patients with health learning or self-care tasks. Patients' personal devices can be used to continually encourage immediate and prolific interactions.

Discussion

VR technologies are becoming more visible and available to consumers, and some patients may already be familiar with VR-enabled devices recommended by a practitioner. Increased commercial viability makes VR devices and applications more affordable to produce and purchase. Commercial availability and affordability, however, do not automatically make these devices easier to use in healthcare learning applications. It is important to prioritize usability testing that measures levels of user satisfaction with devices and applications. The usability of VR treatments and preventatives has a significant impact on their successful adoption by patients and practitioners. Many of the MMVR 22 researchers had to consider the user experience (UX) of novice, disabled, and at risk users within their VR design.

The Broecker et al.'s (2016) SafeHOME simulator design compared the usability of multiple visualization technologies for patients recently discharged from the hospital. Depending on the needs and abilities of the discharged patient, one of the four display methods was recommended as the content delivery system to be implemented during discharge planning. Tong, Gromala, Gupta, and Squire (2016) also conducted usability comparisons of head-mounted displays and stereoscopic desktop displays in a VR environment with pain patients. UX designers must consider potential hazards and setbacks patients may experience when using VR technologies. Specifically, discomfort, nausea, and anxiety have all been reported side effects of VR use. Correa-Agudelo et al. (2016) designed their augmented reality experience to help stroke patients reconnect with a recently paralyzed limb, while Headleand et al. (2016) helped disabled patients learn to use a powered wheelchair for the first time. Mierzwa et al. (2016) and Santhanam et al. (2016) both created VR devices for sensitive patient populations that need to carefully monitor delicate health status and intricate medical treatments.

Conditions for usability testing should reflect real-world use whenever possible. Headleand et al. (2016) promised to outfit their simulator experience with a real but stationary wheelchair. Usability tests staged in a lab environment will fall short of assessing usability in a clinic or home setting. Barmpoutis et al. (2016) built a prototype for home-based physical therapy sessions that included wearable haptic robotics and sensors. This iteration of their research lacked evaluation of the user experience, but Barmpoutis et al. did commit to future usability testing when the prototype proved beneficial to patients. The self-management system that Nguyen et al. (2016) designed for asthma patients was only evaluated for technical feasibility, but the literature is still peppered with considerations regarding how patiets will carry and use the device.

Technical and instructional support models need to be robust and agile to serve a growing and diverse population of VR users. Patients and practitioners will need adaptive support that moves seamlessly from clinic to home-based settings. Supporting learners in a home environment comes with unique challenges and barriers. M. J. Taylor et al. interviewed the day-center staff running the motion-sensor games with intellectually disabled patients regarding the likelihood of users playing the VR game at home. The staff perceived multiple challenges their clients would face when using VR devices at home. Home-based technologies require more support than the day-center staff could remotely supply. Clients may have an unpredictable or low-speed internet connection. Motivation to complete gaming sessions might also decrease when patients are away from the day-center environment and a structured activity schedule. The growing presence of VR learning in healthcare requires increased commitment to supporting varied technologies in uncontrolled settings. Turnkey solutions and customization rarely go hand in hand. Programming flexible tools and support paths for individual users is more challenging than supplying rigid protocols to large patient populations.

Future Research

MMVR 22 researchers laid plans for future investigations into the benefits and drawbacks of wearable VR devices. They will continue to compare immersive visualization delivery devices for comfort and effect while also conducting more rigorous usability testing for VR technologies in the lab, clinic, and home settings. MMVR 22 researchers have also tasked themselves with evaluating the effect of haptic touch inclusion on the immersive VR experience. Wheelchair simulators will add haptic feedback for collision effect, and physical therapy sessions will add it to enhance affirmative touch. Qualitative studies could determine the potential of haptic devices to deliver essential physical contact in tele-therapy sessions. Future trends in VR technologies will be designed to enhance and improve the traditional doctor visit, not supplant it. It is important to keep advancing good technology that does not distract doctors and caregivers from spending meaningful time with patients.

Conclusion

MMVR 22 researchers believe integrating virtual reality applications into medical education curriculum will produce better-trained clinicians who offer better outcomes to their patients. Those patients can, in turn, use VR enhanced healthcare education to lower their rate of hospital readmittance, practice self-care, and generally lower healthcare costs through increased preventative maintenance. Whether alone or with a member of a healthcare learning community, patients can train longer in a VE while being guided with robotic sensors and haptics. They can interact with pre-recorded, personalized avatars or with live practitioners broadcast through video and voice conferencing. Application enabled smartphones can even track and improve patients' health habits through active and passive monitoring and gaming. No matter the application, experience designers must prove they can program for the individual in order to successfully implement VR into healthcare learning. Differentiated and customized solutions should consider curricular content, learning context, intended audience, delivery platform, and available devices for each patient.

MMVR 22 researchers often found there was no one-size-fits-all solution regarding the perfect VR platform or device. Instead, each patient's situation and platform's advantage guided a personalized path for delivery and training. Broecker et al. tested multiple visualization technologies and compared their advantages for each SafeHOME simulator patient. The researchers say the reason, "VR scenarios do not scale to the clinical needs of a broad range of patients awaiting discharge is that they are very specific to a given task in a given environment." (pp. 54) Life is nuanced but task-based simulation programming needs to be exact. Effective VR learning aligns detailed goals for healthy, independent living with potential technology solutions.

The need for individualization and precision makes programming for scalability and plasticity difficult to accomplish. In order for future VR tools to better adapt to changing users and environments, designers should embrace what Linde and Kulkner (2016) refer to as "openness balance". Their research on the evolution of medical simulation in the U.S. military found that publically available open source tools and open architecture "reduce development costs and democratize access to technology" (pp. 212). Open source tools like software, algorithms, and libraries are available to be freely distributed, and modified without caveats. Systems built on open architecture have compatible parts that can be easily integrated and upgraded. Surgical simulators benefit most from affordable open source VR resources (Dindar, Nguyen, & Peters, 2016; Müller, Bihlmaier, Irgenfried, & Wörn, 2016; Obeid et al., 2016; Parthiban, Ray, Rutherford, Zinn, & Pugh, 2016), but learning patients can also access low cost, high fidelity technology built upon open source elements. The Correa-Agudelo et al. prototype for stroke patient therapy was built with open source image libraries and plugins. The app that D. Taylor et al. (2016) used for bariatric patient monitoring was free, and so was the website that the M. J. Taylor et al. (2016) test subjects accessed for sensorimotor games. It is conferences like the NextMed / Medicine Meet Virtual Reality symposia where colleagues and collaborators become more inspired to share solutions freely and openly.

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