An Emotion-Adaptive VR Experience for Recreational Use with People Living with Dementia

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Integrated Product Design
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This work is dedicated to my parents Shanthi and Raja, and my family for supporting me through my entire education and for inspiring me every day to help those in need.

I also thank my incredibly supportive committee who supported me in pursuing this ambitious project.

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Abbreviations

PLWD	Person Living with Dementia
VR	Virtual Reality
BPSD	Behavioural & Psychological Symptoms of Dementia
VE	Virtual Experience
EMG	Electromyography
EDA	Electro-Dermal Activity
EEG	Electroencephalography
ECG	Electrocardiography
bvFTD	Behavioural Variant Frontotemporal Dementia
SD	Semantic Dementia
VRISE	Virtual Reality Induced Symptoms and Effects
NPC	Non-Player Character
HMD	Head Mounted Display
LSL	Lab-Streaming Layer

Expertise Area Legend

This project is the confluence of three main expertise areas. These indicate the main expertise area of respective chapters.

Cultural Contexts

Virtual Experience

Technology

Executive Summary

The study covered in this report represents the graduation thesis assignment for the Integrated Product Design master's program at the faculty of Industrial Design Engineering at the Delft University of Technology. The assignment was completed over the course of five months from September 2022 to February 2023.

Dementia is an umbrella term for progressive loss of cognitive abilities, which mainly affects elderly- affecting relationships, feelings and behaviour. A person living with dementia (PLWD) might forget the names of their grandchildren, the face of their loved ones, important places and life events. Due to the rising population growth with more than 55 million people living with dementia (8.1 % of women and 5.4% of men over 65 years) and increasing life expectancies, dementia is already recognized by the WHO (World Health Organization) as a public health priority, and it is now the 7th leading cause of death (WHO, 2021).

The population pressure that care homes are currently under cannot be easily remedied without significant monetary investment into the manpower of the industry. Therefore it would be more fruitful to enable PLWD to function more independently from the help of their carers.

VR technology has seen immense growth in the last 10 years especially within the field of child and elderly care. Although dementia has been understood since 700BCE, the decrease in stigma has allowed the current era of dementia care to flourish using music, art and drama therapy- amongst other person-centred care techniques. Combining these reminiscence therapy techniques with the booming technology of VR is therefore the next logical step in improving immersion. To this end, VR offers control and consistency in testing virtual environments that guarantee safety. However, a key obstacle in the uptake of VR for PLWD is the risk of behavioural and psychological symptoms of dementia- negative behaviours. To reduce these behaviours, a balance must be struck between stimulation and overload- namely stress.

Emotion classification models were established using the valence-arousal circumplex model before identifying the physiological embodiments of such emotion. Of the stress sensing technology surveyed, electromyography was the only technology reviewed that showed evidence of accurate, low-latency, sensation of arousal and valence by way of measuring contractions in the trapezius and zygomaticus muscles respectively.

To design a conducive VR environment, overarching goals for reminiscence in VR were identified as presence, occupation, comfort, inclusion and novelty. The method of reminiscence therapy was broken down into three forms- place, object and interaction based. The parameters of brightness, volume and non-player character movement were established to be adapted in VR for stress reduction over the course of a 10 minute exploration test.

Results of the study showed a 26% decrease in average stress experienced during the three modulation stages over the control stage. Volume modulation was identified as the most effective parameter showing a 32% stress reduction.

Participants reported that the presentation of familiar environments in VR did in fact promote feelings of nostalgia and reported moments of reminiscence. Future work opportunities call for more studies with PLWD, multi-modal & multi-channel stress sensing and concurrent parameter modulation.

Technology improvements such as integrating all peripherals into a standalone system as well as utilising more convenient and ergonomic sensors that could be applied semi-permanently to form a more holistic data overview for PLWD outside experimental conditions.

Contents

Chapter 1.

Introduction

Chapter Introduction

The motivation of this project is first outlined using social and economic factors. The aim and approach to the project is defined through experimental methods. Finally, the structure of the report is outlined through the lens of cultural contexts, virtual experiences and technology.

Introduction

1.1 Motivation

Dementia is an umbrella term for progressive loss of cognitive abilities, which mainly affects elderly- affecting relationships, feelings and behaviour. A person living with dementia (PLWD) might forget the names of their grandchildren, the face of their loved ones, important places and life events. Due to the rising population growth with more than 55 million people living with dementia (8.1 % of women and 5.4% of men over 65 years) and increasing life expectancies, dementia is already recognized by the WHO (World Health Organization) as a public health priority, and it is now the 7th leading cause of death (WHO, 2021).

Although decreasingly common, it is often the case in the developing world that the (often) non-working female family members are expected to care for their parents with dementia. Whereas in the developed world, care-home infrastructure is more widespread and there is less stigma in signing PLWD into care-homes. Care-homes like these often have a ratio of carer to PLWD of 1:6-10 in the United States (Intriago, 2021). So not only is it often seen that PLWD receive very generic care, this care is also administered by highly pressurised care workers that are focussed on meeting their PLWD's physical needs over their emotional needs. This is particularly frustrating for PLWD who are in care homes in a sub-culture that is not their own (Bruggen-Rufi, 2010).

The population pressure that care homes are currently under cannot be easily remedied and would require a significant monetary investment into employing more personnel. Therefore it would be more fruitful to enable PLWD to function with less help of carers rather than increase the number of available carers.

Virtual reality (VR) applications enable us to escape our everyday life, explore new destinations, or socialize with family and friends. While this technology brings entertainment to many people, it yields an even bigger opportunity for PLWD. Recently, VR technology has been increasingly addressing seniors, people in care homes, or people with age-related diseases, such as dementia (e.g., Siriaraya & Ang, 2014, Kim et al., 2021). A key feature in designing VR experiences for the PLWD, 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 (Vero Vanden Abeele et al. 2021, Hodge et al., 2018).

1.2 Project Approach & Aim

I 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, brightness, and number of non-player characters (NPCs) to mitigate negative emotions and stress in the VR experience. In this paper, I report on design choices, implementation, and a proof-of-concept user test using an analagous group (N=3), as well as give future reccomendations.

Participants with dementia were limited to GDS level 3-4 or less to mitigate the risk of overstimulating PLWD more sensitive to external input from technology they are not accustomed to.

Reisberg et. al defined the GDS scale in 1982 with indicators that differentiate between the stages of progression of dementia. GDS level 3 is defined as mild cognitive impairment while GDS level 4 is defined as mild dementia. Between levels 3-4, indicators of dementia include: getting lost, poor work performance, aphasia, knowledge retention difficulties, name retention difficulties, losing belongings, concentration deficits, memory deficits, denial of conditions, mild anxiety, personal history memory losses and inability to perform complex tasks. These stages were selected as the last stages before which adaptation to technology such as VR becomes difficult.


Figure 1: Roger, 2021

1.3 Project Outline

Out of all non-pharmacological treatments, the use of reminiscence therapy has proved the most effective in providing emotional engagement and provoking nostalgic, positive feelings. The fields of art, music and drama therapy are explored to distil successful elements that are integrated into the goals of the newly developed VR reminiscence therapy. A literature study is performed in which goals of an effective reminiscent VR therapy session are identified and guidelines are formed about how to achieve these goals by focussing on elements of the VR environment such as nature and audio. The VR environment is then created and perfected using a number of pilot and user studies.

Using existing literature, the parameters of brightness, volume and non-player-character movement (NPC) are identified as elements of the VR setting most likely to benefit from real-time adaptation for the user. Simultaneously, the stress measurement technology of EMG is selected and tuned to the particular use case of providing multimodal data input to the VR environment. Data processing methods are explored and logic systems are explored to determine how the VR system can be best adapted. Through a ten minute research study, the following research questions are answered. Finally, the results are discussed, limitations are identified and the scope for future work is outlined.

Does the real-time adaptation of a virtual reality environment decrease the stress felt by the participants in said environment?

Does the presentation of familiar environments, in a virtual reality context, to participants with dementia promote feelings of nostalgia and allow for reminiscence?

Chapter 2.

Analysis of Reminiscence with Dementia

Chapter Introduction

The history of dementia as an illness is considered in its impact on the current era of care. Art, music and therapy was analysed as a person-centered system for dementia care. The current repertoire of medical approaches were considered before highlighting the demonstrable successes of VR for PLWD.

Reminiscence

2.1 History & Impact of Dementia

Dementia, as an umbrella term for decline in cognitive health in old age, has been understood by humans since the time of the ancient Greeks. One of the earliest references to age-related mental deficiency is attributed to Pythagoras in 700 BCE, he described mental stages with milestones of age 7, 21, 49, 63 and 81. At 63 one would see a decline in mental health and at age 81 one would have childlike cognitive tendencies. Hippocrates in 400 BCE and Galen in 150 AD contributed to the notion that the disease was not necessarily linked with age. Cicero in 50 CE was the first to suggest that 'senility' could be combated through engaging in mental activity. It was not until the 18th and 19th century did William Cullen and Jean-Étienne Dominique Esquirol confirm this through medical research. Finally, in what is understood as the modern era of dementia care heralded by Alois Alzheimer, dementia could finally be correlated with sections of the brain afflicted by identifiable medical processes. (Assal, 2019)

What is commonly referred to as the current era of dementia care is characterised by a more conscientious and caring approach to dementia treatment. Alongside medical care, care homes have become more and more popular in line with modernising family values as well as an increase in disposable income allowing for the option of admitting elderly family members into care facilities. With the formalisation of dementia care through the development of training principles, care homes have also improved their image as trustworthy carers of elderly- in stark contrast to the asylums of the 18th century. The dementia village in Hogewyk is an example of how the Dutch have taken particular efforts to address the problem of rising dementia cases. The Netherlands in particular invests heavily in dementia care since they expect care costs to rise from €6.6 bn in 2015 to €15.6 bn in 2040. Companies like Tover are examples of how technology has been used to attempt to offset the manpower requirements of the dementia care industry. (Rijksoverheid, 2020)

However, despite the improvements in care systems, the economic and social impact of dementia has been increasing. The expected triplicate increase in dementia cases from 57 million in 2019 to 153 million in 2050 can primarily be attributed to an ageing population caused by improvements in available healthcare - although risk factors such as obesity, smoking and unhealthy diets also fuel the increase. (Rijksoverheid, 2020)

The increase in dementia cases have an understandably immense social impact, but economic factors compound the effect. An ageing global populace not only puts pressure on the care home infrastructure, but also tasks a shrinking youth population with paying for their parents' senior care. Known as the 4-2-1 problem, this effect can already be observed in Japan where a single grandchild is tasked with supporting 2 parents and 4 grandparents. The western world generally copes well with this issue as there tends to be more support from the government into care homes as well a lowered stigma against admitting elderly into care homes. The expectation that family members care for the elderly is still prevalent in the eastern world- this disproportionately affects women who comprise of 70% of the informal care industry. 50% of dementia carers say that their health suffered as a result and 60% say that their social life suffered. (Lindeza, et al., 2020)

> The history of dementia care shows that we as a society have liberalised our views on dementia care towards accepting the role of external carers. Facing even heavier pressure in the future, it is vital to important that we find a solution that alleviates either the emotional or physical needs to the elderly in their care.

2.2 Existing approaches for independent and group play

Music Therapy

Music therapy has a strong positive effect on the reminiscence of elderly people with dementia (Brotons, 2000, Vink 2000). Music also has the powerful ability to enable and encourage communication beyond the stages in which aphasia (loss for words) can diminish language abilities. Music's tie to the auditory and in turn limbic system of the brain can provide a strong conduit for memory and the evoking of reminiscence- this is the basis for the use of music therapy with PLWD. (Broersen, 1995)

Figure 2: Vonnie (pictured right)in 1945 (Bruggen-Rufi & Vink, 2016)

Bruggen-Rufi & Vink (2016) investigated the effects of music therapy principles on a resident of a care-home in the Netherlands in 2016. 'Vonnie', as she was referred to, was an 83 year old woman who had moved from Dutch ruled Indonesia to the Netherlands in 1945. At the time of beginning music therapy, she had been widowed for 10 years and did not have regular visits from her son. She had been suffering from early stage dementia with symptoms of depression, confusion, social isolation and delusional paranoia. She felt particularly isolated due to her unique cultural heritage in comparison to other residents. Bruggen-Rufi, herself part-Indonesian, introduced herself to Vonnie by singing a song in Bahasa about an Indonesian bird that Vonnie was drawing. This prompted Vonnie to begin opening up emotionally to Bruggen-Rufi and inspired a sense of safety amongst excitement. By supplementing the experience with props, Bruggen-Rufi elevated Vonnie's immersion and her rate of reminiscence. Vonnie began identifying more with her own sense of self and improved her communication and socialisation with other residents over the course of the music therapy sessions. She was even able to talk about sensitive negative memories in a safer environment and process them comfortably. The multisensory experience showed the value of immersive reminiscence using tools of stimulation such as sound and visuals. (Bruggen-Rufi 2016).

2.2 Existing approaches for independent and group play cont.

Art Therapy

Although art therapy was leveraged by Bruggen-Rufi to support music therapy, evidence also exists that art creation and art appreciation therapy can provide PLWD with a recreational activity that enriches them socially and emotionally. Duncan et al. (2014) found in a study of 41 people living with early stage dementia, 83% of participants sustained attention for 30-45 minutes, 80% expressed pleasure with 39% verbalizing happiness and 78% verbalized positive self-esteem. In studying prolific Dutch artist Willem de Kooning, Duncan remarked that the increasing trend of focussing on memory and life-event based elements was observable as his Alzheimer's progressed. Art therapy allows PLWD the agency to express emotion that would normally be supressed by their diminishing ability to communicate via language.

In a personal interview, Duncan expressed the successes of art appreciation therapy in providing conversational topics to PLWD. The mere display of generationally universal themes such as school suburban life provided a central topic for further discussion to blossom from (Raja & Duncan, personal communication, 2021). This motivates the use of the particularly accessible resource of visual observation in further therapeutic studies. Similarly, Duncan also mentioned the strength of drama therapy to provide a central thematic concept for PLWD to work through as a group.

Figure 3: Art Therapy (Pathways, 2017)

Drama Therapy

In their study, Jaaniste et al. (2015) found that drama therapy was an effective tool for discussing and improving aspects of PLWD's quality of life that had undergone changes due to their progressing dementia. These themes included: relationships, environment, physical health, sense of humour, independence, ability to communicate, sense of personal identity, ability to engage in activities. ability to practise faith or religion and their ability to be treated fairly. Themes were provided each week during group drama therapy around which skits and activities would be planned. It was in these safe spaces that PLWD began to observably open up and speak to issues they were facing.

Within the roles they and other participants had selected, participants were able to openly speak about their issues and solve them with each other. Group reflection allowed participants to internalize newly learned and iterated concepts. It was noted that the roles they embodied improved their sense of independence, personal identity and their engagement with peers. Pictures and images assisted participants in engaging with previously unexplored roles and allowed them to go beyond the boundaries of traditional reminiscence. However the researchers acknowledged the necessity for a trained and capable facilitator to monitor and actively modify the session to ensure that it remained a safe and engaging environment. (Jaaniste et al., 2015)

Music therapy has been shown to help PLWD build trust and express themselves with more than just words. Art therapy helps participants socialise and build connections with others. Drama therapy helps participants address issues they face but are hesitant to speak about. However, all three therapy techniques emphasise the necessity for a facilitator to be present for safety and success.

2.3 Medical Approach

54% of people with mild dementia are being treated with symptomatic drugs (Wittenberg et al., 2019). Since 55% of PLWD have mild cases, this means that more than 25% of the dementia having population is being medicated for their symptoms. However Duncan et al. found that cholinesterase inhibitors, memantine, antipsychotics, and antidepressants do not substantially improve neuropsychiatric symptoms or relieve caregiver burden (Levy et al., 2012).

Laxton & Lozano (2013) found that deep brain stimulation, the process of using small electrical currents to stimulate parts of the brain showed promising preliminary results in reactivated certain neural pathways . Cameron et al. also found that transcutaneous electrical nerve stimulation (TENS) also showed promising signs for future applications however with only two studies on this topic in the past 20 years, the solution was never pursued (Cameron et al., 2003).

Light therapy, already proven for diseases such as depression and anxiety, has been more extensively studied and proven to improve dementia symptoms through enforcing healthier sleep patterns. Hanford and Figeuiro (2013) found that an impulse of 1000 lux or higher from a white source of light for at least 2 hours during the day could work to reinforce a healthy circadian rhythm. Existing literature enforces the notion that apart from pharmacological or invasive biomedical procedures, person-centred care is the only reliable form of care that seems to delay the onset of dementia. (McGreevy, 2015).

> Since dementia is an incurable disease, it is the goal of this study to investigate a person-centred solution that can act as a recreational tool.

2.4 Power of Virtual Reality

Since Flynn et al.'s (2003) work, the viability has been recognised for VR to enhance the lives of elderly- especially those living with dementia. Reis, Duarte & Rebelo (2013) contend that VR can provide a safe and malleable space for therapeutic techniques to be trialled and perfected. VR offers control and consistency of its environmental conditions supporting repetitive and hierarchical delivery of therapy. The real-time performance feedback ensures an observable impact of the virtual experience while allowing easy variability by designers. The options for independent and guided exploration allows the system to be adapted to different types and levels of dementia. The customizability is also evident in allowing different levels of interaction using different user-interfaces; touching objects is a possibility but if this level of stimulation is alienating to the participant, other modes can be engaged. The malleability of the system allows for games to be designed within VR that allow for error-free learning environments that reward learning rather than punish failure. Finally, scalability can be achieved by overlapping cultural environments to target particular cultural groups with relevant VR environments. In this sense, VR allows for the freedom to game factors to enhance motivation and gently persuade the user to pursue goals that were identified through literature to create healthy and positive emotions in PLWD.

Baker et al. contends that VR is a unique opportunity to promote reminiscence in a context unhindered by age-related difficulties such as mobility and logistical limitations. Travel to visit places of reminiscence can be difficult when disabilities and other logistical constraints limit the sphere of interaction of the PLWD (2019). This is especially true in cases of displacement of the individual away from their main cultural centre, as was the case of Vonnie in Bruggen-Rufi's study (Bruggen-Rufi & Vink, 2014). Roberts et al. (2019) confirmed that VR could also help fight the alienation felt by PLWD who are unable to reliably leave the safe watch of their carers and explore their environments. They urged a focus on content related to travel, education on cultural reminiscence by focusing on excitement, immersion, novelty, escapism and parasocial interaction. Van Schaik et al. (2008) support this as it was observed that test groups of elderly participants experienced similar levels of novelty and excitement in exploring environments congruent to real life locations previously explored.

> VR offers control and consistency in experimental setups, real-time performance feedback and a malleable system suited to PLWD.

Figure 4: VR for the Elderly (Heathman, 2017)

Takeaways

The three aforementioned therapy techniques all bring different elements of therapeutic care of PLWD to the surface. Music therapy proves the strength of culture specific care to improve reminiscence and increase the scope of the participant to socialise with others. Art therapy provides a space in which to discuss difficult topics and bring to light interests and concerns of participants. Finally, drama therapy offers a stage for participants to work through participants, particularly in a safe environment aided by their peers. It is clear through these therapy techniques that a multisensory experience powered by technology could offer a significant enhancement to traditional therapy techniques in the form of VR.

Analysis of medical techniques employed for PLWD makes it clear that person-centered care is the only technique available that delays onset of dementia. Finally, through research into existing projects it became clear that VR offers control and consistency in experimental setups, real-time performance feedback and a malleable system suited to PLWD.

Therefore, limitations must be considered before moving forward with a VR technology based design.

Chapter 3.

Analysis of Stress Monitoring with Dementia

Chapter Introduction

The necessity for stress monitoring of PLWD in VR is first considered due to negative behavioural tendencies. The circumplex model is introduced as the ideological basis for emotion categorisation and EMG, EEG and EDA technology considered for viability.

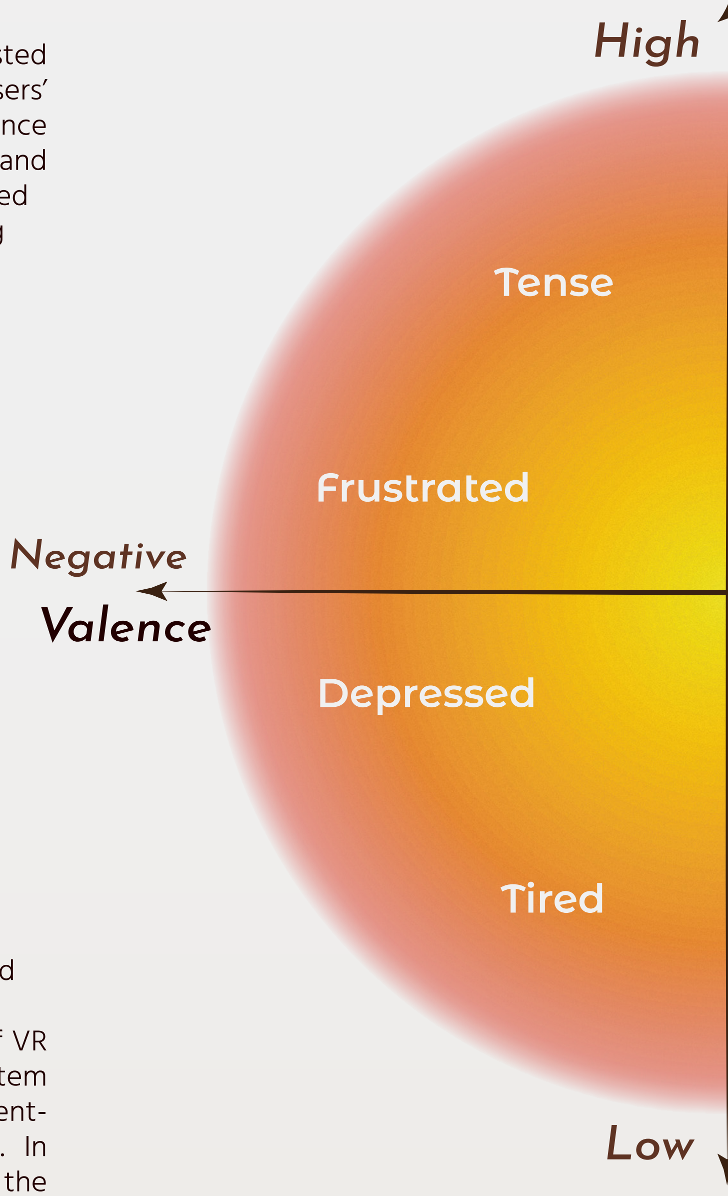
Stress Monitoring

3.1 Stress Monitoring in VR

Recent research by Kim, Park & Lim (2021) suggested that VR environments depicting nostalgic features of users' pasts could be used to prompt feelings of reminiscence and temporarily alleviate symptoms of behavioural and psychological symptoms of dementia (BPSD). The study noted that the need for comfort was rated highest in providing relief from BPSD with 37% of participants; the lack of comfort created points of complaining, agitation and violence (Kim, Park & Lim, 2021). This suggests the need for an adaptive experience. Beyond comfort, the need for identity, occupation and inclusion were identified as necessities in a fulfilling virtual experience.

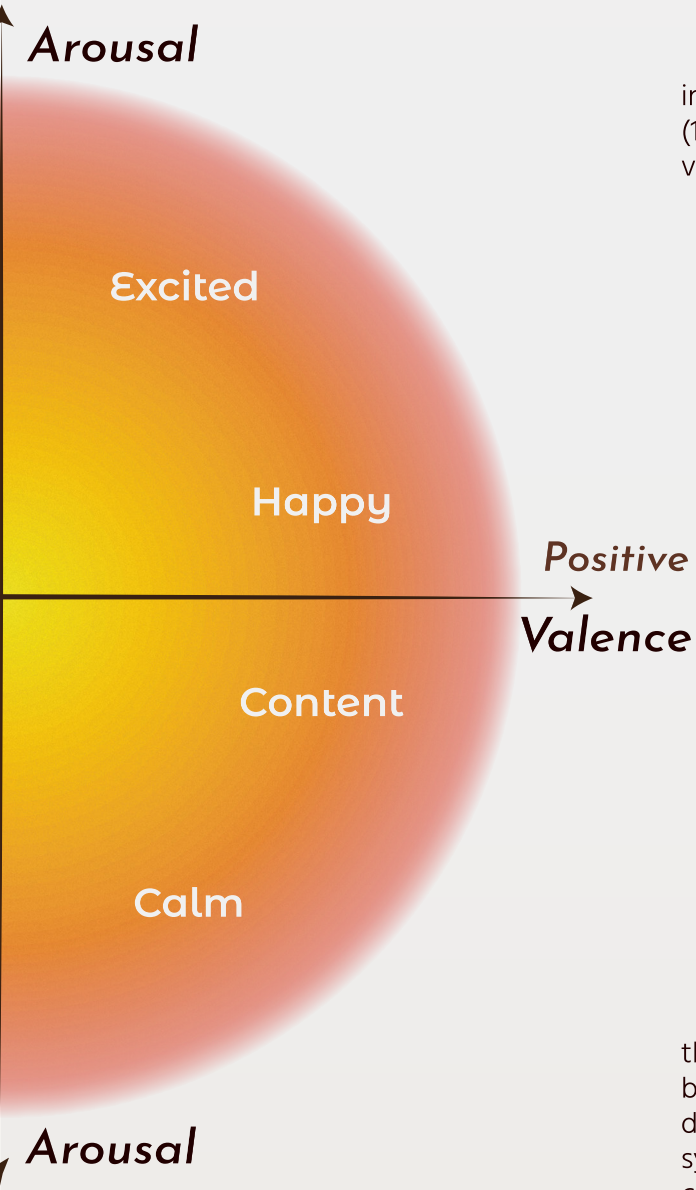
McGlynn & Sean (2017) maintain that a balance must be struck in order to avoid this overload. Older, and in particular cognitively diminished, users tend to face difficulty with their diminished ability to balance a signal-noise ratio. This impacts their ability to focus on the signal (the virtual experience) over noise (environmental distractions). It is therefore important to consider not only the amount of stimulation delivered to the participant, but the relevance of the stimulus itself as well. Virtual embodiments of objects that have no relevance to the PLWD participant tend to distract them and take attention away from their reminiscence of relevant material. This is especially problematic as it has been shown that attention, memory and most importantly presence is sacrificed when stress and negatively valanced emotion are felt.

Thach et al. (2020) explored the setup of a series of VR design guidelines that would ensure the success of the system as well as the avoidance of failure to ensure a safe environment- this will be explored in more detail in later sections. In particular, they posited that increased personalization of the VR environments could lead to improved positive behavioural outcomes such as the reduction of agitation and aggression in PLWD. They particularly recommended tailoring the VR experience to reduce stress in VR so as to create a more fruitful experience for the users. The way in which stress can be observed and calculated was then considered.



Negative behaviours arise when stress is experienced by PLWD in VR. Therefore stimulation must be balanced. Design guidelines should be consulted before desigining in VR.

Figure 5: VR for the Elderly (Desmet, 2022)



3.2 Existing Stress Monitoring Technologies

Most researchers studied based their framework in the industry standard circumplex model first introduced by Russel (1980). The model contends that the scales of arousal and valence are the two defining factors on which emotion can be classified. Arousal refers to the amount of physiological activation that occurs when an emotion is triggered, while valence indicates the pleasantness of an emotion on scale of positive to negative (Harley et al., 2012). Although a third axis of 'focus' has been considered in more recent studies, this requires an element of gaze detection that has been deemed out of scope for this paper (Pekrun, 2017). To adapt the virtual experience (VE) in real-time, a reliable stream of data indicating stress levels and valance of emotion needs to be made available to the VE.

Electro-Dermal Activity

EDA refers to the variation of electrical characteristics of the skin due to sweat gland activity (Horvers, 2021). Most commonly, EDA sensors are placed on the palmar (hands) or plantar (soles) regions. The conductivity of the skin increases when greater amounts of sweat is detected- this is measured in micro Siemens (μS).

Electrodermal activity (EDA) was proven using galvanic skin response (GSR) by Kikhia et al. (2016) to be 76% accurate- however it could only display binary stress levels and needed thorough calibration. This calibration was most often done by machine learning programs training the GSR monitoring data against data gathered by other proven stress indication systems. Manual stress reporting of wandering behaviour was a common metric provided by caregivers to assess the patient's level of stress and is currently in use in care homes. Charts similar to figure 7 are common in dementia focussed care homes and observe the patient over the 24 hour cycle in hourly measurements.

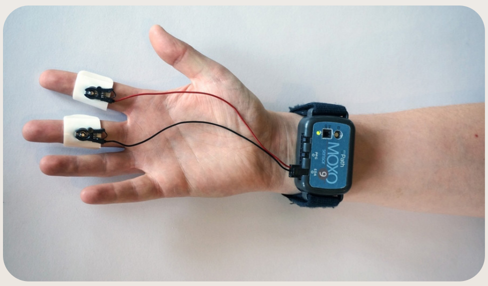


Figure 6: EDA sensors (Matheson, 2017)

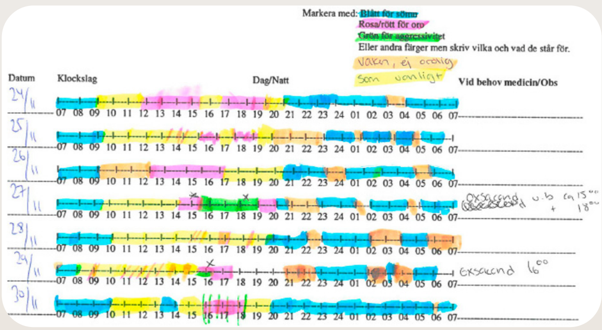


Figure 6: Emotion Chart (Kikhia, 2016)

Electroencephalography (EEG)

EEG records the electromagnetic signal emitted by the brain during neural activity. The electrical impulses in the brain primarily depict grey matter and higher brain functions. There has been substantial evidence of EEG systems being used to diagnose dementia; dementia is evident in the diminished beta and alpha wave region (Huang et al., 2019). Researchers were able to identify particular emotions at an accuracy of 80% but commented that their study was inherently limited in its use of expansive EEG technology that was difficult to adapt per user (Tseng, et al., 2013) .

Studies using EEG as a control mechanism have been notoriously difficult to organize and replicate especially for users of varying cognitive ability. Kumfor et al. (2018) found that frontotemporal dementia (bvFTD) causes social cognitive deficits and atrophy in regions related to autonomic emotional responses. bvFTD patients and semantic dementia (SD) patients both showed diminished changes in signals rising from diminished integrity of the caudate, amygdala and the temporal lobe. These abnormal responses are usually related to cortical and subcortical brain atrophy which manifests itself in varied EEG signalling- proving that without individual calibration, EEG technology would be susceptible to misinterpretation of data by software and ultimately an unsafe VR experience. For these reasons, EEG was not pursued as a technology to develop.

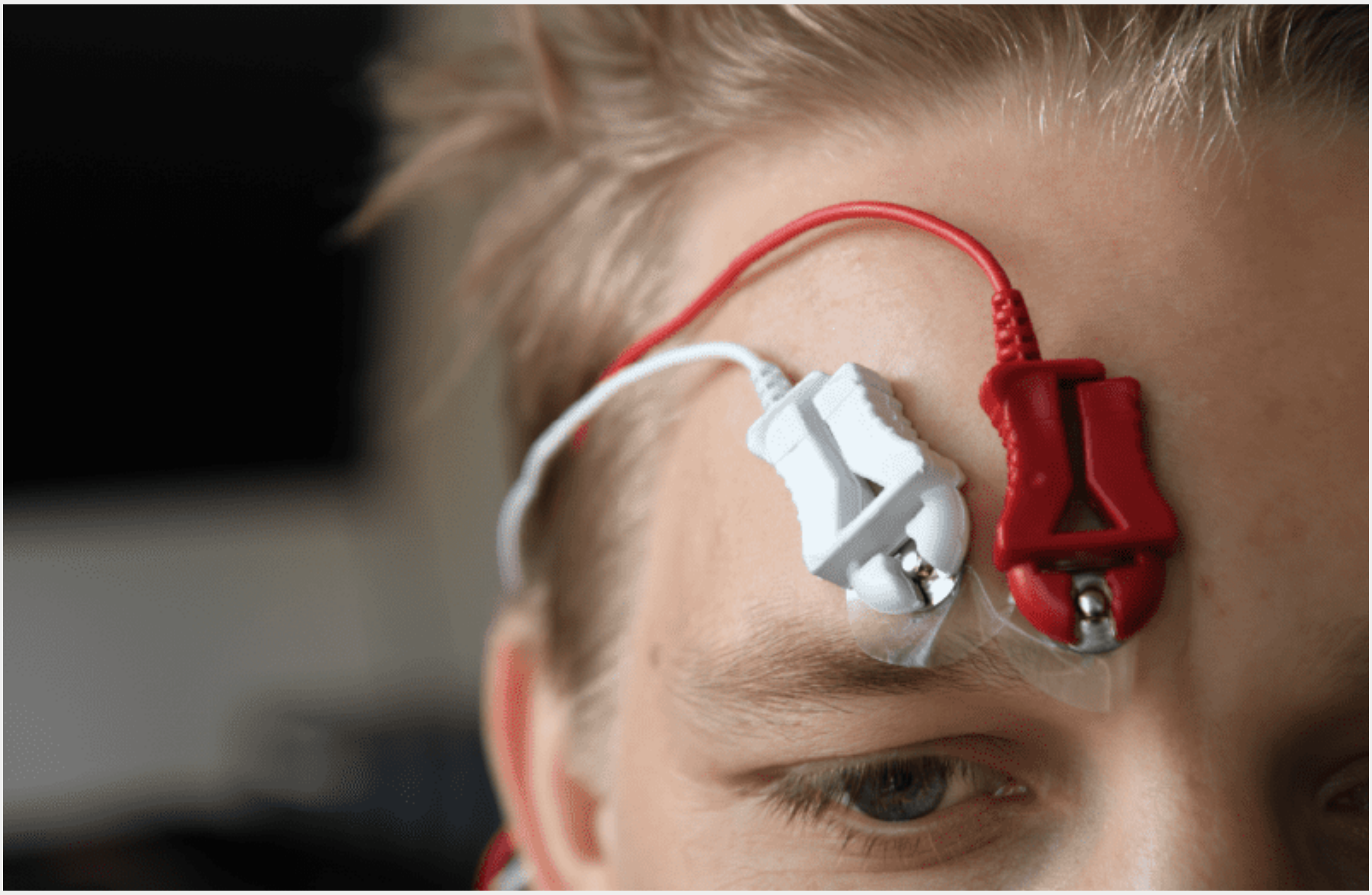
Electromyography (EMG)

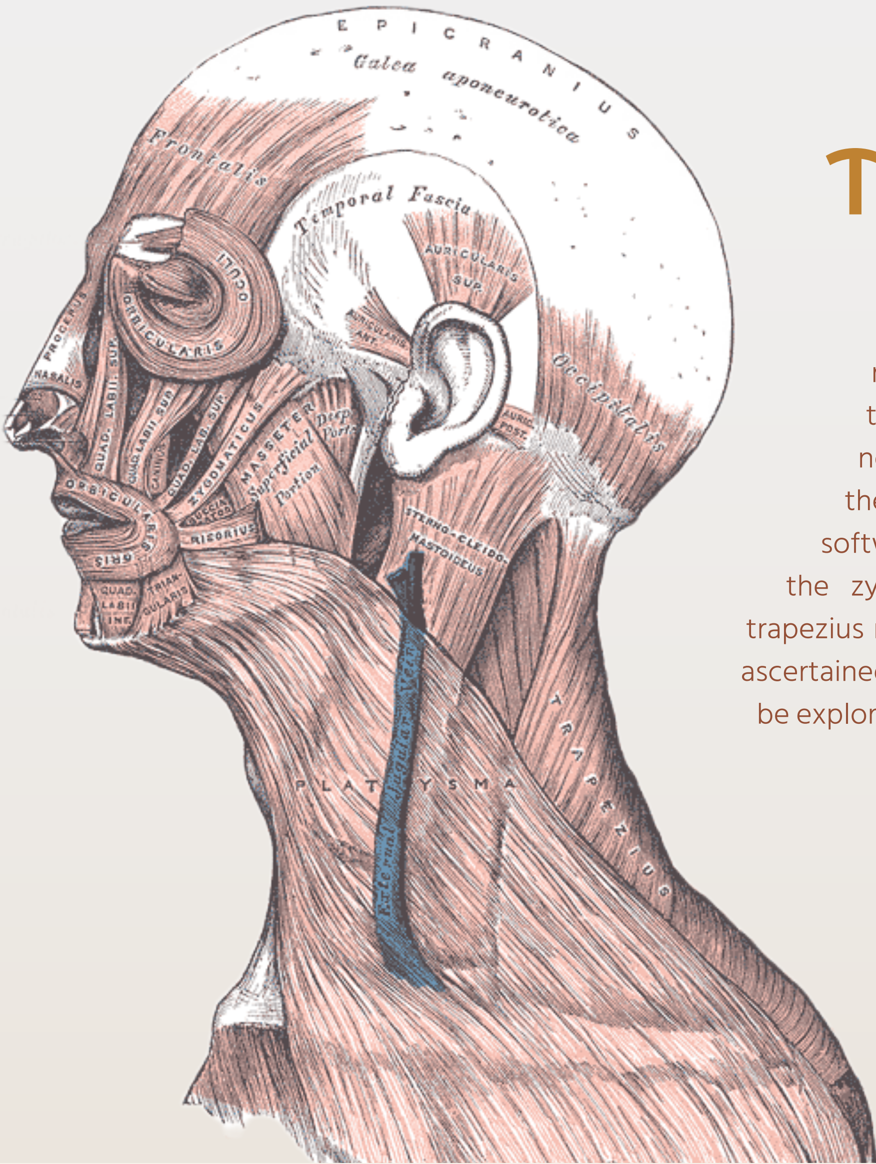
EMG was one of the only technology reviewed that showed evidence of accurately sensing both arousal and valence of emotion showed. Wijsman et al. (2013) proved that the trapezius muscle in the shoulder contracted by 15% under stressful conditions. The researchers employed the Stroop Color Word test as well as mental arithmetic tests to induce mental stress in participants of the study and correlated the EMG readings at the trapezius with self-reported stress readings via a questionnaire. Wijsman found that both frequency and amplitude were classifiers of this data and that thresholding was needed to identify absolute states of stress. Pourmohammadi & Maleki (2020) went further to find that when compared with ECG readings, an industry standard in stress testing, the trapezius EMG reading was accurate at between 96-100% at reading arousal. The signal in this case was gathered as raw data, pre-processed, underwent feature extraction and selection then finally classification resulting in stress detection. The accuracy of these results was accomplished by tuning the EMG device in accordance with heart rate variability (HRV) values- data that nowadays can even be gathered from smart watches.

Fatima et al. (2020) also found that facial EMG data could be used as arousal classification data. The researchers also employed puzzles and mental arithmetic tests to induce baseline levels of stress. Results showed that the trapezius muscle was in fact the more accurate predictor of stress with larger, more observable amplitudes and more widely oscillating frequencies in EMG signal. However, facial EMG data is in fact useful for emotional identification. Longstanding work by Cohn and Ekman (2008) 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. (2006), who found non-deliberate zygomaticus activation values to be between 20-30%: 30% was taken as the threshold for emotions to be classified as happy. Since the findings typing facial muscle contraction to particular muscles date all the way back to Darwin in 1872 (Darwin, 1872), the associations are rather robust and reliable as seen in figure X.

Elementary emotions	Muscles involved	Associated actions in iMotions
Joy	Orbicularis oculi Zygomaticus major	Eye closure Smile
Surprise	Frontalis Levator palpebrae superioris	Brow raise Eye widen
Fear	Frontalis Corrugator supercilii Levator palpebrae superioris	Brow raise Brow furrow Eye widen
Anger	Corrugator supercilii Levator palpebrae superioris Orbicularis oculi	Brow furrow Eye widen Closing eyelids
Sadness	Frontalis Corrugator supercilii Depressor anguli oris	Brow raise Brow furrow Lip corner depressor
Disgust	Levator labii superioris Levator labii superioris alaeque nasi	Upper lip raise Upper lip raise and nose wrinkle

Figure 8: Facial Muscle Emotions (Farnsworth & Fischer, 2022)





Takeaways

Within the scope of this project, multimodal stress sensing exists only to differentiation positive arousal from negative arousal in order to differentiate the necessity for intervention of the software. Therefore using the input of the zygomaticus in combination with the trapezius muscle, both stress and valance can be ascertained. Other muscle groups could however be explored in future projects.

Chapter 4.

System Design

Chapter Introduction

Overarching goals are outlined to inform the development of the VR environment, reminiscence levels are also broken down. Guidelines are outlined to combat VRISE and promote a beneficial experience for PLWD. Parameters of modulation are selected and a VR environment is developed for the experiment. An EMG sensor is selected and logic is established for emotion classification.

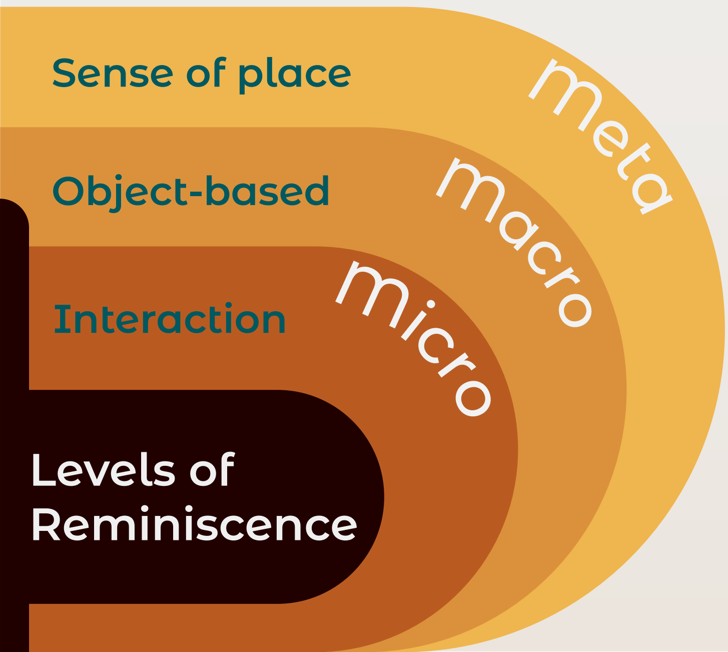
System Design

4.1 Principles from Literature

Overarching Goals

Prescence as first proposed by Flynn et al. (2003), a measure of how immersed the user feels in the VE, is the leading factor that contributes to the actualisation of therapeutic goals. Identified by Kim, Park & Lim (2021), these goals comprise mainly of "comfort (being free from distress and pain, experiencing reduced anxiety by receiving tenderness and friendliness, and feeling soothed), identity (having a sense of self, knowing details of their life history, knowing who one is in relation to significant others, and having a sense of continuity with the past), attachment (feeling security and safety, and trust), occupation (having a purpose in life and being empowered to have an impact), and inclusion (a feeling of belonging, being encouraged to interact with the social environment physically and emotionally)." To achieve this level of immersion while maintaining comfort for the user, guidelines of preferable and avoidable features have been proposed.

Others such as Hodge et al. (2018) have also proposed goals of a more specific scope. Careful physical design ensures the exclusion of triggering articles. Furthermore, careful design includes the conscientious inclusion of activities applicable physically and emotionally for users. Socialising allows the deeper intimacy of sharing personal moments with others. A well personalized environment will improve relevancy and ultimately improve presence.



Since reminiscence was a key goal, it was valuable to detail this out further into activity based sub-goals (Siriaraya & Ang, 2014). Reminiscence from a sense of place occurs when the overall environment at a meta level corresponds to relevant environments in a user's life. For example, rural settings will have characteristic elements of architecture like the centering of a church in the town. Virtual object-based reminiscence will arise from triggering elements of the environment on a macro level, for example the presence of farm animals will be relevant to a rural resident. Finally, reminiscence from motion will trigger micro level emotions- in this case an example would be the action of feeding or petting the farm animals.

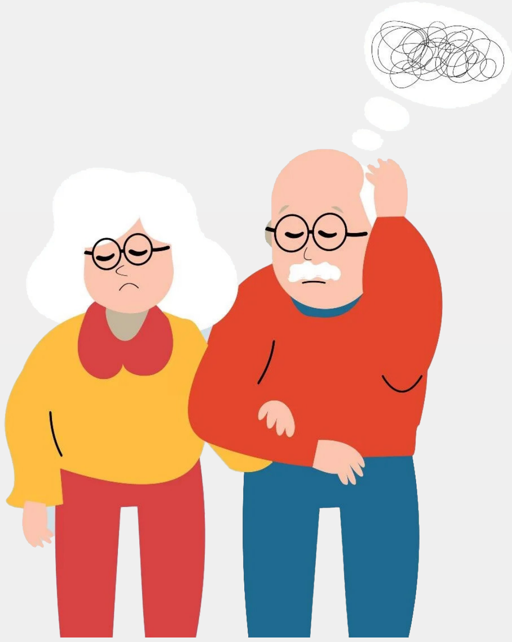
Dementia Specific Techniques for Stress Reduction in VR

The summation of literature reviewed led to an exhaustive list of guidelines as represented below. The guidelines were sorted into the categories of usability (U), user experience (X) and accessibility (A). Usability was defined as guidelines pertaining to the cognitive ergonomics of the experience, user experience referred to how a feature contributed to the overall goals of the experience and finally accessibility pertained to mobility and physical limitations.

Guideline	Source	Category
Multisensory input	Hodge, Kim, Siriaraya, Bruun-Pedersen, Abeele	U, A
Careful physical design	Hodge	U, A
Personalized content	Hodge, Baker, Abeele	X
Active Inclusion	Hodge	X
Shared experience	Hodge, Thach	X
Be aware of triggers	Kim, Reis	U, A
Consider historical accuracy	Kim	U, X
Consider interaction with environmental objects	Siriaraya	U
Make tour self-propelled or guided	Siriaraya	U, A
Objects better than fauna	Siriaraya	U
Balance interest & novelty with accesibility	Siriaraya	U, A
Consider mobility concerns	Siriaraya	A
Independence from facilitator	Baker	U
Leverage VR to overcome mobility concerns	Baker, Abeele	X
Use lifelike avatars to improve presence	Korsgaard	X
Use parasocial interaction	Roberts	U
Visual and audio elements should be congruent	Bruun-Pedersen	U
Monitor participants for signs of discomfort	Abeele, Kim	A
Avoid unattractive busy streets	Abeele, Van Schaik, Reis	U
Use landmarks to guide and associate with destination	Abeele, Van Schaik, Reis	U
Provide verbal or visual prompts between stages (flash of light)	Abeele	U
Present ecologically valid setup- no collisions	Abeele	X
Focus on nature	Abeele, Van Schaik, Reis, Bruun-Pedersen, Kim	U, X
Provide scenic views	Abeele, Van Schaik, Reis, Bruun-Pedersen, Kim	X
Avatars should appear natural	Abeele, Korsgaard	X
Use sounds from urban landscapes as well	Bruun-Pedersen	X
Birds, water & wind must all be present	Bruun-Pedersen	U
Experience should be within limits of cognitive load	McGylnn	U, X
Avoid dependence on source memory- focus on general idea	McGlynn	U
Avoid traffic & other generally hazardous elements	Van Schaik	U

Resultant negative behavioural embodiments of stress in PLWD in VR

Reis et al. (2013) identified certain virtual reality induced symptoms and effects (VRISE) to be cognizant of during VR play. Dizziness, vertigo, ocular motor disturbance, fatigue and headaches can all be experienced during longer periods of VR play. Kim et al. (2021) documented how overstimulation could lead to negative behaviours including but not limited to complaining, agitation, wandering, hitting, grabbing, pushing, throwing objects, biting, hurting self or others, tearing objects or destroying property, and making physical/verbal sexual advances. The occurrence of these negative behaviours were grouped into behavioural and psychological symptoms of dementia (BPSD) and were often noted as occurring in the day-to-day lives of PLWD and are usually solved by simply removing the psychosocial or environmental risk factors associated with BPSD.



The researchers were able to observe the preceding behaviour to be a reduction in visual alertness and verbal engagement however with no way of intervening or adapting the environment, they had no way of stopping the negative behaviour before it occurred. This suggests the need for an adaptive environment that responds to the overload of the user. (Kim et al., 2021)

As previously stated, McGlynn & Sean (2017) maintain that a balance must be struck in order to avoid this overload. By actively mitigating the overwhelming effects of negative stress, a VR system would maintain the highest level of presence and give the participant the safety and comfort needed to pursue the aforementioned goals through reminiscence.

> Overarching goals for reminiscence in VR include presence, occupation, comfort, inclusion and novelty. Reminiscence can be broken down into 3 forms- place based, object based and interaction based. Guidelines are laid out to combat VRISE and other negative behaviours.

4.2 Design Iterations

Parameter Selection

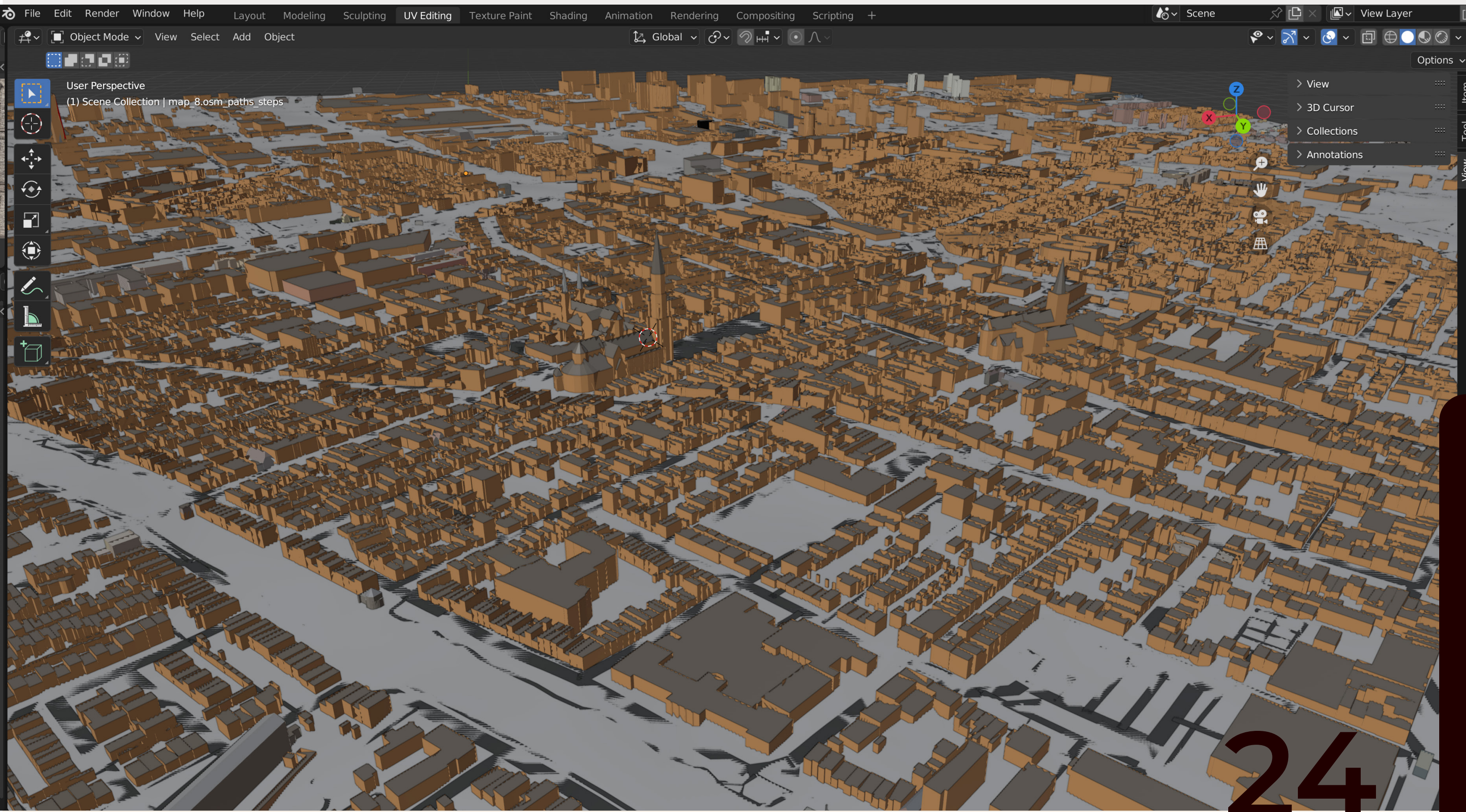
Saredakis et al. (2020) contends that high visual stimulation contributes heavily to stress and ultimately, VRISE. They posit that factors that exacerbate VRISE include audio-visual stimulation, locomotion and exposure times. Content related factors include bright lights and noise as well as fast movements within the visual field. This is supported by Kim et al. (2014) who claimed that rapid vergence-accommodation changes (the asynchronous moving of the eyes to focus on movement) cause visual discomfort- hence amount of visual movement was selected as the first parameter to modulate.

Hall & Buckwalter (1987) documented that PLWD have a reduced stress threshold to many environmental stimuli such as light and sound. Furthermore, Dewing, (2009) maintains that sensory stimulation by way of light and sound can lead to undue stress to PLWD living in dementia care facilities and can lead to BPSD behaviours. Alzheimer's Australia (2004) state that of all stimuli, noise has the most significant and damaging effect on people with dementia.

Therefore sound and light levels were taken as the remaining parameters to vary within the environment. 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 removing the non-player characters (NPC's) within the visual field of the user. Parameters of the VE are modulated via C# scripts loaded in the chosen development software Unity as 'components'.

Development of VR Environment

Initial goals of the study indicated an interest by future participants, as well as relevance to the university's research goals, of developing the city of Delft in the Netherlands as an explorable environment. However upon further research, it was revealed that a more focussed area should be investigated as a location that can be thoroughly explored.



It was estimated through traversal of the virtual map of Delft that within a ten minute session, an estimated region of 300m x 500m could be explored. Rural environments were selected as sites for exploration as it was expressed by care-home employees that many of the older residents have fond memories of a pre-industrialized childhood. This was supported by Van Schaik's (2008) research explaining that urban environments in general should be avoided.

Many towns outside the Randstad (more populated and urbanized section of the Netherlands) were explored and general features were noted including architectural elements.

Dijkdorp

Using the applic
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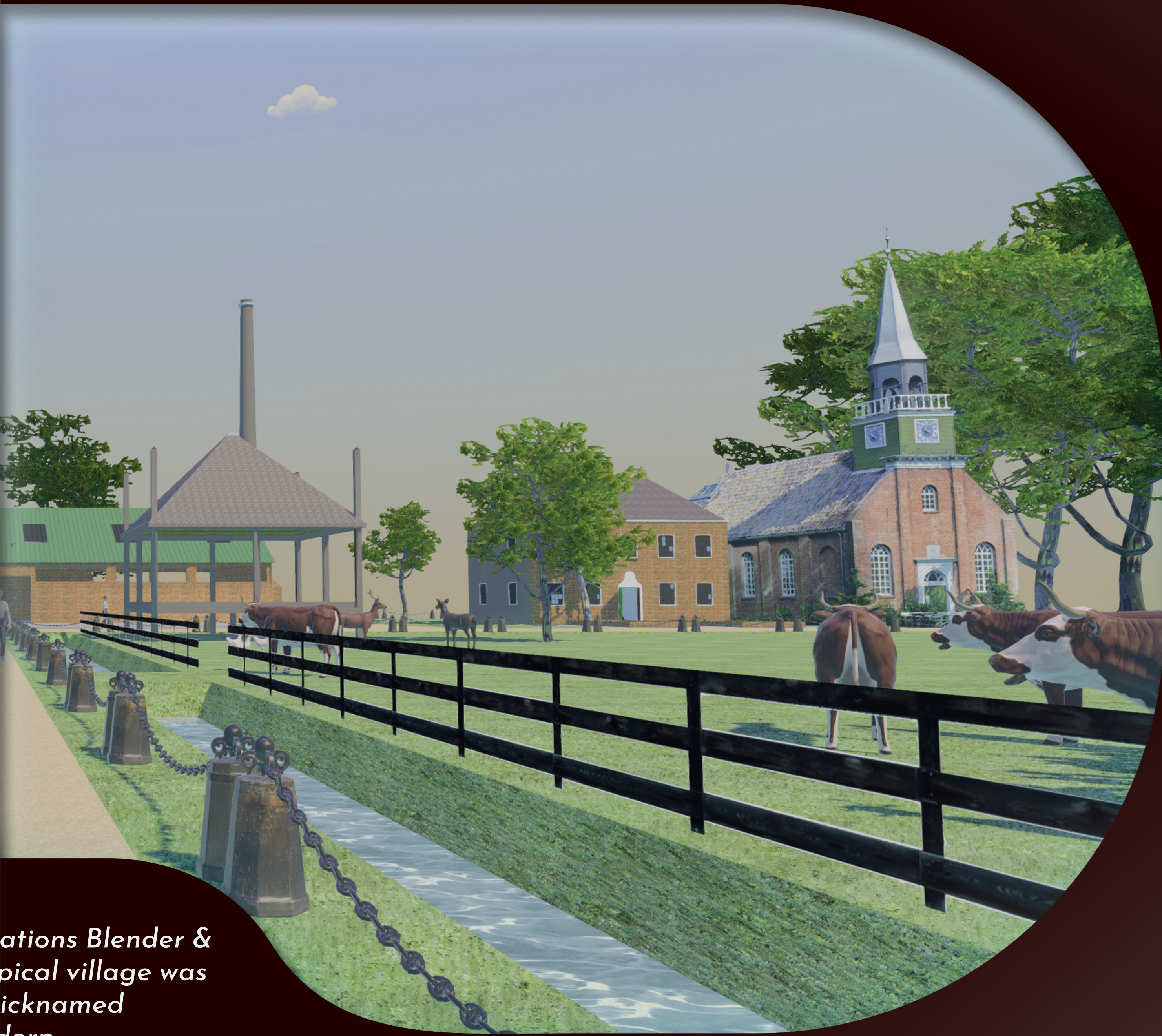

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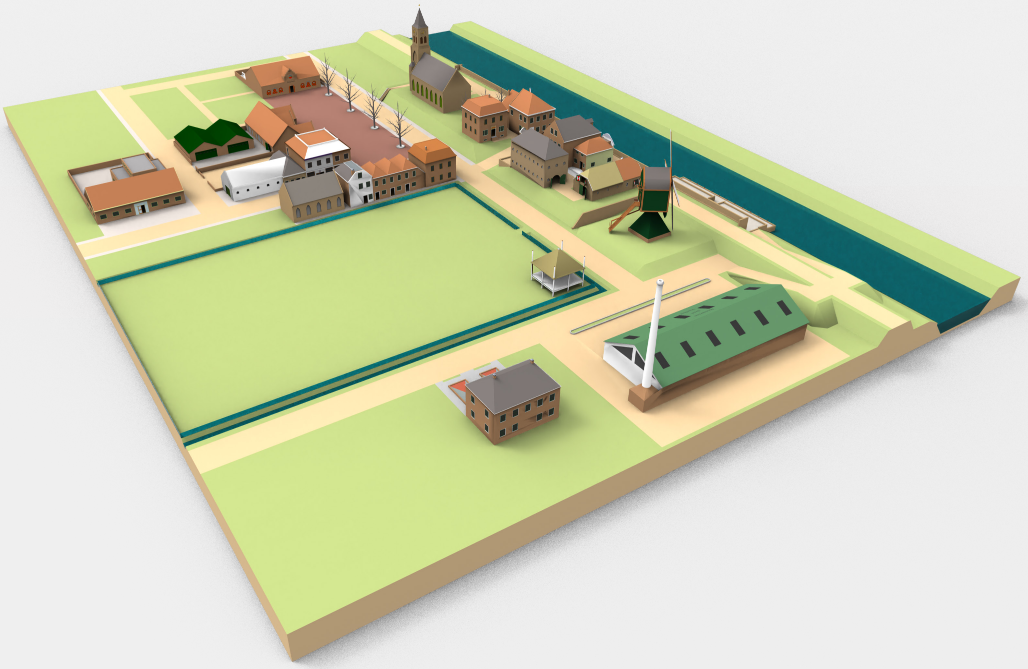
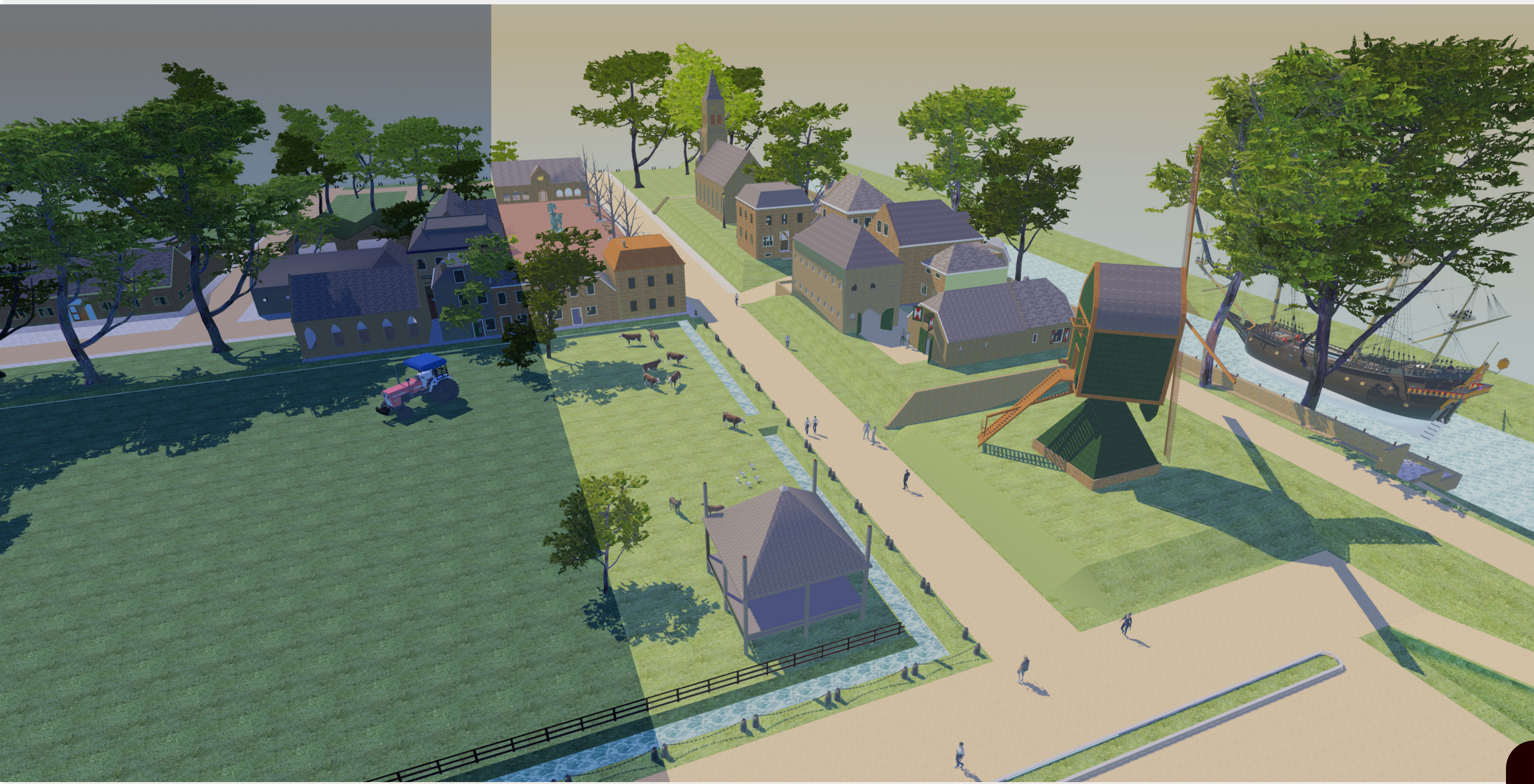
4.2 Design Iterations cont.



Important elements

- *School*
- *Farming areas*
- *Village stage*
- *Large field*
- *Windmill*
- *Church*
- *Village square*

Improvements in realism came with the inclusion of trees that moved in the wind- these were interspersed naturally across the map in areas along the paths that users would be expected to walk down.



Post-Processing

Colour grading, similar to that seen in animated films, was applied as a layer over post-processing to improve the perceived mood of the environment. Warmer and more saturated colours tend to inspire better moods and increases surrealism- an element that Siriaraya & Ang (2014) found to be valued more by participants than realism. The escape from reality appeared to contribute to the novelty felt by participants.

Fauna

The inclusion of idling animals was inspired by Bruun-Pedersen's (2016) guideline regarding active fauna. Animals selected were also narrowed down using what was expected to be seen in rural communities in the Netherlands particularly pertaining to domesticated animals. Chickens were navigated on a random pattern around the map providing a humorous take on quaint village life and providing a unique experience to the user.

Birds

Animated birds were also set on randomised patrol routes that cast shadows on the ground in front of the user. This was done to encourage the user to explore their upper field of vision, this would also inspire the user to set goals such as following the bird or navigating towards objects in the distance.

NPC's

NPC's are varied in their actions in accordance with the aforementioned guidelines. Some are set on patrol routes marked with blue diamonds in figure X while others are set to wander the map randomly. Grouped NPC's have idle animations that show them interacting with each other. This improves the realism of the environment by giving NPC's their own lives and also allows the player to explore the environment without the feeling of observations by the other NPC's.

Music

Background music is present in the environment reminiscent of the Dutch folk genre. The accordion music is often heard and village fairs and other Dutch cultural events. In addition, ambient sounds of water, birdsong and wind noise punctuates the air. Element dependent ambient noise like birdsong is also spatially mapped such that volume diminishes as players move away from the birds- this improves sense of space and presence.

Development of Stress Monitoring Setup

The OpenBCI Ganglion is a 4 channel EMG biosensing device that uses its accompanying software to measure and transmit electrical signals from attached sensors via Bluetooth to the hosting computer (Figure 9, OpenBCI, NY, USA). The OpenBCI platform was chosen for its accessibility of support as well as its ability to process and communicate data in real time. The platform iMotions was considered but ultimately rejected because of its lack of real-time data accessibility. Manufacturers Emteq, produce a similar integration of facial EMG sensors into the a Pico VR headset however were ultimately rejected because their post-processing software requires cloud operability and in its current stage cannot be accessed real-time (Figure 10, Emteq, 2022).

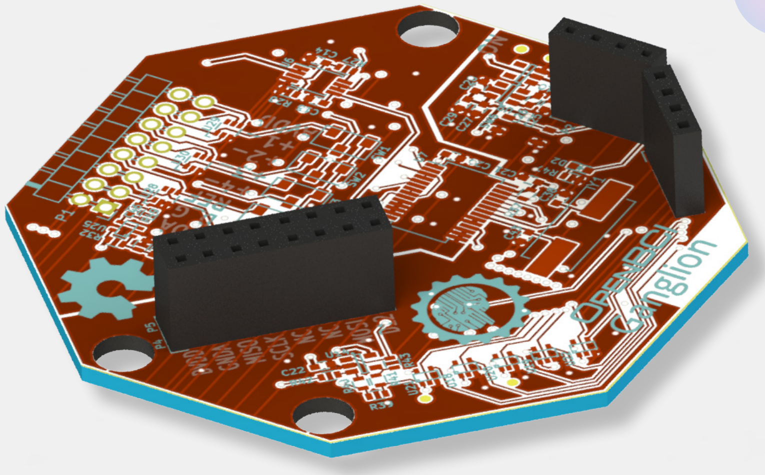


Figure 9: OpenBCI Ganglion (OpenBCI, 2021)

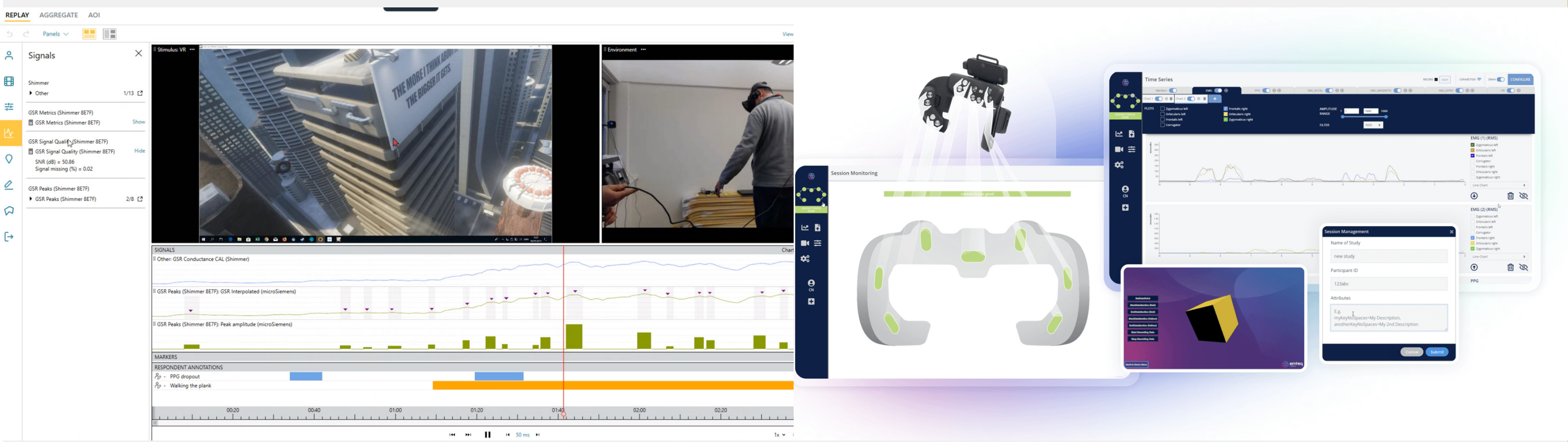
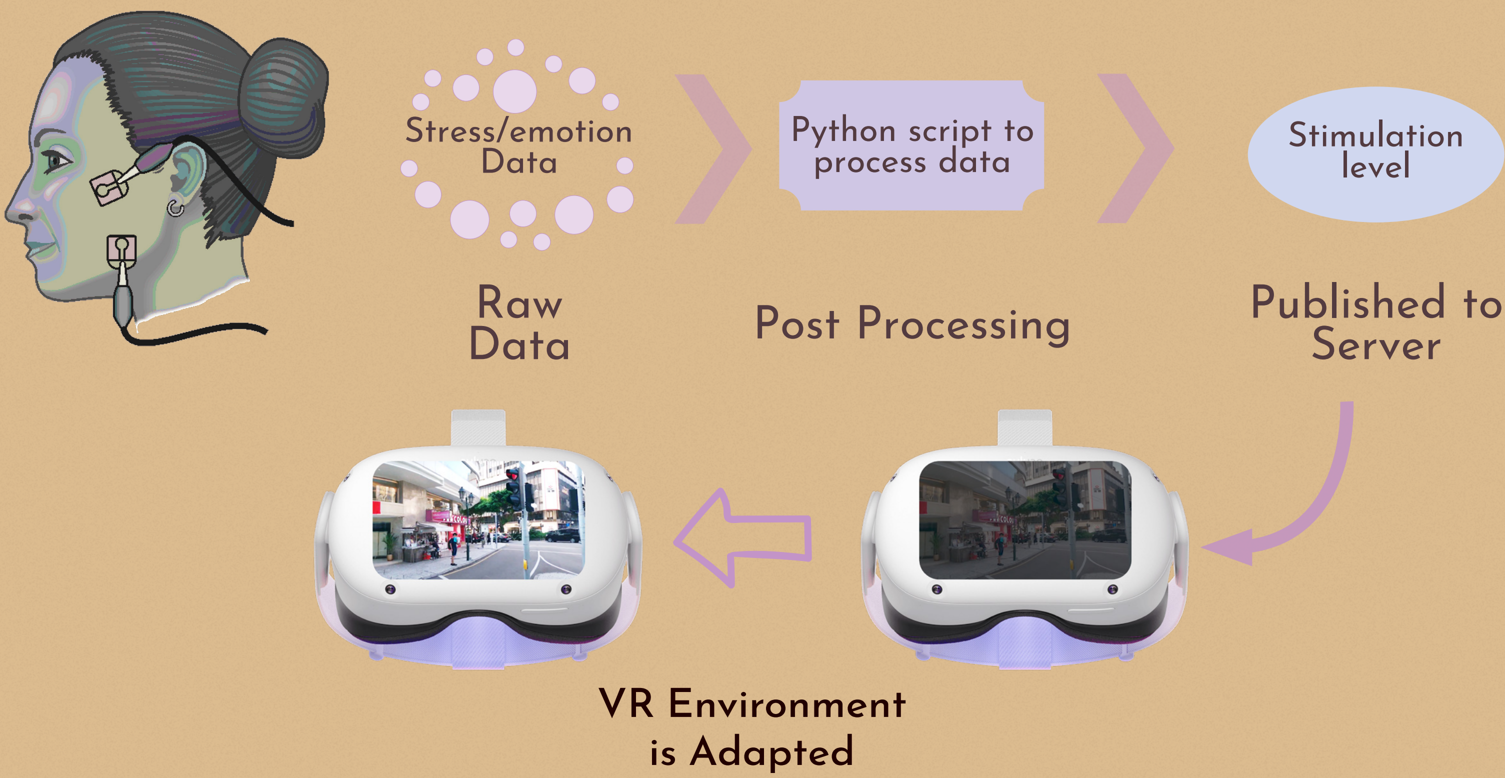


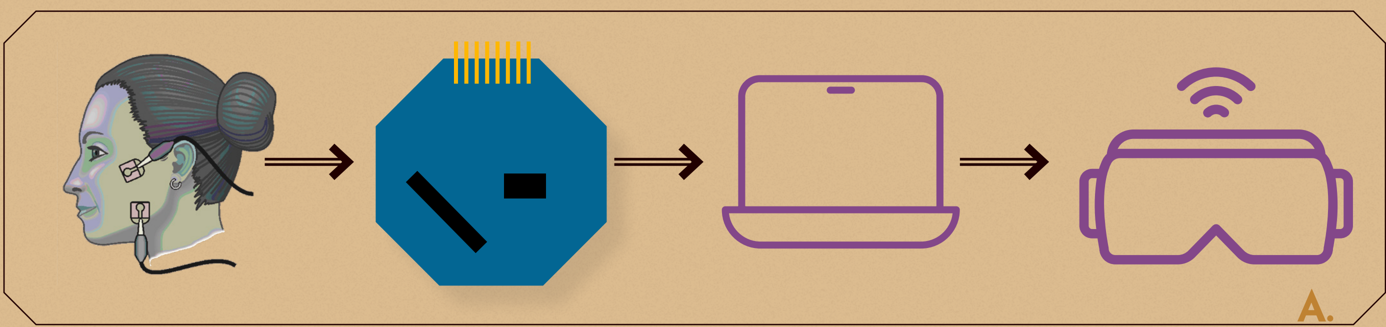
Figure 10: Emteq Pro (Emteq, 2022)

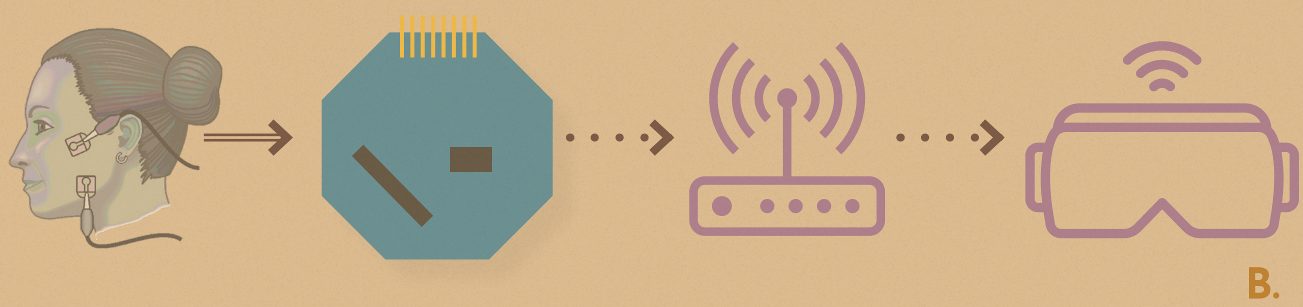
Attaching the positive and negative ECG quality electrodes to the trapezius feeds EMG signals to the OpenBCI board which will be filtered into values indicating tension/stress. The gold capped positive and negative electrodes are adhered directly to the foam insert of the VR headset to ensure consistent contact with the zygomaticus muscle in the cheek. A reference electrode pair is connected to the earlobe where the non-muscular tissue provides a reference signal.

An overview of system architecture was planned according to the scope of the project.



A fully wireless version of the product A was considered but ultimately rejected in favour of the wired version B for system simplicity and integrity of transmitted data.





Multiple controller methods were attempted but ultimately rejected in favour of control using the Oculus controller itself.

Data Processing Logic

The OpenBCI GUI hosted performs thresholding values within the first 1 minute of the control section of the test- allowing for exposure to high stimulation as well as 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 script also held on the laptop- this script also stores the data anonymously.

After signal processing using a pre-calibrated moving average window of between 2-5 seconds depending on the user's EMG fluctuation frequency. If zygomaticus muscle activation is above a minimum of 30%, then whatever arousal is detected 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- these are scaled to the level of stress detected. The following states were considered as in figure X.

The Python script sends an output to the Unity program that indicates at what level of intervention each intervening parameter should be scaled to.

Table 1

Emotion	Arousal	Cheek Emotion	Resultant Classification	Output
	Low	>30%	Happy/Neutral	0
	Low	<30%	Under-Stimulated	0.1
	High	>30%	Excited	0
	High	<30%	Stressed	High

Note. Table showing classification of emotion based on zygomaticus and trapezius contraction

Takeaways

Overarching goals for reminiscence in VR include presence, occupation, comfort, inclusion and novelty. Reminiscence can be broken down into 3 forms- place based, object based and interaction based. Guidelines are laid out to combat VRISE and other negative behaviours.

The VR environment was developed taking into consideration the guidelines ascertained from previous literature.

Raw data of emotion and stress are fed through the OpenBCI GUI to a Python script that applies post-processing filters to clean the data and sort the data into emotional states. These emotional states dictate the level of parameter modulation experienced by the participants in the virtual environment.

Chapter 5.

Study Design

Chapter Introduction

Research questions are devised in accordance with previous literature research. The participant group is identified and the procedure and setup outlined.

Study Design

5.1 Research Question Substantiation

Research questions were devised in order to limit the scope of study to focus on the effects of aforementioned parameter modulation as well as the effect of the overall VR experience.

Previous literature tells us that non-pharmacological treatments, specifically reminiscence therapy is effective at engaging PLWD and providing them with a sense of emotional fulfilment. Elements of art, music & drama therapy were explored and integrated into the development of VR reminiscence therapy. Various literature sources provided evidence that immersion is a key component and with certain goals in mind, guidelines were developed. Breaks in this immersion can reduce the effectiveness of the overall experience and were most often caused by overstimulation of audio, visual and movement levels.

These were embodied as scripts within the VR game hosting software modulated in accordance with stress values sensed by the zygomaticus and trapezius muscles. In previous studies surrounding this topic, negative behaviours were observed after the fact and suggestions were made after the conclusion of the study. However as of yet, there have been no embodiments of a system that adapts itself in real-time to reduce stress and negative emotions felt by the user. This resulted in the formulation of the first research question.

By implementing guidelines resultant of the literature review, we hope to generate an experience that embodies the most successful components of art, music and drama therapy in a virtual experience that promotes reminiscence. This resulted in the formulation of the second research question.

Does the real-time adaptation of a virtual reality environment decrease the stress felt by the participants in said environment?

Does the presentation of familiar environments, in a virtual reality context, to participants with dementia promote feelings of nostalgia and allow for reminiscence?

5.2 Study Parameters

Participants

A pilot test was organised using participants 81, 83 and 62 years old without dementia. They were recruited through personal approach and were able to complete the full test without issue. The only disabilities noted were common disabilities experienced by those in their age group- such as difficulty in prolonged movement

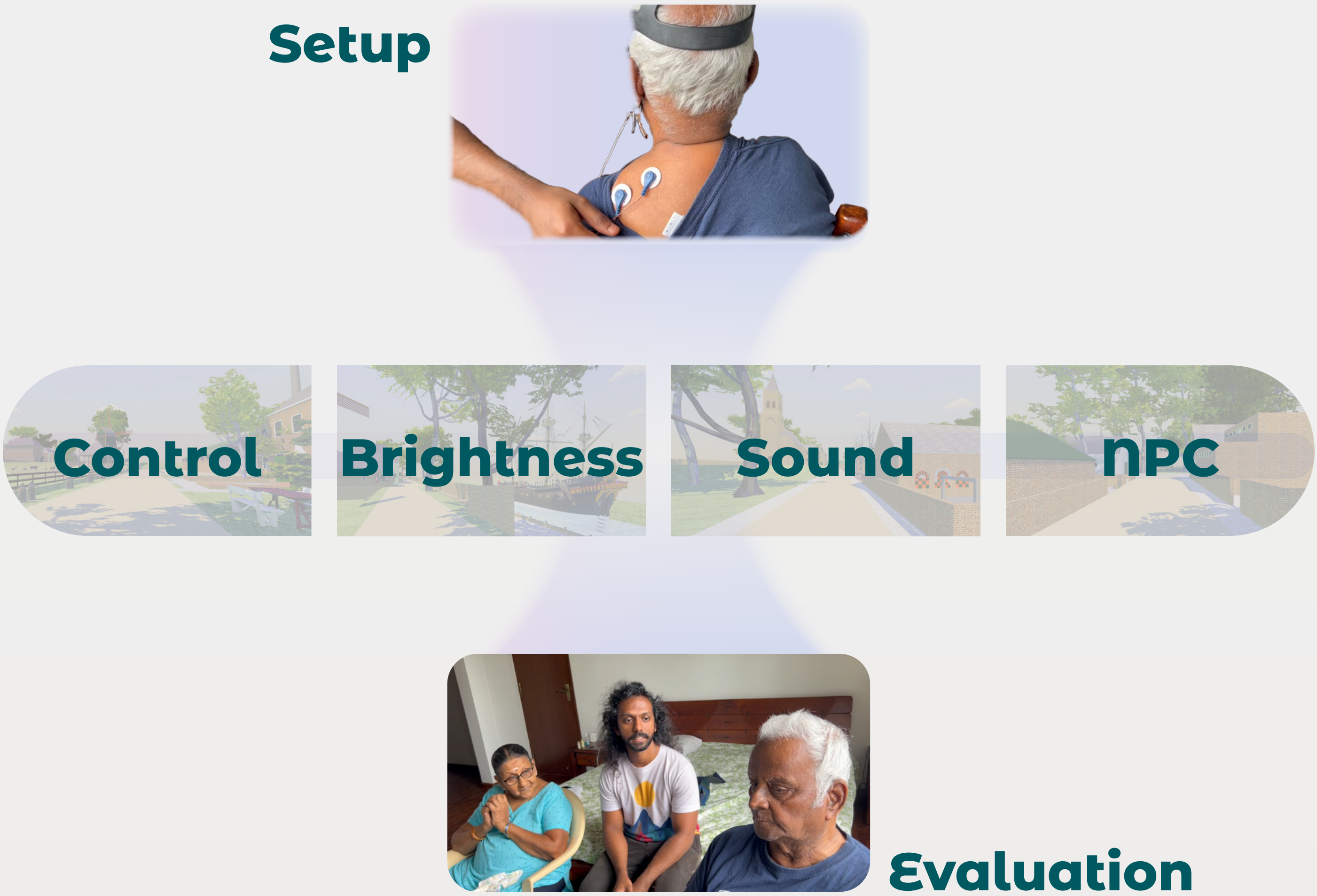
Before testing occurred, the user study was approved by the TU Delft Human Research Ethics committee and executed in accordance to our University's ethics and data management guidelines. No compensation was offered to the participants of the study. The experiment was video recorded for posterity.

Unfortunately, due to logistical difficulties, a study with PLWD participants could not be organised. The implications on the results of this experiment is discussed in later sections.

5.3 Study Parameters cont.

Procedure

In preparation for the test, participants were asked to sign an informed consent form which includes information regarding the data management and privacy plan. They were then briefed about the procedure of the test during the setup of the electrodes.



The test was divided into 4 sections beginning with 2.5 minutes of a control stage in which general exploration was conducted without any parameter modulation. The following stages were NPC modulation, brightness modulation and sound modulation- the order of which were randomised between the participants so that learning of controls did not factor into the stress levels of the participants. Between each 2.5 minute section of the experiment, 10-20 seconds of semi-structured interviewing was conducted in which participants were asked to describe and comment on any changes they witnessed and any feelings that arose from the stage.

The 10 minute test was then followed by 2 minutes of general questioning in which the qualitative responses were gathered through semi-structured conversation in which a general understanding of fulfilment of the criterion presence, comfort, identity, occupation, novelty and inclusion were assessed. The caretaker was present during the entirety of the study tasked with constantly monitoring participants for VRISE or any other signs of discomfort. Participants were vetted and rejected if signs of severely diminished sight or hearing were present.

Apparatus and Setup

The embodied system consists of three main hardware items- the OpenBCI Ganglion board used sensors to gather data, the Oculus Quest 1 head mounted display (HMD) and the laptop computer which hosts all programs. The Ganglion communicates with the computer via bluetooth which in turn drives the VR environment on the Oculus Quest through a USB-C cable.

Figure 11: Sustem infrastructure

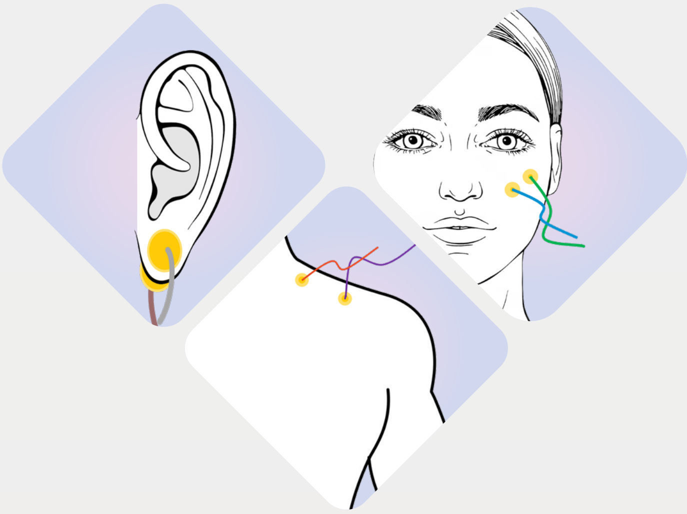


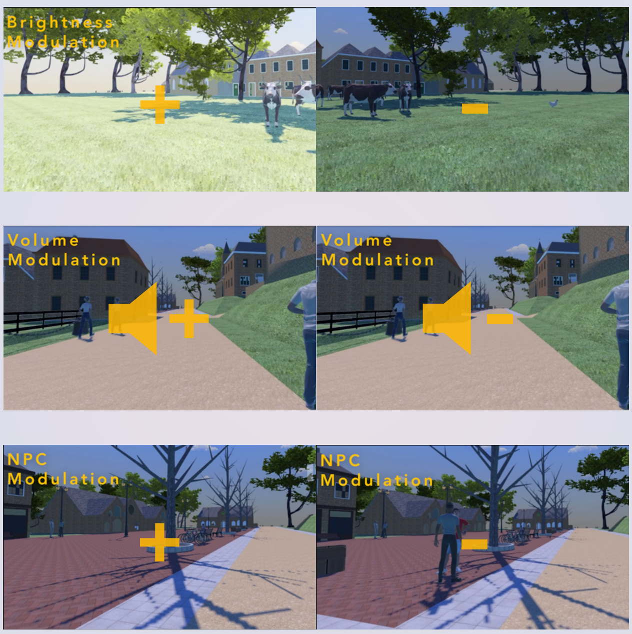
Figure 12: Electrode application regions

Adhesive ECG type electrodes were placed on the participant's trapezius muscle on the non-dominant side of the body as in figure 12. A set of gold cap electrodes is connected to the earlobe using a clip to provide the reference feed.

The aforementioned electrodes were connected to the OpenBCI Ganglion in combination with the gold cap electrodes previously fastened to the 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 lab-streaming layer (LSL) to a local network at 50Hz.

The Unity program is then 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 anonymised participant number at the rate of 0.5 Hz..

Modulation Methods



High stress decreased brightness
Low stress increased brightness.

High stress decreased volume
Low stress increased volume.

High stress decreased number of NPC's.
Low stress returned number of NPC.

Chapter 6.

Results

Chapter Introduction

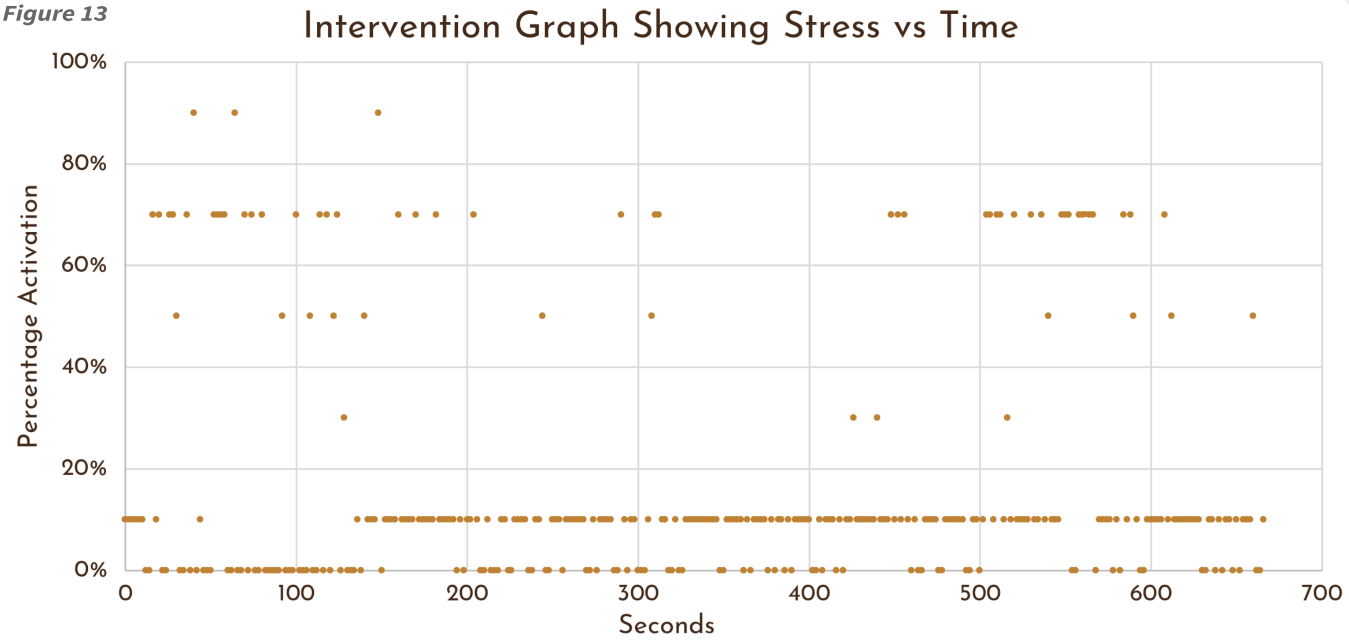
Stress and emotion data are analysed from a quantitative lens. Qualitative data provided contextual and experiential findings.

Results

6.1 Quantitative

The quantitative data presented are the total data gathered over the 10 minute active testing session divided into 2.5 minutes (150 seconds) for each stage. The piecewise graphs show the changes in stress and happiness over the course of each modulation parameter while the intervention graph 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. Since the order that the stages were shown to the participants were randomized apart from the control stage being first, the average impact of interventions per stage could not have been affected by their order. The data was collected at a rate of 0.5 Hz, each section of 150 seconds containing 75 data points- one every 2 seconds.

Figure 13



Note. Interventions recorded within the first control stage were hypothetical interventions to show where an intervention would occur

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.

Figure 13 shows at which points the system intervened in the virtual environment and by what scale. The system refrains from intervening in the cases classified as 'happy' with both low and high arousal. Those moments are represented in the graph by the points of 0% activation. Neutrality was classified as less than 30% activation of the zygomaticus muscle and between 0-20% activation of the trapezius- the lowest activation band. These are grouped in the graph as the points of 10% activation. The remaining activation points are the moments in which modulation of the chosen parameters was present to a level scaled to the perceived stress of the moment. Both arousal and emotion are depicted separately in figure 14-17.

Average stress was highest at the beginning of the experiment during the control stage in which no modulation was provided. In this stage, the lowest number of (hypothetical) interventions were recorded. The lowest stress levels were recorded in the volume modulation stage while this stage observed the highest number of interventions. This shows a minor inverse correlation between 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. As seen in figure 13, the points of change between stages is clearly visible in the stress values at 150 second intervals.

Figure 14

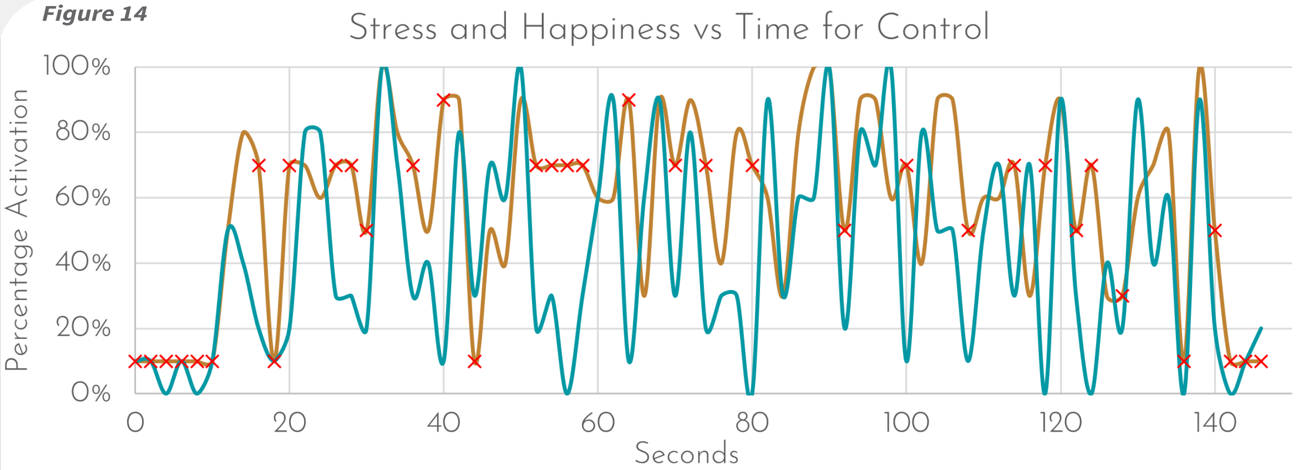


Figure 15

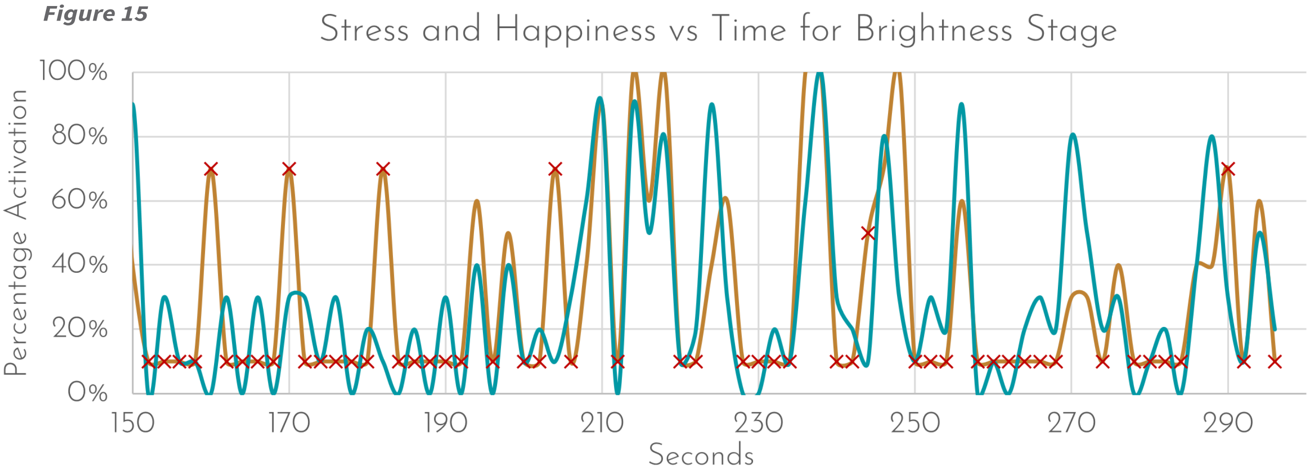


Figure 16

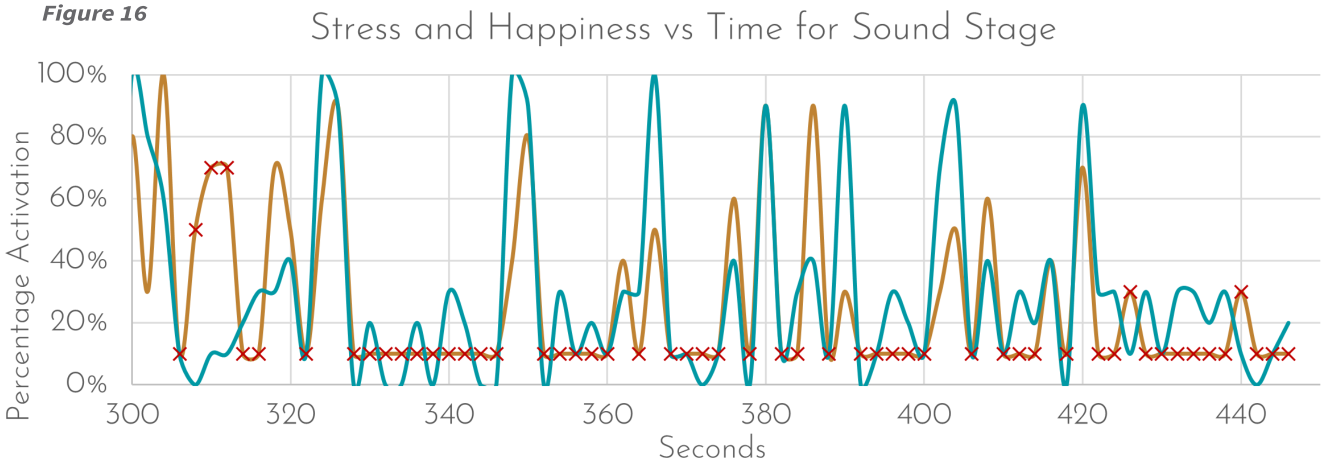
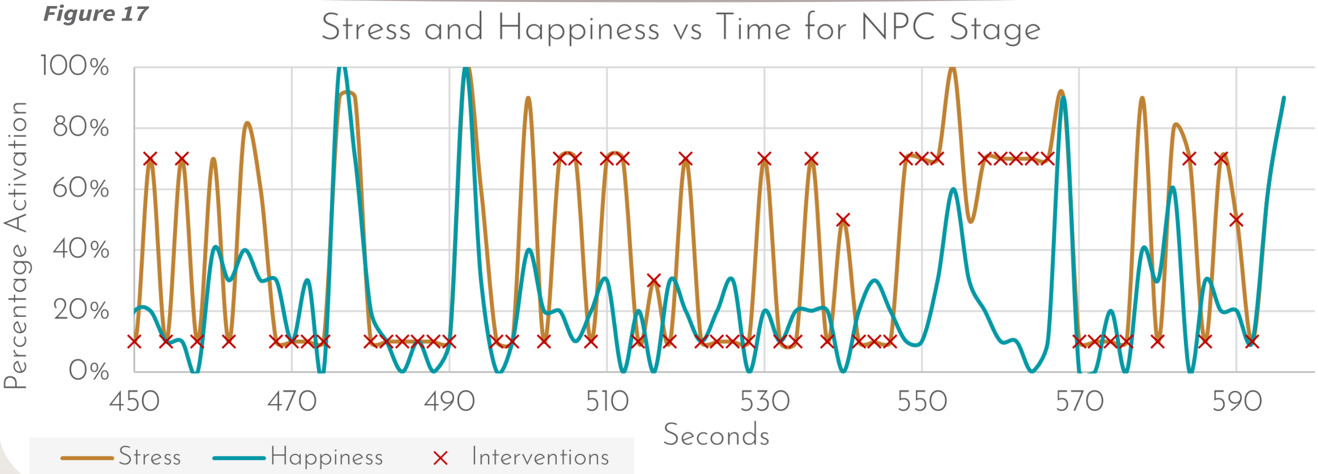


Figure 17



Note. Separated values of stress and happiness divided into each stage of the experiment.

Figure 18 **Graph Showing Distribution of Intervention levels for All Stages**

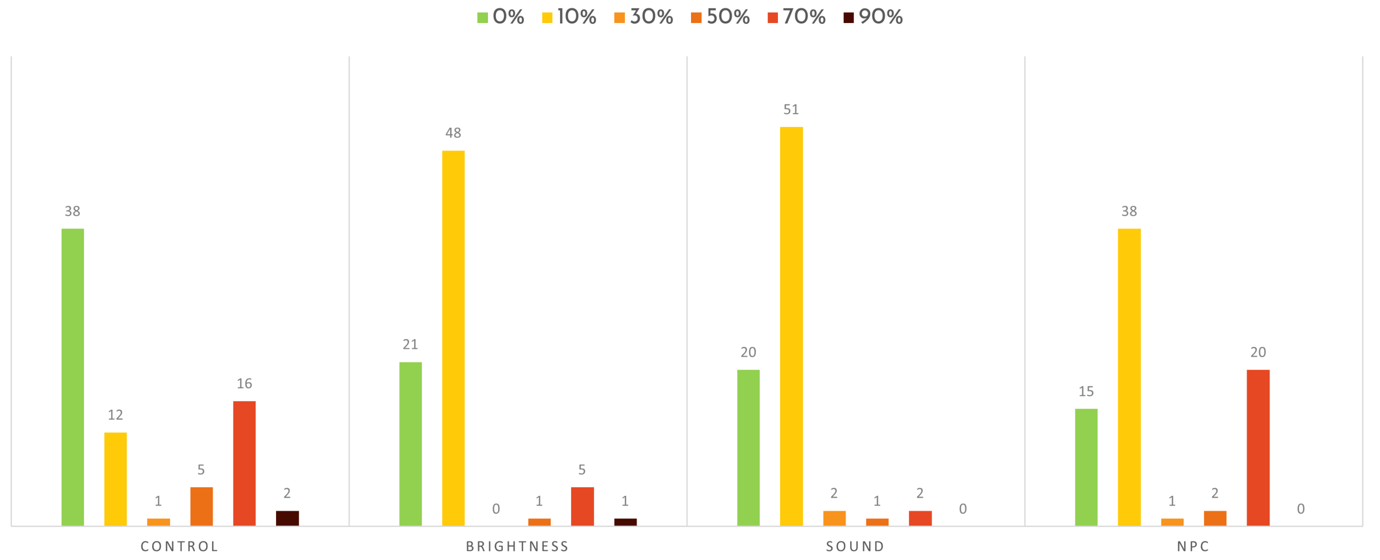
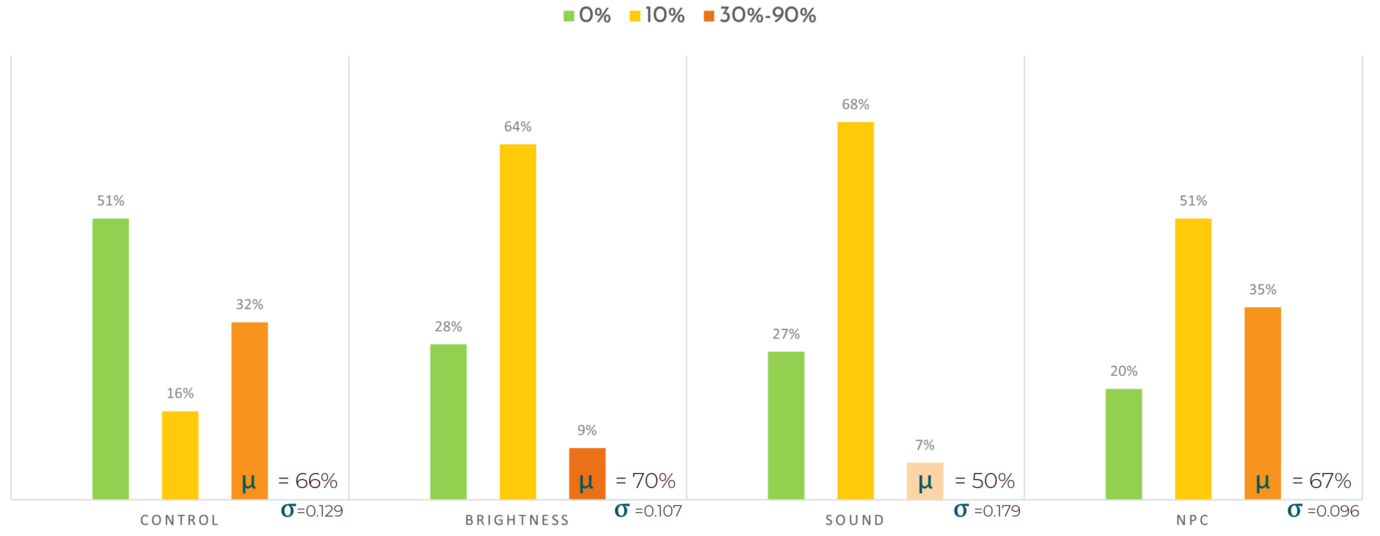
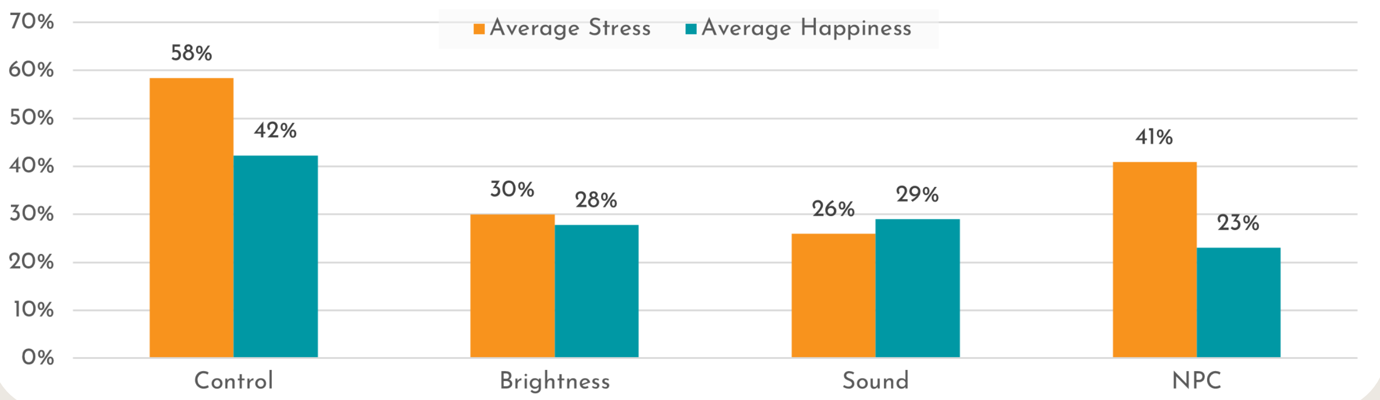


Figure 19 **Graph Showing Distribution of 3 Categories of Intervention Levels as Percentages of All Moments**



Note. Mean and standard deviation only pertain to the 30%-90% range

Figure 20 **Graph Showing Average Stress and Happiness for All Stages**



6.2 Quantitative cont.

Table 2

	Average Stress	Average Happiness	Interventions
Control	58%	42%	37%*
Brightness	30%	28%	54
Sound	26%	29%	55
NPC	41%	23%	52

***Note.** Table showing summary data of average happiness and stress for each stage.*
**37 intervention points were detected but no interventions were made during this stage*

Despite the lower latency of the system compared to other stress measurement systems, it is evident that interventions took one interval of data gathering (in this experiment 2 second intervals) to take effect in lowering stress. This is particularly evident between the 150-190 second mark in which sustained portions of low stress is punctuated by peaks of stress at 70% activation. This means that peaks of stress were modulated by the system at a 0.7 scale and resulted in momentary low stress periods (roughly 10 second intervals). This trend presented itself more strongly in the modulated periods in contrast with strongly fluctuating stress levels during the control stage. Although observable, it is difficult to assign causation of lower stress with interventions.

Interesting trends are observed when classifying the interventions themselves into their respective degree of intervention- 0%, 10%, 30%, 50%, 70% and 90%. As per table 1, interventions happened according to emotional states of the participants. The 'happy' state received 0% intervention, 'neutral' state received 10% intervention and all other emotional states were classified as 'stress' and received higher scaled interventions. Figure X6 shows a distribution of what levels of interventions were observed per stage. Only three moments of the 90% stress state occurred over the course of the whole experiment- the majority of the negative stress interventions happened at a 70% scale. 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 its testing stage.

Brightness and sound modulation had a fairly distributed range of interventions with sound modulation having the most even distribution as evidenced by its standard deviation being the highest among all stages (seen in figure 18). To compare the occurrence of all three emotion occurrences, figure 19 shows the distribution of emotion while grouping together all negative stress interventions. 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.

The control stage had the highest number of documented 'happy' states, the brightness and sound stages observed 20 & 21 moments of 'happiness' respectively while NPC modulation observed only 15 moments of 'happiness'. Meaning in the NPC modulation mode only 20% of the time was spent in 'happiness' mode. 'Neutral' moments were more varied in number amongst the tests with the most observed during the sound modulation section and the lowest observed during the control section. In summation, it is observed amongst the modulated stages, that during the sound modulation stage, the highest happiness level is observed while maintaining the lowest average stress. During the NPC modulation stage the highest average stress is observed while displaying the lowest average happiness- the statistical reason for this being the larger presence of neutral and stressful moments.

6.2 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, realness was greatly improved by NPC's, trees and other visible movement. They reported however that hand graphics would improve immersion. Participants reported that the experience was comfortable and informed the researchers that they had no history of motion sickness outside VR. Identity was determined to be out of scope since the participant's own character cannot be seen and the game included no interactions with environment.

Upbringing location played a part in relevance as the urban raised participant was less interested in the natural aspects by the end of the experience. Participants found the experience to be very novel, they however admitted that their lack of experience with computer games may have caused this. One participant compared it to walkthrough videos they had seen of travel blogs. Participants were engaged and occupied throughout but reported felt bored towards the last section as exploration without activities was difficult to facilitate.

Participants felt included overall, however participants who struggled to use controller felt less engaged as the facilitator needed to take over controls. Remaining participants still needed clues given by the researchers such as "Shall we go see the church?". A number of moments of reminiscence were also observed amongst all participants often motivated by the sight of small features such as moving bird or animals.

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 NPC's 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 compared to the control stage, all participants were in agreement that they preferred the modulated stages.

Chapter 7.

Discussion

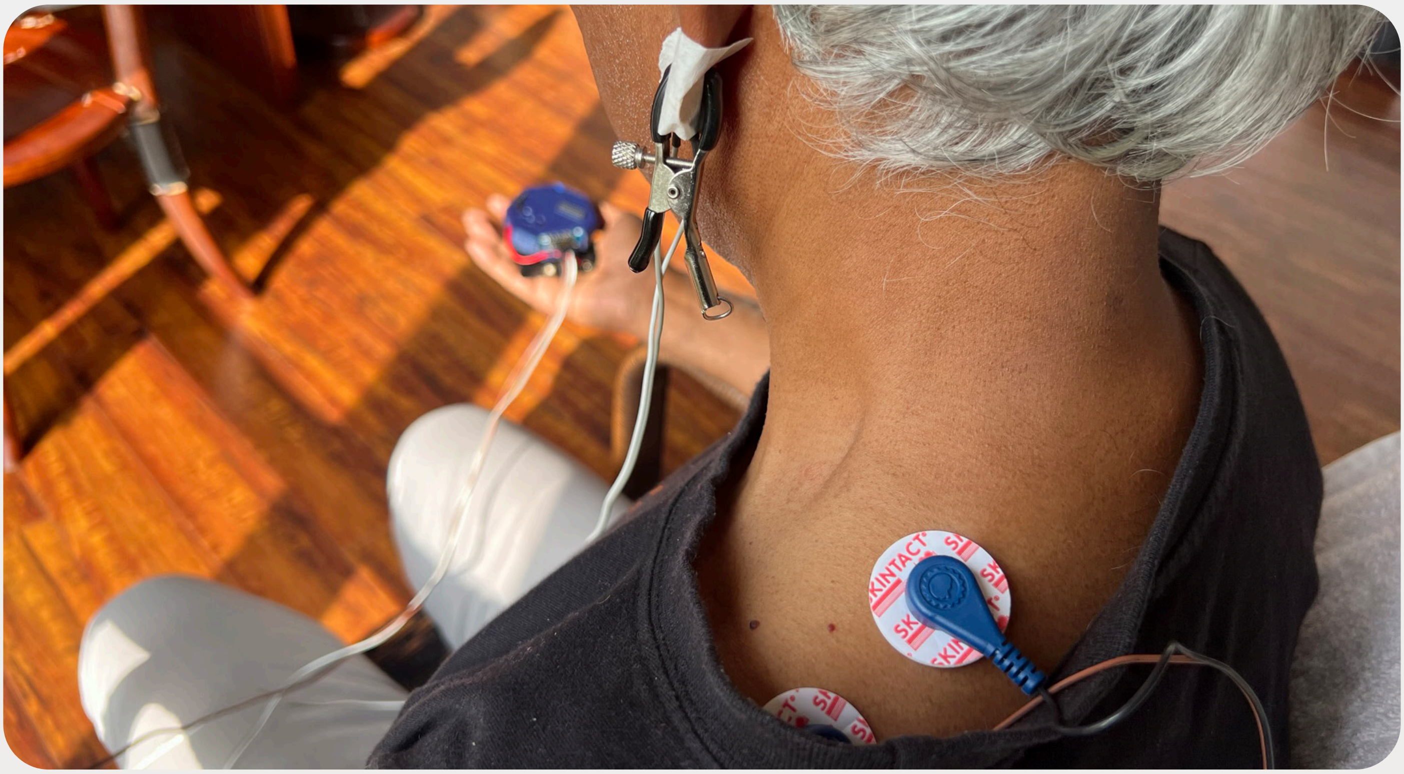
Chapter Introduction

Findings are discussed and implications are derived from the results. Limitations of the current study are outlined and possible future work opportunities are explored. Limitations of using an analagous group are considered and an improved final concept is presented.. Finally, the discussion is concluded.

Discussion

7.1 Findings

While analysing the results, it is important to note the two main questions addressed in the experiment. Firstly relating to the first research question, whether the modulation stages did in fact show decreased stress levels over the control stage. Secondly, amongst the three parameters of brightness, sound and NPC movement, which modulating parameter was the most effective at reducing stress.



Although stress was highest in the control stage, requiring the lowest number of moments where intervention-necessitating negative stress could have occurred, this could partially be explained by the fact that the control stage was the first time the participants experienced the environments. Given that the participants were new to the experience of virtual reality as a technology, a certain amount of tension can be expected during period in which participants get used to the technology. The novelty of the experience could also at least partially explain the significantly higher average happiness level in which participants spent 51% of the stage in 'happy' moments. This could be addressed by having a second control stage at the end of the experiment akin to a cool-down stage which could also speak to the possibility of boredom experienced by the participants- this will be elaborated on in the following section.

Although the difference in number of interventions (both neutral and stress moments) were minor across the three modulated stages, there was an observable drop in the average stress from the non-modulated control stage and the modulated stages. When comparing stress levels of the individual participants, it was observed that there was a discrete reduction in stress between the non-modulated and modulated stages as opposed to a gradual decline in stress. A gradual decline would indicate the subject's decline in stress would be more correlated with their acclimatization to the system as opposed to discrete decline supporting the effectiveness of having modulation stages at all.

The fact that moments of 90% stress levels were only observed in three moments throughout the test speaks to accuracy of the thresholding system as well as the ability of the interventions to stop an increase in stress to this level before it occurs. Since the majority of stressful moments were observed at the 70% mark, it is possible that there exists a certain amount of time that the interventions take to take effect at reducing stress levels. Wilson et. al (2005) proves that elderly, particularly less cognitively seniors, experience sharper mood changes and have a less constant mood. Therefore it is possible that a lower system latency would allow quicker onsets of intervention moments and therefore could address rising stress before it reaches the 70% mark that we see most commonly in the data.

This could also form a possible explanation as to why the mean stress level amongst negative stress moments is lowest during the sound modulation stage. It is possible that sound modulation allowed for a quicker reduction in stress before it reached a 70% stress level. This is further evidenced by the fact that the distribution of levels of intervention within the 30%-90% band is far more even than any of the other stages. In figure 19, the sound modulation stage is shown to have the highest standard deviation of all the stages' negative stress level data between 30%-90% intervention.

To evaluate the effectiveness of the three stages, we note that the sound stage had the lowest average stress of all four stages and the highest average happiness of the three modulated stages. NPC modulation in contrast had the highest stress amongst the modulated stages and the lowest average happiness of all four stages. With the lowest number of stressful interventions observed, sound also required the lowest scale of intervention averaging 50%. NPC modulation in comparison had by far the most occurrences of negative interventions with 35% of the stage spent in the stress state compared to just 7% stress time in the sound stage. NPC modulation also had the lowest standard deviation of the scale of stress interventions among all four stages- possibly showing that the parameter of NPC modulation has a weaker effect on reducing stress levels compared to the sound stage which has the strongest effect.

From the qualitative data, it is also evident that participants preferred the gentler onset of the sound interventions in contrast to the unnatural appearing interventions brought on in the NPC modulation stage. Intervention. However, qualitative results indicate that our the system as a whole contributes to a successful stimulation of reminiscence and feelings of nostalgia as reported by (Siriaraya & Ang, 2014, Kim et al, 2021, van Schaik, 2008, McGlynn & Sean, 2017).

Overall, the early results promote safer VR experiences, particularly for the cognitively declining and/or stress-prone elderly PLWD. 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, facilities could use VR and decrease the amount of one-on-one time required between staff and the elderly as well as facilitate conversations between care home residents (Intriago, 2017). Prior research already showed that by improving presence and immersion in improving the mental health of care home residents without dementia exemplifies how VR can elevate this experience (Gowans, 2004).

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. Offering elderly users a safe recreational activity, such as an adaptive VR experience, could thus alleviate carers. (Lindeza 2020). 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 PLWD.

7.2 Limitations and Future Work Scope

With the current sample size, it is difficult to point to particular sets of data as evidence of the direct effect of an intervention to reduce stress, however patterns such as that in the 150 -190 second band of data are markers for this behaviour. Increasing sample size and contextually analysing these particular moments could be useful to identify whether it was truly the intervention that caused the reduction in stress or other factors. With improvements in data filtering to decrease noise, decreasing the latency below 2 seconds would enable finer analysis of the effective difference between the scale of intervention. The current 6 levels of intervention could eventually be expanded to a continuous adaptation. However, further studies should also be performed to observe the effects of experimental parameters such as frequency of intervention and the effect of discrete versus continuous intervention.

While results showed that sound modulation was observably more correlated with a decrease in stress than the other parameters tested, there are far more parameters that could have an effect on stress levels. For example, parameters such as perceived time of day in the virtual environment could be tested to showcase the principle of 'sundowning'- described by Canevelli et. al. (2016) as the emergence or worsening of stress symptomatic behaviour. This could be taken one step further by combining modulation parameters to identify a balance between decreasing stress levels and the noticeability of these changes by the user. It could be possible that combining too many parameters in a system that modulated both brightness and sound would cause overstimulation in the participant.

The implementation of a cooldown stage at the end of the experiment would aid in the refining of data and learnings from the data. Since the control stage had to remain at the beginning of the experiment so as to decrease the influence of novelty on the modulated stages, it is difficult to compare the validity of having modulation on the system at all. By implementing a cooldown stage at the end of the experiment, the impact of novelty at the beginning of the experiment and boredom at the end could be used to justify the validity of the modulated stages.

During participant recruitment, we limited the scope to members of the GDS 3-4 dementia progression level. Later stages of dementia can lead to increased apathy, thus, further research is needed to determine the applicability of our intervention for this group (Kumfor, 2018). Furthermore, the scalability of our system should be investigated further. Siriaraya observed that personally irrelevant elements of the VR experience reduced overall immersion (Siriaraya & Ang, 2014). 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) similar to prior literature's identification of certain natural elements to be universally attractive (Bruun-Pedersen, 2016).

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 VR experience by (Kim et al., 2021). Further exploration of modes of interaction and the creation of interaction-based challenges and motivations could lead to a more engaging and inclusive design.

Currently, the EMG system only operates on a bimodal basis comparing the detection of joy and stress. Other facial muscles such as the corrugator supercilia have been identified to be indicative of anger (Tian, 2001). Having a more detailed overview of emotion could lead to a clearer picture of which elements should be promoted in importance, leading to greater immersion. The higher latency technologies of EDA and ECG could factor into training algorithms that identify states of high stress in EMG. These systems could also act as a fail-safe mechanism to replace the EMG-based modulation systems should there be a fault.

7.2 Limitations and Future Work Scope cont.

Context aware interventions could be a strong benefit to the system. In all modulation stages, the most common emotion by a factor of 2 was the neutral state. It is difficult to predict the effect that having a large number of neutral states has on enjoyability of the experience as the neutral state in the circumplex model encompasses many emotions. This is especially true as the current form of the EMG system only captures activations of the zygomaticus muscle. For example, both doubt and diligence are classified in the circumplex model as neutral state emotions in both arousal and valence. However both these emotions are important to the pursuing of curiosity and unfortunately, in the current form of the system, indistinguishable from boredom. Limiting the EMG system is the fact that these emotions are displayed using the facial muscles of the orbicularis oris and the depressor labii inferioris moving the lower lip according to Youn et al. (2012). Expanding the number of facial muscle sensors would not assist in differentiating these emotions and therefore it can be surmised that some form of context aware intervention is required. This could come in the form of speech recognition in tandem with natural language processing to provide nuance within emotions identified by the EMG system.

A certain percentage of neutral states should also be accepted by the virtual system as it is unfeasible and possibly overstimulating to have an experience made up exclusively of happy moments. This is supported by Hodge et al. (2018) who maintains that variety of experience is important to prevent the onset of boredom. Assumptions can be tested that may provide some nuance; such as assuming that users are less likely to smile while speaking because as Gaudy et al. (2000) proves, activating both the zygomaticus and masseter (jaw) muscles require significant effort. Therefore an acceptable portion of expected neutral states can be developed per participant- this could inform future improvements to the virtual experience.

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. The primary beneficiaries of our study are elderly users who are unfamiliar with VR and prone to stress. 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.

Hopefully, these 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.

7.3 Comparing the Analagous Sample Group to Target Group

Care was taken to select participants within the age group of the target group of GDS stage 3-4 elderly participants with dementia. The participants all had mild physical impediments typical of the age group- mainly difficulties with sustained muscle movement. Therefore it can be said that this study accurately addresses any ergonomic concerns fairly well. However the key difference between the analogous sample group and the target group was the lack of any diagnosed dementia symptoms. It is imperative that predictions are made for how the target group would react under the same experiment structure and how the experiment can be adapted in the future for them.

McGlynn and Sean (2017) posit that source memory difficulty is a key inhibitor for PLWD in VR. Meaning that users may recall having seen an element of the environment before but are unable to remember where this memory comes from. The virtual experience was designed in a free-roam gameplay dynamic which encourages self-discovery and therefore has no possibility punishment in the case of memory lapses. However it is expected that stressful moments will develop around the moments where source memory is called into question. Increased average stress across all stages can be expected as well because, as Bruun-Pedersen (2016) contends, technology adoption amongst PLWD is slower. The aim of introducing VR technology to PLWD at GDS stage 3-4 however is to help them develop the skills to safely use the VR device on their own when their dementia progresses. Therefore, an argument can be made that the prevalence of stress factors will reduce as the PLWD develop experience with the system.

This is where context based adaptation could be of value to the virtual experience. Drama therapy studies such as that of Jaaniste et al. stress the importance of a facilitator to avoid peak stressful moments during virtual experiences. If a virtual facilitator was integrated into the system to indicate moments of stress regarding issues such as source memory failures, overall stress levels could be reduced to the levels seen in this study.

The aforementioned punishment-avoidant aspects of the free-roam game architecture also addresses other dementia related cognitive issues such as difficulty with visual and spatial abilities resulting in the participants getting lost in the environment. In fact wandering behaviour is considered a key indicator of early onset dementia- therefore it is expected that wandering behaviour in-game would not arouse stress in the PLWD. Complex tasks that require problem solving and interaction with virtual objects are also out of scope within the current virtual experience- thereby eliminating the possibility that fixation could occur resulting in increased stress. (Shaw, 2002).

The changes in results that are expected are mostly related to general irritability and PLWD's mercurial emotional state. The results of this study show changes in emotion and stress of participants that often linger for ten seconds or more. The consistency of both positive and negative emotional states are equal among all participants- this is evident in figure 17. However Shaw (2002) noted that PLWD tend to cling to negative states of stress longer than people without dementia and have shorter bursts of intense positive emotion. Therefore future studies of this system with PLWD should expect a more uneven structure of lengths of emotional states during the experiment.

Facilitators of future studies involving PLWD should take this into consideration and be more observant of BPSD behaviours. The consistency of mood with the analogous group of participants allowed for a low involvement of the facilitator however a facillitator's input may be required in PLWD studies to avoid cascading effects of negative stress. Facilitators may also have to take on extra responsibilities such as assisting with the game controller at the beginning of the uptake of the system. However a certain amount of adaptation to the technology is expected to be maintained over the course of usage of the device- as evidenced by Tover's adoption rates of the ToverTafel.

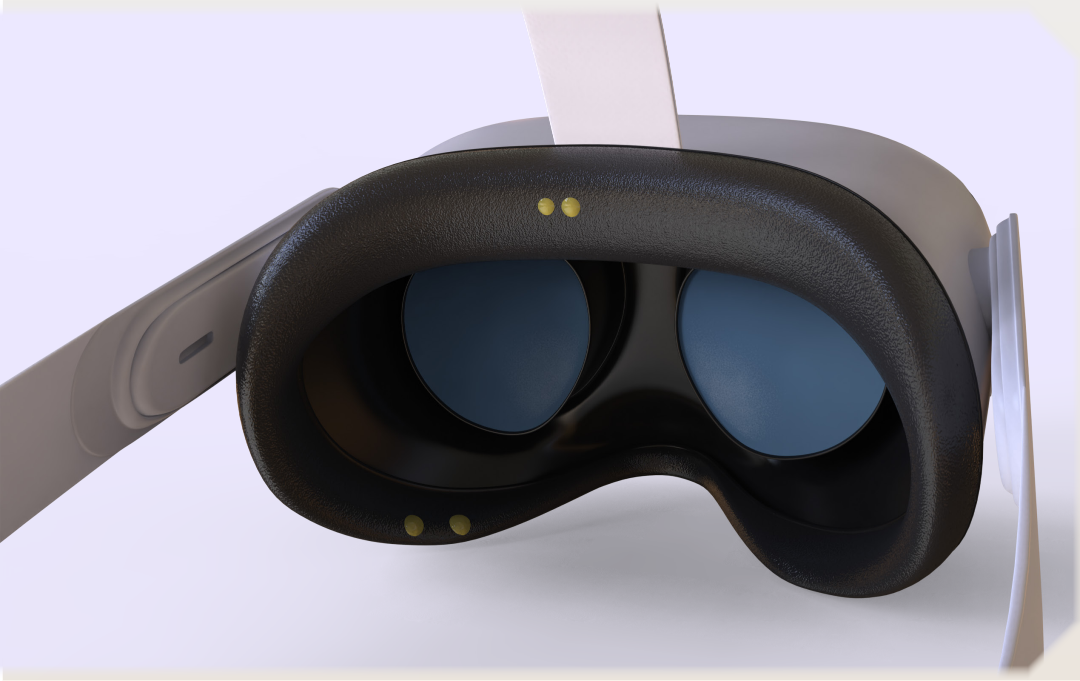
Future iterations of the product should include a more seamless integration of sensors into the system. Ballard et. al (1999) found that with the onset of boredom and under-stimulation, restless behaviours of pulling at clothes and other objects that 'stick out' to the PLWD is a common observation. A standalone system that integrates the sensor modules into the VR device would be an ideal setup- so as to not provide irritation points to the user.

Overall, the key difference of the more fluctuating moods in PLWD should lead to structural changes in the expected data of future studies. However it is expected that with time, PLWD will adapt to the use of the device and require less supervision generating a safer and more enjoyable experience.

7.4 Evaluation of Final Concept

Addressing the limitations of the tested system, the envisioned final version of the product was developed. In this iteration, the device functions as a standalone device- since the Oculus infrastructure is built on an Android platform, the game can be stored as an app on the device itself. The Ganglion is mounted to the front of the device to which sensor wires connect within the device body.

These sensor wires are routed through the foam of the facial interface to the gold cap electrodes mounted in the foam. The existing pressure applied by the elastic bands that mount the headset provide ample contact for minimal impedance between the skin and the electrodes. In this iteration, the corrugator supercilia is also targeted to integrate brow movements into a more nuanced emotion detection model.



Physical Technology

For the trapezius mounted electrodes, the medical field was consulted to source ergonomic, long-term wearable sensors. The Dutch company Onera manufactures synthetic fabric backed EMG, EEG & PPG sensors that report data for the purpose of sleep monitoring and preventative care (figure 21-22). These sensors could be applied by either the user's caretaker or if the user is dextrous enough, themselves.

This provides the opportunity to collaborate and integrate EMG sensing into the user's medical repertoire.

Although higher latency, other forms of wearables such as the Corsano smart watch provide extra layers of confidence for stress monitoring software and can also be used to train machine learning programs to recognise individual's particular stress indicators.

Once the scope of controls are decided upon by a software development, the controller system could be significantly simplified to something more understandable to a more elderly, technology averse user. Strong options for these include ergonomic joysticks similar to those found on electric wheelchairs.

Digital Technology

From a software perspective, there is endless opportunity for expansion. It was stressed by both the literature and pilot participants that the necessity exists for an experience facilitator. Literature also tells us that a social aspect to the game experience greatly elevates attention and reduces boredom. With the rising sophistication of natural language models of artificial intelligence, an AI facilitator could be a helpful easement to human caretakers' schedules.

However, if other loved ones would like to join the user in the environment and participate in group play, they could take the roles of avatars in the virtual experience. iClone software uses a modern smartphone's inbuilt LiDAR camera sensors to capture facial expressions and map them onto a realistic avatar that could roam the virtual environment alongside the PLWD user.

Figure 21: Onera Electrodes (Onera, 2021)

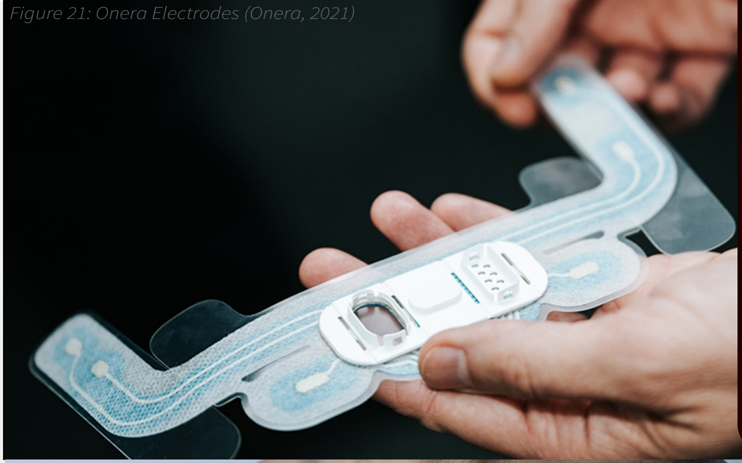
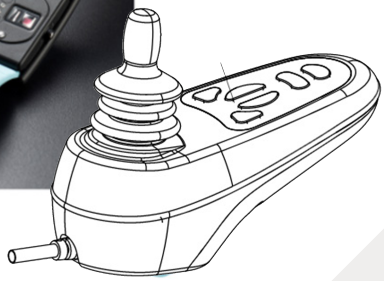


Figure 22: Onera Electrodes (Onera, 2021)

Figure 23: Corsano EDA Bracelet (Corsano Health, 2022)



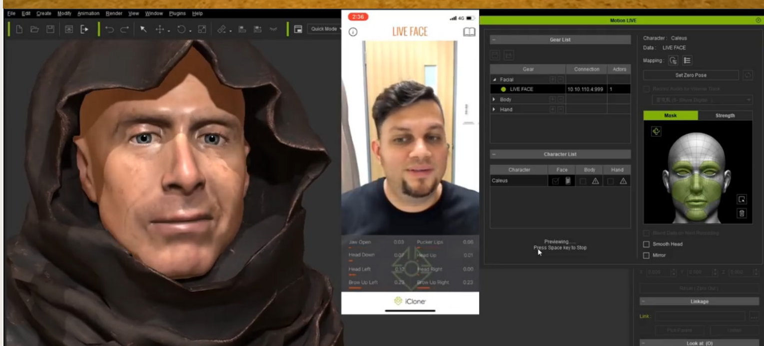


Figure 24: iClone Facial Animation and compositing (Reallllusion, 2022)

Digital Technology

The design of the virtual experience remains a challenge to scale up to remain relevant to a wider audience. This scale-up becomes far more feasible when virtual environments can be shared by multiple people with a particular shared relevant cultural factor. Accessing relevant environments could be a task for caretakers by way of form-filling or even biodata collection by the service providers as in figure 25.

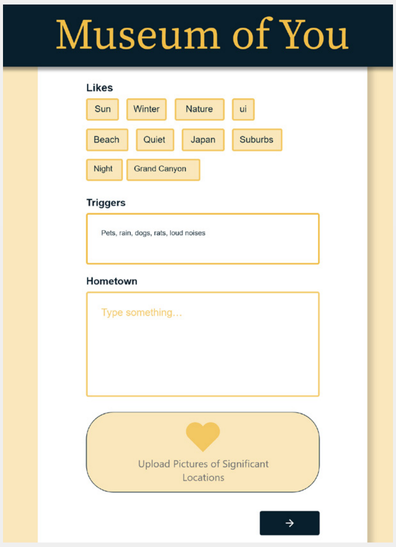


Figure 25: Example form to be filled out by caretakers

For this experiment, the rural Dutch village experience played the role of the common cultural experience. Future experiences that replicate the environments of more and more Dutch cities will lead to these environments being relevant to more and more people- drawing more people to the experience. Services like Dordrecht 5D seen in figure 26 emulate this but since the services are often sparse and of varying levels of fidelity, uniformity becomes a priority to virtual designers in order to create a predictable experience. The monopolization of data also presents itself as a problem as services like Google Maps and ArcGis tend to hold their 3D data developed by scans as proprietary. A user driven solution to this could be photogrammetry.


Figure 26: Dordrecht 5D 3D exploration (Gemeente Dordrecht, 2022)

Successfully implemented in Dijkdorp in figure 27, photogrammetry utilises computer visualisation software to stitch together photos of an object to create a 3D version of the same object with accurate textures. This democratization of 3D development will help create the most personally relevant environment that PLWD will connect to the most. Sharing these assets will also help other, less technically inclined, users access valuable objects. This could even be gamified to be an enjoyable experience for loved ones- not dissimilar from common video games such as Sims. The pricing of these environments are not expected to exceed that of common video games which could be accessed in a system similar to the Xbox game storet, costing €15 per month.


Figure 27: Dijkdorp church made with photogrammetry

As mentioned by Siriaraya & Ang (2014), the avenues of reminiscence are not only object and place dependent but also interaction dependent. Interactions with objects can be further explored to develop mini-games such as apple-bobbing or gardening. These games should be risk-free and punishment-free so as to not create undue stress in users. Any extra stress should be attenuated by a variety of parameters being modulated in tandem by multiple platforms of stress detection.

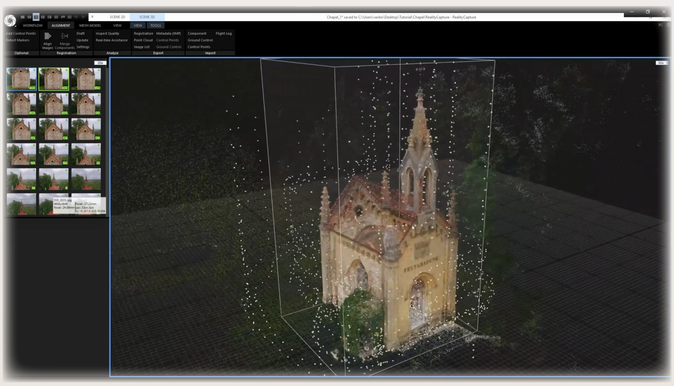
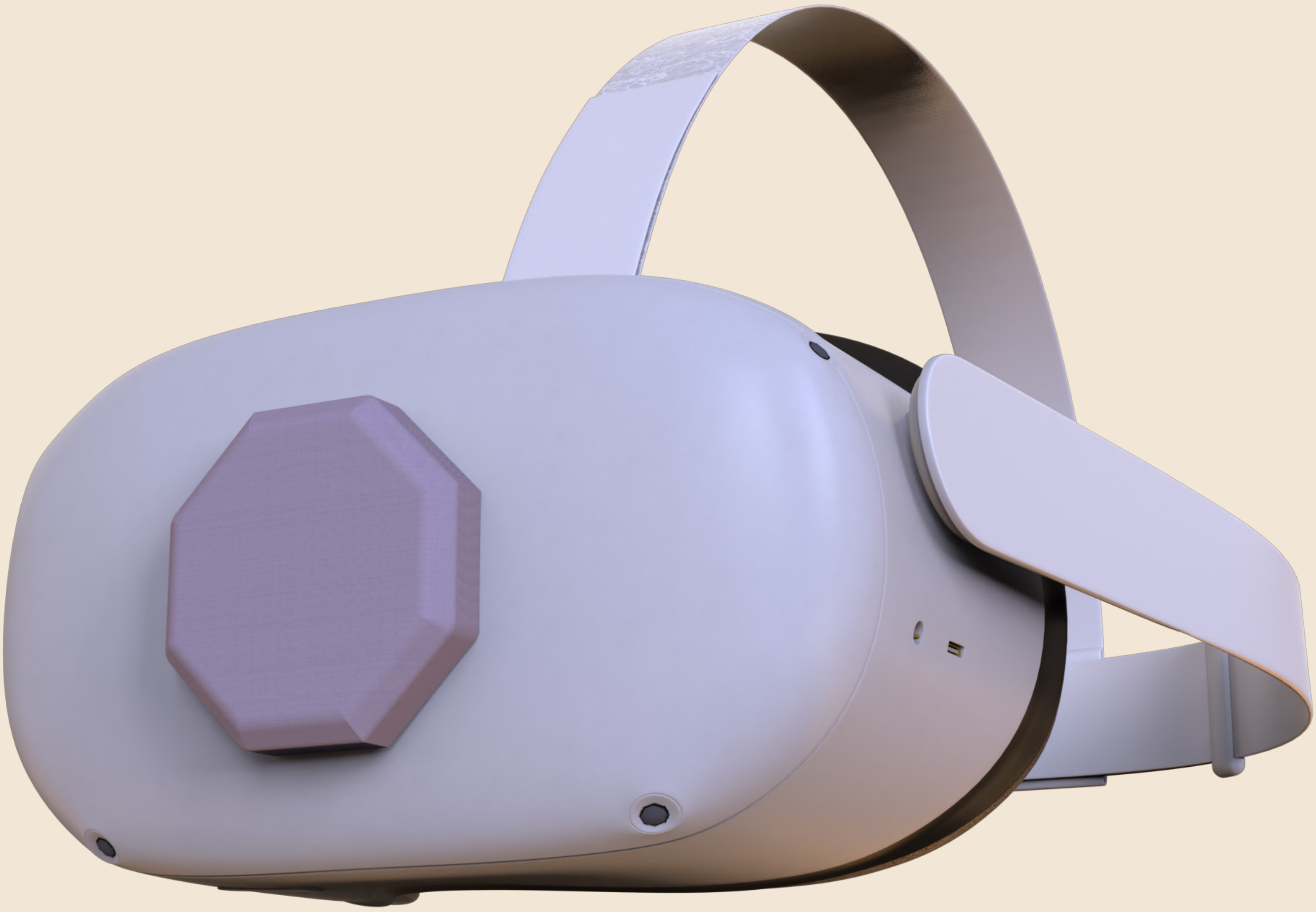


Figure 28: Photogrammetry process



7.5 Conclusion

The subject of this study was to validate the use of emotion adaptive VR environments to give PLWD access to a technology they would normally feel unsafe using. The study sought to answer the two questions:

Does the real-time adaptation of a virtual reality environment decrease the stress felt by the participants in said environment?

Does the presentation of familiar environments, in a virtual reality context, to participants with dementia promote feelings of nostalgia and allow for reminiscence?

To do this, firstly the existing person-centred therapy techniques of art, music and drama therapy were analysed to formulate VR reminiscence therapy. From the circumplex model, the axes of valence and arousal were used to classify emotions. Negative behaviours were identified and the necessity to reduce stress justified. To monitor stress, EMG was selected and prototyped using the OpenBCI Ganglion. The zygomaticus and trapezius muscle were identified to represent joy and stress respectively.

Overarching goals of presence, occupation, inclusion, comfort and novelty were identified and targeted through the VR design. The method of reminiscence therapy was identified and broken down into the three elements of place related, object related and interaction related reminiscence. The parameters of brightness, volume and NPC movement were identified as strong candidates for effective modulation to reduce stress. Using literature based guidelines, the VR environment of Dijkdorp was developed and the study performed on the analogous group.

7.5 Conclusion cont.

From the study it was ascertained that real-time adaptation of the VR environment did in fact decrease stress felt by participants. A 26% decrease in stress was observed between the unmodulated control stage and the average of the modulated stages. Among the parameters, volume modulation seemed to have the strongest and fastest effect of reducing stress with a 32% stress reduction over the control stage. This stage also had the most evenly distributed levels of intervention of all stages, implying that volume modulation had a proactive effect in reducing stress before it reached high 70% levels. NPC modulation, in contrast, was he least effective parameter modulated although still displaying 17% less average stress than the control stage. Among the modulated parameters, the NPC modulation stage had the most negative interventions at the highest levels.

Participants reported that the presentation of familiar environments in VR did in fact promote feelings of nostalgia and reported moments of reminiscence.

Future work opportunities call for studies with PLWD, improvements in test structure such as including a cooling down period. As well as the expansion of technology used to multi-channel, multi-modal systems leveraging other stress monitoring technology such as EDA. Expanding testing scope by running concurrent modulation parameters and training machine learning algorithms to predict stress more accurately would greatly improve the system's confidence levels.

Technology improvements such as integrating all peripherals into a standalone system as well as utilising more convenient and ergonomic sensors that could be applied semi-permanently to form a more holistic data overview for PLWD outside experimental conditions.

The introduction of socialising factors such as an AI facilitator and including loved ones in the experience would vastly expand the target audience of this device. Finally, scaling the system up to include more relevant virtual environments would create a system with a larger appeal. This could be done by leveraging photogrammetry to promote user-generated content.

7.6 Reflection

Having had very little experience with dementia as a disease before my first project with Tover in 2021, my first instincts were to tackle this problem with an engineering solution. Only by getting to know the person-centred approaches of art, music and drama therapy was I exposed to the importance of human contact. It was my goal to leverage my skills and interests in human machine interfacing to expand the possibilities within the field of reminiscence therapy. With VR having such an immense speed of technological growth, I am excited to follow and contribute to it as it relates to the field of dementia care.

1.62 million people die of dementia related deaths every year, if this technology can reach even a small portion of those people then people like Bruggen-Rufi's music therapy subject Vonnie have a chance to live out their final years with dignity and the care of their fellow humans.

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Appendix A

Project Brief

5923

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: RAJA

initials: A given name: ADHITYAN

student number:

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD | DfI | SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: Honours Programme Master

specialisation / annotation: Medisign | Tech. in Sustainable Design | Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Evangelos Niforatos dept. / section: SDE

** mentor: Christina Schneegass dept. / section: HCD

2nd mentor:

organisation:

city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Evangelos Niforatos date 21 - 09 - 2022 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 32 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 32 EC

List of electives obtained before the third semester without approval of the BoE

x YES all 1st year master courses passed

NO missing 1st year master courses are:

name K. Veldman date 23 - 9 - 2022 signature

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: V APPROVED NOT APPROVED

Procedure: V APPROVED NOT APPROVED

comments

name Monique von Morgen date 4/10/2022 signature MvM

Stress monitoring in virtual reality for people living with dementia

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 15 - 09 - 2022

24 - 02 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Dementia is an umbrella term for progressive loss of cognitive abilities, which mainly affects elderly- affecting relationships, feelings and behaviour. A person living with dementia (PLWD) might forget the names of their grandchildren, the face of their loved ones, important places and life events. Due to the rising population growth with more than 55 million people living with dementia (8.1 % of women and 5.4% of men over 65 years) and increasing life expectancies, dementia is already recognized by the WHO (World Health Organization) as a public health priority, and it is now the 7th leading cause of death (WHO, 2021).

Although decreasingly common, it is often the case in the developing world that the (often) non-working female family members are expected to care for their parents with dementia. Whereas in the developed world, care-home infrastructure is more widespread and there is less stigma in signing PLWD into care-homes. Care-homes like these often have a ratio of carer to PLWD of 1:6-10 in the United States (Intriago, 2021). So not only is it often seen that PLWD receive very generic care, this care is also administered by highly pressurised care workers that are focussed on meeting their PLWD's physical needs over their emotional needs. This is particularly frustrating for PLWD who are in care homes in a sub-culture that is not their own (Bruggen-Rufi, 2010).

The population pressure that care homes are currently under cannot be easily remedied and would require a significant monetary investment into employing more personnel. Therefore it would be more fruitful to enable PLWD to function with less help of carers rather than increase the number of available carers.

I tackled this in my advanced concept design course by creating a VR environment for PLWD to explore (figure 1). The interest in virtual reality was determined after conducting 10 interviews with dementia care personnel and PLWD- the findings showed that independence and confidence in conversation was attained when visual stimuli was introduced in familiar environments. This was supported by Bruggen-Rufi in her exploration of how music therapy elevated confidence through reminiscence (Bruggen-Rufi, 2010). The VR environment I created stimulated conversation in my small user study, albeit with saturation points of stimulus leading to stress and VR sickness.

Sources:

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introduction (continued): space for images

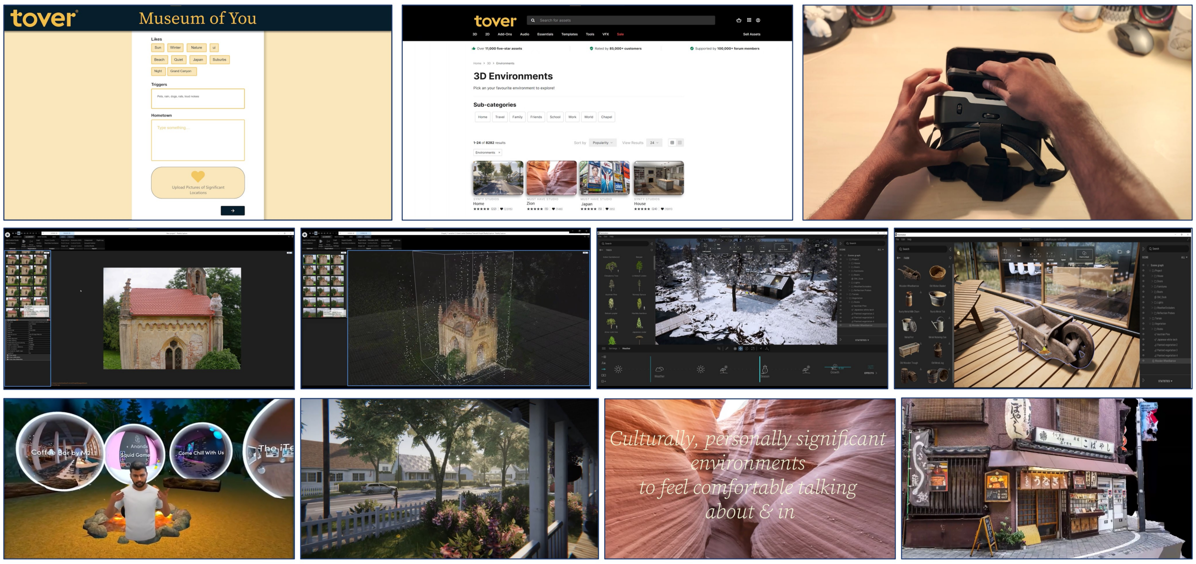


image / figure 1: Virtual reality environment proof of concept created in advanced concept design by A.Raja

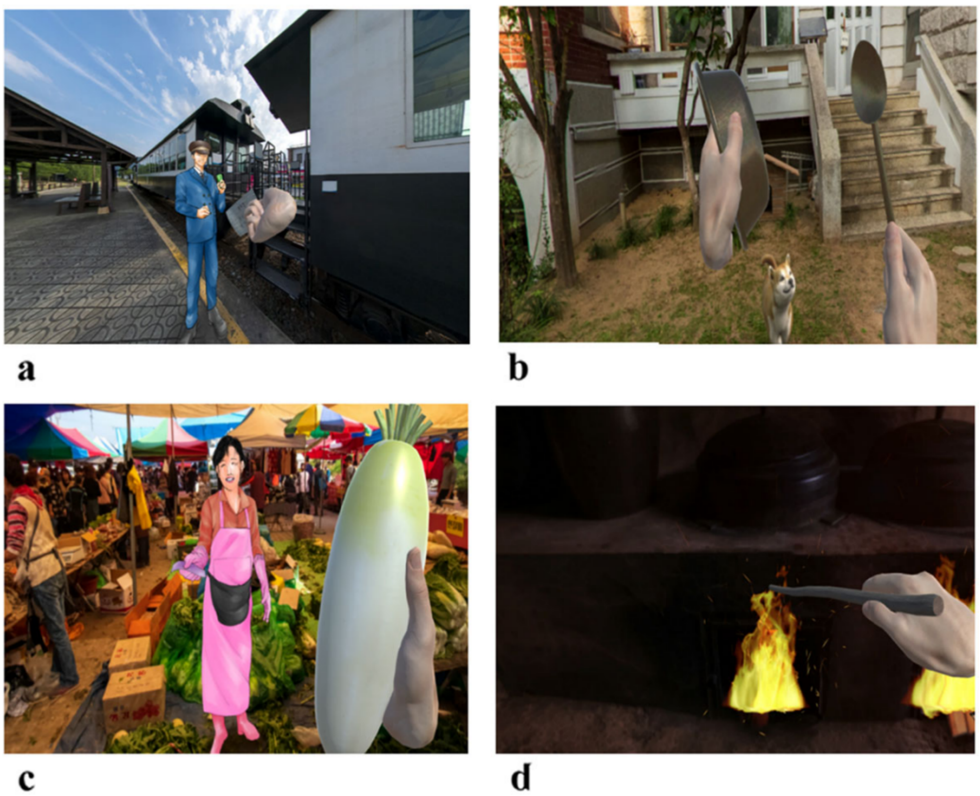


image / figure 2: Virtual reality environments nostalgic to South Korean users created by Kim, Park & Lim, 2021

Initials & Name A RAJA Student number 5442028

Title of Project Stress monitoring in virtual reality for people living with dementia

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Very recently, research by Kim, Park & Lim in 2021 suggested that VR environments depicting nostalgic features of users' pasts could be used to prompt feelings of reminiscence and temporarily alleviate symptoms of behavioural and psychological symptoms of dementia (BPSD) (figure 2). The study noted that the need for comfort was rated highest in providing relief from BPSD with 37% of participants and the lack thereof created points of complaining, agitation and violence (Kim, Park & Lim, 2021). This suggests the need for an adaptive experience.

Although most examples of using virtual reality for PLWD are still in the academic stage of development, some commercial applications of augmented reality have been used to arouse interest in a proven capacity. Hodge et. al. find that key elements of using virtual reality in a safe way with PLWD are careful design, collaboration, utilising senses, personalisation and ensuring inclusion (Hodge, et.al, 2018). The commercial availability of virtual reality systems designed without these key elements in mind is seen as a threat to the user (possibly causing alienation and further isolation) as well as a possible blocker for the proliferation of this technology into the highly regulated field of dementia care. For example, electroencephalography (EEG) is currently mainly used as a diagnostic tool in the dementia field, due to its arduous and inaccessible setup process (Micanovic & Pal, 2013).

Zao et. Al in 2016 compared the applicability of both EEG and electrooculography in measuring stimulation- they observed success with both techniques but noted that their system architecture only allowed for one-way flow of data and therefore could only be used for post-experience feedback implementation. Additionally, it is known that neurodiverse groups exhibit variations areas of brain activity and therefore any processing of data would have to be adjusted to the user group of PLWD. (Zao et. Al, 2016).

Although research exists of the use of VR with PLWD, VR with stress monitoring and stress monitoring with PLWD, a successful implementation of these 3 aspects in one product has not been observed in research.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

In this project, I will create virtual reality environments that will inspire reminiscence and confidence of speech in people living with dementia. My product will implement a system of stress sensing to adapt the virtual environment in real-time to avoid negative behavioural tendencies. The tangible realised application of this will be tested on people living with early stage dementia (Stage 3-4) in the Netherlands.

The ultimate end result of this project is the design, prototyping and testing of an exploratory, game-like, experience in virtual reality to be used by PLWD. By exploring familiar environments from the users' pasts such as their hometowns, users should be inspired to reminisce and hold conversations about their pasts as well as their new experiences in the environment. Stress sensing technology implemented in the virtual reality headset will augment and attenuate the virtual environments using parameters such as brightness, contrast and number of game elements- this will ensure that over-stimulation does not foster negative behaviours.

Currently, my virtual reality system exists in the Google cardboard framework- this will be ported to a fully fledged virtual reality system such as the Oculus Rift. Sample environments commonly known to residents of the Netherlands will be developed and modeled as virtual environments to support testing. Technology such as electroencephalography and electromyography will be explored as options for stress monitoring- data from this will be used to modulate the environment in real-time.

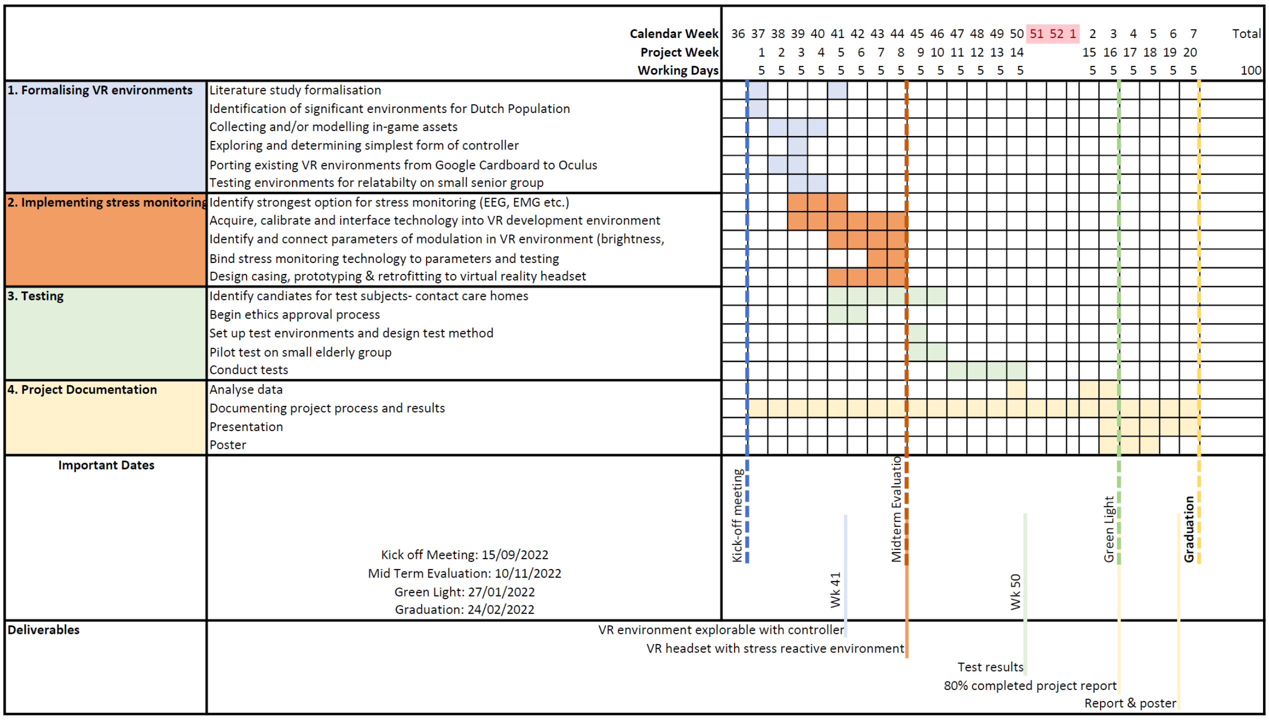
Testing will be done with PLWD living in care-homes in the Netherlands to confirm the effectiveness of the technology in stimulating conversational reminiscence. Data gathered from the chosen stress monitoring technology will be used to prove the reduction of stress and negative emotion.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 15 - 9 - 2022

24 - 2 - 2022 end date



The project will begin with a phase to create the real virtual reality environments, I chose to begin by aggregating my literature sources to highlight key features of the VR experience that will become important to relating virtual environments to the individual users. By the end of week 41, I will deliver the working environment explorable by controller.

This will be followed by a stage in which stress sensing technologies will be explored- currently the most feasible option is an electromyographic sensor which can gather facial muscle contraction data. By matching the incoming data with existing data sets, I can highlight with a degree of certainty certain emotions felt by the user. Alternatively, electroencephalographic nodes could be used to gather more detailed data however the difficulty in calibration and filtration affects the feasibility for this project. Before the midterm evaluation I hope to have a working prototype of an adaptive virtual reality environment aimed at my user group of Dutch people living with dementia who are familiar with particular sample locations developed by myself in the first stage.

Using my connections from my previous project, I will reach out to care homes across North Holland and Rotterdam to begin testing. Acquiring ethics approval for this testing will be a key step in this stage and special care will be taken to ensure this does not act as a blocker for future progress. Success of the system will be measured by two metrics: success in inspiring reminiscence & success of the stress monitoring system. Success in inspiring reminiscence can be measured qualitatively while the stress monitoring system can provide data of time-stamped emotional graphing. By using the data from the sensor to identify moments of joy and moments of stress, an accurate timeline of the user's experience in virtual reality can be developed. After Christmas break, the results will be analysed and the report, presentation and posted will be created.

There will be a planned break from week 51 - 1.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Having completed my bachelor in mechanical engineering, I chose to change fields to industrial design for its emphasis on user experience. During my advanced concept design course, I was exposed to this through my project with a Dutch dementia care company. In the research stage of the project, I discovered that there was a large gap between the capabilities of current technology and their application in the field of dementia care. Most dementia related products focus on practical goal achievement such as reminder devices and workflow focusing applications of simple products such as post-it notes.

Diving deeper into the project, I contacted the Dubin center in Florida- an association that provides training and resources to carers of people living with dementia. After many interviews with neuroscientists, professional nurses, art therapists and actual people living with dementia & their carers, I found that the empathetic treatment of dementia was unfortunately ignored and cast onto the carers themselves. They expressed that at points, the pressure to take care of chores and responsibilities left them too drained to provide the empathetic care that has been proven to stave off the onset of dementia by years. When asked about the current materials they use to provide themselves with mental stimulation, carers and PLWD mentioned music, art and reminiscing through photographs. Many PLWD in the early stages of 3-4 are still clear on their memories and are eager to speak about them but lack the initiative due to lack of confidence or sheer boredom. I noticed that in my own Singaporean and Indian culture, this gap is filled by the support of family members and more accessible care staff- access to which is shrinking in both the East and West.

My motivation to explore virtual reality as a solution arises from my interest in digital-physical product interfacing. Having academic background through my computer science classes in my bachelor's program, I realised the vast opportunities that lie in implementing computation processes in everyday products. I began working with the programming language C# in the existing virtual reality environment but I am eager to explore the possibilities this yields in the typically object based development program Unity.

During my elective course Prototyping for Interaction and Participation (PIP), I had the opportunity to explore co-design process improvements for visually-impaired people. There I began to understand the importance of testing our product with in-person conditions and with the final target market- especially when part of the design challenge is accessibility based. By involving a visually impaired colleague at Visio, an organisation that provides support to the visually impaired, If found how user dependent the design process could be and the importance of personalising products to the end user.

Through this project I hope to bring to West the Eastern ethos of personalised dementia care focused on experiences over exclusively task based care. By implementing the safety feature of stress monitoring to these familiar virtual reality environments, I hope to create an impactful product experience for people living with early stage dementia and bring attention to the necessity of ensuring the safety of more sensitive users in the field of virtual reality.

Personal learning goals: Improving programming skill in C#, improve digital game development skills in VR, improve ergonomics centered prototyping for headset and controller, attain hands on experience in working with elderly (interviewing, testing methods), improve communication skills with the accessibility group of the elderly.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Appendix B

Consent Forms

Virtual Reality for People with Dementia- Stress Reduction.

You are being invited to participate in a research study titled *Virtual Reality for People with Dementia- Stress Reduction*. This study is being done by Adhityan Raja from the TU Delft.

The purpose of this research study is help reduce stress in people with dementia when they use a virtual reality device. The experiment will take you approximately *12* minutes to complete. The data will be used for research purposes within TU Delft. First we will watch a short video about what the game will be like, then we will ask you to wear the Virtual Reality device and explore a game for 12 minutes. Finally, we will ask you some questions about how you felt playing the game.

Your answers in this study will remain confidential. There is little risk in this study as your data is never shared with anyone other than the researcher. The caretaker will be present with you the whole time in case you need help or want to stop the experiment.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to not answer any question you do not want to.

If you have any more questions, you can contact the lead researcher:

Adhityan Raja
TU Delft
Faculty of Industrial Design Engineering-
MSc. Integrated Product Design
Landbergstraat 15
2628 CE, Delft

or

Evangelos Niforatos

TU Delft

Virtual Reality for People with Dementia- Stress Reduction.

	YES	NO
1. I have read and understood the study information dated 11/12/2022 or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	✓	
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	✓	
3. I understand that taking part in this study involves		
a. Wearing a virtual reality device and playing a game	✓	
b. Talking briefly about your past experiences (voluntarily)		
c. Have your conversation recorded and written down	✓	
i. The recording will be delete after		
d. Talking about how you felt in the game	✓	
4. I understand that the experiment will end after 12 minutes. The project will end on 24/02/2022	✓	
5. I understand that taking part in the experiment also involves collecting personally information such as my hometown or past memories- this information does not have to be given. The researcher will take my name off all the information collected after the experiment is completed.	✓	
a. This information will not be given to anyone outside the research team	✓	
b. Any sensitive information will be destroyed as well	✓	
6. I understand that after the project is completed, it will only be available to other TU Delft students and teachers.	✓	

Virtual Reality for People with Dementia- Stress Reduction.

	YES	NO
7. I agree that photos and videos can be taken of me during the experiment- this is voluntary	✓	
8. I agree that (sticky) sensors will be placed on the skin during the experiment and I understand their use	✓	
9. I agree that my answers, views or other statements can be published in the report	✓	
10. I acknowledge that the researcher has shown a negative COVID test, is wearing a mask and has not been in contact with anyone with COVID in the last 48 hours. He will also maintain a reasonable physical social distance	✓	

Signatures

[redacted]

Name of participant [printed] Signature Date

I, as caretaking representative, have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask [redacted]

Name of witness [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to [redacted]

Researcher name [printed] Signature Date

Study contact details for further information: [*Name, phone number, email address*]

Virtual Reality for People with Dementia- Stress Reduction.

	YES	NO
7. I agree that photos and videos can be taken of me during the experiment- this is voluntary	✓	
8. I agree that (sticky) sensors will be placed on the skin during the experiment and I understand their use	✓	
9. I agree that my answers, views or other statements can be published in the report	✓	
10. I acknowledge that the researcher has shown a negative COVID test, is wearing a mask and has not been in contact with anyone with COVID in the last 48 hours. He will also maintain a reasonable physical social distance	✓	

Signatures

[redacted]

Name of participant [printed] Signature Date

I, as caretaking representative, have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

[redacted]

Name of witness [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to [redacted]

Researcher name [printed] Signature Date

Study contact details for further information: [*Name, phone number, email address*]

Virtual Reality for People with Dementia- Stress Reduction.

	YES	NO
7. I agree that photos and videos can be taken of me during the experiment- this is voluntary	✓	
8. I agree that (sticky) sensors will be placed on the skin during the experiment and I understand their use	✓	
9. I agree that my answers, views or other statements can be published in the report	✓	
10. I acknowledge that the researcher has shown a negative COVID test, is wearing a mask and has not been in contact with anyone with COVID in the last 48 hours. He will also maintain a reasonable physical social distance	✓	

Signatures

[redacted]

Name of participant [printed]   Signature   Date

I, as caretaking representative, have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

[redacted]

Name of witness [printed]   Signature   Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to [redacted]

Researcher name [printed]   Signature   Date

Study contact details for further information: [*Name, phone number, email address*]