Review Paper

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Keywords:
- Virtual Reality
- Clinical Research
- VR Standards
- VR Theory
- VR Immersion
- VR Presence
Virtual Reality Clinical Research: Promises and Challenges

Abstract

Virtual Reality (VR) therapy has been explored as a therapeutic approach in a number of medical applications, where three dimensional virtual environments can be explored in real time. Some significant successes have been claimed. A number of studies have asserted positive outcome for patients using VR for clinical conditions such as anxiety disorders, addictions, phobias, post-traumatic stress disorder, eating disorders, stroke rehabilitation, and pain management. Nevertheless, the implementation of clinical VR research outside of the laboratory presents many clinical challenges. This paper explores some of the key issues in implementing clinical VR research including theoretical ambiguity and immaturity, a lack of technical standards, problems of media vs. medium, practical in-vivo issues and costs. It is argued that careful attention to addressing these issues in research design and pilot studies are needed, in order to make clinical VR research more rigorous and meaningful.

Introduction

Contemporary research on computer-based virtual reality (VR) dates back to the early 1980s, although devices for presenting stereoscopic imagery (using a slightly different image for each eye) such as the Stereoscope started in the 1830’s.[1] However, the exploration of VR use in clinical applications is accelerating rapidly with the advent of more powerful computer and graphics processors capable of rendering real-time 3D imagery,
and the availability of relatively low cost VR headsets such as the Oculus Rift or HTC Vive (See Figure 1).

![Figure 1: VR Clinical Application Papers Published by Year (PubMed)](image)

As researchers with a number of years of experience in researching VR for clinical applications, we have identified some significant issues in the development of clinical VR research. Significant challenges remain with theoretical ambiguity and immaturity, a lack of technical standards, problems of media vs. medium, practical in-vivo issues and economic feasibility.
Background

There has been a rapid growth in the reported use of VR in the treatment of a variety of clinical conditions, such as acute and chronic pain management,[2–9] anxiety disorders,[10–12] phobias,[13–15] post-traumatic stress disorder (PTSD),[16–18] eating disorders,[19] autism,[20] and rehabilitation.[21–26] Additionally, its use in professional healthcare education has also been expanding rapidly.[22,27–32]

One early clinical application of VR was for the treatment of acrophobia.[33] Graduated exposure to virtual environments (VEs) with foot bridges, balconies, and a glass elevator were used with a railing placed around the user in the real world for them to hold on to. The intervention was reported as effective. Over the last 20 years VR clinical applications have expanded to address other phobias and anxiety disorders. The most common approaches in this field have been to model VEs after existing exposure therapies using graduated exposure to a VR version of the thing that causes distress, and use of VR cognitive behavioural therapies (CBT).[34–37] For PTSD, VEs have been used to simulate complex traumatic scenarios under control to treat war survivors.[18,38] Similarly, VR has been used in the treatment of body image and eating disorders.[39–41] These approaches leverage education, visual feedback, and simulations of critical situations to improve body self-perception.

These studies largely focus on health outcomes to determine the efficacy of VR treatments. Whilst they reported positive clinical effects over a variety of VR experiences, they often pay limited attention to the nature of the hardware and software used. Furthermore, the VR therapies usually relied on custom VEs. However, the literature often eschews commentary...
on the design and development of them. Despite these limitations, VR-based treatments for treating fear-related, and anxiety disorders appear to be the most established clinical applications of VR.

Another key area has been in the use of VR for pain management. The mechanism of VR pain control is primarily thought to be distractive, although mode of action remains unclear. [6,42,43] For example, VR has been used to manage acute pain during in-hospital treatments for burns patients. [5,44–47] Using VR for needle-stick pain has also been researched. [6,48]

In the field of chronic pain, VR has also been applied. [8,49–51] Several researchers have explored VR use to treat phantom limb pain (PLP). [52–55] VR allows clinicians to present patients with a virtual representation of their missing limb; through perception and motor training, patients experienced relief from PLP by seeing their virtual limb move in accordance to their voluntary motor signals.

In the rehabilitation field, there has also been great interest in pairing assistive technologies (robotics, treadmills, wheelchair on rollers, wearable sensors) and VR. The primary goals here have been the development of tools that support patient motivation to engage with rehabilitation and to leverage the logistical advantages of digital technology, namely performance monitoring, telehealth, and patient self-management. Additionally, translating physiotherapy exercises and activity training into the VR space allows for much greater control over and variety of scenarios. For example, robot-assisted upper limb therapy paired with VR visual feedback allows for graded exercises contextualized in a videogame environment. [56–58] In wheelchair simulators, VR enables users to practice wheelchair navigation skills in more dangerous situations such as traffic crossings and crowds without risk. [59,60]
Clinical VR research to date has generally been positive, but overall research in this field is in the early stages and faces technical and theoretical hurdles. The majority of the studies have used non-standardized techniques and tools in small scale pilot studies. Over the last four years the authors have conducted several clinical VR research projects,\cite{6,8,49} and found a number of challenges in the field that may limit the validity and generalizability of the work.

**Challenges**

**Theoretical Ambiguity and Immaturity**

As with the development of any new discipline, establishing a sound theoretical basis and standards is key to the growth of the field. However, there exists some theoretical ambiguity in the field due in part to its immaturity. Overall, VR may be considered as a growing field, defined by both its technology and its effects. The desired effect is to create an immersive experience, whereby the user is placed in a simulated environment that looks and feels as engaging as the real world. The person in this synthetic environment has a specific sense of self-location within it, can move to explore it, feels that the space surrounds them, and can interact with the objects within it. Overall, they feel a sense of presence in this environment, and their actions partially determine what happens within it.\cite{61,62}

Technically, the sense of immersion in a VR environment is largely achieved through visual and auditory stimuli that simulate three-dimensional (3D) visual and auditory cues available in the real world. Haptic feedback can also contribute to immersion this. Visually, this is delivered to the user via a head mounted display (HMD), which presents
computer-generated imagery (CGI) of the VR scene from the perspective of each of the user’s eyes. The literature suggests that immersion is largely influenced by both visual and audio qualities, although a universally accepted definition is yet to emerge.[63–67]

Immersion has been defined as the extent to which a user feels present in the CGI environment, rather than in their actual physical environment.[68,69] In computer science, immersion has more often been defined in terms of the technology and by the extent to which the computer is capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of the participant.[67] Therefore, Immersion is often referenced by technical considerations, such as field of view (FOV) and positioning of the virtual body in the CGI. The inclusion of stereoptic imagery is widely thought to be the dominant factor that enhances the immersive experience; other technical factors, such as greater display resolution or increased FOV are also significant.[52,70]

Presence, on the other hand, refers to the sense of being within an environment that is generated through technological means.[68,71] It is viewed as the sense of actually being in a constructed world.[68,69,71,72] Two experiential and technology-dependent dimensions are considered to contribute to a sense of presence. The first dimension is vividness, or the production of a sensory rich–mediated environment. The second is interactivity, defined as a user’s ability to engage with the environment and modify its form or alter events through interaction with it.

This differentiation of immersion from presence (which is seen as more of a subjective element) is fairly well-established in computer science, but less so in clinical VR research, where the terms are often used interchangeably. For clinical use, a technical definition of
immersion is limited, as it ignores the participant as a co-construct of the experience. Therefore, concepts of presence and telepresence[68] are likely more useful to clinical applications. An immersive VE can be usefully considered to be a computer-generated environment that elicits the user’s sense of presence or “being there”. It can be seen as an environment that produces an esthetic perception connected to the ideal of total immersion in virtual space involving the willing suspension of disbelief.[69,71,73] In clinical contexts, this sense of presence is likely the key element of interest that differentiates the impact of VR from other distractive and cognitive approaches. Assessment tools that separate these aspects, such as the igroup Presence Questionnaire (IPQ) have been developed.[74] However, the clinical VR literature rarely discusses these theoretical aspects, nor provides robust theoretical explanations of how VR theory applies to the specific problem under investigation. As VR is, in essence, a technology mediated phenomenon, this lack of theoretical distinction, between what actually constitutes a VR experience, at the least, makes meaningful comparisons between clinical studies complex.

Adding additional complexity is the issue that the actual nature of the effect of VR on the clinical problem of interest is also often unknown. For example, VR environments are hypothesized to reduce pain by mediating cognitive attentional and distractive mechanisms. The use of VR might act directly and indirectly on pain perception in a number of ways by altering neurological signaling pathways involving attention, emotion, concentration, memory, touch, and the auditory and visual senses. However, there are competing theoretical explanations of pain and the exact mechanisms of how VR may attenuate it remain unclear.[48,75–82]
The validity of clinical VR research also needs to be considered in the context of the theory development process. Overall, there are four major processes that occur in the development and establishment of a theory: 1) creating conceptual meaning, 2) structuring and generalizing the theory, 3) generating the theoretical relationships, 4) applying the theory, and then 5) theory validation by testing in different real-world applications. At this stage of VR development for clinical use, the underpinning theory has yet to reach the higher levels of established validity.

**Standardized Implementation**

The type of VR technology implemented varies greatly between clinical studies. It is arguable that the current state of the art is very much technologically led rather than theoretically led, with each new iteration of clinical research using the latest VR applications and hardware with disparate approaches for a variety of clinical conditions. As the hardware and software continues to advance rapidly, studies even a year apart may be using completely different hardware or software and, in many cases, the technology is only vaguely defined.

**3D vs 2D**

Many clinical studies have used the term VR to describe significantly different multimedia technologies, including two-dimensional (2D) video screen presentations, 2D rendered images presented on screens and HMDs, 360-degree 2D presentations on HMDs or computer-assisted virtual environment (CAVE) room-scale projection systems. Others used 3D rendered VR in motion tracked stereoscopic HMDs, with a wide field of view. There are similar differences in audio use in these studies, with
some using positional stereo sound (location specific sound that moves as the user moves their head) and others using non-spatial audio. Although health outcomes may be comparable, the nature and value of 3D vs 2D applications has not been widely explored in clinical applications.

**Study Design**

In addition to the theoretical issues, the nature of VR study design itself represents another significant hurdle. Systematic reviews/meta-analyses illustrate that many of these studies are statistically underpowered, although positive statistical results are frequently claimed. In order to establish clinical efficacy of a therapy, large scale, quality randomized controlled trials are required. Comparative clinical studies also require a suitable control environment to contrast with the VR experience. Few studies make an adequate attempt to address this and frequently neglect to differentiate the effects of the media from the medium itself (both theoretically and in practice). Failing to explore if it is the VR experience itself or the medium used that is eliciting an effect is problematic. A good design will contrast a VR experience with a non-VR equivalent of the same experience, controlling for the effects of the medium compared to the media. These issues likely reflect some degree of confirmation bias amongst researchers, but this illustrates the need to implementing larger scale high quality clinical VR studies.

**Usability and Technical Proficiency**
Another more practical challenge faced by clinical researchers is the usability of VR systems and the level of technical proficiency required to run them. Although current VR iterations are designed to be more user friendly, significant technical limitations remain. The use of HMDs is problematic for some patients; they remain cumbersome, particularly for patients with head or neck injuries, or for those who are particularly susceptible to eye strain. In general, prolonged exposure to a screen a few centimeters from the eyes often leads to eye strain or headaches and represents an ongoing issue with VR systems.[96,97] Users with limited head or neck mobility often reported the systems were uncomfortable to use.[8] Furthermore, most advanced HMDs have a cable tether which can prove a distraction from the experience or tripping hazard for older patients.

Cybersickness, as a side effect of VR, is also well documented and limits use by many patients, particularly those taking medications that provide a predisposition towards nausea.[8,98–102] Newer systems that operate at room-scale (where the user can walk around in a pre-determined area) have addressed this to some extent, but many patients also have limited mobility and must use the system in a seated position. This gives rise to another problem: most VR applications are currently designed to be used as either room-scale or seated, with few working well in both configurations. The issue derives from the fact that room-scale VR navigation affords the user much greater range of motion to physically approach virtual items, while the seated position requires a set visual height, longer reaching movements, and controller-based navigation of the environment. The environment design and implementation requirements generally do not transfer well from seated to room-scale and vice versa. Many VR systems have implemented teleportation
navigation systems to support moving through larger distances to overcome this issue, but
again those designed for room scale use do not adjust well to use from a seated position.

The design and game paradigm of many VR experiences itself can also prove challenging for
older patients. For users who have grown up with computer games, the nature of VR
experiences is more readily understandable: traversing 3D rendered worlds, using menus,
navigating levels, storing and retrieving items, saving progress, solving game puzzles, and
relating button-presses to abstract actions are all mechanics learned through experience.
This alignment of VR with recreational gaming is exemplified by the marketing and delivery
of HTC Vive and Oculus Rift VR applications through the Steam online gaming platform. The
majority of clinical users are likely to be older adults, who have no such videogame literacy
and often find learning these elements frustrating and distracting to their VR experience.
Little work exists exploring the VR preferences of these users and the VR market is firmly
dominated by the younger consumer.

**Lab vs In-vivo Practical Issues**

Much of the existing VR research has taken place in lab or clinic settings. These
environments can be optimized for VR systems. However, much remains to be known about
the effects of regular and prolonged VR use for real-world and home applications, where
they will be used for many chronic conditions. Certainly, there are common challenges for
research requiring any kind of at-home technology implementation such as logistics,
remote technical support, learning curve, compliance, etc. However, there are a few unique
challenges to consider in the implementation of VR systems outside the lab.
Current VR systems require dedicated space and are susceptible to interference. Room-scale systems require a five-foot square space, which may be intrusive to a patient’s living space. Cables may pose tripping hazards and infrared sensors, such as those used by systems such as the HTC Vive, may be interfered with by devices such as TV remotes, resulting in display cutting out, choppy visuals, and loss of tracking, thus disrupting the user’s experience. Other environmental factors that disrupt infrared tracking, such as climate and reflection of light off windows or mirrors, can be easily mitigated in a lab setting but can be more difficult to cope with in a home. Furthermore, calibration for motion tracking of VR equipment is sensitive and thus movement of equipment must be minimized. Effective installation of VR equipment while still maintaining the usability of the home space is challenging and may be further complicated if there are pets or children in the home.

For clinical research, where a study may take weeks or months, these technological burdens are important to negotiate with participants in advance. Despite these challenges, our experience has shown that research participants are often enthusiastic and willing to accommodate the various needs of the equipment and research study. However, these attitudes may not necessarily carry over to commercial or non-research contexts.

**Costs**

Finally, the cost of VR still presents a challenge to implementing large-scale trials. [11] Although costs of HMDs are dropping, quality VR environments still require high-end computer systems with advanced graphics processing to run them. VR Applications are also expensive to develop. The current cost of a full system to run a quality VR clinical
experience is around $2,500 USD per unit plus maintenance costs, making clinical research with multiple users costly. As with any information technology, attrition of value is also rapid; newer technologies rapidly make older systems obsolete. A practical assumption of minimal resale value of a VR system after three years is not unreasonable.

Conclusions

Although clinical VR research looks promising, there remain significant theoretical and practical challenges. Issues remain with theoretical ambiguity and immaturity, lack of technical standards, differentiating effects of media vs. medium, value of 2D vs 3D applications, study design, usability, conducting in-vivo research and economic feasibility. Defining the impact of presence in clinical VR studies and differentiating the concept of presence from immersion (as they are often used synonymously) is a problem, and current research designs are often ill-equipped to differentiate the role of VR from confounding factors. More robust; study designs contrasting VR experience with an equivalent non-VR control are required.

Practical challenges also remain, as existing high-end VR systems remain cumbersome and require technical proficiency to use. VR systems are not always user-friendly for patients. Moreover, issues of eye and neck strain and cybersickness remain as practical barriers to wider use. For those undertaking clinical VR research, it is important to keep these issues in mind during in efforts to improve the evidence-base for these technologies as health interventions.
Author Disclosure Statement

No competing financial interests exist.

REFERENCES


25. Casale R. Virtual reality in the rehabilitation of phantom limb pain: What are we
doing and how do we measure it in research and in daily practice......12th Congress of 
European Forum for Research in Rehabilitation / XXX. J Phys Med Rehabil Sci / Fiz 
Tup ve Rehabil Bilim Derg. IRCCS Scientific Institute of Montescano Department of 
Clinical Neurophysiology, Pain Rehabilitation Unit, Montescano, Italy: Galenos 
Yayinevi Tic. LTD. STI; 2013; 28–28 1p. Available: 
http://search.ebscohost.com/login.aspx? 
direct=true&db=ccm&AN=104141134&site=ehost-live

26. Levin M, Weiss P, Keshner E. Emergence of Virtual Reality as a Tool for Upper Limb 
Rehabilitation: Incorporation of Motor Control and Motor Learning Principles. Phys 

27. Merians AS. Sensorimotor Training in a Virtual Reality Environment: Does It Improve 
doi:10.1177/1545968306286914

28. Mikropoulos T a., Natsis A. Educational virtual environments: A ten-year review of 
doi:10.1016/j.compedu.2010.10.020

29. Cecil J, Gupta A, Pirela-Cruz M. An advanced simulator for orthopedic surgical 
017-1688-0

of Fine Motor Skill Performance in Dentistry: Brain Activity During Dental Tasks in a
doi:10.2196/jmir.8046

doi:10.1016/j.compedu.2010.06.008


47. Jeffs D, Dorman D, Brown S, Files A, Graves T, Kirk E, et al. Effect of virtual reality on adolescent pain during burn wound care. J Burn Care Res. From the *Arkansas Children’s Hospital; tUniversity of Arkansas for Medical Sciences College of Nursing; tUniversity of Arkansas for Medical Sciences; SSSeattle Children’s Hospital; and Arkansas Children’ Hospital Research Institute.: Lippincott Williams & Wilkins;


52. Cole J, Crowle S, Austwick G, Slater DH. Exploratory findings with virtual reality for phantom limb pain; from stump motion to agency and analgesia. Disabil Rehabil. Department of Clinical Neurophysiology, Poole Hospital, Longfleet Road, Poole, UK; 2009;31: 846–854. doi:10.1080/09638280802355197


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67. Slater M, Wilbur S. A framework for immersive virtual environments (FIVE)...


72. Osimo SA, Pizarro R, Spanlang B, Slater M. Conversations between self and self as
Sigmund Freud--A virtual body ownership paradigm for self counselling. Sci Rep. 2015;5. doi:10.1038/srep13899


80. Gold JI, Belmont Ka, Thomas DA. The neurobiology of virtual reality pain attenuation. Cyberpsychol Behav. Keck School of Medicine, University of Southern California, Los Angeles, California, USA. jgold@chla.usc.edu: Mary Ann Liebert, Inc.; 2007; 10: 536–544. doi:10.1089/cpb.2007.9993


102. Barrett J. Side effects of virtual environments: A review of the literature [Internet].