Exploring Perceptual and Cognitive Effects of Extreme Augmented Reality Experiences

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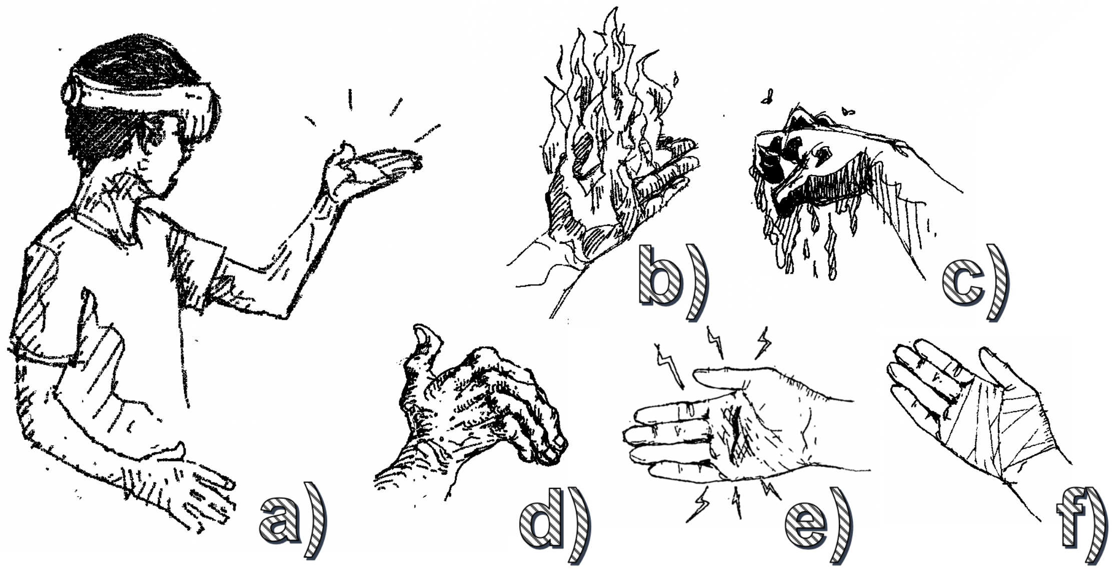

Figure 1: We will investigate perceptual and cognitive responses of users of several extreme Augmented Reality experiences on an Optical See-Through Head-Mounted Display (*a*). They will see their hands: on fire (*b*), being covered by dirt (*c*), affected by arthritis (*d*) and a wound (*e*), and applied with virtual bandage.

Abstract

In this proposed Ph.D. research, we are aiming to create several extreme Augmented Reality (AR) that evoke measurable physiological and neurological responses in the human brain.

These experiments will run on a platform capable of tracking the user's body and recreating a volumetric representations of it. On a Head-Mounted Display, we will overlay real-time photo-realistic stereoscopic graphics on the user's body.

To investigate our hypotheses, we will build a set of systems each capable of measuring various biomarkers, including cardiac biomarkers, skin conductance, muscle tension, electroencephalogram (EEG) and hormone levels. Additionally, we will use questionnaires and think aloud protocols.

This research allows insights into the perceptual and cognitive effects unique to AR experiences that can't be reproduced in VR. These insights are from a highly significant clinical interest in psychology, possibly capable of creating new non-invasive ways of treating or accelerating the therapy of many diseases; e.g., mental disorders such as phobias or Obsessive-Compulsive disorder.

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

1 Introduction

"What is real? How do you define real?" (Matrix, 1999). This is a simple yet profound question. Answering this question has become increasingly difficult in recent years. Advances in research and technology are blurring the boundaries of reality and Virtual Reality (VR). Already, VR experiences can induce significant feelings of presence, making people respond realistically to situations in VR experiences [14].

AR experiences have the potential to fool various sensations of its users, leading to neuroplastic change: the brain's ability to adapt its functions and activities in response to environmental and psychological factors. The phenomenon of the brain to change its perception of one's own body is the cutting edge of current neuroscience research.

There has been much research conducted about the effects of VR on neural plasticity and the possibility to use it to treat anxiety disorders (e.g., phobia treatment) whereas AR receives only little attention. In comparison to VR, AR allows the therapy to be seamlessly integrated into the daily life of patients. This could lead to more effective ways of therapies.

We hypothesize that the stimulation of visual perception presented in realistic interactive real-time AR experiences can induce an involuntary experience in an additional sensory pathway. For example, an extreme AR experience, enabling the user to see the illusion to see their hands covered in dirt (See Figure 1 *(c)*) might make a user suffering from Obsessive-Compulsive disorder (OCD) react the same way as the dirt would be real.

This phenomenon is called cross-modal transfer. The cross-modal transfer phenomenon is defined as virtual synesthesia [11]. A perceptual illusion can result in a perceived stimulation to an unconnected sensory modality that receives no apparent stimulation from the augmented environment. We further believe that extreme AR experiences evoke stronger involuntary sensations (e.g., heat, cold, touch, the feeling of presence) than VR.

In this proposed research, we will conduct several extreme AR experiments, that integrate visual intending to evoke measurable physiological and neurological responses in humans. These experiments will run on a platform capable of tracking the user's body and recreating volumetric representations of it in real-time. On a Head-Mounted Display, we will overlay real-time photo-realistic stereoscopic graphics on the user's body.

The results of these experiments allow insights into the perceptual and cognitive effects unique to AR experiences. Most related work has been only done in VR, using avatars to provide a virtual proxy representation of the user's body. However, we will integrate the actual user's body into the experience.

Insights gained from our proposed extreme AR experiences are from a highly significant clinical interest in psychology, possibly capable of creating new ways of treating mental disorders such as phobias or OCD.

2 Related Work

Related work in the areas of perceptual and cognitive effects from visual perception are discussed in this section.

Recent research in neuroscience has demonstrated that our sense of possessing a body is not inherent but built upon sensory experiences. The illusion of owning a part of a body or an entire body is referred to as body ownership. Body ownership can be induced by manipulating the visual perception of the user.

The Rubber Hand Illusion (RHI) [2] is an important experiment in the area of body ownership and has been well studied over the last fifteen years leading to an understanding of neuroplasticity, the brain's ability to change itself due to change in behavior, environment, or by physical stimulation. The RHI experiment analyzed the perceived ownership of an artificial hand which was simultaneously stimulated with a participant's occluded hand placed next to it. Both the participant's left arm and the fake arm were synchronously stroked with small paintbrushes for ten minutes, after which they completed a questionnaire about their experience. The results indicated that the participants seemed to feel the touch of the viewed brush on the fake hand. There have been many applications of this research in VR:

Regenbrecht et al. [10] introduced the ART system to test hypotheses about limb presence and perception, belief, and pain under laboratory conditions in VR. He has shown in several experiments that there is a sense of perceived ownership of virtual limbs. They were also able to manipulate the perceived size of the user's hands.

Bills et al. [1] demonstrated that, when undergoing treatment for burns, patients might be placed in a virtual environment that depicts snow and ice, and be given the task of throwing snowballs. He could prove that this strategy significantly reduced pain-related brain activity.

Other researchers have used multisensory VR experiences to induce ownership over avatars with differing gender [15] or race [6], leading to a change in implicit racial biases [6].

While there has been much research about the perceptual and cognitive effects in VR, there has been only a little research about the AR. VR severely limits the realistic display and motion of body parts.

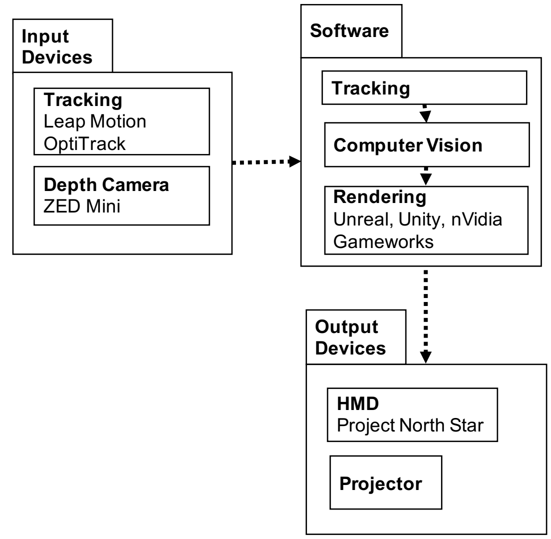

Figure 2: A functional decomposition of our proposed system.

An AR system called Hand-displacEMent-based Pseudo-haptics (HEMP), Pusch et al. [9], actually induces haptic-like sensations from purely visual input, using a VST-HMD to displace the visual representation of the user's hand dynamically.

Another closely related work relying on AR is BurnAR by Weir et al. [17], a system enabling users to experience the illusion of seeing their own hands burning by looking through a Video-See Through Head-Mounted Display. In a questionnaire-based user study, some of the participants reported an involuntary heat sensation of their hands. However, their findings solely rely on questionnaires and reports from participants. While questionnaires are a cheap and easy way to measure various factors, Slater [13] has shown that it is quite easy to obtain seemingly meaningful questionnaire responses based on an entirely invented feeling simply by asking questions about it. So the questionnaire-grounded results of Weir et al. [17] need to be re-evaluated.

There is plenty of scope for innovation using AR and recent advances in computer vision, image processing, and color/depth (RGBD) camera technology. Many of the experiments performed previously using these limited VR systems, could be repeated using AR technology implemented on the proposed platform developed by this research project, with the possibility of generating much stronger responses.

3 Design and Implementation

During our proposed research, we plan on doing several extreme AR experiments, exploring its cognitive and perceptual effects. All experiments will be driven by the same platform. In Figure 2 we propose a functional decomposition of our platform.

Input Devices All experiments will alter the perception of the user's body. Therefore, our system needs to be capable of precise body tracking and recreating its volumetric representations in real-time.

For first experiments (e.g., burning hands experiment) just tracking the user's hands will be sufficient, where we will use a Leap Motion controller. For higher fidelity body tracking, we plan on using am OptiTrack motion capturing system.

Recreating volumetric representations in real-time can be implemented by a set of depth cameras as described by Duo et al. [4].

Output Devices The project will focus specifically on AR experiments using real-time video display technology. Co-located stereoscopic images of the hands and lower parts of the upper limbs with the egocentric view are presented to the user.

The platform will use Optical-See-Through Head-Mounted Displays (OST-HMD), Video-See-Through Head-Mounted Displays (VST-HMDs) as well as projectors.

For most experiments we will be using a Project North Star AR headset, a OST-HMD. Compared to other commercially available OST-HMDs it features a much higher field of view of 100°and a vertical of 80°. The display is shown in Figure 3 *(c)*.

Software From a software design perspective, the prototype consists of several components based on a closed layer architecture, only allowing data flow between adjacent layers. This modular approach will be helpful in later experiments, where we will exchange layers.

The bottom Tracking layer drives the display, streams video images, depth maps, camera poses and body pose data to the computer vision layer. In the computer vision layer, the video images and the depth map are being used to segment the user's body. The resulting volumetric representation of the body is streamed to the rendering layer, where we are using game engines such as Unreal or Unity or Notch, a node-based visual programming language for real-time interactive graphics.

Evaluation Once the proposed platform is developed and functional, the major problem that arises is the measurement of the responses that may be evoked by the multisensory scenarios presented through the use of the platform.

One big challenge is the objective measurement of subjective experience. In many related works, only questionnaires and self reports have been used. While they represent an inexpensive and quick way to evaluate experiences, there validity should be doubted as described by Slater in [13].

Psychophysics can be defined as the quantitative study of perception, examining the relations between observed stimuli and their subsequent responses.

A stimulus is followed by neurophysiological processing in the brain. There are three objective way of measuring brain activity: Electroencephalography (EEG), positron emission tomography (PET), or functional magnetic resonance imaging (fMRI).

We will be using EEG instead of fMRI, as fMRI and PET are too invasive as well as too expensive. In addition, experiencing AR while being in an MRI scanner is heavily limited.

Continuous EEG has indeed been used to investigate which EEG pattern might be indicative of experimentally induced pain [7]. Chang et al. [3] showed about the which EEG activations might indicate of thermal stimuli.

Additionally, it will be helpful to be able to measure stress. According to Selye et al. [12] stress is being triggered by situations which are being interpreted as novel, unpredictable and the participant must have the feeling that he/she does not have control over the situation. Stress is indicated by a high heart rate and low heart rate variability. Sudden changes in the skins conductance can also indicate stress. The number of those moments is called "Skin Conductance Response" (SCR).

In conclusion, to investigate our hypotheses, we will build a set of systems each capable of measuring various biomarkers, including cardiac biomarkers, skin conductance, muscle tension, electroencephalogram (EEG) and hormone levels. Additionally, we will use questionnaires and think-aloud protocols.

Fidelity Research by Pusch et al. [9] took a look into the effects of hand representation fidelity when viewed through a Video See-Through HMD, indicated the higher fidelity real hand video was preferred by subjects over a virtual high-level 3D hand model.

Perani et al. [8], demonstrated that different neural networks are activated when participants view sequences of a real hand, virtual hands, as well as video on a two-dimensional flat screen. In the cases of the virtual hands, they found only limited differences in activation due to the different degrees of realism, compared to the response of viewing the real hand. The views that lacked depth information showed less activation of the brain in the Positron Emission Tomography (PET) scans.

Snijders et al. [16] show that a higher fidelity visual hand feedback leads to a stronger visual-proprioceptive integration.

The discussion in this paragraph above leads to the conclusion that in order to maximize an evoked sensory response in a given AR scenario, the level of realism should be able to simulate a neural profile as close as possible to the real-life scenario. This follows the concept of *neurally inspired VR* from Gallace et al. [5], resulting in a specific multisensory perception for a given perceptual experience, especially for complex behavioral situations that far exceed low-level tasks such as pointing.

3.1 Study One: Burning Hands Experiment

Our first pilot study consists of rebuilding the experiment of BurnAR from Weir et al. [17], which enables the users to experience the illusion of seeing their own hands burning when being viewed through a VST-HMD.

In their user study, some of the participants reported an involuntary warming sensation of their hands. However, while their findings are novel, they are solely based on questionnaires and self reports of the participants.

In this pilot study, we are going to conduct a similarly designed user study, confirming the findings of evoking heat sensation by measuring various biomarkers.

To achieve a realistic real-time interactive fire and smoke simulation in our Renderling Layer, we are using an implementation from Nvidia called nvflow which we integrated in the Unreal Engine. A prototype can be seen in Figure 3. The user (a) is wearing an OST-HMD (c), experiencing the illusion of his hands being on fire.

We experimented with different kind of displays such as VST HMDs (Oculus Rift, Canon VH-2002), OST-HMDs (Microsoft HoloLens, Project North Star) as well as a Magic Mirror. Finally, we chose a Polaris AR Project North Star, an OST-HMD.

3.2 Outline for Following Experiments

In this section, we outline possible uses in therapy using extreme AR experiences based on our platform.

VR has been proven to induce ownership over avatars with differing gender [15] or race [6], there have been no experiments done in AR. We propose repeating these experiments in AR, changing the perception of the user's age, skin color, or gender.

As shown in Figure 1 *(f)*, the system could reduce the anxiety of seeing an open wound (right before the injury, or perhaps more adequately during its treatment) by applying a virtual bandage. This could have a beneficial psychological impact on the perceived outcome, thus helping and accelerating the actual healing process.

The same process could be applied post-surgery or during slow progressing disease. This, of course, is a subject of a serious and delicate study - could a melanoma be slowed down by psychological factors?. Scientific research is revealing the bases of psychological resilience (e.g., optimism) and physiological well being. The proposed system could provide ways to lifting the mood of the patients when the therapist seems this strategy fit.

Another possibility, as briefly outlined in the introduction, could be to treat OCD (Obsessive Compulsive Disorders). For the sake of simplicity, we are taking as an example the phobia of germs and the obsession of washing hands. Figure 1 *(b)* shows what the sufferer would see: their own hands covered with dirt. However, being at the same time consciously aware of the illusion (and therefore knowing that such perception does not represent any real threat), she/he may not incur, or at least be in more control or compulsory behaviors. In other words, this is AR-based "exposure therapy". A very interesting