Promoting Relaxation Using Virtual Reality, Olfactory Interfaces and Wearable EEG

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***Abstract*— The ability to relax is sometimes challenging to achieve, nevertheless it is extremely important for mental and physical health, particularly to effectively manage stress and anxiety. We propose a virtual reality experience that integrates a wearable, low-cost EEG headband and an olfactory necklace that passively promotes relaxation. The physiological response was measured from the EEG signal. Relaxation scores were computed from EEG frequency bands associated with a relaxed mental state using an entropy-based signal processing approach. The subjective perception of relaxation was determined using a questionnaire.**

A user study involving 12 subjects showed that the subjective perception of relaxation increased by 26.1 % when using a VR headset with the olfactory necklace, compared to not being exposed to any stimulus. Similarly, the physiological response also increased by 25.0 %. The presented work is the first Virtual Reality Therapy system that uses scent in a wearable manner and proves its effectiveness to increase relaxation in everyday life situations.

I. Introduction

Virtual Reality (VR) is increasingly being used for therapeutic purposes to treat conditions like Post Traumatic Stress Disorder (PTSD) [1], phobias and different levels of anxiety [2]. Unlike traditional Behavioral Therapy, Virtual Reality Therapy (VRT) engages the patient into a simulated, but vivid reality. It can be digitally controlled by the therapist, without the associated risks or costs of a real-world environment. Current research is looking into immersive experiences for treating people suffering from psychological and physical disabilities. Users are confronted with their fears and phobias, leading to a state of high suggestibility. Most of these phobias are triggered by visual and auditory stimuli. However, when it comes to pain perception, relaxation or concentration, the sense of smell can play a crucial role [3], [4].

The sense of smell differs from other forms of human perception by being closely tied to the emotional center of the brain. The olfactory bulb has direct connections to the amygdala and the hippocampus, two brain areas of the limbic system responsible for processing and controlling emotions and memories [4]. Previous work has shown that odors modulate pain perception [5], [6] and reduce stress and anxiety [7], [8]. Researchers suggested a close relationship between olfactory and affective information processing, with the power of odors to modulate mood, cognition, and behavior [3]. Furthermore, scent has a strong, pervasive characteristic that has widely been used to influence human behavior for marketing and advertising purposes [9]. However, the use of olfactory interfaces as an ubiquitous technology has not been fully exploited and was mostly limited to non-portable and non-fashionable devices, not well suited for a comfortable and unobtrusive use in everyday situations. When coupled with virtual reality or mixed reality, the addition of smell significantly enhances the sense of immersion and unveils new opportunities for altered states of mind. Pleasant ambient odors have shown to relieve stress and improve mental relaxation [8], thereby supporting the claim that stimulating and relaxing odors should be considered for relaxation purposes in Virtual Reality Therapy.

For that reason, this article introduces a lightweight and wearable system integrating a virtual reality experience, an olfactory necklace [10], and a low-cost, wearable EEG headband to promote relaxation (see Figure 1). We believe that our system can contribute in the field of ubiquitous computing and wearable technology by integrating the already proven effectiveness of scent for relaxation and immersive virtual reality therapy techniques.

II. Related Work

A. Virtual Reality Therapy and Scent

The history of multi-sensory immersive technological research can be first dated when scents were released during the viewing of a film, so that the viewer could associate certain smells with scenes of the movie [11]. In 1962, Mort Heilig patented Sensorama, which could be considered as the first virtual reality system. It was an immersive device including stereo sound, smell, and tactile stimulation for providing multi-sensory experience.

Most recent research has looked into the challenges, possibilities, and applications for multi-sensory immersive technology. Limited work has been published regarding olfactory displays for Virtual Reality Therapy (VRT), specifically for relaxation purposes. Researchers have discussed the potential use of olfactory displays for VRT and encouraged future research [12], [13], but no studies or systems have been published yet that show their effectiveness.

While there have been research projects and commercial products that use virtual reality to improve wellbeing and mindfulness [14], or help with mental disorders, the use of olfaction for VRT has been underexplored. For that reason, we present the first ubiquitous system that integrates an

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Fig. 1: Pilot study setup. Subjects are experiencing a 360° beach video with sound, accompanied with scent from the *Essence* necklace and an EEG headband to monitor brain activity.

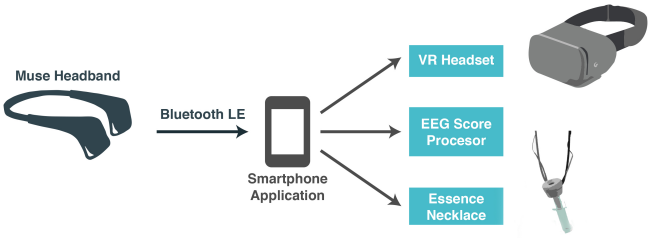

Fig. 2: Visualization of system pipeline. The smartphone application receives and processes data from the EEG headband. It furthermore controls the *Essence* necklace and provides the video for the VR headset.

olfactory wearable for Virtual Reality Therapy and shows its effectiveness in relaxation.

B. Studies on Olfaction

Previous work has demonstrated that odor-evoked memories produce stronger emotional arousal than events triggered by other sensory modalities [15], [16], [17]. Researchers administered Heliotropin (a vanilla fragrance) to patients undergoing cancer treatment and were able to show a decrease in anxiety by 63 % compared to a placebo [18]. Diego et al. examined the effects of aromatherapy on users' mental states. EEG activity, alertness and mood were assessed before, during and after performing math computations [19]. Users subjected to lavender scent performed math computations faster and more accurately, and reported feeling more relaxed. These studies reflect the importance of designing systems that add scent to create innovative alternative treatments for reducing stress and anxiety.

III. Methods

The system consists of three main parts: **(1) Virtual Reality Headset**, **(2) Olfactory Necklace**, and **(3) EEG Headband** (as shown in Figures 1 and 2).

EEG live data were recorded by the headband and streamed via Bluetooth Low Energy. An application for Android-based smartphones was developed to process incoming data in real-time and to control the scent release from the necklace. The smartphone was furthermore used as VR display using a mount strapped to the users' heads.

A. Virtual Reality Headset

For the virtual reality experience, we selected a 360° video recording of a beach. The video was displayed to the user

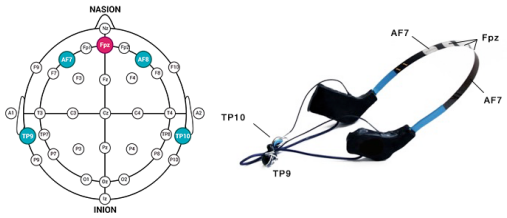

Fig. 3: *Left:* Muse electrodes on 10-20 electrode position system with channel electrodes (blue) and reference electrodes (red); *Right:* Muse wearable EEG headband used for the system.

in a Samsung Gear VR (as shown in Figure 1) and Google Daydream VR, both head-mounted virtual reality displays. The choice of this environment was based on previous research that has already proven the positive impact of nature scene images for achieving a relaxed mental state [20]. Because the same effect holds for nature sounds [21], we used a pair of Bluetooth headphones to play the sound accordingly to the imagery and provide a fully immersive experience.

B. Olfactory Necklace

Essence is a wearable olfactory display developed in previous work [10]. It has embedded computational capabilities, so that the frequency and intensity of scent release can be controlled via Bluetooth using a smartphone application. In order to minimize the users' need to interact with the system and relax as much as possible, we defined a fixed duty cycle of 1 second of scent release every 10 seconds.

The type of scent used in this work is diluted natural lavender essential oil. This type of fragrance is commonly employed in aromatherapy and has been proven to reduce anxiety, stress and improve sleep quality [22].

C. EEG Headband

The EEG, serving as a measure for brain activity and the current mental state, was recorded using a modified version of the commercial Muse headband (Interaxon Inc., Toronto, Canada)[1]. It is a low-cost wearable EEG system for non-medical purposes, shown in Figure 3. The flexible headband provides four active electrodes, located at 10-20 positions *TP9*, *AF7*, *AF8*, and *TP10*, and a common mode reference electrode at *Fpz*, which also acts as driven right leg (see Figure 3).

In order to determine the users' relaxation levels, we targeted brain waves of the *alpha* and *theta* frequency band. Alpha waves commonly occur when a person is awake, but in a calm and resting mental state, when the eyes are closed and with certain types of meditation [23], [24]. Theta waves can be observed while meditating, during daydream, state of flow or phases of drowsiness and hypnagogia [25].

We used an algorithm from previous work for real-time mental state recognition, in order to quantify how relaxed the users were during the study procedure [26]. The algorithm

[1] http://www.choosemuse.com

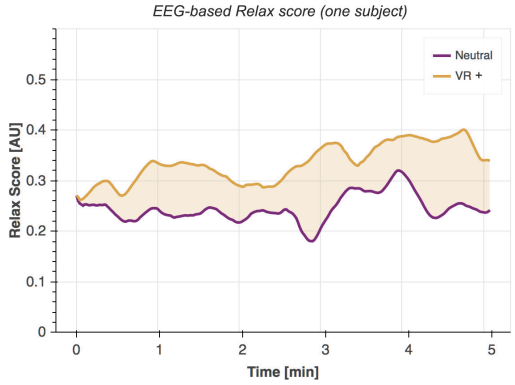

Fig. 4: EEG *Relax* score over time for a typical subject during the *Neutral* and *VR+* phases.

computed a *Relax* score based on the *Rényi* entropy [27] of relative frequency band powers from alpha and theta bands.

IV. Evaluation

A. Study Design

Data from 12 participants (4 female, 8 male) aged 28.2 ± 4.4 years (M $\pm$ SD) were collected for the user study which was conducted in a neutral office space environment. During the procedure, subjects wore the Samsung Gear VR headset, the *Essence* olfactory necklace, a pair of Bluetooth headphones, and the Muse EEG headband (see Figure 1).

Measures included a physiological assessment of the processed EEG signal (*Relax* score) as objective measure, as well as a questionnaire about the perceived relaxation as subjective measure. Since there is no standard instrument for measuring the perception of being relaxed, we used the Relaxation Rating Scale (RRS) questionnaire proposed by Labb et al. [28]. The Perceived Stress Scale (PSS) [29] is the most widely used psychological instrument for measuring the perception of stress, but it is a long term measurement based on the last month experience. As this user study required the current relax perception before and after using the system, we used a computer-based questionnaire that required the participant to rate their current level of relaxation on a scale with 1 being "Not relaxed at all" and 7 being "Totally relaxed".

B. Procedure

The study consisted of two phases, with a duration of 5 minutes each. The *Neutral* phase (also referred to as *No stimulus*) was used as reference measurement for 5 minutes, with no specific instructions given, except not to close their eyes. During the *VR, Scent, Audio* phase (also referred to as *VR+*), the subjects were asked to use the system for another 5 minutes. In both cases, we computed the *Relax* score in real-time, based on the acquired EEG data. After the participants completed the study, they were asked to fill out a questionnaire about their perceived Relax score before and after the two different phases, respectively.

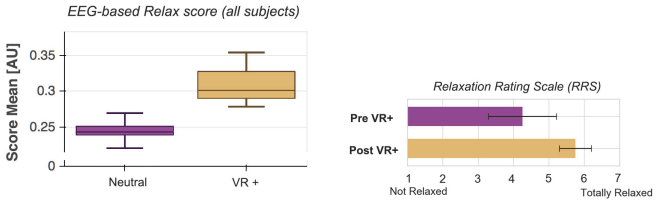

Fig. 5: *Left:* Box plot of EEG *Relax* score for all participants; *Right:* Relaxation Rating Scale (RRS) for study participants (1 = Not relaxed at all, 7 = Totally relaxed).

V. Results

The results of the EEG-based Relax score for a typical subject during the *Neutral* and the *VR+* tasks are visualized in Figure 4. A box plot of the Relax score for all subjects is shown in Figure 5 (Left), with the corresponding values listed in Table I. The Relax score increased significantly $(p < 0.05)$ between the two tasks, $t(11) = -3.39, p = 1.43 \cdot 10^{-4}$. Furthermore, the perceived relaxation on the Relaxation Rating Scale is visualized in Figure 5 (Right) and also showed a considerable increase.

TABLE I: Mean and standard deviation of *Relax* scores during study.

	Test Conditions	
Phase	**M**	**SD**
No stimulus	0.352	0.024
VR, Scent, Audio	0.438	0.047

Difference: Mean: $+25.02$ %, Standard Deviation: $+15.69$ %

VI. Discussion

The results of the user study indicate that users were more relaxed after and while using the proposed system (*VR+* phase) than they were before (*Neutral* phase). The physiological response measured by the wearable EEG increased by 25.0 %, matching the increased 26.1 % subjective perception of relaxation. The course of the EEG-based *Relax* score shows a moderate increase throughout the *VR+* phase, leading to the assumption that the impact on the users' relaxation increased with the duration of exposure to the system. However, the significance of this effect has to be evaluated by future work.

Although initial results were very promising, further research is still required in the display and stimulus, such as music or sound selection, scent and the content presented to the user (computer generated imagery, real imagery, etc.).

The use of pervasive computing technologies for influencing users' mental state presents promising opportunities and challenges for the future of Human Computer Interaction (HCI), particularly in the context of Virtual Reality Therapy for relaxation. Future work should address each one of the independent variables and analyze more detailed aspects of the system, such as the timing of the tasks and increased number of participants. Furthermore, we speculate that our

system brings new research opportunities for the integration of virtual reality and olfactory interfaces for biofeedback and real-time analysis of mental states for therapeutic purposes.

VII. Conclusion & Outlook

In this article, we described the first portable system that incorporates VR, a low-cost wearable EEG system, and an olfactory necklace for relaxation purposes. We used lavender scent based on its previously demonstrated relaxation effects and a 360° beach environment with its real sounds. Our study results demonstrated the effectiveness of the system for increasing both the perceived relaxation as well as the *Relax* score obtained from the users' EEG.

We hope our article encourages discussion within the community and opens up contributions in the promising area of wearable systems that integrate olfaction for virtual reality therapy.

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