Interactive gaming reduces experimental pain with or without a head mounted display

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ABSTRACT

While virtual reality environments have been shown to reduce pain, the precise mechanism that produces the pain attenuating effect has not been established. It has been suggested that it may be the ability to command attentional resources with the use of head mounted displays (HMDs) or the interactivity of the environment. Two experiments compared participants' pain ratings to high and low levels of electrical stimulation while engaging in interactive gaming with an HMD. In the first, gaming with the HMD was compared to a positive emotion induction condition; and in the second experiment the HMD was compared to a condition in which the game was projected onto a wall. Interactive gaming significantly reduced numerical ratings of painful stimuli when compared to the baseline and affect condition. However, when the two gaming conditions were directly compared, they equally reduced participants' pain ratings. These data are consistent with past research showing that interactive gaming can attenuate experimentally induced pain and its effects are comparable whether presented in a head mounted display or projected on a wall.

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1. Introduction

Pain is a sensory experience that can be manipulated by changes in attention, cognition and affect (Melzack, 1999). Virtual reality (VR) paradigms are effective at reducing pain ratings 30–40% in clinical and experimental populations (Muhlberger, Wieser, Kenntner-Mabiala, Pauli, & Wiederhold, 2007; Patterson, Hoffman, Palacios, & Jensen, 2006; Schneider, Ellis, Coombs, Shonkwiler, & Folsom, 2003). These environments can be created with a number of technologies (e.g., goggles or helmets) that occlude visual and auditory sensations from the real world and immerse participants in a three-dimensional virtual world (Hoffman et al., 2004). In studies investigating pain, participants are typically asked to engage in a game as they navigate the virtual environments. Although the exact analgesic mechanism has not been determined, it is believed that virtual environments engage affective, cognitive, and concentrative processes (Gold, Kant, Kim, & Rizzo, 2005); components known to play a role in the pain experience.

For example, increases in positive affect reduce pain ratings to experimental pain (Villemure & Bushnell, 2002). Bruehl, Carlson, and McCubbin (1993) demonstrated a reduction in ratings to pressure pain when subjects remembered a pleasant event. Similarly, viewing positive pictures from the International Affective Pictures System also resulted in reductions in pain ratings in the cold pressor task (de Wied & Verbaten, 2001) and to electrical stimulation (Kenntner-Mabiala & Pauli, 2005). These emotional distractors do not rely on the kind of sophisticated technology that VR does, but are able to modulate the pain experience either through changes in affect, increased demand for attention, or both.

Because interactive gaming can be considered by some participants to be a positive emotional experience, it is possible that the affect that accompanies gaming may underlie its effect on pain reactions. Moreover, VR environments decrease anxiety (Gold et al., 2005). Given that anxiety typically increases pain reactivity (Rhudy & Meagher, 2000), VR may be further capitalizing on affective changes. By introducing an emotional induction condition in our study, we could compare the relative advantages of both techniques as a pain control method. If virtual gaming is simply another, albeit indirect, emotional distractor, then we might not expect differences between these two conditions. Furthermore, if there is no advantage of VR then the simplicity of an emotional distractor may be a preferred technique in some painful situations.

Similarly, the degree to which a head mounted display (HMD) is a necessary component of the virtual gaming experience is an open question. The HMD allows both occlusion of the external environ-

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ment and, audiovisual immersion that is superior to immersion with only a single sense modality (Wismeijer & Vingerhoets, 2005). Recently, researchers have begun to refine the comparisons between different VR paradigms and have discovered that interactive environments are better than passive ones (Dahlquist et al., 2007) and that higher quality virtual reality environments are better than lower quality ones (Hoffman et al., 2004; Hoffman et al., 2006). Surprisingly, few studies have directly compared the same interactive virtual environment with and without the HMD. This is an important gap that should be filled since the sensory experience of the VR environment and the ability to interact in the environment have not been clearly dissociated.

For instance, two recent studies did attempt to compare interactivity between display modalities, however, neither study used a head-tracking HMD (Dahlquist et al., 2010; Leibovici, Moagora, Cohen, & Ingber, 2009). Dahlquist and colleagues used a within subjects design to test a group of children on the same interactive game either played on a computer or displayed through an HMD. They did not find any differences between conditions. Yet, it possible that an HMD with head-tracking may have resulted in differences between these conditions, since high-tech HMDs are more effective than low-tech ones. Similarly, Leibovici and colleagues used a between-subjects design with a clinical sample to compare an interactive game displayed either through a computer or HMD. Again, the HMD did not have head-tracking. It is possible that a comparison between the game being played in a VR environment with a head-tracking HMD and the game displayed on a computer would reveal differences since head-tracking increases immersion and subsequent analgesia (Wender et al., 2009). Given the costs and encumbering nature of the HMD, it is important to determine whether the HMD and its head-tracking capability is a necessary part of the interactive gaming experience. Simple, easy to implement, low maintenance paradigms are important considerations for pain treatment. This is particularly important in considering the application of interactive gaming as a possible pain reduction treatment for chronic pain patients, those who are in supine positions or those receiving other treatments to the head region (Gold et al., 2005).

The present research aims to use healthy adult volunteers to examine two aspects of virtual gaming analgesia. In the first experiment we tested the effectiveness of our virtual reality paradigm (i.e. interactive gaming) to low and high levels of painful electrical stimulation. We were interested in first determining the effectiveness of our interactive gaming paradigm by comparing it to a baseline condition. We also wanted to examine the relative effectiveness of a no-tech paradigm that has some of the qualities of interactive gaming (i.e. distraction and increase in positive affect) and reduces pain. The second experiment examined the necessity of wearing the helmet. Pain ratings with the helmet were compared to an interactive condition that projected the virtual game on the wall. Easily implemented (affect modulation) and economical tasks (projection) increase the techniques available to pain patients.

2. Methods

2.1. Experiment 1

2.1.1. Participants

Nineteen students between the ages of 18 and 25 years (*Mdn* age = 19) were recruited from the psychology subject pool at the University of North Carolina, Charlotte. The Beck Depression Inventory (Beck, Steer, & Brown, 1996) was used to screen volunteers who may be experiencing depressive symptoms. None of the student volunteers were excluded for this reason. Fourteen of the sub-

jects were male, all were right handed, 74% were White. African–American, Latino and Asian were each 5% of the sample. They provided written informed consent and received partial course credit for their participation. All procedures were approved by the University of North Carolina, Charlotte Institutional Review Board.

2.1.2. Materials and emotion task

2.1.2.1. *Subjective assessment.* To gauge how emotionally expressive our subjects were, we used the Affect Intensity Measure (AIM) (Larsen & Diener, 1987). The AIM is a 40-item scale designed to measure how intensely participants experience positive, neutral, and negative emotions; a necessary measure since we are asking them to produce emotion. Participants used a 6-point Likert scale (where 1 = Never and 6 = Always) to indicate how much they agree to such statements as "I get overly enthusiastic" (positive), "When I feel guilty, this emotion is quite strong" (negative), and "'Calm' and 'cool' could easily describe me" (neutral). Both the reliability (cronbach's alpha of .88) and validity of this instrument have been previously documented (e.g., (Larsen & Diener, 1987). A mean 'affect intensity' score was calculated from participants' responses. The responses ranged from 3.0 to 4.3.

2.1.2.2. *Neurometer.* Transcutaneous phasic pain delivered as an alternating current sine wave was administered by a portable device (Neurometer CPT; Neurotron Inc., Balitmore, MD). The stimuli were brief electrical pulses (3-s ON and 2-s OFF) delivered at 5 Hz.

2.1.2.3. *Interactive gaming with HMD.* Participants experienced the virtual interactive gaming environment with a VFX-3D head mounted display (HMD; Interactive Imaging Systems; www.iisvr.com). The HMD fits over the participant's head with adjustable straps around the top and back of the head. There was 640 × 480 resolution in each eye and a 35-degree field of view. The interocular distance between the two screens in the HMD could be adjusted by each participant for comfort. The HMD allowed immersion of the participants in a three-dimensional (3D) gaming environment named *Ringo*. Headphones were built into the HMD and allowed auditory information to be heard in stereo. Although the HMD allowed for stereoscopic viewing, *Ringo* was not rendered in stereo.

Ringo is a custom-designed interactive aquatic environment where the user controls the movement of a clown fish as it swims through the water and collects points to rescue friendly fish imprisoned by an octopus. As the user navigates the fish through the water s/he will encounter small schools of fish, plant life, worms and colored rings. Users gain points by swimming through rings and they acquire energy by eating worms. When rings turn into shark mouths or when worms get caught on hooks, users lose points. Participants navigated the environment with their dominant hand using a wireless joystick. Buttons on the joystick allowed the user to eat worms, escape attacks, and vary the speed of swimming. In addition to the ambient underwater noise presented through headphones, ringing sounds occurred when the fish successfully swam through a ring and slurping sounds were made when a worm was eaten. The researcher also communicated with the participant through a microphone with a direct feed to the headphones.

2.1.2.4. *Emotion induction.* Prior to experimental testing, participants were asked to briefly describe, in a sentence or two, a strong positive emotional experience. During the experimental session, participants were instructed to recall and re-experience (Damasio et al., 2000) the pleasant experience. They were first given a few moments to retrieve the memory. When they began to re-experience the memory and concomitant emotion, they received the stimulation.

2.1.3. Procedure

When participants arrived, the study was explained to them, informed consent was obtained, and they completed questionnaires. Students participated individually in an experimental session that lasted around 60 min and included a thresholding procedure followed by baseline testing and the two experimental conditions (interactive gaming with the HMD and emotion induction).

The thresholding procedure was used to determine the stimulus intensities associated with cutaneous threshold (CT), low, and high pain sensations. Four sites were marked along the ventral surface of the non-dominant arm for electrode placement (1.5 cm diameter, gold electrodes). These sites were one inch from each other and at least one inch distal from the elbow. To protect against possible sensitization (or habituation) to the stimulation, a different site was used for thresholding and each condition. The order in which these sites received stimulation was randomized and counterbalanced across participants.

We employed the method of limits to establish a stimulus–response curve for each participant. Accordingly, stimulation was individualized such that participants had the same *degree* of sensory experience even when the stimulus values were different. The thresholding procedure began by determining the intensity at which the participant first detected a sensation. This value was defined as the CT and used in the experimental protocol to detect false positives. The intensity was then progressively increased in increments of 5 and 10 mA. Participants responded verbally to each stimulation by assigning a value between zero and six on a numerical rating scale (NRS; 0 = no sensation, 3 = mildly painful, 6 = intolerable). The NRS was visible to the participants at all times during testing and participants responded verbally after stimulation ceased.

Once participants rated the stimulation above 5.5, the intensities were then systematically decreased to the cutaneous threshold value observed on the first trial. Using this range, the experimenter then randomly delivered intensities that received a rating between two and three (low pain), and between four and five (high pain) to ensure consistency for each participant's pain ratings. Stimuli consistently given a rating of two and four at least three times were designated as low and high pain, respectively. All stimuli were randomly delivered during testing. Table 1 shows the range of stimulus values that were used for the low and high pain stimuli.

The instructions to participants, during the baseline condition, were to use the NRS to describe their perception of the stimulation on each trial. Phasic electrical pulses were delivered in eight 15-s trials consisting of a random ordering of the three stimulus values (CT, low, high). A trial consisted of three stimulus periods during which the stimulation was ON for three seconds and OFF for two seconds. Low and high pain stimuli were each delivered three times and the CT stimulus was delivered twice.

Following baseline, participants engaged in both the emotion induction and virtual reality conditions and the order was counterbalanced across participants. For each of the conditions, there were eight 15-s trials that were presented in the same way as in the baseline condition. In the emotional induction condition, they were stimulated when they began to re-experience the memory and concomitant emotion. Immediately after each 15-s stimulation,

participants responded out loud by using the numerical rating scale (NRS). In the gaming condition, the electrical stimulation occurred while the participant was playing the game. The numerical rating scale was presented in the HMD display (at the top of the screen) as they were playing the game, and the participant was asked to verbally respond to the electrical stimulation. The NRS was removed after they responded.

2.1.4. Results

Mean numerical ratings, presented in Fig. 1, were computed from the participants' responses to low and high pain, and CT stimuli in each condition. The ratings were averaged across the repeated trials for each of the participants. The data were analyzed with a 3×2 repeated measures ANOVA to test for the effects of condition (baseline, virtual gaming, emotion induction) and stimulus intensity (low or high). The F tests that are reported for all of the within group effects include the Greenhouse–Geisser correction when necessary to protect against possible violation of the sphericity assumption. Numerical ratings in response to CT stimulation were less than 0.5 in all conditions and are not included in the analyses. They primarily served to check for false positives (i.e., subjects reporting pain to innocuous stimuli).

The analysis showed that the numerical ratings differed by condition, $F(2,36) = 5.52$, $p = .01$, $\eta^2 = .27$; stimulus intensity, $F(1,18) = 231.05$, $p = .01$, $\eta^2 = .93$; and their interaction, $F(2,36) = 4.84$, $p = .01$, $\eta^2 = .21$. A simple effects test examined the condition effect at each of the stimulus levels and found significant differences in the ratings only when high stimulus values were used ($p < .01$). Follow-up within subject contrasts (at $p < .05$ level of significance) showed that when each of the conditions were compared to baseline, only the interactive gaming with the HMD was found to significantly reduce pain ratings. Mean ratings for the two conditions are 4.3 and 3.1, respectively. Although pain ratings were reduced in the emotional induction condition as well ($M = 3.9$) the change was not significantly different from baseline. Numerical ratings in response to the low stimulus intensity were not found to vary in association with the conditions ($p = .09$).

We examined the possibility that the degree to which a person typically experiences emotion, as measured by the AIM, was related to the effectiveness of the emotion induction procedure. However, no relationship was found between the small change in high pain ratings and the intensity of the positive affect, r (15) = $-.11$, $p = .67$. Mean score for the group on the AIM is 3.5 ($SD = .35$); and the mean change in pain ratings from baseline is .41 ($SD = 1$) for the emotion induction condition.

Table 1
Range and mean (±SD) stimulus intensity values for each experiment.

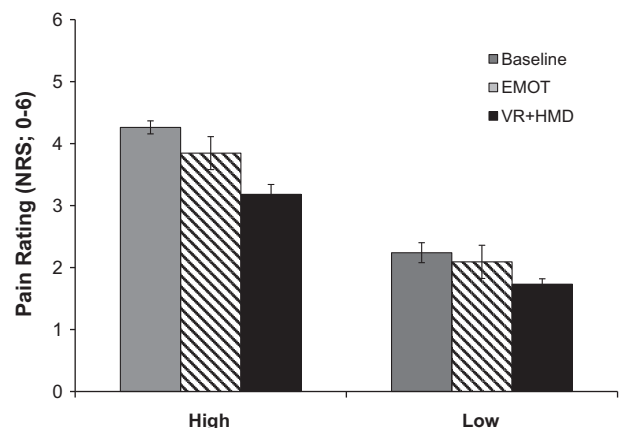| Experiment	Low pain		High pain	
Stimulus intensity (mA)				
1	50–400	138.8 (92.8)	90–675	238.2 (142.9)
2	35–500	163 (135.3)	50–750	264 (225)

Fig. 1. Average numerical ratings (95% CI) of the stimuli during the baseline, emotion induction (EMOT), and virtual gaming (VR + HMD) procedures in Experiment 1.

2.1.5. Discussion

Our virtual gaming paradigm reduced ratings to high but not low painful stimulus intensities; while the emotion induction paradigm was not effective at reducing pain at either level. This demonstrates the relative superiority of interactive gaming to a condition that also engages attentional and affective resources. The finding from the emotion induction condition is not consistent with the results of others who found recalling a pleasant event reduced pressure pain (Bruehl et al., 1993). Researchers have also found that positive IAPS pictures reduced pain to both pressure and electrical stimulation (de Wied & Verbaten, 2001); Kenntner-Mabiala & Pauli, 2005). It is possible that external stimuli such as these are more resistant to intrusions of pain signals than internally generated stimuli (i.e. recalling a memory) Future studies might compare positive pictures to the gaming condition to answer this question.

Some suggest that the gaming experience itself can result in increased positive affect (Hoffman et al., 2006; Wender et al., 2009). However, the findings of Experiment 1 indicate that a change in affect alone is not likely sufficient to reduce pain ratings in this task. It may be reasonable to conclude therefore, that positive affect induced by virtual gaming is not the primary source of its effectiveness. It is unfortunate that we did not ask participants to rate their affect in the gaming condition and can only speculate on this matter.

Gold, Belmont, and Thomas (2007) suggest that virtual reality is effective primarily because of its immersive nature. Experiment 2 was designed to explore whether virtual gaming is effective because of the immersive nature (i.e. wearing a HMD), or because of its interactivity (i.e. playing a game).

2.2. Experiment 2

Because an HMD is expensive and cumbersome, its use in a clinical setting may be somewhat limited. This experiment looked at the necessity of wearing the helmet by comparing a condition with the helmet to one in which the virtual game was projected on the wall. Virtual gaming using the HMD is suggested to have its effect because other sensory information is occluded (Hoffman et al., 2006); or because the helmet increases presence and immersion (Hoffman et al., 2004). Previous research shows that greater occlusion of sensory information is more effective at reducing pain than less occlusion. Yet, occlusion combined with head tracking of the same environment has not been tested. Our goal is to determine whether virtual gaming that occludes sensory information and allows for head-tracking, both of which have been superior individually to lower-tech displays, remains superior if users are allowed to have the same level of gaming interaction. The current experiment measured whether the same benefit in pain attenuation can be found with a computer projection system. As in the previous experiment, pain ratings were measured in response to low and high stimulus intensities while participants were engaged in baseline and the two virtual gaming conditions.

2.2.1. Participants

Fourteen participants (seven females) between the ages of 18 and 23 years (*Mdn* age = 18.5) were recruited from the psychology subject pool at the University of North Carolina, Charlotte. As in the previous experiment, the participants were screened for depression and none of them were excluded based on their score on the Beck depression inventory. All were right handed, 50% were White, 35% African–American, 14% Latino and 7% Asian. They provided written informed consent and received partial course credit for their participation. All procedures were approved by the University of North Carolina, Charlotte Institutional Review Board.

2.2.2. Apparatus

The virtual reality game was presented in two ways—with the HMD (as in Experiment 1) and with a projector. For the projector condition, the interactive game, *Ringo*, was projected with a 35-degree field of view (adjusted for each participant) onto a blank wall with a video projector (Sony VPL-CX5; Japan). Participants sat in a small dimly lit room (8′ by 12′) at a distance of 5 feet from the wall. The audio components of the *Ringo* game were played through stereo speakers placed on either side of participants' heads.

2.2.3. Procedure

The procedure followed closely that of Experiment 1. After completing consent forms and demographic information, participants had their stimulus response curves established with the thesholding procedure. Table 1 reports the stimulus intensity values used during testing. Next, participants engaged in the experimental session, which had three conditions—baseline, virtual gaming with HMD, and virtual gaming with a Projector. The conditions were presented in counterbalanced order across participants. During each condition, stimuli were delivered in eight, 15-s trials. Participants gave their numerical rating of the stimuli aloud at the end of each 15-s trial.

2.2.4. Results

Fig. 2 presents the mean numerical ratings for the interactive gaming conditions compared to baseline. A 3×2 repeated measures analysis demonstrated significant effects for condition, $F(2,26) = 8.3$, $p = .002$, $\eta^2 = .39$; stimulus intensity, $F(1,13) = 23.35$, $p < .001$, $\eta^2 = .64$; and their interaction, $F(2,26) = 3.82$, $p = .04$, $\eta^2 = .23$. A simple effects test for the effect of condition at each of the two stimulus levels showed that numerical ratings in the interactive gaming conditions were associated with a significant decline in comparison to the baseline condition but only in response to the high (painful) stimulus level ($p < .01$). Numerical ratings to the low (mildly painful) stimulus levels were not found to vary in association with condition ($p = .09$). Within-subjects contrasts at the $p \leqslant .01$ level of significance demonstrated that both gaming conditions were significantly different from the baseline condition in response to painful stimuli, but were not different from each other.

3. General discussion

These data suggest that immersion in a 3D interactive gaming environment is more effective, relative to baseline, than a simple emotion distraction task in reducing the subjective experience of pain. However, there was no significant gain in using an HMD with
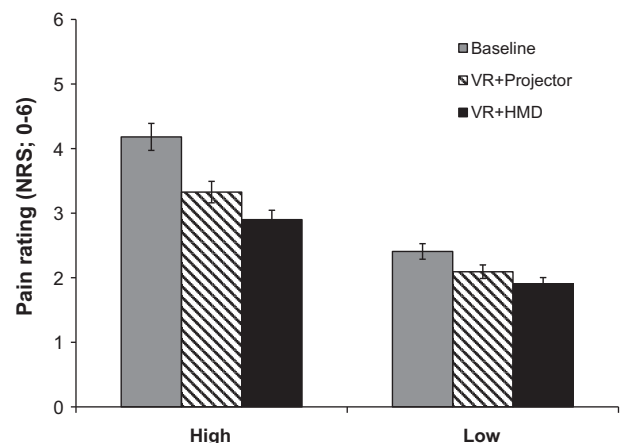
Fig. 2. Average numerical ratings (95% CI) of the stimuli during the baseline, projector (VR + Projector), and HMD (VR + HMD) conditions in Experiment 2.

head tracking compared to projecting the interactive game environment onto a blank wall. These data are consistent with recent findings that HMDs do not offer an analgesic advantage over other interactive audiovisual environments (Dahlquist et al., 2010; Leibovici et al., 2009; Wender et al., 2009). The present data also extend these findings in two key ways, which are elaborated below.

3.1. Manipulating the virtual display

The first extension of these data is that the same interactive game with the same field of view was experienced with and without a head-tracking HMD. This allows some dissociation between immersion and interactivity. Some studies have found an analgesic advantage with high-tech compared to low-tech virtual reality (Hoffman et al., 2004; Hoffman et al., 2006). Low-tech examples include: see-through glasses; low-resolution screens; equipment that does not have head tracking, panoramic view, or earphones; or environments that are not interactive. These all seem to minimize the analgesic effect of VR environments (Hoffman, Papas, Chatkoff, & Kerns, 2007). Yet, Magora, Cohen, Shochina, and Dayan (2006) found that modifying I–O glasses to occlude visual information from the environment was effective at increasing tolerance to ischemic arm pain. Thus, low-tech devices can be effective in some cases. The discrepancy in effectiveness may be resolved by accounting for not simply immersion, but the degree of interactivity participants' experience. In other words, when participants are passive with or without an HMD, they experience less analgesia than when being engaged. In fact, Wender and colleagues (2009) speculate that the analgesic effect attributed to high-tech HMD displays may really be due to interactivity. Our data support and extend this assertion by demonstrating that when the same interactive game is played, an HMD with head-tracking was no more effective on pain ratings than a simple audiovisual display. The other key extension of the current data is the use of a within-subjects experimental design with healthy subjects experiencing experimental pain. When compared to between-subjects designs, it allows greater control over the pain sensation and direct comparison of the conditions.

3.2. Affective manipulation

Pain has an affective component, and studies have demonstrated that manipulating affect can decrease pain ratings. For example, viewing pleasant pictures has effectively increased pain tolerance to cold-pressor pain (de Wied & Verbaten, 2001). Similarly autonomic reactions to electrical pain were decreased during pleasant picture viewing (Rhudy, McCabe, & Williams, 2007). Moreover, subjects have reported lower ratings to pressure pain while recreating a pleasant memory (Bruehl et al., 1993). It is surprising then that our emotion induction technique did not effectively reduce pain ratings. It is possible that our predominately male sample was not able to effectively recall the affective quality of their remembered events (Seidlitz & Diener, 1998), preventing any differences between baseline and the emotion induction condition to be revealed.

That virtual gaming was more effective, relative to baseline, than the emotion induction paradigm may be explained by the fact that in addition to any increase in positive affect (Hoffman et al., 2006; Wender et al., 2009), virtual gaming also has a more complex attention-grabbing component. It is likely engaging multiple components of the pain experience.

3.3. Limitations

It is possible that the reason we did not see a decrease in ratings in response to the low pain stimulus level is because the nociceptive system was not fully engaged. McCaul and Malott (1984) suggest that distraction works best on mild and moderate pain. According to the numerical rating scale that we were using, the low stimulus level was associated with an unpleasant and or mildly painful rather than a moderately painful experience. However, we have used these stimuli and rating system previously and observed decreases in pain ratings to the low stimuli when other treatment techniques are tested (Zeidan, Gordon, Merchant, & Goolkasian, 2010).

3.4. Conclusions

Virtual gaming is an effective means of attenuating pain perception, and it most likely has this effect by engaging multiple cognitive processes: affective, attentional, and sensory. An affect only condition did not significantly reduce pain ratings. However, an interactive game can be effective in reducing moderate pain with or without the use of a head-tracking HMD.

Acknowledgments

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