Virtual Reality Distraction Analgesia

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Introduction

Medical procedures that cause moderate to severe pain occur over a wide spectrum of patient ages and medical settings, yet do not always warrant formal anesthesia or deep sedation. For example, in conscious children with cutaneous burn injuries, the intense and repeated 'therapeutic' pain of daily burn wound debridement and/or post-burn physical therapy exacerbates the significant pain of the underlying burn injury itself, and can contribute to long-term complications of depression, post-traumatic stress disorder, and diminished quality of life. Pharmacologic analgesia and/or sedation are the cornerstones of treatment, but are often inadequate and limited by drug side effects. Thus, analgesic treatment for procedural pain is often complemented by non-pharmacologic techniques, such as cognitive modulation by attention/distraction or hypnosis.

Because pain is a particularly attention-demanding task, several of the most promising non-pharmacologic interventions target conscious attention. Attention is the key determinant of how/why nociception is translated into awareness as pain, and how distraction can displace pain from awareness. When individuals are distracted from their pain by attending to another competing sensory input, pain is perceived as less intense. Further, neurophysiologic studies show that nociceptive central neural activity can be modified by attention interventions [1-3]. Lastly, functional neuroimaging using positron emission tomography (PET) and functional magnetic imaging (fMRI) gives evidence for attention-related reductions in brain activity of the pain matrix (anterior cingulate cortex [ACC], thalamus, somatosensory cortices) during acute [4,5] and chronic pain [6].

Our group is carefully investigating clinical and experimental pain reduction with the application of immersive, interactive virtual reality (VR) -- a highly sensory-stimulating and attention-demanding distractive technique. PC-based VR systems combine high resolution/wide field-of-view video input via a head-mounted display, stereophonic surround-sound, head-tracking or joystick navigation, user interaction with the virtual environment, near-complete visual/aural exclusion of the immediate medical care environment, and customized virtual environment software. The virtual environment 'SnowWorld' was specifically designed for treating those with burn pain (Figure 1), based on patient reports that they tend to think about their original, traumatic burn event during wound care. As a result, SnowWorld portrays an icy, cool virtual environment that directly contrasts the 'hot' scenarios and unpleasant memories that are usually associated with burn injuries. An electromagnetic head tracking system sends the x-y-z coordinates of the user's head orientation to the VR computer in order to track gaze direction. What the user sees in the environment changes as he/she 'looks around' the virtual world. For example if patients look up, they see the dark, starry sky; if they look down they see a slowly flowing, icy animated river; if they look straight ahead they see sky, river, and icy canyon walls, upon which are located various animated objects and characters. In SnowWorld, patients interact with the 3-D computer-generated world by visually targeting and shooting snowballs at snowmen, igloos, robots and penguins on the canyon walls using a simple human-computer interface -- aiming via gaze direction and shooting by

pressing the spacebar on a computer keyboard. Snowballs splash into the river, or explode with 3-D sound effects. When hit by a well-aimed snowball, snowmen disappear into a puff and virtual penguins turn upside down. Using such hardware and software systems, we have (1) demonstrated the analgesic efficacy of immersive VR for procedural pain associated with burn wound care, post-burn rehabilitation therapy, dental care, postoperative rehabilitation therapy, and male urologic procedures, and (2) identified key analgesic determinants of immersive VR using experimental pain and fMRI [7-20]. Two examples of these studies are described in brief detail below.

Figure 1. SnowWorld, the first immersive virtual world designed for pain distraction.
Image by Stephen Dagadakis, copyright Hunter Hoffman, University of Washington

VR Distraction Analgesia in Children During Physical Therapy

Because both native and grafted skin naturally contract during the healing process following a burn injury, patients must perform daily physical therapy exercises to stretch their healing skin (especially burns on joints such as fingers, elbows, shoulders and knees). Such physical therapy helps patients retain full limb range-of-motion, and also helps retain skin elasticity. However, such therapy sessions are moderately painful, which reduces patient compliance and thus, can result in unsatisfactory functional outcomes. VR distraction during such rehabilitation activities (Figure 2), both alone and in combination with pharmacologic analgesia, has been shown to provide superior analgesia (demonstrated by a ~30% reduction in subjective pain reports) compared to standard analgesic conditions without VR, in both adults and children [8,10,14]. In addition, consistent analgesic improvement is maintained over multiple consecutive daily sessions. Finally, measured improvements in passive range of motion following the session were found to be equal or improved in the VR condition. Thus, VR distraction appears to improve patient pain complaints and functional outcome in the setting of moderate physical therapy pain, and may serve to improve patient compliance with such rehabilitation activities.

Functional Neuroimaging VR Distraction Analgesia

Reductions in subjective pain scores with immersive VR distraction have been reported in both the settings of clinical pain and experimental pain, as noted above. In an effort to confirm these findings with assessments of pain-related brain activity, researchers recently developed a non-ferromagnetic, wide field of view, fiberoptic image delivery system that allows participants (e.g., healthy volunteers) to use VR during the performance of functional neuroimaging studies in an fMRI scanner (Figure 3) [13].

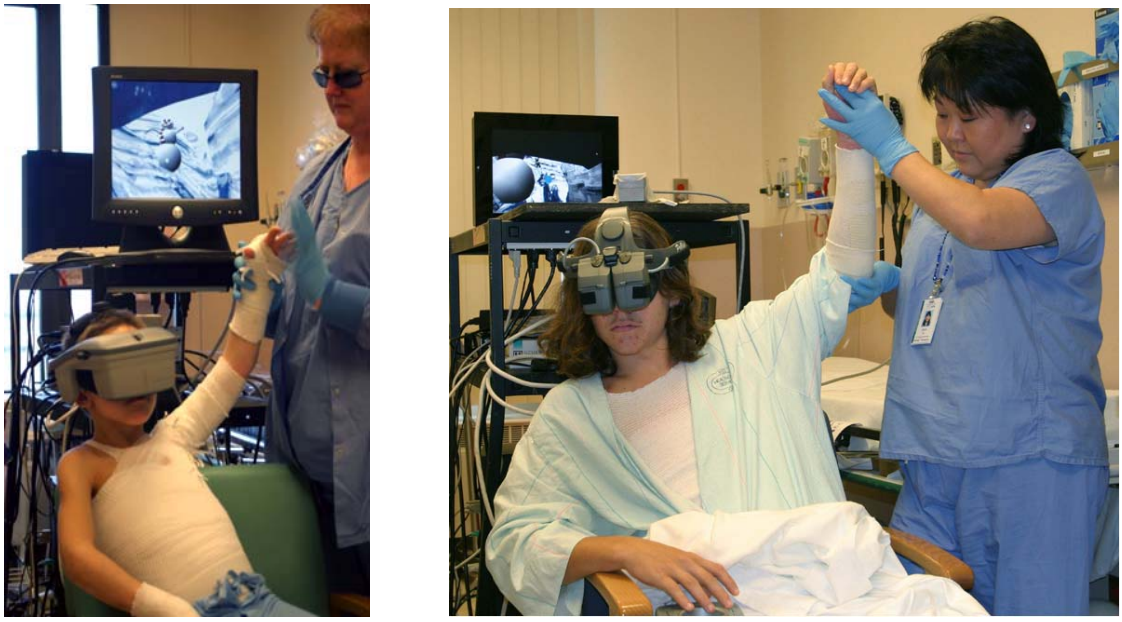

Figure 2. Young burn patients experiencing SnowWorld while undergoing physical therapy. Photo and copyright by Hunter Hoffman, University of Washington

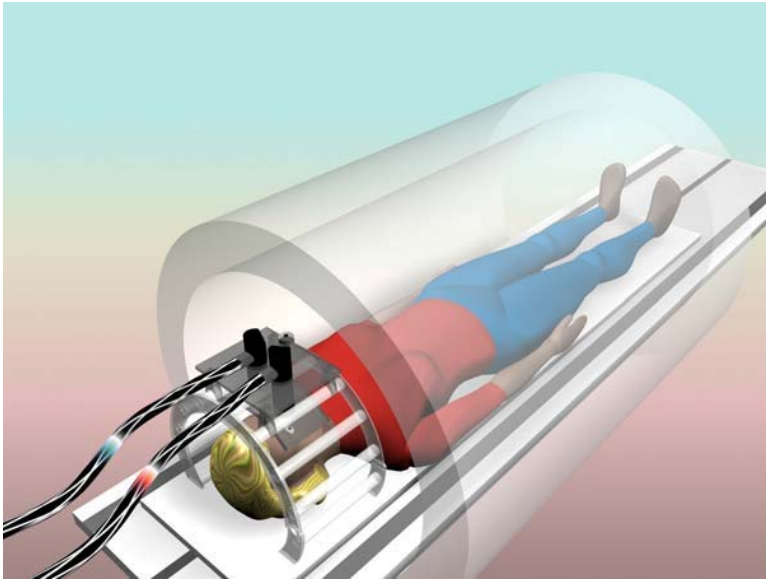

Figure 3. An artist's depiction of a subject experiencing VR while undergoing a functional MRI scan. Image by Duff Hendrickson, copyright Hunter Hoffman, University of Washington

Healthy volunteers were subjected to brief episodes of safe, yet significantly uncomfortable thermal pain, using a computer-controlled thermode applied to the dorsum of their foot, while under two experimental distraction conditions. In the 'no VR' condition, subjects focused their gaze on a static fixation cross in the absence of sound. In the 'VR' condition, subjects participated in 'SnowWorld' as described above, with fingertip-controlled navigation and user-environment interaction using a trackball device. Subjective assessments of the sensory, emotional, and cognitive components of the pain experience were reduced by 25-40% in the VR condition (from a baseline rating of ~8/10 to ~5/10), consistent with previous reports in clinical and experimental pain settings. Associated with these subjective changes were statistically significant reductions in brain activity in five regions of interest associated with pain sensation (ACC, thalamus, insula, and somatosensory cortices I and II) (Figure 4). These preliminary results [17] provide both subjective and associated objective evidence for the analgesic effects of immersive VR distraction in the setting of brief, moderate pain. Further investigations are underway to determine the subjective and objective outcomes of VR analgesia compared to various pharmacologic analgesics, as well as when combined with various pharmacologic analgesics, as would be utilized in most clinical settings of procedural pain. Such information will provide insights into the neural mechanisms of VR analgesia, including its relationship to conscious attention and to various analgesic pathways.

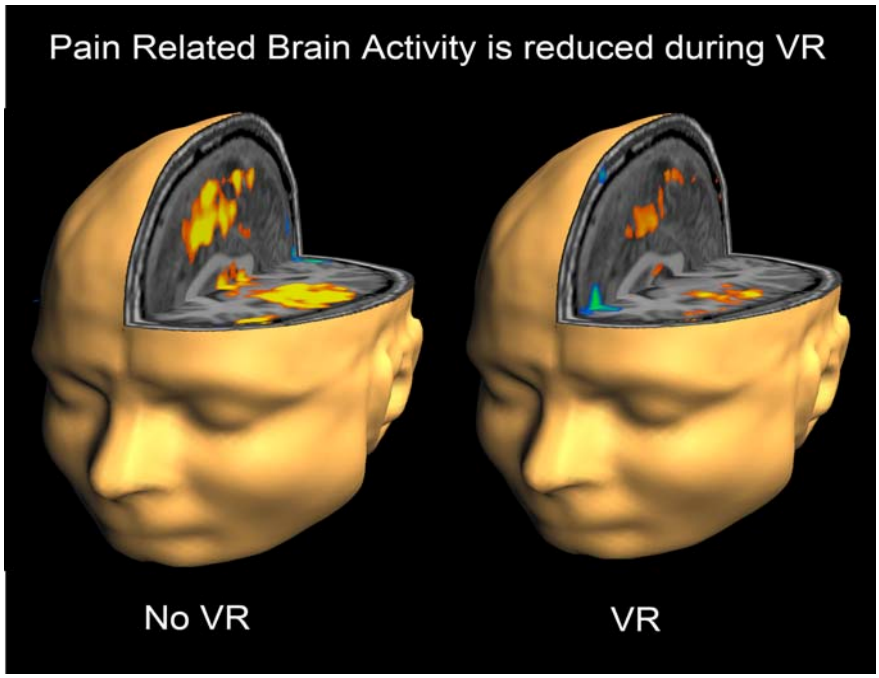

Figure 4. Participants in a pain imaging study [17] showed significant reductions in pain-related brain activity during VR in several pain-related regions, including the ACC (sagittal cut) and insula (transverse cut). Images by Todd Richards and Aric Bills, copyright Hunter Hoffman, University of Washington

Excessive pain is common during a variety of medical procedures in both adults and children, and preliminary evidence suggests that VR distraction may serve as an effective non-pharmacologic analgesic in such settings. This may be particularly true in school-aged children, for whom the use of interactive videogame technology is commonplace. Additional research exploring the use and mechanisms of VR analgesia, including its potency and cost related to less immersive video distraction technologies, is warranted and currently underway.

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