Virtual Reality Immersion Method of Distraction to Control Experimental Ischemic Pain

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Abstract

Background: Virtual reality immersion has been advocated as a new effective adjunct to drugs for pain control. The attenuation of pain perception and unpleasantness has been attributed to the patient's attention being diverted from the real, external environment through immersion in a virtual environment transmitted by an interactive 3-D software computer program via a VR helmet.

Objectives: To investigate whether VR immersion can extend the amount of time subjects can tolerate ischemic tourniquet pain.

Methods: The study group comprised 20 healthy adult volunteers. The pain was induced by an inflated blood pressure cuff during two separate, counterbalanced, randomized experimental conditions for each subject: one with VR and the control without VR exposure. The VR equipment consisted of a standard computer, a lightweight helmet and an interactive software game.

Results: Tolerance time to ischemia was significantly longer for VR conditions than for those without ($P < 0.001$). Visual Analogue Scale (0–10) ratings were recorded for pain intensity, pain unpleasantness, and the time spent thinking about pain. Affective distress ratings of unpleasantness and of time spent thinking about pain were significantly lower during VR as compared with the control condition ($P < 0.003$ and 0.001 respectively).

Conclusions: The VR method in pain control was shown to be beneficial. The relatively inexpensive equipment will facilitate the use of VR immersion in clinical situations. Future research is necessary to establish the optimal selection of clinical patients appropriate for VR pain therapy and the type of software required according to age, gender, personality, and cultural factors.

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Pain has a strong psychological component and, according to meta-analyses, many different cognitive and cognitive behavioral strategies have proven beneficial in complementing traditional therapy in attenuating perceived pain [1,2]. A key element in these methods is the modulation of pain perception and affective distress by the process of diverting attention from the nociceptive signals [3]. Distraction of attention has been used to modify internal thoughts by introducing pleasant mental imagery and requiring mental efforts to solve problems [4,5]. Diverse external means of distraction have also been used with single sensory modality presentation such as music [6], or presentation to multiple sensory modalities as in audio video games and films [7]. The application of mental distraction approaches is an effective adjunct in reducing pain – both experimental pain induced in laboratory settings and pain experienced by patients in clinical situations [5,8].

Virtual reality immersion is a new promising distraction method for use as an adjunct to medication in pain control [9]. It presents a high technology computer-generated environment, known for decades in the entertainment industry. VR uses a computer system that transmits an interactive software program of selected images and sounds via a head-mounted display with earphones. The HMD completely occludes visual and auditory stimuli coming from the real environment. A redirection of the conscious attention available to process pain at any given moment is thus achieved as the patient becomes more and more immersed in the attention-grabbing virtual environment provided by the multi-sensory VR system. Furthermore, in addition to its inherent potential efficacy and multi-sensory input, it has the advantage of completely withdrawing the patient from the anxiety-inducing sights and sounds of the 'sick patient' environment that often contribute to exacerbate the feeling of pain.

The VR immersion technique has proven to be an unusually valuable attention-engaging modality as compared to similar forms of interactive distraction such as Nintendo games or movies [9,10]. Significant diminished reaction to pain perception and affective distress aspects of pain with no adverse effects were reported in case studies using VR during wound care for burns [9], brief dental interventions [10], during chemotherapy for a child [11], in venipuncture for children [12], and physiotherapy for a cerebral palsy adolescent [13]. Controlled research reports also showed the value of VR immersion during brief medical interventions such as physical therapy exercises associated with burns [14]. Subjective reports of perceived pain have also been used in VR studies of experimental ischemic and thermal pain [15,16]. In a study of thermal pain with and without VR immersion [16], self-ratings of experimental thermal pain were validated by functional magnetic resonance imaging, which showed that experiencing VR is associated not only with subjective reports of less pain sensation but also with significantly reduced activity in regions of the brain that are known to be involved in pain perception.

The sophistication of the equipment is critical in obtaining VR results. A study of dental interventions that used video glasses that did not fully occlude the environment and software that was

VR = virtual reality

HMD = head-mounted display

not interactive found that VR did not significantly reduce perceived pain unpleasantness and intensity during the procedures [7]. On the other hand, using state-of-the-art VR equipment and an interactive program, Hoffman and colleagues were successful in reducing pain [10].

Although pain ratings were reduced with VR, the total time tolerated under painful conditions – a traditional measure used frequently in studies of pain – has not been reported to date for the VR method. Since the amount of time that a patient is willing to tolerate a painful procedure is of clinical significance, it is important to determine if VR immersion will extend the pain-tolerance time. The purpose of the present study was to evaluate the influence of VR immersion in extending the length of time participants will tolerate pain. To address this question, prior to a clinical investigation we used an ischemic experimental pain model in which we could measure tolerance time under controlled conditions. The use of VR for pain management is still in its infancy, partially due to the high cost of equipment and its portability. Since expediency is an important consideration, we tested VR immersion with relatively inexpensive VR equipment that will be practical to use in future clinical situations.

Subjects and Methods

Twenty healthy adult volunteers, 10 women and 10 men aged 20 to 62 years (mean 32.5 years), participated in the study. All participants were healthy, were not on medication, and reported that they were not susceptible to motion sickness. Average blood pressure was 109/76. Two potential subjects were excluded as they did not meet the study criteria: one was taking anticoagulant medication and the other reported hypertension.

Equipment

The VR immersion was achieved by using a standard laptop Pentium IV computer connected to modified commercial I-O glasses with earphones for the HMD, an interactive game software program, and a forced feedback joystick. We modified the glasses to completely occlude the actual visual and auditory environment. The modification provided an inexpensive, lightweight and comfortable HMD to replace the actual visual and auditory environment. Furthermore, the VR environment in our experiment was created to present multiple sensations of a spatial, visual and auditory nature designed to draw attention away from the pain and anxiety associated with the experimental pain. The software program (Sonarion Ltd, Israel) was an interactive computer game in which the subject used the joystick to destroy enemy aliens. The program kept a visible tally of successful hits made during the session. Lively music accompanied the visual display.

Experimental design

Each subject participated in two consecutive sessions of experimental pain induced by a tourniquet placed on the forearm in a within-subjects experimental design. Subjects were their own control by experiencing one condition using VR and one without. The order of the experimental conditions was randomized and counterbalanced. Subjects were instructed on the use of the equipment, and before starting the experiment they were given an opportunity to practice using the software program with the joystick until they indicated they understood how to move about within the program. Prior to signing the informed consent form approved by the University Human Studies Committee, the volunteers were informed that they would be participating in two separate conditions designed to study pain control with and without the application of VR exposure. They were told that the pain they would feel is the result of pressure maintained continuously on the forearm by an inflated regular blood pressure cuff and the lack of circulation in blood vessels below the tourniquet. The volunteers were also told that if they wanted to stop the sensation of induced pain and discomfort at any time, the cuff would be deflated and the procedure terminated immediately. Ischemic arm pain was induced by inflation of a regular blood pressure cuff on the left arm to 220 mmHg in both men and women. Participants raised the left forearm over their head for 1 minute prior to inflation of the blood pressure cuff in order to drain the venous blood. The arm was then returned to the horizontal position and covered with a cloth to prevent the subject from viewing changes that occur during the ischemic episode. To minimize an excessively high pain level, the duration of the procedure for each subject and for each condition was not determined by a fixed time but was stopped for any participant according to her/his own report of reaching a point where the pain was uncomfortable/intolerable.

Measures

Pain was the primary dependent variable and four measures of pain were assessed. Duration of the time from the inflation of the tourniquet to the point when the subject requested termination of the session was recorded immediately after each condition and was an objective measure of tolerance time to ischemia. Also, at the completion of each condition, the subject self-rated pain perception and affective distress using three Visual Analog Scale ratings (0 to 10): pain intensity, pain unpleasantness, and the amount of time the subject thought about pain during the tourniquet. Additionally, after the VR condition, subjects rated each of the following on the VAS of 0 to 10: nausea (cybersickness), presence (immersion in the virtual environment), and enjoyment of the VR environment.

Statistical analyses

Student's independent *t*-tests were performed for order of presentation (VR or NoVR first) and for gender. VR effects on the four pain dependent variables were analyzed by Student's paired *t*-tests with a Bonferroni correction for multiple comparisons, alpha level was set at $P < 0.01$.

Results

VR first or NoVR first was tested for each pain-dependent variable. No significant order differences were found and order of presentation did not enter as a factor in the statistical analyses.

VAS = Visual Analog Scale

Table 1. Gender differences in the time tolerance to ischemic pain with and without VR exposure (minutes of ischemia)

Condition	Men	Women	*P*
VR	15.6 (± 4.4)	8.9 (± 3.3)	< 0.002*
NoVR	10.6 (± 5.6)	6.1 (± 3.1)	< 0.05**
	$P < 0.03^{‡}$	$P < 0.001^{‡‡}$	

Numbers represent mean (± SD)

*,** Gender differences for VR and NoVR

‡,‡‡ Differences between VR and NoVR for each gender

Table 2. Experimental ischemic pain VAS and duration of ischemia tolerance time measurements with and without VR

	Pain scores (VAS 0–10)		Duration of tolerance (min)		
	VR	NoVR	VR	NoVR	*P*
Pain intensity	6.3 (± 3.1)				NS
Pain unpleasantness	5.0 (± 2.7)	7.2 (± 2.0)			< 0.003
Time thinking about pain	2.6 (± 1.3)	7.0 (± 1.4)			< 0.001
Tolerance time of ischemia		7.0 (± 2.4)	12.2 (± 5.1)	8.4(± 5.0)	< 0.001

Numbers represent mean (± SD)

Gender

Each pain variable for each condition was tested for gender differences. Significant differences between men and women were found for the tolerance time of ischemia in both experimental conditions. Table 1 shows the mean ± SD in minutes and the *P* values for the 10 men and 10 women. A significant gender difference was found in the time spent in VR exposure. Men spent more time than women, 15.6 (± 4.4) and 8.9 (± 3.3) respectively, $t = 3.84$, $P < 0.002$. The NoVR values were also significantly different, 10.6 (± 5.6); and 6.1 (± 3.1), $t = 2.17$, $P < 0.05$. Although men stayed in the painful situation longer than women, the mean difference in minutes of tolerance time between VR and NoVR was not significantly different for men and women, $t = 1.19$, $P > 0.25$. Both men and women showed a significantly longer duration of time of pain tolerance with VR than with NoVR. Therefore, the two gender groups were combined for the statistical analyses of the pain VAS variables.

VR effects

Tolerance time in minutes for ischemic pain during the VR sessions for the total group of 20 was significantly longer than the sessions without VR 12.2 (± 5.1) vs. 8.4 (± 5.0) respectively, $P < 0.001$ [Table 2]. Although research with ischemic pain indicates that in most instances pain becomes extremely strong and uncomfortable after 10 minutes [17,18], 12 of the subjects in this study were able to stay in the VR condition for more than 10 minutes compared to only 5 in the NoVR condition (Fisher's exact test, $P < 0.03$). Four subjects went the limit to 20 minutes with VR and two of these four went less than half that amount of time without VR. Furthermore, there was a significant correlation for the total group between the length of the tolerance time to ischemia with VR versus NoVR conditions, which suggests a consistency in general individual tolerance threshold regardless of circumstances ($r = 0.65$, $P < 0.008$). Although there were wide individual differences in pain tolerance as well as consistency across situations, VR was effective beyond these factors.

Table 2 also shows the three VAS pain scores, 0 to 10, where 0 indicates no pain and 10 the most intolerable pain. The mean VAS rating for pain intensity, at the time when the subject requested deflation of the cuff, was not significantly different between VR vs. NoVR conditions in spite of the fact that the total time in the VR condition was endured significantly longer. In contrast, the affective distress aspect of pain, pain unpleasantness, was significantly lower in VR, with VAS being 5.0 (± 2.7) vs. 7.0 (± 1.4) in the NoVR, $P < 0.003$. The time spent thinking about pain during immersion in the VR environment compared to that in the session without VR was also significantly less: VAS 2.6 (± 1.3) vs. 7.0 (± 2.4), $P < 0.001$.

Minimal adverse effects of VR were reported only by two women who experienced mild nausea (cyber-sickness) from the VR session. The rating of presence, i.e., the feeling of being immersed in the virtual environment offered by the computer system, was high (mean VAS score 8). The maximum presence rating of 10 was reported by four subjects. Fun/interesting scores were also high, with a mean VAS score of 7.5. The correlation between fun and presence was significant: $r = 0.70$, $P = 0.002$, suggesting that the ratings were assessing a similar concept. Men reported more experience with computer games and this was reflected in the number of hits, which was significantly higher for men than for women ($P < 0.006$). Yet in spite of a lower number of hits, women were not significantly less involved in the VR environment than men according to their self-reported scores of presence and fun.

Discussion

The current study using simple equipment corroborates the findings of previous studies that used elaborate expensive equipment – namely, the power of VR to redirect attention away from pain and to reduce the amount of pain experienced without deleterious consequences [10,19]. Choice of equipment in terms of practicality, cost, comfort and effect are important considerations in future treatment for patients suffering from pain. The use of a standard laptop computer for the VR system and a lightweight helmet makes the use of VR immersion more feasible in clinical situations.

The randomized counter-balanced experimental design with each subject as his/her own control allowed a comparison of tolerance time for VR and NoVR as subjects determined the length of time they would endure the tourniquet pain under each condition. Both men and women tolerated pain longer with VR immersion than without. Women requested cuff deflation in both experimental conditions sooner than men. This gender difference in the number of minutes pain was endured is in agreement with recent investigations that women have a lower pain tolerance level than men for laboratory pain [20].

VR exposure also led to lower VAS ratings of pain for unpleasantness and time spent thinking about pain. The report of awareness of pain only some of the time during VR was in sharp contrast to reports of thinking about pain most of the time without VR. Although sensory perception of pain, as measured by VAS pain intensity scores at the time the patient requested cuff deflation to end the session, was not significantly less in the VR condition than in the NoVR, it is important to examine these results in relation to the specific character of the experimental ischemic pain model. Research shows that with continuous application of pressure by the blood pressure cuff, there is nerve compression that initiates sensory loss and dysesthesia, with the physical aspect of pain increasing steadily for as long as the tourniquet pressure is maintained. In many investigations of experimental ischemic pain, the subjects were instructed to perform dynamic hand exercises every 2 minutes. In the present study, hand exercises were not used in order not to interfere with the subject's immersion in the virtual environment. Therefore, the type of pain represented more the effects of nerve compression than muscular pain. Affective distress from the arm cuff pressure pain and the progressive numbness in the hand appeared later than the physical pain, but intensified more rapidly and became more bothersome than the pain sensation itself, forcing the individual to reach the tolerance level between 4 and 20 minutes [17,18]. Because the period of ischemia was significantly prolonged with VR in our study, it would have been logical to expect that pain intensity scores would be rated higher with VR than in the shorter NoVR sessions. The similarity of VAS ratings of pain intensity in VR and NoVR session may serve to corroborate the hypothesis that VR exerts its effects by also influencing the sensory pain perception because subjects were able to remain in the VR situation 45% longer than in the NoVR condition and still rate the intensity of the pain at the same level in both conditions.

The mechanism of the positive influence of distraction methods on different aspects of pain control is still under investigation. Some research supports the view that the two components of pain – pain perception and affective distress aspects – are determined differently [21]. The difference has even been demonstrated by functional magnetic resonance, which showed that two different sites are activated by thermal stimuli in the brain: one for perception of acute pain, and the other for the affective aspect represented by expectation [21]. On the other hand, many well-controlled clinical and neurophysiologic studies prove that redirection of attention alters both pain sensation and unpleasantness through modulation along the afferent pain system [3,22]. The range of variability among the subjects that we found in all the measurements is consistent with large inter-subject variations in values for threshold and tolerance to pain known to occur in healthy persons as well as in patients with chronic pain. This variation has been recognized in response to multiple experimentally induced noxious stimulation delivered by chemical, electrical, cold, thermal, pressure stimuli or performance of a muscle task [23].

Suggestions were solicited from the participants as to how to improve the program. It became clear that to be most effective, a variety of computer programs should be available to accommodate the individual preferences of participants related to age, gender, sociocultural requirements, and type of pain. For clinical settings it is recommended that the VR equipment selected be easy to use, portable, relatively inexpensive, and that the helmet completely occlude the real environment. The software programs need to be appealing, immersive, interactive, multi-sensory, easy to learn, not dependent on computer experience, provide feedback on success, and be interesting to use on repeated treatments for the same individual. Since emotions and mood are known to modulate pain [3], non-violent, pleasant scenarios, challenge, and humor are recommended as additional desirable features to be incorporated into future software programs used in pain therapy.

It is concluded that although experimental pain does not possess many of the actual dimensions of pain experienced by patients, our observations of the effects of VR add important knowledge concerning practical clinical applications and the role of VR in pain therapy for both men and women.

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