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Heat Pain Threshold Modulation By Experiencing Burning Hands in Augmented Reality

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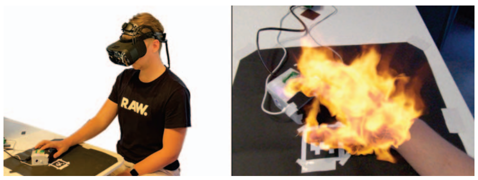

Figure 1: Participant wearing a Video See-Through Head-Mounted Display (left), observing virtual flames on their right hand in Augmented Reality while the heat pain threshold is being measured (right).

Abstract

Visual stimuli can modulate the temperature at which people perceive heat pain. However, very little research exists on the potential use of Augmented Reality (AR) to modulate the heat pain threshold (HPT). In this paper, we investigate whether participants' HPTs can be modulated observing virtual flames on their hands through a video see-through head-mounted display (VST-HMD). In a pilot study ($n = 7$), we found that rendering virtual flames had a significant effect ($p < 0.05$) on the HPT. The virtual flames on the participant's hand led to a decrease in the temperature at which they would perceive pain related to heat. These results indicate that AR-induced stimuli may be an effective way to achieve top-down modulation of the experience of pain.

Index Terms: Human-centered computing—Mixed / augmented reality Applied computing—Psychology

1 Introduction

AR is capable of overlaying visual and auditory cues into the real-world environment, including onto the user's own body. Interestingly, AR can leverage on cross-modal sensory integration to artificially manipulate perception. For example, in an AR system where users see their physical hands burning, some feel an involuntary sensation of heat on the affected hands [4], even resulting in autonomous and measurable thermoregulatory responses [5]. These results show complex cross-modal interactions during the experiences, suggesting that it would be also possible to manipulate pain perception.

The effects of Virtual Reality (VR) experiences on pain perception has been the object of much research, leading to less invasive forms of analgesia [6]. In VR, participants cannot look at their real physical body: their experience can be disembodied, or they are embodying a virtual avatar. Also, the unique immersive power of VR seem to move attention away from the real world, perhaps explaining a reduction of pain perception [6]. On the other hand, there is little research about heat pain modulation through cross-modal illusions induced by AR, in which users perceive virtual visual and auditory cues overlayed directly on their real bodies.

In this work, we investigate to what extent these cross-modal interactions in AR can influence the perception of pain. In particular, we want to address the following research question: **RQ1:** Does the display of virtual flames on the user's hand lead to a change in HPT?

2 Related Work

HPT is the temperature at which a thermal stimulus begins to evoke pain. The HPT in humans is usually determined by applying a thermal stimulator to the skin, slowly increasing the temperature until the subject signals perceived pain. Typically, the HPT is in the range of 42–48°C [12]. In fact, HPTs are influenced by many different factors such as ambient temperature, rate of heating, location on the skin, skin temperature. The HPT also varies between individuals, location on the skin, and time of measurement.

Cognitive factors or cross-modal interactions can greatly modulate the perception of pain. Longo et al. [9] reported that the vision of one's own body part in pain reduces the pain intensity. In their experiments, they induced painful stimuli to the participant's hand while they were looking at it. Participants felt less pain compared to when they were looking at a box or somebody else's hand. The Rubber Hand Illusion (RHI) [1] is an important experiment in the area of body ownership. There have been several studies examining a change of pain perception during the RHI. Two separate experiments by Valenzuela-Moguillansky et al. showed how pain ratings to painful heat stimuli decreased immediately after the RHI [13]. VR has been effectively used as a form of analgesia [6]. In one study, the authors used fMRI to show that their VR system significantly reduced pain-related brain activity. This was mainly attributed to the distraction factor as explained in the introduction. Martini et al. [10] used a VR system that superimposed a red, blue, or green color on a virtual embodied arm. In their experiment, the reddened arm decreased HPT, while the blue skin increased it.

During a RHI or in VR, participants are not looking at their real hand, but at an embodied rubber or virtual hand. AR can directly manipulate how the user is perceiving their own body, perhaps creating experiences qualitatively and quantitatively different from those achievable using a foreign 'embodied' hand.

3 Experiment

To answer our research question (See **RQ1**), we have designed and conducted the following experiment (approved by the ethical committee of the university).

Participants We recruited 7 healthy (3 female, 4 male, 24 ± 2.5 years) right-handed participants from the student population, none of them affected by color or stereo blindness.

Platform Our interactive AR platform simulates realistic fire and smoke following the shape and the dynamics of the user's hand in real time. Unreal Engine takes care of both the simulation and volumetric rendering, while simultaneously generating realistic spatial

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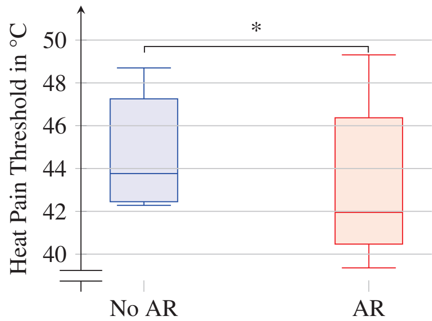

Figure 2: HPT in degree Celsius measured with the Method of Limits without the use of AR (left) and when participant's were experiencing burning hands in AR (right). HPTs decreased significantly ($p < 0.05$) in the AR condition.

sound effects (fire cracking). We used a Varjo XR-3 as a VST-HMD. Thermal stimulation is done using a custom PID-controlled Peltier device in thermal equilibrium with the fingertip (error within 1/10th of a degree Celsius).

Methods We conducted the experiment in a university research laboratory. Prior to the experiment, all participants received information sheets describing the experiment and an informed consent form. After the participant gave consent, the first round of questionnaires was given through an online web interface provided by PsyToolkit. The first questionnaire consisted of a Visual Analog Mood Scale to assess mood before and after the experiment, as mood can have a significant impact on HPT [8]. The scale was followed by the question of whether they had ever experienced AR or VR on HMDs before.

Before the experiment, participants familiarized themselves with the thermal stimulator as well as the procedure by going through one HPT identification run. We asked participants to place their right index finger on the thermal stimulator. The temperature then increased steadily from 30°C to 50°C. Every participant experienced the same temperature increase. We asked participants to press a button with their left hand as soon as they perceived the stimulation as being painful. Immediately after pressing the button, the system recorded the HPT and the temperature rapidly decreased back to a baseline temperature of 30°C. The HPT identification experiment was performed according to the Method of Limits. First, the HPT was identified twice without the participants wearing the VST-HMD and then twice when they saw their right hand burning in AR while looking through the VST-HMD. We also told them to keep looking at their hand in both conditions. Furthermore, in a within-subjects design, carryover effects can occur if the effect of the first condition persists and affects the responses of the second trial [3]. To prevent this, we pseudo-randomized the order of the conditions for each participant. Also, in the AR condition, the virtual flames appeared on the participant's hand one minute before the first HPT identification. After the experiment, participants filled out additional questionnaires to assess motion sickness [7], another Visual Analogue Mood scale as well as an AR presence questionnaire.

4 Analysis

For the analysis we averaged the two HPT measurements for each condition. A paired student t-test revealed a significant difference in HPT with no AR (45.09°C±2.76°C) and when the participants were experiencing their own hands burning in AR (43.84°C±3.59°C); $t(6) = 2.46, p = 0.025$ (See Figure 2).

The Simulator Sickness Questionnaire revealed that no participant suffered from motion sickness after the experiment. The mood scale revealed that participants were significantly feeling less tense ($p = 0.005$) and less sleepy ($p = 0.009$) after the experiment. The mean presence score was 4.49 out of 7.

5 Discussion and Conclusions

The purpose of this pilot study was to determine to which extent experiencing virtual burning in one's own hand thanks to AR modulates the HPT. To our knowledge, this is the first experiment using AR for the purpose of HPT modulation, and we were able to show that HPT was significantly lowered as a result of the AR exposure. These results are particularly interesting because while Longo et al. [9] report that the sight of a painful body part reduces pain intensity, we show with this experiment that it is possible to obtain the opposite effect by overlaying specific visual and auditory cues on the body with AR.

This could be due to the fact that a noxious stimulus associated with a red visual cue hurts more and is actually perceived as hotter than when the same stimulus is associated with a blue visual cue [11]. It has also been shown that pain threshold can be lowered by activating disease- or pain-related memories [2]. In this case, the fire may have activated memories of heat pain, causing participants to perceive pain more strongly.

In light of these results, it would be interesting to conduct a large-scale study to investigate whether the HPT could be modulated with different augmentations (water, ice) or change of skin color (red, blue). These could increase the HTP, therefore reducing the perception of pain, and be used as a non-invasive form of analgesia.

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