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[DC] Psychophysical Effects of Augmented Reality Experiences

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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

My Ph.D. research aims to explore to which extent Augmented Reality (AR) experiences can evoke measurable physiological, psychological, and neurological responses in the user's body. During the first year of my Ph.D. studies, we have developed an AR experience that enables users to see and hear their own hands burning while looking through a Video See-Through Head-Mounted Display (VST-HMD).

In a pilot study, half of the participants reported a heat-sensation on the affected left hand. All participants experienced a significant increase in skin conductance during the experiment. Moreover, participants who experienced a heat sensation had a higher skin conductance response. In a follow up study, we could show that this experience also influences the micro-circulatory blood flow of the hand on some participants.

Our research continues on this with several planned follow-up experiments, to explore more deeply how AR experience can have measurable effects on the user's body and mental state. This allows deeper insights into the perceptual and cognitive effects unique to AR experiences. Insights from our experiment may be of significance in a neuroscientific or medical context.

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

1 Introduction

AR enables the superimposition of graphics on the real world, including the user's own body, which may result in interesting cross-modal illusions. Our AR experience allows the user to see and hear their own hands burning when they are looking through a VST-HMD (See Figure 1). In a pilot study [5] we investigated whether this would lead to an involuntary heat sensation based on visual and auditory stimuli. A think-aloud-protocol and an AR presence questionnaire indicated that six out of twelve participants experienced an involuntary heat sensation on their affected left hand. Despite no significant change of perceived anxiety, we found a significant increase in skin conductance during the experiment for all participants; participants who reported an involuntary heat sensation had higher skin conductance responses than participants who did not report a heat sensation. A personality questionnaire showed no correlation between absorption as a personality trait and the experience of a cross-modal illusion during the AR experience.

This pilot study showed some evidence of a cross-modal audiovisual-to-thermal illusion induced by an AR experience. Furthermore, we started investigating the reason for the high inter-individual variability of illusory effects induced by AR experiences. We examined the influence of absorption as a personality trait by deploying the Tellegen Absorption Scale (TAS) of The Multidimensional Personality Questionnaire™ (MPQ™) [16]. However, these questionnaires require more respondents to establish significant results. In a second study [6], we could show that this AR experience has a significant effect on the skin blood flow of the affected hand.

In our future research we want to, first, validate our initial results in large-scale studies; and second, to research more deeply whether cross-modal illusions in AR trigger similar bodily functions as a real stimuli. In particular, we want to answer the following two research questions: Can the observation of virtual flames on one's own hand result in a change of: **RQ1**: pro-inflammatory cytokines measured in saliva samples (Interleukin 6 (IL-6)) and **RQ2** microcirculation in the tissue the graphics are being superimposed on? Additionally, we have developed **RQ3**: Does the display of virtual effects in AR can change the perception of real thermal stimuli or perception of pain induced through a thermal stimulator?

Related Work

Experiencing such 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 a illusory perception in another sense [4]. There have been several works reporting the occurrence of synaesthesia through AR and VR experiences: Visual-to-haptic illusions have been observed by many researchers [1, 15]. Similar results from other research into cross-modal sensory illusions involve the visual, olfactory, and gustatory senses [13, 14]. Related to thermoception, illusory percepts have been elicited by presenting objects or effects which humans associate with ambient temperatures or thermal sensations: Bills et al. [9] 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. Käthner et al. [10] showed that red or blue lights in a VR environment can significantly increase or reduce the perception of pain induced through by thermal stimulator. To the best of our knowledge, no research has been investigating the influence of AR or VR-experiences on microcirculation or concentration of cytokines in saliva. Most related research relies on either questionnaires or basic physiological measurements such as skin conductance or heart rate.

2 Methodology

In a follow-up experiment to our pilot study [5] we want to further investigate the psychopysical effects of our AR experience by measuring biomarkers (see **RQ1** & **RQ2**). Thermal stimulations greater

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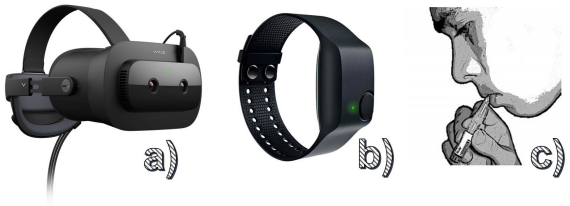

Figure 2: Experimental platform. a) Varjo XR-1, a Video See-Through Head-Mounted Display. b) Wrist-worn Empatica E4 to record various biomarkers. c) Person using a passive drool to collect a saliva sample (Photo: Salimetrics).

than 43°C are detected by a type of thermoreceptor called TRPV-1 [17]. An activation of TRPV-1 on the skin leads to an increased vasodilation (microcirculation) in the affected area and secretion of pro-inflammatory cytokines (IL-6), among other responses.

Our experimental setup to investigate these hypotheses is shown in Figure 2. An increased vasolidation can be measured with a Laser Doppler Imager. Pro-inflammatory cytokines (IL-6) can be detected in saliva. For collecting saliva samples, we are going to use the passive drool method with equipment from Salimetrics (d). To measure other physiological signals, we will deploy the Empatica E4 wristband sensor (b) as described by [3]. The E4 sensor measures: electrodermal activity (EDA), blood volume pulse (BVP), heart-rate (HR), peripheral skin temperature, and motion. We are particularly interested in EDA, HR, and temperature. We are going to use a Varjo XR-3 (a) as a VST-HMD. To investigate on **RQ3** we will use the method of limits to investigate whether visual effects in AR can have an impact on the perception of thermal stimuli induced by a thermal stimulator.

3 Discussion and Conclusions

We have learned many lessons from our pilot studies. For the following experiments, we plan to develop a new prototype focusing on improving two main challenges: First, refine the hand tracking pipeline to allow the recreation of the high-fidelity surface of the actual user's hand in real-time. This could be by working on existing work using modern deep-learning approaches as proposed by Ge et al. [7]. Second, as audio can enhance the immersion in VR or plausibility in AR, we want to make use of a realistic fire-sound synthesis, which reacts to the move of the fire in 3D space and the size of the actual fire. However, this is still an existing research area. Notable works in this are by Chadwick et al. and Liu et al. and [2, 11].

We are also interested to continue looking into the reason for the high inter-individual differences in the perception of cross-modal illusions in AR. Because the sample size was too small, we could not find significant results . Hirschfeld et al. [8] showed that with sample sizes smaller than 500, personality questionnaire such as the Big Five Inventory (BFI) and the International Personality Item Pool Big Five measure (IPIP) show huge variance. Even with less than 10.000 some primary factors are unstable. Another personalities to be examined could be suggestibility as it was shown to related with the experience of the Rubber Hand Illusion [12].

This research explores AR experiences that are capable of inducing involuntary cross-modal illusions in some individuals. We want to show what effects these experiences can have on the user's bodily functions. Previous research work in this area has mostly been done in VR, using avatars to provide a virtual proxy representation of the user's body. Our research can make a significant and original contribution through the expected heightened responses due to increased realism, providing much more insight into the psychophysical effects of AR experiences. Also, the experiment described in this proposal would be the first one to show that cross-modal illusions induced by AR experiences are capable of triggering pro-inflammatory responses in the participant's body, by showing a change of specific cytokines in saliva.

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