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Pain Modulation during Drives through Cold and Hot Virtual Environments

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ABSTRACT

Evidence exists that virtual worlds reduce pain perception by providing distraction. However, there is no experimental study to show that the type of world used in virtual reality (VR) distraction influences pain perception. Therefore, we investigated whether pain triggered by heat or cold stimuli is modulated by "warm" or "cold" virtual environments and whether virtual worlds reduce pain perception more than does static picture presentation. We expected that cold worlds would reduce pain perception from heat stimuli, while warm environments would reduce pain perception from cold stimuli. Additionally, both virtual worlds should reduce pain perception in general. Heat and cold pain stimuli thresholds were assessed outside VR in 48 volunteers in a balanced crossover design. Participants completed three 4-minute assessment periods: virtual "walks" through (1) a winter and (2) an autumn landscape and static exposure to (3) a neutral landscape. During each period, five heat stimuli or three cold stimuli were delivered via a thermode on the participant's arm, and affective and sensory pain perceptions were rated. Then the thermode was changed to the other arm, and the procedure was repeated with the opposite pain stimuli (heat or cold). We found that both warm and cold virtual environments reduced pain intensity and unpleasantness for heat and cold pain stimuli when compared to the control condition. Since participants wore a head-mounted display (HMD) in both the control condition and VR, we concluded that the distracting value of virtual environments is not explained solely by excluding perception of the real world. Although VR reduced pain unpleasantness, we found no difference in efficacy between the types of virtual world used for each pain stimulus.

INTRODUCTION

Research has long shown that guided imagery and relaxation are efficient for pain management for a variety of conditions.[1–3] In addition, distraction has been shown to be an effective method of pain control during painful experimental stimulation[4] and medical procedures.[5–7] However, these techniques have limitations. Some patients have difficulty evoking images vivid enough to be effective. Others are too anxious to be distracted by nonimmersive activities. This is where virtual reality (VR) steps in.

In recent years, researchers have discovered that using VR as an adjunct to these techniques is highly effective for pain reduction. Hoffman et al.[8] pub-

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lished a case study on the effect of a virtual snow environment to control pain during burn wound treatment. Preliminary results indicated that the virtual environment was able to distract the patient from wound care, effectively reducing the pain experienced during the procedure. Since then, researchers have used this virtual environment on more patients, and newer studies reveal that the pain-reducing effect has continued, allowing some patients to tolerate treatment with only half a dose of their usual opioid medications.[9] Moreover, VR appears to be an effective intervention in dental pain and anxiety,[10,11] acute medical procedures,[12] and cancer treatment,[13,14] among other conditions.

Until now, there has been no experimental study to show that the type of virtual world used influences pain perception. In this study, we investigated whether pain triggered by heat or cold stimuli is modulated by "warm" or "cold" virtual environments. Additionally, we examined whether virtual environments reduce pain perception more than does static picture presentation in a head-mounted display (HMD; V6, Virtual Research, Inc., Aptos, CA). We hypothesized that cold environments (e.g., a winter forest) would most efficiently reduce pain perception from heat stimuli, while warm environments (e.g., a yellow and red autumn forest) would most efficiently reduce pain perception from cold stimuli. Additionally, we expected that both virtual environments would reduce pain perception in general.

METHODS

Participants

Our sample consisted of 48 female participants. Most (87.8%) were undergraduate psychology students at the University of Würzburg (UW) who received course credits for participating in our experiment; the remaining participants were undergraduate students of other UW departments. Age ranged from 18 to 26 years, with a mean age of 21.06 (SD = 1.82). Sixteen participants had a slight cold, yet this fact did not influence results (correlational analyses revealed no significant associations with either the initially assessed temperature stimulus or with ratings of this stimulus during the VR). Furthermore, we investigated whether participants had ever had to consult a doctor for burns or frostbite. Six participants (12.5 %) answered these questions affirmatively. However, correlational analysis revealed that prior burn or frostbite injury did not influence pain ratings.

Assessment of individual hot and cold pain thresholds

Temperature stimuli were delivered using a Somedic MSA thermal stimulator (Somedic Sales AB, Hörby, Sweden) and a peltier thermode with an active surface of 25 × 50 mm. The thermode was attached to the inner side of the left or right forearm (according to the balanced experimental design). First, the individual heat pain thresholds or cold pain thresholds were assessed. Beginning at a temperature of 32°C, 16 heat stimuli ranging from 40–48°C were applied with a rate of temperature change of 3°C per second. For assessing the individual cold pain threshold, seven cold stimuli ranging from 7–13°C were applied. Each stimulus was administered for 3 seconds. We tested a reduced number of cold stimuli because the stimulator took a considerably longer amount of time to reach the cold temperatures than the heat temperatures because of the greater temperature shift. Consequently, in the later experimental session, five heat stimuli and three cold stimuli were used in each VR condition.

After receiving the heat or cold stimulus, participants rated each stimulus according to their perceived intensity and valence on two 10-point rating scales ranging from 0 (no pain) to 10 (extremely strong pain) and 0 (not unpleasant at all) to 10 (extremely unpleasant). The first scale addressed the intensity of the experienced temperature, which assesses the sensory component of pain; the second scale asked for the valence of the perceived temperature, which reflects the affective component of pain. Immediately after receiving a temperature stimulus, participants were asked for their perceived intensity and valence of the temperature stimulus. Questions were presented both verbally via headphones and in written form on a computer screen. Participants had to notify the experimenter verbally and choose the score on the corresponding scale that most adequately described the intensity and valence of the stimulus.

If participants rated a temperature stimulus as 2 to 4 (mild pain) on the intensity scale, the corresponding temperature was used to calculate the mean pain stimulus; all temperatures with "mild pain" ratings were averaged. In order to increase variance of the reported ratings during VR, we added 1°C to the average temperature for heat stimuli and subtracted 1°C for cold stimuli. We later used this pain stimulus in the VR. Thus, we received an individually determined pain temperature to better ensure that all participants experienced the same degree of pain. The resulting mean heat stimulus over all participants was 43.88°C (SD = 1.92°C); the average cold stimulus was 11.35°C (SD = 2.05°C).

To assess intensity and valence of the stimulus during the experimental session in VR, the same scales were used. However, since we did not want to disturb the experience in VR by showing a visual scale after each pain stimulus, rating scales were presented only verbally via earphones. In the first phase (assessment of the pain threshold), there was enough time for participants to become familiar with the scales, so it was possible for them to appraise the stimuli in the VR without seeing them.

Virtual reality

Our first goal was to eliminate interference from the surrounding physical world. To exclude visual input from the real world, participants wore an HMD, which supplied them with panoramic pictures of a virtual world. Participants received quiet, relaxing music via earphones and were therefore prevented from hearing noises from outside.

In order to create virtual worlds with the impression of a warm or cold environment, two scenarios were extracted from the virtual reality world "Enchanted Forest" (Virtual Reality Medical Center, San Diego, CA). There are different scenarios within this VR environment that show the same setting (e.g., the same forest), but in different seasons. For example, the winter forest appears to be icy, with snow on the trees and on the ground. We selected this forest for the cold VR condition (cold environment). The same forest in the autumn version included mainly warm colors (e.g., yellow and red leaves on the trees). This version was referred to as the warm VR condition (warm environment). Participants were passively moved on a predetermined path through the forest to standardize perception over conditions and participants. However, to allow the participants to experience the VR conditions as realistically as possible, we used an InertialCube2 (Intersence, Inc., Bedford, MA) head-tracking system that enabled participants to look in any direction and correspondingly see the different parts of the surrounding forest. Except for the seasonal aspects, both forests and movement pathways were identical between warm and cold environments.

Since we were interested in whether the movement through our virtual environments was a crucial component in pain reduction, we also introduced a control condition. During this condition, we presented a still picture of a wide, spatial landscape of hedges. The picture gave neither an extremely warm nor an especially cold impression. Thus, it was likely to be neutral regarding temperature cues. In this control condition, as in the VR conditions, participants wore the HMD (including the earphones) to shut out the physical world. However, no head-tracking was permitted here. Furthermore, participants were not driven through the picture; they looked at a stationary image.

Descriptive measures

Presence. To investigate whether our virtual worlds generally gave the participant the impression of being in a "real" world, participants were required to fill in the IGroup Presence Questionnaire (IPQ)[15] after completing each block of the VR. The IPQ contains 14 items ranging from -3 (not at all) to $+3$ (completely). Factor analyses revealed three presence components: spatial presence (five items, Cronbach's $\alpha = 0.78$), involvement (four items, Cronbach's $\alpha = 0.74$), and realness (three items, Cronbach's $\alpha = 0.63$). Additionally, one item is identified as loading on all three factors and is therefore analyzed separately as a general definition of presence.

Simulator sickness. A simulator sickness questionnaire (SSQ)[17] was used after each block of VR, which contains a list of 16 symptoms rated on a four-point scale (0 = absent, 1 = slight, 2 = moderate, 3 = severe). Three subscales from prior factor analysis are derived and labeled as follows: nausea (Cronbach's $\alpha = 0.86$), oculomotor (Cronbach's $\alpha = 0.82$), and disorientation (Cronbach's $\alpha = 0.85$). The subscales were computed by summing the ratings of the accordant symptoms and multiplying this value by the appropriate weight (9.54 for nausea, 13.92 for disorientation, and 7.58 for oculomotor). The total severity score of cybersickness was computed by adding the sums of the symptoms ratings and multiplying this value by 3.7.

Actual mood. To assess the actual mood of the participants, the Positive Affect and Negative Affect Scale (PANAS)[18] was administered after each block. It contains 20 items in two subscales (PA, positive affect, Cronbach's $\alpha = 0.85$; NA, negative affect Cronbach's $\alpha = 0.86$). On each item, participants rated the intensity of the affective state on a five-point scale, ranging from 0 (not at all) to 4 (extensively). Sums of the accordant 10 items derive the score on the two subscales.

Procedure and design

The design included three within-subject factors: temperature (heat/cold stimuli), VR condition (warm environment, cold environment, control picture), and hand (thermode first fixed at the inner side of left or right forearm). After controlling for order effects through balancing the design, each group included four randomly assigned participants.

The study was conducted in a laboratory of the University of Wuerzburg. After arrival, participants signed an informed consent form. Next, participants filled in several questionnaires concerning demographic variables. Then the thermode was attached to the assigned forearm, and a short introduction about the experiment and the rating scales appeared on a monitor in front of the participants. After that, the assessment of the individual pain threshold began. According to the design, participants received either 16 heat stimuli or 7 cold stimuli and rated each stimulus in regard to intensity and valence. The experimenter noted these ratings and calculated the individual pain stimulus for the experiment (as described previously). Next, participants put on the HMD and the presentation of the virtual worlds began. The order of the worlds was balanced. Each of the three VR conditions lasted about 3 min 50 sec with an intertrial interval of about 10 sec, resulting in a total time of approximately 12 min per block. The first 30 sec of each virtual environment served as habituation time, followed by five heat pain stimuli or three cold pain stimuli respectively. Stimuli occurred regularly within 180 sec, and each lasted for 3 sec. Every stimulus was rated according to intensity and valence, and the judgment was given verbally to the experimenter, who again noted the rating.

After finishing the last world, participants filled in questionnaires regarding simulator sickness and presence in VR. This procedure completed the first block of the experiment. The subsequent procedure mirrored the first block but used the opposite forearm for the thermode and the opposite temperature stimulus. Having completed the second block, participants received their course credits and were dismissed.

Statistical data analysis

Judgments about the intensity and the valence of the temperature stimuli were averaged separately for heat and cold stimuli and for each VR condition. These data were analyzed with repeated-measure ANOVAs containing the within-subject factors "environment" (warm vs. cold vs. neutral) and "temperature" (heat vs. cold). If necessary, Greenhouse-Geisser corrections of degree of freedom (*df*) were applied, and the significance level was set to alpha = 0.05; effect sizes were reported as recommended by Tabachnick and Fidell[16] as partial η^2 scores. Furthermore, to describe actual state and possible changes in mood, simulator sickness, and presence in VR, means on questionnaires were computed for the two times, and paired t-tests were performed on these with a significance level of alpha = 0.05.

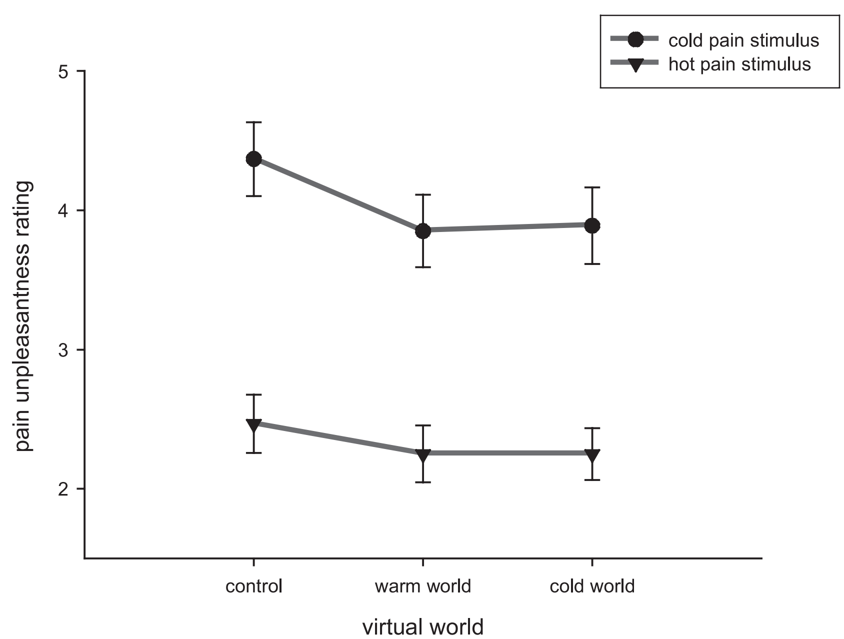

FIG. 1. Mean valence ratings (+ SEM) of the cold and hot pain stimuli during presentation of the three virtual worlds.

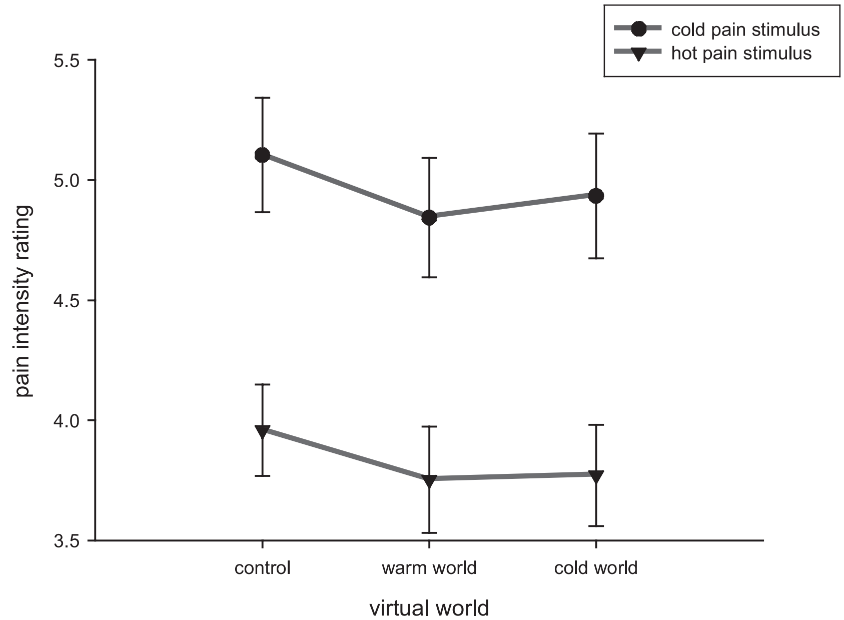

FIG. 2. Mean intensity ratings (+ SEM) of the cold and hot pain stimuli during presentation of the three virtual worlds.

RESULTS

Intensity

Regarding intensity ratings (Fig.1), statistical analysis revealed a significant main effect for both temperature ($F(1,47) = 40.25$, $p = 0.00$, $\eta_p{}^2 = 0.46$) and world ($F(2,94) = 3.15$, $p = 0.05$, $\eta_p{}^2 = 10.06$). Cold stimuli were always perceived as more intense than heat stimuli ($M = 4.96$, $SD = 1.6$ vs. $M = 3.83$, $SD = 1.34$). With respect to the world factor, we further tested linear and square inner

Table 1. Sum Scores (Means and SD) for the Subscales of the IPQ, the Subscales of the PANAS, and the Subscales and Total Scores for the SSQ Separated for the Two Measurements (t1 and t2)

	t1		*t2*			
Scale	*M*	*SD*	*M*	*SD*	*t*	*p*
			IPQ			
Spatial presence	5.1	1.2	4.8	1.2	2.3	**0.03**
Real	3.2	0.9	3.2	1.1	−0.2	0.81
Involved	4.3	1.4	4.0	1.3	2.0	0.06
General	4.8	1.5	4.4	1.6	2.0	0.06
			PANAS			
Positive affect	27.0	5.9	25.4	5.8	2.5	**0.02**
Negative affect	13.5	3.3	12.3	2.0	3.1	**0.00**
			SSQ			
Nausea	23.1	29.0	26.2	27.6	−1.7	0.10
Oculomotor	37.6	27.8	40.9	23.6	−1.3	0.19
Disorientation	42.6	48.0	38.0	49.0	1.4	0.18
Total	39.0	33.7	40.7	32.3	−0.7	0.46

subject contrasts. The linear contrasts showed no significant effects ($F(1,47) = 0.31$, $p = 0.58$, $\eta_p^2 = 0.01$), which means that, contrary to our expectations, there was no difference in pain ratings between the warm and cold virtual environments. Square contrasts, however, were significant ($F(1,47) = 5.92$, $p = 0.02$, $\eta_p^2 = 0.11$). In line with our hypotheses, this result indicates that pain experience was reduced in both the warm and the cold environments compared to the control picture. The interaction between environment and temperature was not significant ($F(2,94) = 0.06$, $p = 0.94$, $\eta_p^2 < 0.01$).

Valence

A similar pattern of results was found for the valence ratings (Fig. 2). Again, significant main effects emerged both for world ($F(2,94) = 3.15$, $p < 0.01$, $\eta_p^2 = .14$) and temperature ($F(1,47) = 50.3$, $p < 0.01$, $\eta_p^2 = 0.52$). Cold stimuli were perceived as more unpleasant than heat stimuli: $M = 3.95$, $SD = 1.78$, and $M = 2.29$, $SD = 1.28$ respectively. Linear contrasts for the factor world revealed no significant effects ($F(1,47) = 0.03$, $p = 0.87$, $\eta_p^2 < 0.01$), whereas square contrasts were significant ($F(1,47) = 17.13$, $p < 0.01$, $\eta_p^2 = 0.27$). These results show again that there is no difference in pain experience between the warm and the cold virtual environments but that pain perception is stronger in the control condition than in the two VR worlds. Additionally, the interaction between temperature and world did not reach significance ($F(1,47) = 0.03$, $p = 0.87$, $\eta_p^2 < 0.01$). Heat stimuli were always perceived as less unpleasant than cold stimuli, regardless of which VR condition was presented.

Descriptive measures

Mean sum scores and *SD*s for the two time points are provided in Table 1. Over time, the feeling of being in the virtual world, presence, diminished slightly, as indicated by the significant *t*-tests for the subscales spatial presence, $t(47) = 2.31$, $p = 0.03$, and nearly significant results for the subscales involvement and general ($p = 0.06$ for both). No significant changes in measures of cybersickness were detected. Interestingly, the scores in both the PA and NA subscales were significantly lower after the second than after the first block ($t(47) = 2.54$, $p = 0.02$ and $t(47) = 3.1$, $p < 0.01$ respectively). Overall, these changes indicate some habituation to the virtual world, with reductions in presence and reductions in both positive and negative affect.

CONCLUSION

Results revealed that both warm and cold virtual environments reduced pain intensity and unpleasantness for heat and cold pain stimuli when compared to the control condition. Since participants wore an HMD in the control condition as well as in VR, it can be concluded that the distracting value of virtual environments is not explained solely by excluding perception of the real world. The interactivity and movement of VR increases efficacy of pain reduction.

The type of virtual environment used for distraction (cold or warm) had no interaction with type of pain stimulus provided (heat or cold). Both environments reduced pain perception equally. Therefore, our results indicate that the common use of cold virtual worlds for burn patients does not enhance pain reduction in a nonpatient population experiencing pain stimuli. It may be that burn patients, because of their trauma, have a different pain perception and require different stimuli for distraction from pain. However, further studies are needed to confirm this conclusion.

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