2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 978-1-6654-4057-8/20/$31.00 ©2021 IEEE | DOI: 10.1109/VRW52623.2021.00167

Investigation of Microcirculatory Effects of Experiencing Burning Hands in Augmented Reality

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Figure 1: We enable users, wearing a VST-HMD (left), to experience the illusion of seeing their own hands burning (right).

Abstract

In this paper, we report on our experiment to investigate the extent to which the human body reacts to virtual thermal stimuli presented in Augmented Reality (AR). Our AR experience enables users to see and hear their own hands burning while looking through a Video See-Through Head-Mounted Display (VST-HMD). We hypothesized that this AR experience can lead to a change in Skin Blood Flow (SkBF). Our results show that the SkBF in the affected hand did change significantly on some participants. They experienced a change of blood flow similarly to real thermal stimulation.

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

1 Introduction

AR overlays graphics on the real world, including the user's own body, which can result in interesting cross-modal illusions. We have designed and developed an AR experience, which allows the user to see their own hands burning when they are looking through a VST-HMD (See Figure 1). We showed in a pilot study that the experience of the virtual burning hands leads to a significant increase of the Skin Conductance Level (SCL) [3]. Moreover, participants who experienced an illusory thermal sensation on their left hand also had a higher skin conductance response. In this work, we want to investigate in more detail to what extent this AR experience is able to influence the user's autonomic response.

A real thermal stimulation on the skin leads to an increase of SkBF on the affected tissue. SkBF responses to thermal stimuli have been extensively investigated using Laser Doppler Flowmetry. SkBF is mainly regulated by neural mechanisms. This leads to our research question, **RQ**: Does the experience of a virtual fire on the participant's hand in AR triggers a similar neural response leading to an increase of SkBF?

Related Work

Experiencing cross-modal illusions can be defined as synaesthesia. Cytowic defined it as an involuntary joining of the senses in which the real information of one sense is accompanied by an illusory perception in another sensory modality [2].

There have been several works reporting the occurrence of synaesthesia triggered by AR and VR experiences: Visual-to-haptic illusions have been observed by many researchers [1, 7, 11]. Similar results have been reported involving the visual, olfactory, and gustatory senses [9, 10]. Related to thermoception, illusory percepts have been elicited by presenting objects or visual effects which humans associate with ambient temperatures or thermal sensations: Bills et al. [5] demonstrated that when undergoing treatment for burns, patients placed in a virtual environment depicting snow and ice, while given the task of throwing snowballs. They could prove that this strategy significantly reduces pain-related brain activity.

To the best of our knowledge, no research has been investigating the influence of cross-modal illusions in AR or VR-experiences on SkBF. Most related research relies on either questionnaires or basic physiological measurements such as skin conductance or heart rate.

2 Experiment: Changes in Micro-Circulatory Blood Flow

To answer our research question (See RQ), we have designed and conducted the following experiment:

Participants We have recruited 9 participants (six female, three male) from the student population at our university. The participant's mean age was 23 ± 1.39 years. The experiment had the approval of the ethics committee at our university.

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 Unreal engine, which also handled spatial fire sound effects. We used a Varjo XR-1 as a VST-HMD. The display has a pixel density 3000 PPI, a refresh rate of 60Hz, and a field of view of 87°. The dual front-facing cameras of the XR-1 have a resolution of 1008×1008 pixels. The Valve Lighthouse tracking system was used to track the headset. We

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978-1-6654-4057-8/21/$31.00 ©2021 IEEE
DOI 10.1109/VRW52623.2021.00167

Figure 2: Experimental platform. a) Varjo XR-1, a Video See-Through Head-Mounted Display. b) Moor DRT4 to measure skin blood flow.

mounted a Leap Motion on top of the headset to track the user's hand.

Outcome Measures We conducted the experiment in a university research laboratory. The temporal sequence of the experiment can be seen in *Figure 3*. As SkBF undergoes periodic changes, we asked the participant to sit down for 15min before the experiment. Before the experiment began, all participants were provided with information sheets and consent forms. The information provided did not reveal beforehand what they would be experiencing. After the participant gave consent and filled all questionnaires, the experimenter set up the LDF for collecting the physiological measurements. This includes attaching the two sensor probes of the LDF on the participant's left thumb (See Figure 2 b)). The participants were asked to keep their left hand still and in the field of view of the HMD. We recorded five minutes of baseline recording before the virtual fire appeared on the participant's left hand. After 5min, the fire stops, ending the AR experience. In the end, participants filled out a seven-point Likert scale AR presence questionnaire, which we adopted from [4].

Analysis and Results The analysis was carried out in Python with the NeuroKit2 [8] package to process the data and JASP [6] to conduct statistical tests. We analyzed six minutes of recorded SkBF. The signals were divided into eight time periods (45 seconds each): four in the baseline and four during the exposure of the virtual flames appearing on the user's hand. We filtered the ascending or descending DC components of the signal. We then averaged the signal over each period, for every participant. A Repeated Measures ANOVA revealed that virtual flames on the left hand of the user had a significant effect on SkBF measured on the thumb of the same hand $F(7,56) = 2.240, p = 0.04$. After we examined the SkBF of each participant, we were able to classify participants into three responders and six non-responders. Responders showed an increase in SkBF after the virtual fire appeared on their hand. We also performed a Sample entropy analysis as described by Richman et al. [12]. However, we did not find significant differences. The seven Likert scale AR Presence questionnaire revealed a high mean score of 5 for our AR experience.

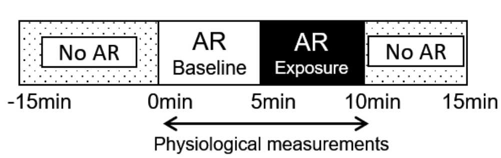

Figure 3: Timeline of the experiment in minutes.

3 Discussion and Conclusions

The purpose of this pilot study was to elucidate to what extent our burning hand experiment can induce autonomic bodily reactions. As some participants in this and previous experiments report a strong heat sensation, we hypothesized that the body might react as if exposed to a real thermal stimulus. We were able to show that the skin blood flow changed significantly for all participants. On top of that, we were able to classify three participants as responders. As the majority were non-responders, even though six participants reported a heat sensation, we hypothesize that through the long duration of the experiment, habituation might play a big role. Watching the virtual fire on the hand for a prolonged amount of time might bore some participants and therefore influence the bodily reactions. In light of these results, it would be interesting to conduct a large-scale study using a Laser Doppler Imager (LDI), including a control group to verify and refine our findings. Compared to an LDF an LDI can capture the blood flow of the entire hand, providing cues as to how much this simulation can induce a located response. Whereas an LDF can only measure the blood flow of a small spatial area.

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