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64.1: Display Technologies for Therapeutic Applications of Virtual Reality

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Abstract

A paradigm shift in image source technology for VR helmets is needed. Using scanning fiber displays to replace LCD displays creates lightweight, safe, low cost, wide field of view, portable VR goggles ideal for reducing pain during severe burn wound care in hospitals and possibly in austere combat-transport environments.

1. Objective and Background

Commercially available LCD-type wide field of view near-to-eye displays have a number of limitations that are impeding expanded clinical use of Virtual Reality (VR) analgesia in burn centers and hospitals. Solving these problems for medical and military applications may also help pave the way for mainstream commercial use of near-eye applications.

Wide field of view VR goggles are marvels of engineering but have a number of limitations stemming from their use of miniature LCD-type displays: Too expensive, too heavy, too hot, too big, not portable enough, too much electricity near the user's head, can't use near water, and can't use in fMRI brain scanners. LCD-type VR goggles take too long to ship when initially ordered, break too often, are expensive to fix and take a long time to fix (months).

VR Analgesia

Immersive VR (e.g., using SnowWorld software, see Figure 1), a technique originated by Hoffman and Patterson at the University of Washington, helps bring the procedural pain of severe burn patients down to more tolerable levels during medical procedures. Severe burn patients report 35–50% reductions in procedural pain while in SnowWorld (Hoffman, Doctor, Patterson et al., [1] and Hoffman, 2004 [2]). Immersive virtual reality visually and aurally isolates patients from the real world. The VR helmet blocks patients view of the hospital room and substitutes computer-generated images. Noise canceling earphones block/replace hospital noises with sound effects and relaxing background music from the virtual world. VR is thought to reduce pain by directing patients' attention into the virtual world, leaving the burn patients brain with less attention available to process incoming signals from pain receptors.

According to a growing number of controlled clinical research studies using commercially available LCD-type displays, immersive virtual reality is an effective adjunctive pain

reduction technique (i.e., used in addition to usual pain medications) that increases analgesia without increasing opioid analgesia drug dose. However, LCD-type microdisplays used in commercially available virtual reality helmets have a number of limitations that are restricting more expanded use of VR analgesia in hospitals and in combat zones.

2. Technical Summary and Results

We present an overview of four different VR display technologies from the University of Washington, Seattle (UW) for therapeutic applications. The first three systems (Water-friendly, Magnet-friendly, and Table-mounted VR goggles) have been prototyped and tested in small, but controlled clinical and/or laboratory pain research studies. We propose a fourth system of photonic goggles (Scanning fiber display) that is only in the proof-of-concept stage of development, but shows great promise in reducing the size, weight, and expense of VR goggles without sacrificing performance and clinical utility.

2.1. Water-friendly VR goggles

At Harborview Burn Center in Seattle, some of the most severely burned patients sit in a tub of warm water during wound care to make their gauze bandages easier for nurses to remove. The layer of gauze directly contacting their sensitive severe burn wound surface is especially painful to remove. Standard VR goggles containing head mounted electronics that require electricity cannot be worn by burn patients sitting in a tub of water, due to risk of electrical shock to the patient and nurse. As a result, commercially available VR helmets are not used for VR pain distraction when severe burn patients need it most, during wound care in the scrubtank.

To address the limitation that conventional VR goggles cannot be used in a scrubtank, Hoffman, Patterson, Seibel et al. [3] and Hoffman, Patterson, Magula et al., [4]) designed and built a pair of water-friendly VR goggles (Figure 2). A high speed computer generates and delivers real time video signals from virtual reality into a conventional projector (one projector per eye). The miniature image from the projector image source is kept small, replacing the projector lens with a relay lens. The relay lens focuses the image onto one end of a 15 foot long fiber optic bundle (one bundle per eye). Light travels 15 ft. from the projector to the patient via 800,000 tiny glass fibers per eye. Each tiny glass fiber is approximately 1/5th the width of a human hair. The entire 800×1000 fiber bundle is only 8 mm $\times$ 10 mm and 15 feet long (housed in protective black sheath in Figure 2). The light is magnified via fiberoptic expanders, and focused into the patient's eyes via LEEP optics with 105 degrees horizontal FOV. While looking into the goggles, the patient interacts with the virtual world via a wireless mouse or joystick. Using this setup, our team has found that VR reduces severe pain during wound care by 35–50%, and reduces the amount of time patients think about their pain. Civilian patients report wound care was mildly fun during VR, compared to “no fun at all” during no VR. In an attempt to further increase the effectiveness of water-friendly VR, we are currently upgrading to 1920 $\times$ 1080 pixel Sony Bravia HD HW-15 projectors (one per eye) with 60:000 to 1 contrast ratio. Patterson's NIH team is expanding use of the water-friendly VR analgesia system at Harborview Burn Center and Shriners Children's Burn Center in Galveston, TX.

2.2. Magnet-friendly VR goggles

Hoffman, Richards, Magula et al., [5] conducted fMRI brain scans to study the neural correlates of VR analgesia, (i.e., objective measures of whether VR reduces pain). Conventional wide field of view VR goggles could not be used in the presence of the 1.5 Tesla magnetic fields generated by the UW's fMRI brain scanners. The electrical fields inadvertently created by conventional near-to-eye displays interfere/distort the fMRI brain scan images, and the large magnetic field of the fMRI scanner precludes the use of any ferrous or electrically conductive materials common in commercially available VR goggles, since strong magnetic fields moving along wires can cause high heat.

Using custom made magnet-friendly VR goggles, Hoffman et al. [6,7] found that in addition to feeling less pain (as evident from their subjective pain ratings), participants showed large drops in pain-related brain activity during fMRI, while in SnowWorld compared to brain activity during pain with no VR, (when just looking at a fixation cross). In other words, VR reduces pain-related brain activity (as shown in Figure 3).

2.3. Table mounted VR goggles

Hoffman and Magula also recently built a pair of table mounted VR goggles for an immersive VR Smithsonian curated museum tour of SnowWorld. Light from two 2650 × 1600 HD 30" Apple Cinema Display computer screens (one per eye) is focused via mirrors and optics into the patient's eyes (see Figure 4). The eyepieces, mirrors and monitors are bolted down to an ionized aluminum optical workbench, creating a ruggedized table mounted VR system that has withstood a one year Smithsonian curated immersive museum exhibit tour (the 2006 Smithsonian Cooper-Hewitt National Museum of Design Triennial), and several long weekend science center exhibits at the Pacific Science Center in Seattle. A replica of this device is now being used for research in England exploring the use of Virtual Reality exposure therapy for treating combat-related Post Traumatic Stress Disorder. Encouraging preliminary evidence for VR analgesia and VR therapy justify investment in creating a more viable VR goggle system, with a new display technology replacing the LCD displays.

As discussed above, Hoffman, Patterson, Seibel, Magula and colleagues have designed, built and tested Virtual Reality analgesia water-friendly goggles, magnet-friendly goggles for fMRI research, and table mounted goggles. Our custom VR goggles use optics and fiberoptics and/or mirrors to transmit LCD generated photons to the user. Thus, in our custom VR goggles, the LCDs are not near the patient's head. Our custom goggles have proved suitable as temporary solutions for research purposes and for interactive immersive VR exhibits at design museums and science centers, but a paradigm shift in image source technology for VR helmets is needed. Using scanning fiber displays as the new image source to replace LCD displays will allow the creation of lightweight, safe, low cost, wide field of view, portable VR goggles ideal for reducing pain and suffering of U.S. soldiers during wound care of combat-related injuries, and ideal for treating some of the approximately 50,000 U.S. civilian children and adults who suffer severe burn injuries each year. This line of research and development may also help pave the way for more immersive gaming applications in the future.

2.4. Scanning fiber display engine

As an alternative to LCDs near the patient's head, or a fiber array to relay an image to VR goggles, our laboratory is developing a miniature scanning fiber display engine that projects modulated laser light through a singlemode optical fiber that is resonantly scanned in two axes to project a image (Schowengerdt, et al., [8]). Figure 5 shows a scanning fiber display proof-of-concept prototype that projects a color image from red, green, and blue low-power laser sources (Schowengerdt, et al., [9]). By replacing the LCD with a scanning fiber display engine as the image source in VR goggles, dramatic improvements in size, weight, energy efficiency can be achieved. Because the scanning fiber engine uses very low current levels (millivolts) and packaged for *in vivo* endoscopic use [10], the goggles will be safe to use within a water tank. Future models that do not use ferrous materials will be magnet-friendly, as initial tests suggest scanning fiber displays can also be used within an fMRI magnet. Scanning fiber photonic (non- electronic) goggles are expected to have high resolution, brightness, and color saturation because they use pre-mixed color pixels from laser light sources. When head worn, the advantage of placing the light sources away from the user is expected to increase comfort and portability of the near-eye display.

2.5. Designing content for near-eye displays

Content can benefit from being customized to use with near-to-eye displays. SnowWorld was specifically designed to be used by people wearing near-to-eye displays. SnowWorld is a good example of how content for near to eye displays can be specifically designed to elicit high immersion while minimizing simulator sickness. "Off the shelf" video games are designed for desktop computer monitors, or game consoles such as the Xbox and Playstation. Our experience has been that trying to play those games "as is" using near-eye displays reduces performance and is nauseogenic. New versions of video games specifically designed, or customized for, near-eye display use could enhance the gaming experience compared to the current console based hardware/software.

3. Summary

Four novel display technologies are reviewed for VR therapeutic applications which have custom designed hardware, software, and content. All immersive VR applications have been driven by medical needs. However, as the VR photonic goggles reduce in size, weight, and cost with new technology (such as the scanning fiber projector), these systems will no doubt start entering the entertainment and gaming industries. For the military, scanning fiber displays could potentially make VR analgesia available closer to the battlefield (e.g. during Medivac transport of severely injured soldiers) and for future relief of Post Traumatic Stress Disorder via virtual reality exposure therapy, (e.g., Gaylord et al., 2009 [11]; Hoffman, 2004 [2]).

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References

1. Hoffman HG, Doctor JN, Patterson DR, Carrougner GJ, Furness TA III. Use of virtual reality for adjunctive treatment of adolescent burn pain during wound care: A case report. *Pain*. 2000; 85:305–309. [PubMed: 10692634]
2. Hoffman HG. Virtual-reality therapy. *Scientific American*. 2004; 291:58–65. [PubMed: 15298120]
3. Hoffman HG, Patterson DR, Seibel E, Soltani M, Jewett-Leahy L, Sharar SR. Virtual Reality Pain Control During Burn Wound Debridement in the Hydrotank. *Clin J Pain*. 2008; 24:299–304. [PubMed: 18427228]
4. Hoffman HG, Patterson DR, Magula J, Carrougner GJ, Zeltzer K, Dagadakis S, Sharar SR. Water-friendly virtual reality pain control during wound care. *J Clin Psychol*. 2004; 60:189–95. [PubMed: 14724926]
5. Hoffman HG, Richards TL, Magula J, Seibel EJ, Hayes C, Mathis M, Sharar SR, Maravilla K. A magnet-friendly virtual reality fiberoptic image delivery system. *Cyberpsychol Behav*. 2003; 6:645–648. [PubMed: 14756930]
6. Hoffman HG, Richards TL, Van Oostrom T, Coda BA, Jensen MP, Blough DK, Sharar SR. The analgesic effects of opioids and immersive virtual reality distraction: evidence from subjective and functional brain imaging assessments. *Anesth Analg*. 2007 Dec; 105(6):1776–83. [PubMed: 18042882]
7. Hoffman HG, Richards TL, Coda B, Bills AR, Blough D, Richards AL, Sharar SR. Modulation of thermal pain-related brain activity with virtual reality: evidence from fMRI. *Neuroreport*. 2004 Jun 7.15:1245–1248. [PubMed: 15167542]
8. Schowengerdt BT, Kundrat MJ, Lee CM, Johnston RS, Melville CD, Reinhall PG, Seibel EJ. P-251L: Late-News Poster: Miniature Wide-Throw-Angle Scanning Fiber Projection Display. *SID Symposium Digest of Technical Papers*. 2008; 39:2102–2105.
9. Schowengerdt BT, Lee CM, Johnston RS, Melville CD, Seibel EJ. 37.1: Invited Paper: 1-mm Diameter, Full-color Scanning Fiber Pico Projector. *SID Symposium Digest of Technical Papers*. 2009; 40:522–525.
10. Lee CM, Engelbrecht CJ, Soper TD, Helmchen F, Seibel EJ. Scanning fiber endoscopy with highly flexible, 1-mm catheterscopes for wide-field, full-color imaging. *J Biophotonics*. (in press).
11. Gaylord, K.; Hoffman, HG.; Maier, A.; Maani, C.; Miyahira, SD.; Garcia-Palacios, A.; Rothbaum, B.; Difede, J. VR Exposure Therapy + D-Cycloserine (DCS) for Treating PTSD in Patients with Combat-Related Burn Injuries. *Frontiers in Neuroengineering; Conference Abstract: Annual CyberTherapy and CyberPsychology*; 2009;

Figure 1.
SnowWorld, image by firsthand.com, copyright Hunter Hoffman, www.vrpain.com.

Figure 2. Patient in water-friendly virtual reality. Photo and copyright Hunter Hoffman, www.vrpain.com.

Figure 3.

A, B, and C are renditions of a patient looking into magnet-friendly VR goggles during an fMRI brain scan. (Image is by Duff Hendrickson, copyright Hunter Hoffman). As shown in D, results of an fMRI study found strong pain-related brain activity during no VR (D left), and large reductions in pain-related brain activity during VR (D right). Image is by Aric Bills & Todd Richards, copyright Hunter Hoffman, UW.

Figure 4.
Photograph of Ms. Howard Chambers looking into the table mounted VR display system,
photo and copyright Hunter Hoffman.

Figure 5.
Photograph of the scanning fiber display engine being held as a projector (between thumb and forefinger) while displaying a color image onto a screen.