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The Illusion of Presence in Immersive Virtual Reality during an fMRI Brain Scan

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ABSTRACT

The essence of immersive virtual reality (VR) is the illusion it gives users that they are inside the computer-generated virtual environment. This unusually strong illusion is theorized to contribute to the successful pain reduction observed in burn patients who go into VR during woundcare (www.vrpain.com) and to successful VR exposure therapy for phobias and posttraumatic stress disorder (PTSD). The present study demonstrated for the first time that subjects could experience a strong illusion of presence during an fMRI despite the constraints of the fMRI magnet bore (i.e., immobilized head and loud ambient noise).

An immersive virtual reality (VR) system typically consists of virtual reality software, a head-tracking sensor, a helmet-mounted visual display that blocks the patients view of the real world, three-dimensional (3-D) sound effects, and an input device the subject uses to interact with the environment (to navigate through it, shoot snowballs, and/or manipulate or influence virtual objects). In a typical setup, patients wear a virtual reality helmet that positions two goggle-sized miniature computer monitor screens near their eyes. Electromagnetic position tracking devices let the computer know any time the person in VR changes their head location or orientation. Sometimes hand location is tracked with a second sensor. The scenery in the virtual world changes as the user moves their head (e.g., they may see a river when they look down, canyon walls when they look to either side, and a blue sky when they look up). Sometimes the patients can physically touch the virtual objects, using real object props,[1] or computer generated force feedback devices like the pHanTom. The converging multisensory combination of sight, sound, touch, and sometimes taste[2] and smell gives users a uniquely compelling experience of "being there" in the virtual world. The essence of immersive virtual reality is the illusion it gives users that they are inside the computer-generated environment, as if it is a place they have gone. This unusually strong illusion is theorized to contribute to the successful pain reduction observed in burn patients who go into VR during woundcare[3–5] and the successful use of virtual reality exposure therapy for phobias[6,7] and posttraumatic stress disorder (PTSD).[8,9]

fMRI is a powerful new technology for studying patterns of brain activity associated with various types of mental activities. In order to study patterns of brain activity, stimuli are often presented to manipulate brain activity. Patients/subjects typically wear prismatic glasses so they can watch slides presented on a rear-projection screen or computer screen located outside of the magnet bore. Researchers investigating neural correlates of spatial navigation have used "desktop" virtual reality.[10,11] With "desktop" virtual reality (not involving

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a virtual reality "VR" helmet), participants are unlikely to have a strong illusion of going inside the computer-generated virtual reality environment, which they see far away, through the tunnel of the bore hole with only a narrow angle of their visual field. Researchers have begun exploring whether virtual reality goggles could be brought inside the scanner. Displaying images close to the patient's eyes helps give patients the illusion of "presence," the sensation that they are actually inside the computer-generated environment, interacting with virtual objects, instead of merely watching the virtual world on a distant computer screen.[12] And increasing the field-of-view of a VR display has also been shown to increase presence.[13] A wide field-of-view, interactive virtual reality image delivery system will allow more realistic interactions between patients and stimuli during fMRI scans. And brain activity patterns elicited by immersive VR stimuli might in some cases be more ecologically valid than brain activity elicited by conventional stimuli.

Attempting to elicit a strong illusion of presence from subjects during an fMRI is challenging because position sensors cannot be used, the patient's head must be kept very still during the scans, the scanner makes loud noises, and the patient is laying inside a magnet tube, which they may find distracting. The present study is designed to determine whether subjects are able to experience the illusion that they have gone inside the virtual world during an fMRI brain scan.

Hoffman, Richards et al.[14] recently built a custom display into the MR radio frequency head coil to project high resolution, wide field-of-view stereographic images to subjects during an fMRI brain scan. Using virtual reality during an fMRI scan is challenging because the strong magnetic field interferes with performance of electronic equipment (e.g., CRT screens that use magnetic fields to direct electrons onto a phosphor TV screen), and electricity creates electromagnetic fields that can ruin the brain scan images. Although Hoffman, Richards et al. (submitted) used only non-conductive, nonferrous materials in their device, the present study is the first to test whether their fiberoptic magnet-friendly image delivery system causes any interference, ruining the brain scans.

MATERIALS AND METHODS

Subjects

Seven healthy human subjects (ages 20–30, median age = 23 years) participated in return for monetary compensation. All participants gave informed written consent. This study and consent forms were approved by the University of Washington Human Ethics Committee.

Experimental task

Each subject was placed horizontally in the MRI scanner and goggles were used to display the visual stimulus to both eyes in stereo (Fig. 1). The magnet-friendly fiberoptic virtual reality image delivery system is described in detail by Hoffman Richards et al.[14] Instead of mounting miniature computer screens in the helmet (conventional VR helmet), with the magnet-friendly system, the virtual images are first converted from electrons to photons via 1024×768 Infocus LCD projectors located outside the magnet room. After being converted into light images, the real-time VR images are minified with lenses and relayed to the patient via two 15-foot long optic fiber image guides manufactured by www.Schottfiberoptics.com. Each 8 mm $\times$ 10 mm image guide is comprised of 800×1000 very thin strands of glass (fiberoptics) packed very close together into an ordered array. After traveling through the 15-ft. long image guides, the light images enter custom-made VR goggles where they are magnified and seen by the patient as wide-field-of-view images with special VR optic lenses. Only light, no electricity, reaches the subject's head. Each subject sees two independent computer-generated images of the virtual world (one for each eye), one image slightly offset from the other, which their brains fuse into a single 3-D illusory world with depth, simulating the normal visual depth cue called retinal disparity.

The VR computer system consisted of a Dell 530 workstation with dual 2-gig CPUs, 2 gigs of RAM, a Wildcat 6210 video card, and Windows 2000 operating system, coupled with the custom fMRI VR image delivery system, with approximately 67 degrees horizontal and 29 degrees vertical field of view (circular eyepieces), with nearly 100% overlap in the images. The subject kept their head still, and looked around in the virtual world by moving a magnet-friendly trackball. The computer quickly updated the virtual environment presented to the user by changing the viewpoint in VR when the user moved their trackball. The subject had the illusion of flying through SnowWorld, a virtual environment created with Creator™, Alias modelling software packages, and VEGA™ development software from www.MultiGen.com. SnowWorld depicts an icy 3-D virtual canyon with a river and waterfalls. The

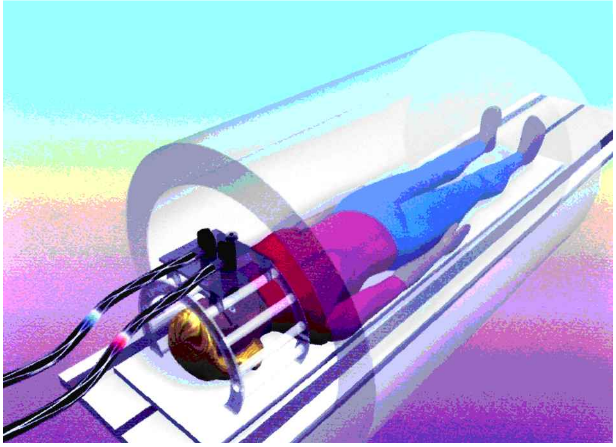

FIG. 1. Subject in an MR magnet looking into VR goggles.

subjects shot snowballs at snowmen and igloos, robots and penguins by aiming with their gaze, controlled via trackball and pressing the trigger button on the plastic magnet-friendly trackball. The snowballs exploded with animations and 3-D sound effects on impact.

The "on" condition consisted of an unobstructed 3D Virtual Reality view of snow world and this condition was defined as high-tech virtual reality (Fig. 2). The "off" control condition consisted of the same snow world but with a white cross that obstructed part of the view, and this condition was defined as low-tech (Fig. 3). In the present study, subjects heard sound effects in both experimental conditions and viewed SnowWorld through the same magnet-friendly VR image delivery system. The high- and low-presence conditions were presented to the subjects alternating every 30 sec during a 6-min fMRI scan.

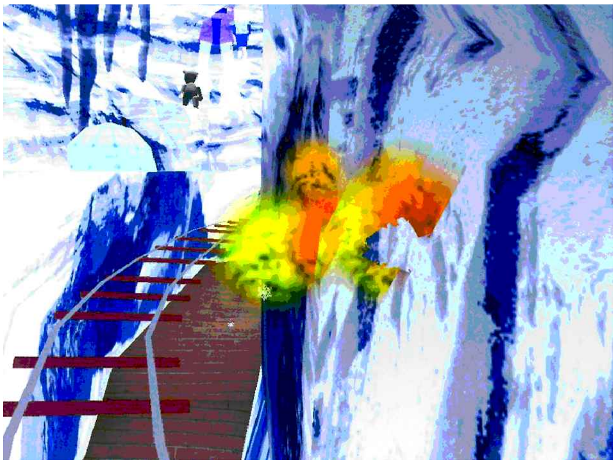

FIG. 2. Example of Snow World high-presence condition.

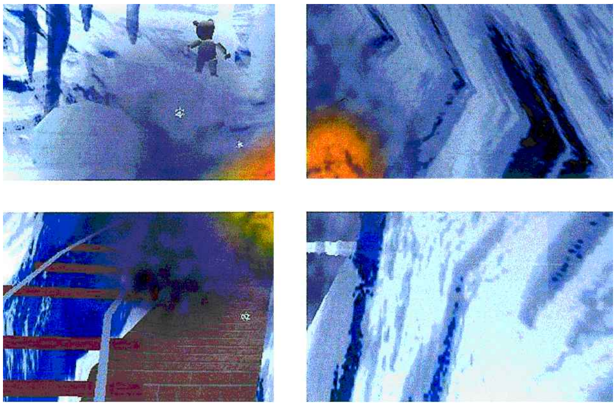

FIG. 3. Example of Snow World low-presence condition.

RESULTS

Immediately after the fMRI brain scan, the experimenter asked each subject two questions over the intercom. Subjects were verbally asked to give a number from 0 to 10 to indicate how present they had felt in the virtual world on the stimuli that did not have a white cross (the high-tech SnowWorld condition) and to give another rating of their presence when they were in SnowWorld with the white cross (the low-tech condition). The question they were asked was as follows "While experiencing the virtual world with *no* white cross, to what extent did you feel like you went inside the virtual world? 0 = I did not feel like I went inside at all, 1–4 = mild sense of going inside, 5–6 moderate sense of going inside, 7–9 = strong sense of going inside, and 10 = I went completely inside the computer-generated virtual world. "While experiencing the virtual world *with* the white cross, to what extent did you feel like you went inside the virtual world? 0 = I did not feel like I went inside at all, 1–4 = mild sense of going inside, 5–6 moderate sense of going inside, 7–9 = strong sense of going inside, and 10 = I went completely inside the computer-generated virtual world. They were told they could give fractions if they wanted. Their answer did not have to be a whole number. On the scale from zero to ten, subjects rated presence in the high-tech condition significantly higher than presence in the low-tech condition (mean presence rating = 7.0 for high-tech and 4.1 for low-tech), $t(6) = 10.59$, $p < 0.001$, SE = 0.28. In fact, each of the seven subjects showed higher presence in the high tech condition than the low tech condition.

As can be seen from Figure 4, MR anatomical scans and echoplanar images (both showing brain structure but not brain function), acquired from

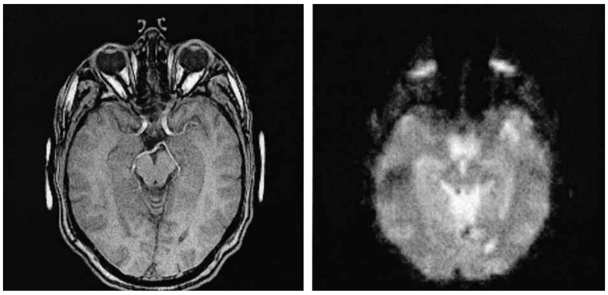

FIG. 4. Magnetic resonance (left) and echoplanar (right) structural scans indicate that the fiberoptic VR image delivery system did not interfere with image acquisition.

one of our subjects did not interfere with image acquisition. This was also verified with additional "phantom" scans using a head shaped like a ball of water. The functional MRI results showing patterns of brain activity associated with high- versus low-presence VR are not presented in this preliminary report because of concerns that the results would be misinterpreted. Further (more carefully designed) research exploring presence-related brain activity is needed.

DISCUSSION

Subjects reported experiencing a strong illusion of presence in VR via the magnet-friendly VR image delivery system, in spite of the constraints of lying down with immobilized head in an enclosed environment (the fMRI bore) with loud knocking noises. Subjects reported a stronger illusion of presence in VR in the high-tech condition than in the low tech condition. And our magnet-friendly fiberoptic image delivery system did not interfere with the brain scans. VR could be used during fMRI to study a number of psychological phenomenon (e.g., fear-related brain activity in phobics and PTSD patients before and after therapy, drug craving of substance abusers, and patterns of brain activity associated with the illusion of presence in virtual reality). Combining VR and fMRI could potentially lead to a better understanding of the relation between what people are thinking and experiencing, and their associated patterns of brain activity.

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REFERENCES

1. Hoffman, H.G., Garcia-Palacios, A., Carlin, C., et al. (in press). Interfaces that heal: coupling real and virtual objects to cure spider phobia. *International Journal of Human–Computer Interaction.*
2. Hoffman, H.G., Hollander, A., Schroder, K., et al. (1998). Physically touching and tasting virtual objects enhances the realism of virtual experiences. *Virtual Reality: Research, Development and Application* 3:226–234.
3. Hoffman H.G., Doctor J.N., Patterson, D.R., et al. (2000). Use of virtual reality for adjunctive treatment of adolescent burn pain during wound care: A case report. *Pain* 85:305–309.
4. Hoffman H.G., Patterson D.R., & Carrougher, G.J. (2000). Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: a controlled study. *Clinical Journal of Pain* 16:244–250.
5. Hoffman, H.G., Patterson, D.R., Carrougher, G.J., et al. (2001). The effectiveness of virtual reality based pain control with multiple treatments. *Clinical Journal of Pain* 17:229–235.
6. Rothbaum, B.O., Hodges, L.F., Kooper, R., et al. (1995). Effectiveness of virtual reality graded exposure in the treatment of acrophobia. *American Journal of Psychiatry* 152:626–628.
7. Garcia-Palacios, A., Hoffman, H. G., Carlin, C., et al. (2002). Virtual reality in the treatment of spider phobia: a controlled study. *Behaviour Research and Therapy* 40:983–993.
8. Rothbaum, B.O., Hodges, L.F., Ready, D., et al. (2001). Virtual reality exposure therapy for Vietnam veterans with posttraumatic stress disorder. *Journal of Clinical Psychiatry* 62:617–622.
9. Difede, J., & Hoffman, H.G. (2002). Virtual reality exposure therapy for World Trade Center Post Traumatic Stress Disorder: a case report. *CyberPsychology & Behavior* 5(6):529–536.
10. Shelton, A.L., & Gabrieli, J.D. (2002). Neural correlates of encoding space from route and survey perspectives. *Journal of Neuroscience* 22:2711–2717.

11. Maguire, E.A., Burgess, N., Donnett, J.G., et al. (1998). Knowing where and getting there: a human navigation network. *Science* 280:921–924.
12. Prothero, J., Hoffman, H.G., Parker, D.E., et al. (1995). Foreground/background manipulations affect presence [On-line]. Available: www.hitl.washington.edu/publications/p-95–3//p-95–3.rtf.
13. Prothero, J., & Hoffman, H. (1995). Widening the field of view increases the sense of presence in immersive virtual environments (R-95-5) [On-line]. Available: www.hitl.washington.edu/publications/r-95–5/.
14. Hoffman, H.G., Richards, T., Magula, J., et al. (submitted). A magnet-friendly virtual reality fiberoptic image delivery system.

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