Virtual-Reality Distraction and Cold-Pressor Pain Tolerance: Does Avatar Point of View Matter?

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Abstract

This study tested the effects of distraction using virtual-reality (VR) technology on acute pain tolerance in young adults. Forty-one undergraduate students, aged 18–23 years, used a VR head-mounted display helmet, steering wheel, and foot pedal to play an auto racing video game while undergoing exposure to very cold water (cold pressor set at 1°C). Two different game views were tested that were hypothesized to affect the degree to which participants felt “present” in the virtual environment: a first-person view, in which the participant saw the virtual environment through the eyes of the game character being manipulated; and a third-person view, in which the participant viewed the game character from a distance. The length of time participants tolerated the cold-water exposure (pain tolerance) under each distraction condition was compared to a baseline (no distraction) trial. Subjects also rated the degree to which they felt “present” in the virtual environment after each distraction trial. Results demonstrated that participants had significantly higher pain tolerance during both VR-distraction conditions relative to baseline (no distraction) trials. Although participants reported a greater sense of presence during the first-person condition than the third-person condition, pain-tolerance scores associated with the two distraction conditions did not differ. The types of VR applications in which presence may be more or less important are discussed.

Introduction

A VARIETY OF DISTRACTION TECHNIQUES have been successfully employed to minimize the acute pain and distress associated with invasive medical procedures.¹ Emerging laboratory and clinical research suggests that a novel form of distraction using virtual-reality (VR) technology may also prove to be a successful pain-management technique for both children and adults.^{2–7} In VR distraction, the individual interacts with a computer-generated virtual environment by way of a head-mounted display (HMD) that provides visual and auditory information (while at the same time blocking sensory input from the real environment) and the manipulation of some sort of controller (such as a joystick or body-movement tracking device). However, at this time, there is a limited understanding of whether or not VR distraction provides better pain management than other distraction techniques and the aspects of VR distraction that contribute to its efficacy.

One aspect of VR distraction that has been hypothesized to contribute to its effectiveness is the degree to which the individual feels “present” in the virtual environment versus the real environment.⁸ Researchers have proposed several features of VR that may enhance presence, such as the rate of

update in the virtual environment,⁹ the field of view,¹⁰ the vividness of the virtual environment, the amount of control the individual has over the virtual environment, head tracking, localized sound, and how “real” the virtual environment feels to the individual.^{11–15}

Presence can also be enhanced by providing a meaningful stimulus in the virtual environment (such as an avatar) that the individual can manipulate.¹⁶ For example, participants who manipulated an avatar of their own body in a virtual environment reported significantly higher presence than individuals who manipulated an arrow cursor in the same virtual environment.¹⁷

The way in which the avatar is presented also may affect presence.¹⁸ In a first-person point of view, the individual “sees” the virtual environment through the eyes of the avatar and is only able to see its limbs (or a parallel part of the avatar, such as the hood of a car or nose of an airplane). In a third-person point of view, the individual is able to see the entire body of the avatar as if the individual were “following” the avatar in the virtual environment.¹⁶ Some researchers have argued that viewing the avatar from the third-person perspective distances the individual from the avatar and the virtual environment and thus reduces the experience of presence.¹⁸

This study evaluated the effects of a novel VR-distraction intervention and avatar point of view on cold-pressor pain tolerance. After a baseline no-distraction cold-pressor trial, participants underwent two additional cold-pressor trials during which the same VR-distraction intervention was provided from either a first-person or a third-person point of view. Based on the distraction literature, both VR-distraction conditions were expected to result in greater cold-pressor pain tolerance than the no-distraction baseline condition. However, the first-person avatar VR-distraction condition was expected to result in higher presence ratings and concomitantly higher pain-tolerance scores than the third-person avatar VR-distraction condition.

Method

Participants

Participants were 41 undergraduate students aged between 18 and 23 years ($M = 20.29$, $SD = 1.29$) recruited from both the authors' institution and local post-secondary-education institutions. Of the participants, 46.3% were male, 68.3% were Caucasian, 14.6% were Asian/Pacific Islander, 7.3% were African-American, 7.3% were Hispanic, and 2.4% were biracial; 7.3% of participants were students from post-secondary institutions outside the university.

Apparatus

Cold pressor. A NESLAB RTE-17 Circulating Water Bath (Thermo Scientific, Waltham, MA) was used as the pain stimulus to ensure a constant water temperature of 1°C. Water was kept at this temperature to reduce the likelihood of ceiling effects.

Virtual-reality equipment. Participants viewed and heard the video game through a 5DT head-mounted display (HMD) helmet (800 Interactive Personal Display System; Fifth Dimension Technologies, Irvine, CA). The HMD was connected to a Sony Trinitron television (Model KV-20V80; Sony, New York) through a multi-function converter (Impact Acoustics, Moraine, OH). Participants viewed a stereoscopic 1.44 million pixel color display with a 26° diagonal viewing angle (300×200×240 mm) through eye goggles and heard auditory effects through headphones that were integrated into the HMD helmet.

Video game. Participants played the game *Need for Speed Underground 2* (Electronic Arts, Inc., Redwood City, CA) on a Playstation 2 (Sony, New York), using a full-featured racing wheel with foot pedal (Game Stop, Grapevine, TX) to steer the car. The same game segment (the Quick Race Circuit) and same car model (the Mitsubishi Lancer with Automatic Transmission) were used in both the first-person view and third-person view VR-distraction conditions.

Biofeedback monitor. A DT-100 Thermal Feedback System (Model DT-100; Power ID-91; Biofeedback Systems, Inc., Boulder, CO) was used to measure ambient room temperature and participant hand temperature.

Measures

Demographics. Each participant completed a questionnaire, which collected basic demographic and medical infor-

mation. Exclusionary criteria included circulation or heart complications, hearing or vision problems, pain-medication use, or motion-sickness disorders. No subjects were eliminated from the study based on these medical concerns.

Presence. A single-item measure of presence, "In the computer generated world, I had the sense of 'being there,'" adapted from the Nichols et al.¹⁹ presence questionnaire, was used to obtain participants' subjective ratings of their sense of presence in the virtual environment. Participants rated this statement on a 7-point Likert scale anchored "Not at all" and "Very much." Higher scores indicated a greater sense of presence in the virtual environment. Similar estimates of presence have been used by other researchers and have been shown to discriminate between virtual environments that have been manipulated to produce a greater or lesser sense of presence.^{10,20,21}

Procedure

The study was approved by the university's Institutional Review Board. Participants signed an informed consent form prior to participating.

Setting. A 4.87×3.65 m carpeted room served as the research environment. Participants sat in a chair facing the television with the cold-pressor machine to the side of their non-dominant hand. The positions of the pedal and steering-wheel controllers corresponded to their location in a real automobile.

Cold-pressor trials. Participants were exposed to one or two baseline trials: one trial in which they played the video game from the first-person point of view (first-person VR distraction), and one trial in which they played the video game from the third-person point of view (third-person VR distraction). The number of baseline trials and the order of the first-person and third-person VR-distraction trials were counterbalanced and assigned via a random-numbers table.

Participants first underwent one or two baseline cold-pressor trials in which there was no intended distraction. The experimenter measured the participant's non-dominant finger temperature, then instructed the participant to place their non-dominant hand into the cold water up to the wrist and to remove it when the stimulus became unbearable. The total duration of cold-water exposure in seconds was recorded as pain tolerance. After the hand was removed from the water, the experimenter took the finger temperature and rewarmed the hand in water that was 38°C.

First-person virtual-reality-distraction trial. During the first-person VR-distraction trial, the experimenter first placed the HMD on the participant's head and the participant was then allowed to practice playing the game in the first-person view for 1 minute. Then the experimenter restarted the game and placed the participant's non-dominant hand in the cold pressor after 30 seconds of playing the game. Both the length of time the participant was allowed to practice the game and the length of time before the participant's hand was immersed in the water were based on pilot data that studied the length of time participants required to master the game controls. When the participant removed their hand from the

water, the experimenter recorded the elapsed time (pain tolerance) and the hand temperature. Finally, the experimenter administered the presence rating and rewarmed the participant's hand.

Third-person virtual-reality-distraction trial. The instructions and procedures for the third-person VR-distraction trial were identical to those for the first-person trial except that the game was set to the third-person view.

Participants received course credit for participating in the experiment, if applicable, and were entered into a pool to be eligible to win an iPod Shuffle at the culmination of the study.

Results

Preliminary analyses

Chi-square analyses revealed that there were no significant differences in gender or ethnicity between groups, $\chi^2(1, n=41)=0.56, p=0.45$ and $\chi^2(4, n=41)=2.03, p=0.70$ respectively. The pain-tolerance scores for each of the trials demonstrated positive skewness and kurtosis;²² thus LOG-10 transformations were conducted. These transformations resulted in skewness and kurtosis values that were within normal limits. All analyses of pain-tolerance scores reflect the transformed scores.

In order to rule out the possibility that participants might show a change in pain tolerance simply due to familiarization with the cold-pressor apparatus, the baseline pain-tolerance scores of the participants who underwent two baseline trials ($n=14$) were examined. Results showed no significant differences in pain tolerance across the two baseline trials, $F(1, 13)=0.10, p=0.75$. Therefore, in subsequent analyses, only the last baseline trial was included.

Two mixed model 2×2 (trial $\times$ order) analyses of variance (ANOVAs) were conducted to determine if changes in pain tolerance from the last baseline trial to the respective VR-distraction trial were affected by the order of experimental-condition presentation. The two VR-distraction conditions (first-person vs. third-person point of view) were examined separately. Results indicated no significant differences in pain-tolerance scores as a function of order for either first-person VR distraction, $F(1, 39)=0.38, p=0.54$, or third-person VR distraction, $F(1, 39)=0.03, p=0.86$. Therefore, in subsequent analyses, the data were collapsed across order.

Main analyses

Pain tolerance. A within-subjects ANOVA was conducted to examine changes in pain tolerance over the three cold-pressor trials (baseline, first-person VR distraction, third-person VR distraction). Results revealed a significant main effect for trial, $F(2, 80)=30.31, p<0.001$. Post-hoc paired

t tests revealed a significant improvement in pain tolerance from baseline, $M=1.43, SD=0.27$, to the first-person VR-distraction trial, $M=1.64, SD=0.37, t(40)=6.45, p<0.001$, and from baseline to the third-person VR-distraction trial, $M=1.66, SD=0.33, t(40)=5.97, p<0.001$. However, the pain-tolerance scores obtained during the two VR-distraction conditions did not differ significantly, $t(40)=-0.66, p=0.51$. (See Table 1.)

Presence. A within-subjects ANOVA demonstrated the expected differences in participants' experience of presence in the two VR-distraction conditions. Subjects reported significantly higher levels of presence during the first-person VR-distraction trial, $M=4.12, SD=1.38$, than during the third-person VR-distraction trial, $M=3.44, SD=1.43, F(1, 40)=8.24, p=0.007$. However, contrary to prediction, presence ratings were not significantly related to the magnitude of change from baseline to VR distraction in either the first-person, $r=-0.08, p=0.31$, or third-person condition, $r=0.24, p=0.07$.

Discussion

The results of this study provide further evidence that distraction techniques that utilize VR technology can improve pain tolerance in healthy adults undergoing laboratory-induced pain. Consistent with the findings of other studies of VR distraction,^{2,6,10,23-25} participants were able to tolerate cold-pressor pain longer during VR-distraction trials than during a baseline trial without VR distraction. Moreover, the observed improvements in pain tolerance did not appear to be because of habituation to the cold pressor. Participants who merely experienced repeated exposure to the cold pressor showed no improvements in pain tolerance.

As predicted, participants reported a greater sense of presence when they viewed the virtual world from the first-person perspective compared with the third-person perspective. However, the two distraction conditions did not result in significantly different improvements in pain tolerance, and the degree to which subjects felt present in the virtual environment did not account for a significant portion of the variance in improvements in pain tolerance. These findings call into question the degree to which the experience of presence is essential to achieving acute pain reduction via VR distraction. It may be sufficient to redirect attention away from the pain stimulus and on to the virtual environment, especially when the interaction with the virtual environment is fast-paced and requires sustained, ongoing cognitive processing and motor activity, such as in the driving game used in the present study.

Inducing a strong sense of presence may be more important when the VR application involves the individual

TABLE 1. RAW AND TRANSFORMED PAIN-TOLERANCE SCORES ACROSS TRIALS ($N=41$)

	Raw scores (sec)						Transformed scores	
	Range	Mean	SD	25th percentile	Median	75th percentile	Mean	SD
Last baseline	7-106	32.67	21.75	17.69	25.35	42.52	1.43	0.27
First-person VR distraction	7-240	62.45	59.32	26.50	38.22	79.00	1.64	0.37
Third-person VR distraction	7-240	59.95	48.94	27.39	40.94	79.52	1.66	0.33

interacting with the virtual environment at a slower pace or in a less structured manner, such as when exploring a setting or conversing with other virtual characters. In such applications, the virtual environment does not compel the user to respond continuously and rapidly. For such applications, pain management may be more dependent on developing an ongoing sense of presence in the virtual environment, rather than on the constant, competing engagement of multiple sensory systems offered by the VR distraction used in the present study. If so, one would expect the first-person avatar point of view to be more beneficial and account for a greater proportion of the variance in pain reduction in the less structured virtual environment.

Limitations

Although the participants represented different ethnic/racial groups, the limited age range (18 to 23 years) and college education level of the sample may limit the generalizability of the findings. Familiarity with video games and other electronic technology may have influenced the efficacy of this distraction technique. Comparable results might not be achieved with older adults or individuals with less experience with video games or less interest in VR technology.

In addition, the VR technology used in the present study may have limited the degree of presence that participants could experience. Although comparable equipment has been successfully used for pain management by other researchers,^{2,3,23,26,27} the presence ratings obtained during the VR-distraction trials were only moderate in magnitude. A more sophisticated HMD with a wider field of view might have yielded a more powerful effect.

Additionally, at this time, it is unclear how much time is needed to establish a sense of presence. The participants in this study only played the game for 30 seconds prior to submerging their hands in the cold pressor. Additional time to play the game before the pain stimulus may have resulted in a greater sense of presence.

Finally, although a number of researchers have relied on a single Likert-type rating of presence,^{5,10,21} this approach to measuring the construct of presence may not be optimal. Future studies should examine whether alternative methods of assessing presence, such as Witmer and Singer's (1998) Presence Questionnaire,¹⁵ yield more sensitive indices.

Despite these limitations, the results of this study contribute to a growing body of evidence documenting the efficacy of VR distraction for acute pain management. Further research is needed to identify the underlying mechanisms that account for the pain-attenuating effects of VR distraction, and to identify the specific aspects of VR applications that are essential for success. Research is also needed to determine whether the current findings generalize to the less controllable and potentially more emotionally charged acute pain experienced in clinical settings.

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