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Manipulating presence influences the magnitude of virtual reality analgesia

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Abstract

Excessive pain during medical procedures performed in unanesthetized patients is frequently reported, but can be reduced with virtual reality (VR) distraction. Increasing the person's illusion of going into the virtual world may increase how effectively VR distracts pain. Healthy volunteers aged 18–20 years participated in a double-blind between-groups design. Each subject received a brief baseline thermal pain stimulus, and the same stimulus again minutes later with either a Low Tech or a High Tech VR distraction. Each subject provided subjective 0–10 ratings of cognitive, sensory and affective components of pain, and rated their illusion of going inside the virtual world. Subjects in the High Tech VR group reported a stronger illusion of going into the virtual world (VR presence) than subjects in the Low Tech VR group, (4.2 vs. 2.5, respectively, $P = 0.009$) and more pain reduction (reduction of worst pain is 3.1 for High Tech VR vs. 0.7 for Low Tech VR, $P < 0.001$). Across groups, the amount of pain reduction was positively and significantly correlated with VR presence levels reported by subjects ($r = 0.48$ for 'worst pain', $P < 0.005$).

Keywords: Virtual reality; Presence; Analgesia; Distraction; Attention

1. Introduction

Excessive pain during medical procedures performed in unanesthetized patients is frequently reported (Gilron and Bailey, 2003; Karling et al., 2002; Melzack, 1990; Schechter, 1989; Shang and Gan, 2003) despite the widespread use of analgesic therapies. In clinical settings, side effects of opioid analgesia (e.g. nausea, post-procedure sedation, cognitive dysfunction, and constipation) limit dosage. In contrast, non-pharmacologic techniques typically produce minimal and short-lived side effects, and may serve as valuable adjuncts to traditional pharmacologies. One such non-pharmacologic technique is distraction, which has been shown to help reduce procedural pain in several settings (Fernandez and Turk, 1989; Tan, 1982).

Researchers have recently explored the use of immersive virtual reality (VR) as a pain control technique that can be used in combination with traditional pharmacologic therapies. Subjective reports of pain during a variety of painful medical procedures in the clinical setting have been shown to drop approximately 40–50% when patients are distracted by immersive VR (Hoffman et al., 2000a,b, 2001a,b, 2004a; Steele et al., 2003).

We theorize that VR analgesia works via an attentional mechanism. Humans have a limited amount of conscious attention available (Kahneman, 1973). Pain requires conscious attention (Chapman and Nakamura, 1999; Eccleston and Crombez, 1999). VR systems provide computer-generated multi-sensory input (sight, sound, and more rarely touch, taste and/or smell). Such converging sensory input, and the interactive nature of the experience help give patients the illusion of going into the virtual environment, which can make the virtual world presented difficult for the user's brain to ignore. We theorize that the more intense

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the patient's illusion of going inside the virtual environment, the more his/her attention will be drawn into the virtual world (Hoffman, 1998; Hoffman et al., 2003a), leaving less attention available to focus on pain.

In the present study, some subjects (High Tech VR) used VR hardware (VR helmet, headphones and headtracking system) designed to elicit a strong illusion of VR presence. Others (Low Tech VR) used VR hardware designed to elicit a less compelling illusion of VR presence (see-through VR glasses, no headphones, no headtracking). Regardless of the mechanism of VR analgesia, we predicted that (1) subjects' illusion of 'going into' the 3D virtual world (i.e. VR presence) would be greater for the High Tech VR group, and (2) the High Tech VR group would experience more pain reduction than the Low Tech VR group. And we predicted (3) the amount of VR presence reported would be positively and significantly correlated with the amount of pain reduction in VR. In essence, we predicted a measurable dose (increasing VR presence) response (pain reduction) relationship.

2. Method

Thirty-nine healthy undergraduate Psychology students 18–20 years of age (14 males, 25 females) from the University of Washington participated. Both written and verbal informed consent were obtained using a protocol approved by the University of Washington's Human Subjects Review Committee.

2.1. High Tech VR vs. Low Tech VR

Towards the goal of creating an immersive VR display (Slater and Wilbur, 1997), we used a High Tech VR system designed to: (1) shut out physical reality (helmet and headphones that exclude sights and sounds from the real world), (2) provide converging evidence to multiple senses, (both sight and sound), (3) provide a surrounding/panoramic view rather than limited narrow field of view, (4) be vivid/high resolution, (5) permit the participant to interact with the virtual world and (6) use head tracking, which allows subjects to view different portions of the virtual world merely by changing their head position/orientation. We also used a Low Tech VR system that (1) does not shut out physical reality (see-through VR eyeglasses and no earphones), (2) provides only one sensory input (sight only, no sound), (3) is not surrounding/panoramic but is instead limited to a narrow field of view, (4) is not vivid/high resolution, (5) does not permit the participant to interact with the virtual world, and (6) has no head tracking.

According to Slater and Wilbur (1997), immersion is an objective, quantifiable description of what a particular VR system can provide to a participant. Immersion is different from the subjective psychological illusion of going into the virtual world (defined here as VR presence), which is a psychological state of consciousness. Although immersion and presence are distinct concepts, increasing the immersiveness of a VR system often leads to a stronger illusion of presence. Several studies have identified 'high tech' improvements in VR hardware that increase the objective immersiveness of a VR system and simultaneously increase participant's subjective illusion of going into the virtual world (presence). For example, increasing the size of the eyepieces in the VR helmet (i.e. field of view, Prothero and Hoffman, 1995), adding head tracking so what the participant sees changes in the virtual environment as they change their head position (Hendrix and Barfield, 1995), and adding or improving the quality of sound in VR (Hendrix and Barfield, 1995), have all been shown to increase participants' subjective illusion of going into the virtual world. Adding tactile feedback to virtual objects has also been shown to increase presence (Hoffman et al., 2003b), but tactile cues were not used in the present study.

2.2. Experimental thermal pain model

Controlled thermal pain stimulation was applied using a commercially available Peltier thermode (www.medoc.com) designed to provide noxious heat, noxious cold, and non-noxious thermal stimulation over a range of 0–50 °C (Becerra et al., 1999; Coghill et al., 1994; Edwards et al., 2003; Kwan et al., 2000; Talbot et al., 1991). The noxious heat stimulus temperature was individually determined for each subject immediately prior to study, using the psychophysical method of ascending levels as follows. A 30-s heat stimulus (always 44 °C for the first stimulus, which all subjects found tolerable) was delivered through a thermode attached to the dorsal surface of the right foot, and the subject was asked to rate the stimulus using a 0–10 graphic rating scale (see below). With the subject's permission, the temperature for the next stimulus was then increased by 1 °C (e.g. 45 °C) and rated, and this sequence was continued until the subject reported a stimulus that was painful but tolerable. To avoid excessive pain, stimulus increments of less than 1 degree were sometimes administered at the researchers discretion, as subjects approached severe pain. The experimenter's unannounced goal was to achieve either a pain unpleasantness or worst pain rating of 7, but a number of subjects chose to stop before achieving a pain rating of 7, and this was permitted. Individualized stimulus temperatures ranged from 44 to 48 °C (mean of 46.5 °C, and were associated with ratings of 'worst pain' on a 0–10 scale ranging from 2 to 8 (mean of 5.94). The noxious baseline temperature selected (30 s thermal stimulus without distraction) also served as the pain stimulus temperature during the VR intervention phase of the study protocol (30 s of thermal pain during virtual reality).

After each pain stimulus subjects received the following instructions prior to answering six separate queries. 'Please indicate how you felt during the past 30 s pain stimulus by making a mark anywhere on the line. Your response doesn't