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Heat Pain Threshold Modulation Through Experiencing Burning Hands in Augmented Reality

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Category: Research



Figure 1: Participant wearing the VST-HMD, experiencing burning hands in VR and measuring the HPT.

ABSTRACT

Evidence exists that visual stimuli can modulate the temperature at which humans start to perceive heat pain. Yet, there is very little research examining the possibilities of heat pain threshold (HPT) modulation through visual and auditory stimuli induced by Augmented Reality (AR) experiences. In this paper, we investigated the research question of whether experiencing virtual flames on the participant's right hand through a Head-Mounted Video See-Through Display (VST-HMD) modulates their HPT. In a pilot study ($n = 7$), we found that our AR experience has a significant effect on the HPT. The burning hand made participants feel a heat pain at lower temperatures than they would normally do. These results show a top-down influence of AR experiences on the perception of pain.

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

1 INTRODUCTION

AR allows the superimposition of visual and auditory cues on the real world, including the user's own body. The cross-modal interaction of these cues can lead to interesting phenomena. For example, in an AR experience, which allows the user to see their own hands burning when they are looking through a VST-HMD, makes some users feel an involuntary thermal sensation [15], resulting even in some real thermoregulatory responses [4]. These results show complex cross-modal interactions in users, suggesting that it would be possible to also manipulate how they are perceiving pain.

Pain modulation has been effectively researched in Virtual Reality (VR). However, in VR, participants are not looking at their real hand, but at an embodied virtual hand. There is little research about pain modulation through AR experiences, where users are looking at their real hand.

Thus, we want to investigate to what extent these cross-modal interactions in AR can influence the perception of pain. In particular, we wanted 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 that increases in temperature until the HPT is reached. Typically, the HPT is reached at temperatures

of 42–48°C [2, 11]. These values are influenced by many different factors such as the ambient temperature, rate of heating, location on the skin, skin temperature. The HPT also varies between individuals, place of measurement, and time.

It has been shown that cognitive factors or cross-modal interactions can greatly modulate the perception of pain. Longo et al. reported that the vision of one's own body part in pain reduces the pain intensity [9]. 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 [14].

VR has been effectively used as a form of analgesia [6]. In a later study, the authors could show using fMRI that their VR experience significantly reduces pain-related brain activity. This has been mostly accredited to the distraction factor. Martini et al. [10] used a VR system that overlaid a red, blue, or green color on a virtual embodied arm. In their experiment, the reddened arm decreased, whereas the blue skin increased the HPT.

With a rubber hand 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, possibly creating different effects than with a foreign embodied hand.

3 EXPERIMENT

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

Participants We recruited 7 healthy (3 female, 4 male, $24 \pm$ SD age: 2.5 years) right-handed participants from the student population. None suffered from a loss of stereo vision, which has been assessed before the experiment using a randot stereo test.

Platform Our interactive AR platform simulates realistic fire and smoke effects taking into account the shape and movement of the user's hand. For this, we have implemented a real-time fire synthesis and volumetric rendering running on the Unreal engine, which also handled spatial fire sound effects. We used a Varjo XR-3 as a VST-HMD. The display has a pixel density of 3000 PPI, a refresh rate of 90Hz, and a field of view of 115°. The dual front-facing cameras of the XR-3 feature a 12-megapixel video pass-through. The Valve Lighthouse tracking system was used to track the headset.

Thermal Stimulator Thermal heat stimuli were delivered by a PID-controlled Peltier device. Pain thresholds were assessed with the Method of Limits. The probe temperature was increased from a constant baseline temperature (30°C) at a steady temperature increase. To prevent tissue damage, the maximal temperature was set at 50°C. Every participant experienced the same temperature increase.

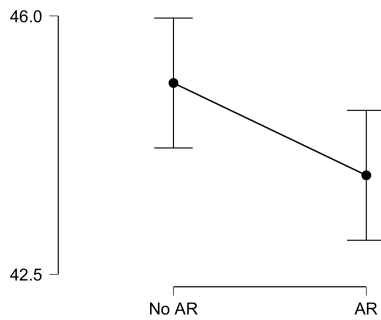


Figure 2: Heat pain threshold (HPT) in degree Celsius measured with the Method of Limits in the baseline without the use of AR (left) and when participant's were experiencing their own hands burning in AR (right).

Outcome Measures We conducted the experiment in a university research laboratory. Before the experiment began, all participants were provided with information sheets and consent forms. After the participant gave consent, the first round of questionnaires was given through an online web interface provided by PsyToolkit [12, 13]. This included a Visual Analogue Mood Scale to assess the mood before as well as after the experiment as well as a question as to whether they have experienced AR or VR on HMDs before.

Before the start of the real experiment, we made participants familiarize themselves with the thermal stimulator as well as the procedure by going through one HPT identification run. Participants were asked to place their right index finger on the thermal stimulator. The temperature then increased steadily from 30°C to 50°C. We asked participants to press a button with their left hand as soon as they perceived the stimulation as being painful. Immediately after pushing the button, the HPT was identified and the temperature rapidly decreased back to the baseline temperature of 30°C.

The HPT identification experiment is using the Method of Limits design. We identified the HPT without the participant wearing the VST-HMD two times and two times when experiencing their right hand burning in AR when looking through the VST-HMD. When using a within-subjects design, carry-over effects sometimes occur when the effect of the first condition persists and influences the responses of the second treatment [3]. To prevent this, we have pseudo-randomized the order of the conditions for each participant.

After the experiment participants filled out additional three additional questionnaires to assess motion sickness [8], another Visual Analogue Mood scale as well as an AR presence questionnaire inspired by Gandy et al. [5].

4 ANALYSIS

The analysis was carried out in JASP [7]. We averaged the two HPT measurements for each condition (AR and no AR). A paired student t-test revealed a significant difference in HPT with no AR ($45.091^{\circ}\text{C} \pm 2.755^{\circ}\text{C}$) and when the participants were experiencing their own hands burning in AR ($43.841^{\circ}\text{C} \pm 3.590^{\circ}\text{C}$); $t(6) = 2.459$, $p = 0.025$ (See Figure 2).

The Simulator Sickness Questionnaire revealed that no participant suffered from motion sickness after the experiment. The VAS mood scale revealed that participants were significantly feeling less tense ($p = 0.005$) and 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 elucidate to what extent our burning hand experiment can influence the perception of pain. We

were able to show that the HPT was significantly lower during the AR exposure. This is to our best knowledge the first experiment using AR for HPT modulation.

In light of these results, it would be interesting to conduct a large-scale study to include the investigation of 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. Hofmann et al. already used VR to reduce pain the pain of patients with severe burn injuries [6]. However, compared to VR, AR can be easily integrated into the daily life.

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