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# An Emotion-Adaptive VR Experience for Recreational Use in Eldercare

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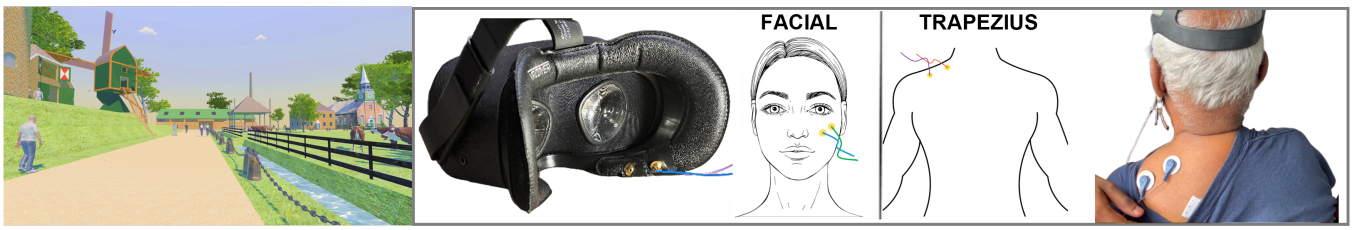


**Figure 1: VR environment (left), EMG electrode placement on the zygomaticus muscle (middle) and the trapezius muscle (right).**

## ABSTRACT

Virtual Reality (VR) technology provides the elderly, and people with dementia, the opportunity to reminisce by exploring places outside their (care) home, free from age-related (physical) restrictions. However, the elderly are particularly vulnerable to overstimulation. Irresponsible VR design can cause stress and anxiety, potentially even exacerbating cognitive decline, and diminishing well-being. We present an electromyography (EMG) driven stress- and emotion-adaptive VR environment for the elderly that provides an immersive but controlled experience targeted at preventing negative emotions. We report our results and insights from a pilot study with elderly participants (N=3). Our system detects and mitigates signs of stress and negative emotions while promoting pleasant recollections.

## CCS CONCEPTS

• **Human-centered computing** → *Accessibility systems and tools*; **Virtual reality**; • **Social and professional topics** → *Seniors*; • **Hardware** → *Sensor applications and deployments.*

## KEYWORDS

virtual reality, stress and emotion sensing, adaptive, elderly

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## 1 INTRODUCTION

Virtual reality (VR) applications enable us to escape our everyday life, let us explore new countries, fly in a spaceship, or meet friends from the other side of the world. While this technology brings entertainment to many people, it yields an even bigger opportunity for the elderly. Recently, VR technology has been increasingly addressing seniors, people in care homes, or people with age-related diseases, such as dementia (e.g., [8, 17]). A key feature in designing VR experiences for the elderly, who are unfamiliar with this technology, is to tailor the VR environment to the individual user's needs and preferences. However, providing sufficient stimulation to make the environment exciting to explore, while avoiding overstimulation and stress, is an act of balance that requires careful adjustments and interventions [1, 6]. Here, we introduce a VR experience for recreational use in care homes, in which multiple parameters of the environment are automatically adapted according to the emotional valence and level of stress, measured in real-time using Electromyography (EMG). Based on prior research, our implementation continuously adjusts sound volume, brightness, and the number of non-player characters (NPCs) to mitigate negative emotions and stress in the VR experience (described as interventions). In this paper, we report on our design choices, implementation, and a proof-of-concept user test (N=3). Our initial results show that our adaptive VR experience promotes reminiscence and nostalgia and effectively mitigates stress in our test users. The study showed a 32% decrease in stress between the control stage and the average of the intervention stages. Volume modulation allowed for the lowest necessary mean amplitude of intervention at 50% intervention strength.

## 2 DESIGNING VR ENVIRONMENTS FOR THE ELDERLY

The design of VR experiences for the elderly, and people living with dementia (PLWD), requires careful consideration but can enhance inclusion and quality of life. For example, in care homes, VR can reduce alienation when people are unable to safely explore their environments without support [14]. VR experiences that integrate nostalgic features from the past congruent to real-world locations previously explored can induce feelings of reminiscence free of age-related difficulties such as limited mobility [1, 8]. However, guidance is necessary through landmarks, signage, and caretaker-given support during VR play. Semantically congruent audio-visual stimuli are instrumental in attaining high levels of immersion. Natural ambient sounds like birdsong, water sounds, and audio-visual wind movements create an immersive environment with restorative effects for the elderly, particularly those with dementia [3]. Tailoring the VR experience to individual contexts and preferences would therefore heavily benefit those living with dementia.

However, older, and in particular cognitively declining, users tend to face difficulties in balancing a signal-noise ratio, impacting their ability to focus on the input stimulation (signal), i.e., the VR experience, over noise (environmental distractions) [11]. Thus, the intensity and relevance of the stimulation are key. This can be problematic since attention, memory, and most importantly presence are sacrificed when stress and negative emotions are exhibited, leading to undesired behaviors, such as agitation, hitting, throwing objects, and hurting oneself or others [8]. By actively mitigating the overwhelming effects of negative stress, a VR system would maintain the highest level of presence. Safety and comfort are prerequisites to pursuing the aforementioned goals through reminiscence.

## 3 SYSTEM DESIGN

Electromyography (EMG) measures the electrical signals in muscles under contraction- Wijsman et al. [19] found that under stress testing, the trapezius muscle contracted 15% in line with self-reported stress levels. During low-stress rest periods, the muscle returned to 0% contraction- this unintrusive method of stress measurement was therefore selected. Due to the inconsistency of brain wave output in dementia patients, EEG was not considered [9]. However, it was noted that unimodal sensing of stress in EMG could not differentiate between positive stress (excitement) and negative stress. Cohn and Ekman [4] found that subconscious activation of facial muscles could also be measured by EMG and in particular, the activation of the zygomaticus muscle in the cheek was closely correlated with the expression of the emotion of joy. This is supported by Schmidt et al. [16], who found non-deliberate zygomaticus activation values to be between 20-30% - hence in this paper, 30% was taken as the threshold for emotions to be classified as happy. Therefore, by combining input from the zygomaticus with the trapezius muscle, both stress and valance can be ascertained.

**Stress Measurement**. The OpenBCI Ganglion[1] is a 4-channel EMG biosensing board that measures and transmits electrical signals from attached sensors via Bluetooth to a host computer. Attaching the positive and negative electrocardiogram (ECG) type electrodes to the trapezius feeds EMG signals to the OpenBCI board which are filtered into values indicating tension/stress. The gold-capped positive and negative electrodes are embedded directly into the foam insert of the VR headset (Figure 1), to ensure consistent contact with the zygomaticus muscle in the cheek. A reference electrode pair is connected to the earlobe. The OpenBCI GUI app performs thresholding values within the first 1 minute of the control section of the test. This adjusts for exposure to high stimulation and the rest state's EMG activation values. These activation states, represented by a value from 0.0–1.0 are transmitted via the Lab Streaming Layer (LSL) protocol to a processing python scriptAfter signal processing, we use a pre-calibrated moving average window of between 2–5 seconds depending on the user's EMG fluctuation frequency.[2]

**VR Environment**. The virtual reality environment (VRE) is displayed within the Oculus Quest 1 head-mounted display (HMD) with a computer running a Unity game engine using the Oculus SDK. The VRE was designed in the image of a quaint suburban village. The location was selected to invoke fond memories of a de-urbanized area that would be familiar to participants that belong to the main target group. For PLWD who are displaced from their self-described home culture, familiar images, sounds, and cultural artifacts can invoke reminiscence and improve verbalization levels in non-verbal care home residents [18].

**VR Stress Modulators**. Parameters of the VRE are modulated via C# scripts loaded in Unity as 'components.' We derived the parameters from principles in dementia care recognized as markers of stress in the elderly. Reis et al. [13] identified the need to be cognizant of VR-induced symptoms and effects (VRISE) such as dizziness, vertigo, ocular motor disturbances, fatigue, and headaches. Saredakis et al. [15] contend that high visual stimulation contributes heavily to stress and ultimately, VRISE: bright lights, noise, and fast movements within the visual field. Kim et al. [7] claim in particular that rapid vergence-accommodation changes (asynchronously moving the eyes to focus on movement) cause visual discomfort- hence the amount of visual movement was selected as the first parameter to vary. Further, PLWD have a reduced stress threshold to many environmental stimuli such as light and sound [5]. Therefore, we choose to vary sound and light levels as additional parameters in the VRE. Light was varied by adjusting a post-processing layer's exposure settings to decrease the overall brightness of the environment in accordance with stress levels. Sound was varied by decreasing the volume of background music and ambient sounds of birdsong, water and wind noise with stress levels. Finally, movement was varied by adjusting the number of NPCs within the visual field of the user.

## 4 PILOT STUDY

A pilot test was organized using three elderly participants without dementia or other symptoms of cognitive impairment, recruited through the authors' personal networks. The study was approved by the TU Delft Human Research Ethics Committee and executed in accordance with their ethics and data management guidelines. No compensation was offered to the participants of the study. The experiment was video recorded for posterity.

Participants were informed about the procedure and asked to sign an informed consent form including information on data management and privacy before beginning electrode setup. The test

[1]https://shop.openbci.com/products/ganglion-board, last accessed June 07, 2023

[2]The zygomaticus muscle activation threshold was set at above a minimum of 30 % in accordance with research by Schmidt et al. [16]. Any stress with above 30% zygomaticus activation is considered happy arousal-excitement. If zygomaticus activation remains below 30 %, any stress is considered negative stress and parameter modulation components of the VR system activate, adapted to the level of stress measured.

was divided into four sections of free exploration in VR, beginning with a 2.5 minutes control stage in which general exploration was conducted without any parameter modulation (i.e., baseline). The following stages were NPC, brightness, and sound modulation, the order of which was counter-balanced across participants to cancel out any carry-over effects. Between each 2.5-minute section of the experiment, a brief semi-structured interview was conducted where participants described changes they noticed and commented on feelings they exhibited. The 10-minute test was followed by a brief semi-structured interview in which a general understanding of the fulfillment of the criterion of presence, comfort, identity, occupation, novelty, and inclusion was assessed. The caretaker was present during the entire study and asked to constantly monitor participants for VRISE or any signs of discomfort. Participants were vetted and rejected if signs of severely diminished sight or hearing were present.

## 4.1 Apparatus, Setup & Participants

Adhesive ECG-type electrodes were placed on the participant’s trapezius muscle on the non-dominant side of the body as in Figure 1. A set of gold cap electrodes was attached to the earlobe using a clip for reference. The aforementioned electrodes were connected to the OpenBCI Ganglion in combination with the gold cap electrodes previously embedded into the Oculus HMD. The OpenBCI GUI is started on the host computer and is automatically connected via the BLED112 Bluetooth dongle to the Ganglion board. The GUI streams via LSL to a local network at 50 Hz. Participants were seated during the experiment and used the Oculus controller with their dominant hand. Then they were briefly taught to use the joystick on the controller. After finishing the setup, the Unity program was started on the host computer and connected via a USB C cable to the HMD. The HMD is carefully placed on the participant’s head, the straps tightened and the participant is asked to self-adjust the headset until the image of the environment is within focus. The Python program is then started- this automatically stores the data in CSV format on the host laptop with an anonymized participant number at the rate of 0.2 Hz. The participants were 62, 81, and 83 years old (2 male, 1 female) without diagnosed or indicated dementia or diminished sense of sight or hearing. Two participants had a rural background, one had an urban upbringing. None were familiar with VR or gaming technology and were using an HMD for the first time.

## 4.2 Results

*4.2.1 Quantitative.* The graphs in Figure 2 show the changes in stress and happiness over the sound modulation parameter as well as control while 3 shows how much the parameter was modulated overall- if happiness was detected over 30 %, the parameter was not modulated and defaulted to the levels identical to the control section.

The data collected was shown as an amplitude percentage of overall EMG activation values between the thresholds automatically set by the OpenBCI GUI. This was then averaged across participants. Average stress was highest at the beginning of the experiment during the control stage in which no modulation was provided as seen in Figure 4. In this stage, the lowest number of (hypothetical) interventions were recorded. The lowest stress levels

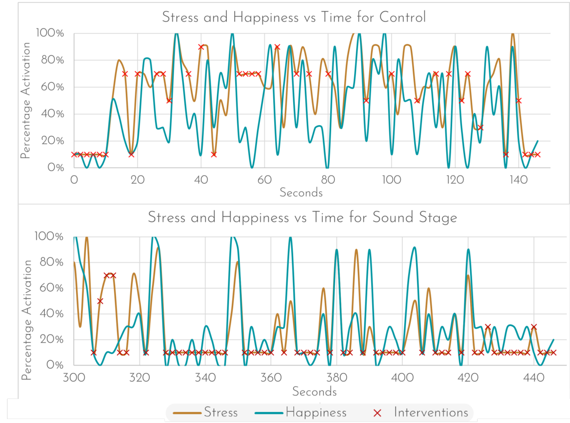


**Figure 2: Data gathered over a 10-minute active testing session divided into 2.5 minutes for sound modulation and control conditions.**

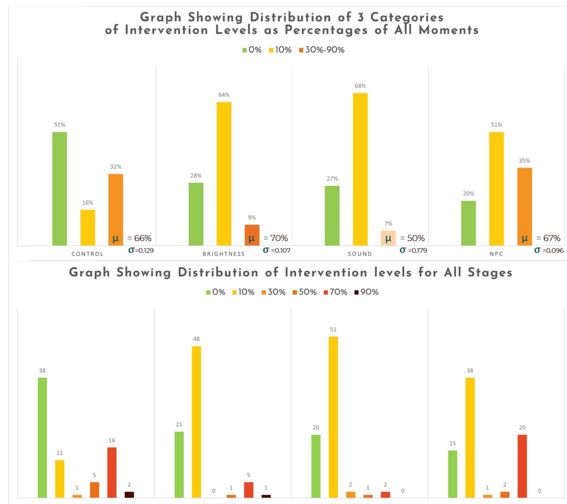


**Figure 3: Distribution of intervention levels across all stages.**

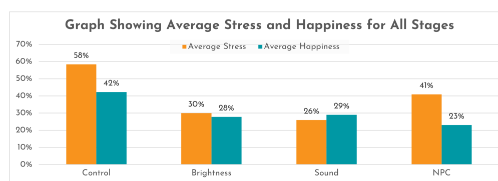


**Figure 4: Stress and happiness data averaged over each stage. Data represented as a percentage of muscle activation between the automatic thresholds set by the OpenBCI GUI.**

were recorded in the volume modulation stage while this stage observed the highest number of interventions. This shows a minor inverse correlation between the number of interventions and stress perceived amongst the stages with intervention modules and a strong inverse correlation between overall stress and the presence of parameter modulation. Interesting trends are observed when classifying the interventions themselves into their respective degree of intervention- 0%, 10%, 30%, 50%, 70% and 90% as in Figure

3. Interventions were triggered according to the emotional states of the participants- a 'happy' state received 0% intervention, the 'neutral' state 10% and all other emotional states were classified as 'stress' and received higher scaled interventions. Figure 3 shows that out of all the stages including control, the NPC modulation mode had the most 70% level interventions making up 27% of the moments in the testing stage. Although significantly more infrequent than the other modulation stages, the brightness modulation stage had the highest mean negative stress intervention level at 70%. Sound modulation had an even lower occurrence of negative stress interventions as well as having the lowest mean stress intervention. As seen in Figure 3, the points of change between stages are clearly visible in the stress values at 150-second intervals, as well as the positive happiness reaction of users to strong interventions.

*4.2.2 Qualitative.* The qualitative results were summarised from the audio transcription of the experiment. All participants reported an overall enjoyable experience. Their responses were manually grouped to address each aforementioned goal. Regarding presence, participants found the experience very immersive and realness was greatly improved by NPCs, trees and other visible movement. They reported however that visibility of their own hands would improve immersion. Identity was determined to be out of scope since the participant's own character cannot be seen and the game included no interactions with the environment. Upbringing location appears to be relevant as the urban-raised participant was less interested in the natural aspects by the end of the experience. Participants found the experience very novel, likely due to their lack of experience with computer games. One participant compared it to walkthrough videos they had seen of travel blogs. Participants were engaged and occupied throughout but felt bored towards the last section as exploration without activities was difficult to facilitate. Participants felt included overall however participants who struggled to use the controller felt less engaged as the facilitator needed to take over controls. The remaining participants still needed clues given by the researchers, such as "*Shall we go see the church?*". When asked to compare the three modes, all participants reported that the sound modulation mode was the most seamless and therefore natural. Two of the participants remarked that the NPC modulation was slightly unnatural as the NPCs simply disappeared from their visual field-something that decreased the realism of the experience and pulled them out of the flow of the experience. When asked to compare their experience in the modulated stage to the control stage, all participants agreed that they preferred the modulated stages.

## 5 DISCUSSION

Our early results confirmed that the presence of system interventions to modulate stress-causing parameters leads to lower overall stress levels. A decrease in average stress as well as the degree of intervention required was observed in volume modulation compared to other stages of modulation. Qualitative results indicate that our system contributes to a successful stimulation of reminiscence and feelings of nostalgia as reported by Siriaraya and Ang [17]. Our early results promote safer VR experiences, particularly for the cognitively declining and/or stress-prone elderly. Concerns about the onset of overstimulation through sound, brightness, and movement can be managed via the creation of similar parameter modulation software. To address staffing shortages in care homes [2], facilities could use VR and decrease the amount of one-on-one time required between staff and the elderly, and facilitate conversations between care home residents. A safe reminiscence tool can also benefit the caretakers. 50 % of dementia carers report that their health and social life have suffered from taking up caring responsibilities [10]. Offering elderly users a safe recreational activity, such as an adaptive VR experience, could thus alleviate carers [10]. The application of real-time adaptation via EMG stress readings should also be weighed significantly. While technology such as EDA monitors and ECG sensors provide medium latency data of stress levels, neither system has been used successfully in a multimodal, emotion-adaptive intervention. The system functionality for filtering positive stress (excitement) from negative stress in real-time can also be implemented in other areas such as IoT home automation and general monitoring of stress-prone residents.

### 5.1 Limitations and Future Work Scope

During participant recruitment, we were limited to the selection of cognitively healthy elderly. Later stages of dementia can lead to increased apathy, thus, further research is needed to determine the applicability of our intervention for this group [9]. Furthermore, the scalability of our system should be investigated, particularly through technology such as neural radiance fields to expand the number of virtual environments available [12]. Siriaraya and Ang [17] observed that personally irrelevant elements of the VRE reduced overall immersion. We expect that with a larger set of users, more 3D assets and environments could be shared, leading to a greater selection of environments and elements. Future studies could look into the cross-cultural relevance of features and target universally attractive aspects (e.g., parks) [3]. Machine learning could be applied in this aspect to predict reminiscent moments with the appearance of certain VR elements and promote them in VR scene design. Interactivity in VR was noted as a valuable addition to the VRE by Kim et al. [8]. Further exploration of modes of interaction and the creation of interaction-based challenges and motivations could lead to a more engaging and inclusive design.

## 6 CONCLUSION

Our early results indicate that VR is a powerful tool for reminiscence by inducing feelings of nostalgia in elderly users. Furthermore, the use of EMG-driven real-time adaptation of VREs leads to a reduction in stress and therefore a safer overall VR experience. We see the primary beneficiaries of our study to be elderly users who are unfamiliar with VR and prone to stress- particularly stress brought on by cognitive illnesses such as dementia. Future research should involve the integration of machine learning in identifying and streamlining the VR design process and improving scalability. A multimodal physiological sensing approach could further improve reliability in the detection of negative emotions and stress. We hope that our contributions will help designers and developers create safer and more balanced VR environments that ultimately lead to an increase in the uptake of VR amongst the elderly population for reminiscence and therapy.

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