Bachelor's thesis

Information and Communications Technology

2022

Jussi Haapasaari

Using the iMotions biometric platform to compare biosensor data from two virtual reality serious games

TURKU AMK
TURKU UNIVERSITY OF APPLIED SCIENCES

Bachelor’s Thesis | Abstract

Turku University of Applied Sciences

Information and Communications Technology

2022 | 47 pages

Jussi Haapasaari

Using the iMotions biometric platform to compare biosensor data from two virtual reality serious games

This thesis aimed to find out which kinds of biosensors are available for analysing VR games and whether the eye-tracking and other biosensor data collected during a VR play session can be easily analysed with the help of the iMotions platform.

Ten test subjects played two VR memory games, one of which the author of this thesis had developed. Both games had a memory card game similar to each other that had the goal of finding a few pairs of matching cards. The biosensor data of both games gathered from the test subjects was compared to find potential signs of stress. Only one of the two games had a timer of 60 seconds as an additional source of stress.

The goal of the tests was to utilize the iMotions biometric platform and the Varjo VR-1 HMD to discover some noticeable changes in the players’ heart rate, skin conductance and eye movements as the stress levels rose.

The results showed elevated heart rates and Galvanic Skin Response (GSR) values at the beginning of the sessions and also towards the end of the second game when the timer was running low. The eye-tracking heatmaps show that the players focused most of their attention on the center of their field of view and almost none of it outside the area where the cards were laid. Games researcher Suvi Holm was briefly interviewed about the findings, and she said the results were rational and expected.

Keywords:

Virtual reality, iMotions, biosensor, eye tracking, heart rate, GSR, serious game

Opinnäytetyö AMK | Tiivistelmä

Turun ammattikorkeakoulu

Tieto- ja viestintätekniikka

2022 | 47 sivua

Jussi Haapasaari

Kahdesta VR-hyötypelistä saadun biosensoridatan vertaus keskenään käyttäen apuna iMotions-alustaa

Tämän opinnäytetyön tarkoituksena oli selvittää, millaisia biosensoreita VR-pelien analysointiin on tarjolla ja miten niistä saatua dataa voisi iMotions-alustan avulla hyödyntää VR-hyötypelien pelisessioiden analysoinnissa.

Tutkimuksessa verrattiin kymmenen testihenkilön pelisessioiden biosensoridatasta saatuja eroavaisuuksia kahdesta muistin testaamiseen kehitetystä VR-pelistä, joista toista tämän opinnäytetyön kirjoittaja oli itse ollut kehittämässä. Osana molempia pelejä oli keskenään lähes samantapaiset korttimuistipelit, joissa tavoitteena oli löytää keskenään samanlaista kuvapareja. Vain toisessa peleistä oli mukana 60 sekunnin ajastin antamassa yhden ylimääräisen stressin lähteen.

Testien tavoitteena oli havaita muutoksia pelaajan sykkeessä, ihon sähkönjohtavuudessa sekä silmien liikkeissä stressitason kohotessa käyttämällä apuna iMotions-alustaa sekä Varjon VR-1-laseja.

Testituloksissa havaittiin merkkejä stressistä, kun pelaajien syke ja GSR olivat selvästi koholla testien alkaessa sekä toisen pelin loppupuolella, jos pelissä oleva aika oli juoksemassa vähiin. Silmänliikkeiden lämpökartoista voi havaita, että pelaajat keskittivät katseensa pääosin pelialueen korttien päälle ja vain äärimmäisen harvoin ulos korttipelin pelialueelta. Pelitutkija Suvi Holm kertoi löydöksistä kysyttäessä, että testitulokset olivat järkeviä ja odotettuja.

Asiasanat:

Virtual reality, iMotions, biosensor, eye tracking, heart rate, GSR, serious game

Contents

List of abbreviations **7**

1 Introduction **9**

2 The use of biosensors to extract biometric data **11**

2.1 Eye-tracking 11

2.2 Galvanic Skin Response (GSR) and heart rate 13

2.3 Electroencephalography (EEG) 13

2.4 Facial Expression Recognition systems 14

3 Biometric research platforms **16**

3.1 iMotions 16

3.2 NeeuroOs 17

3.3 MindMotion 17

4 VR games dealing with memory impairment diseases **19**

4.1 Sea Quest Hero 19

4.2 Dementia: First Hand 20

4.3 A Walk Through Dementia 22

5 Utilized VR serious games **24**

5.1 A Day to Remember 24

5.1.1 The House 24

5.1.2 The Path 25

5.1.3 The TV Show 26

5.2 Perception of Memory Impairment in Alzheimer’s Patients 27

5.2.1 Orientation exercise 28

5.2.2 Memory card game 29

5.2.3 Other activities 31

6 Testing **33**

6.1 Testing scope 33

6.2 Results 36

6.2.1 Heart rate 36
6.2.2 Galvanic Skin Response 38
6.2.3 Eye movements and pupil size 40
6.3 Discussion 43

7 Conclusion **46**

References **48**

Pictures

Picture 1. 3D stereoscopic video footage from a real actress is inserted inside the virtual environment along with 3D models [29]. 21
Picture 2. The scene On the Road was shot with a 360 camera making the surroundings very realistic. 23
Picture 3. The code that opens the safe is on the fridge door and is easy to miss when playing the first time. 25
Picture 4. The player has at this point already attempted to turn around 6 pairs of cards. 26
Picture 5. The player has completed the questionnaire at the end and received a score of 22 out of 25. 27
Picture 6. The Player has to find four pieces of a painting around the house. 28
Picture 7. Evaluation of player performance based on the time they spent finding the paintings. 29
Picture 8. The player has found the first matching pair of cards. 30
Picture 9. The player can easily see the time remaining for the task. 31
Picture 10. Shimmer3 electrode placements on the index and middle fingers. 34
Picture 11. Four signals from top to bottom: Gaze fixation duration, pupil size, GSR conductance and heart rate. The stimulus, in this case, footage from PMIAP, is shown on the right side. 35
Picture 12. The bottom figure shows how the participant's heart rate was elevated at the start of the session, at a noticeably lower point during the middle part and elevated again at the end. 37

Picture 13. The heart rate (bottom graph) of a tester elevates slowly throughout the game session from 90 BPM to 110 BPM. The audio clue (the orange bar below the graphs) given at 30 seconds remaining had no visual effect on HR. 38
Picture 14. Two clear spikes are visible in the GSR graph (third graph from the top) for many testers while playing A Day to Remember – one at the beginning and one at the end. 39
Picture 15. GSR graph (2nd from the top) spiking after the player had been given a notice of 30 seconds remaining. 40
Picture 16. Eye fixation duration (top) and pupil size graph (2nd from the top) do not show much fluctuation over time. 41
Picture 17. Pupils dilate for the duration of the memory card game and contract back after the game is finished (second graph from the top). 42
Picture 18. The participants focused their gaze mostly on the cards on the table and usually at the end at the "scoreboard" to see how many tries they had needed to complete the game. 42
Picture 19. According to the heatmap, players took only a few glances at the timer while playing PMIAP. 43

List of abbreviations

A Day to Remember	A game developed by Future Interactive Technlogies in association with health care professions for detecting early phase dementia.
GSR	Galvanic Skin Response. Skin conductance. Changes in the electrical conductance of the skin in response to sweat production.
Biosensor	Biological sensor. An analytical hardware device that detects biological changes and shows them in a digital form.
EEG	Electroencephalography. A method to measure changes in the electronic impulses in the brain.
Emotional arousal	A state of heightened physiological sensitivity such as feeling of fear or excitement.
Eye fixation	Duration of a person’s gaze on a target.
Eye-tracking	A technology used to track human eye movement and position.
FER	Facial Expression Recognition. A Method that is used to categorize human emotions, such as anger, fear and happiness, based on the facial expressions they make
Heat map	A visual presentation of the relation between areas that have greater density in eye fixation versus those that have a lesser density
PMIAP	Perception of Memory Impairment in Alzheimer’s Patients. A virtual reality game developed by an international student group for detecting early phase Alzheimer’s disease.

TUAS	Turku University of Applied Sciences.
VR	Virtual reality. An immersive simulated environment that resembles the real world. Can be viewed through a VR headset.

1 Introduction

In recent years, technology in gaming has been gravitating towards virtual reality (VR) games. VR requires the user to wear a headset but also allows for a more lifelike gaming experience in a completely virtual world unlike games based on more traditional technologies. The more realistic the digital environment looks and sounds, the more immersive it feels, and currently, Varjo headsets can offer the most detailed virtual reality experience on the market.

Varjo VR-1 headsets have an integrated eye-tracking solution and together with the iMotions software, which can collect, merge and synchronize data from several biosensors, these technologies can be used to analyse useful data from the gaming sessions afterwards. The immersiveness of virtual reality and the access to new user data such as eye tracking make VR an appealing technology to be used for education- and healthcare-related games.

Within the last couple of years, there have been several VR applications that have utilized the newest technologies hoping to benefit the healthcare sector, and this study will focus on two such applications. The first game, named A Day to Remember was funded by Business Finland as a BEE project and developed by a research group called Future Interactive Technologies in association with medical health care professionals, to help diagnose and screen early phase dementia. A game labeled Perception of Memory Impairment in Alzheimer’s Patients was developed for detecting early phase Alzheimer’s disease as a part of an international student project called IC-xR-P, which was funded by a German funding agent Baden-Württemberg Stiftung. The author of this thesis personally contributed to developing the latter game.

The purpose of this study was to find out whether the use of biosensors and a biometric platform such as iMotions could be useful for analysing data from serious games played in virtual reality. While there are other biometric platforms, such as NeeurOos and MindMotion, that can be used to analyse human behaviour and could have been used for this thesis, iMotions was chosen because it was readily available from the client and it supports a wide variety of biosensors, including Varjo VR-1 and its eye-tracking technology.

Since both of the VR games in question have similar but slightly different minigames for finding a few pairs of matching cards, it was decided to have ten people play both of these versions of the card game, and to compare the collected biosensor data between those two. The minigame in A Day to Remember did not have a timer but rather a counter to keep track of the players' attempts at turning cards while PMIAP had a one-minute timer for the players to finish the game, which meant that the players' stress levels could elevate noticeably when approaching higher attempt count numbers or when the time was about to run out. The goal was to utilize the iMotions platform and the Varjo VR-1 headset to detect changes in the players' heart rate, Galvanic Skin Response (GSR) and eye movements while playing the different minigame versions.

This thesis consists of two parts. The theoretical part (chapters 2-4) offers an in-depth look into the biosensors that could be used for analysing VR gaming sessions, a few biometric platforms, that can be used to synchronize all the biosensor data for easy analysis, and also a review of some of the publicly available VR games dealing with memory impairment diseases.

The practical part (chapters 5-6) of the thesis consists of a full explanation of the two VR serious games that were utilized in this thesis and the results of the tests that were conducted on the ten test subjects playing the two different memory games.

2 The use of biosensors to extract biometric data

Biosensors or biological sensors, hardware devices that can detect changes in human physiology, have been utilized in health technology for decades, since at least 1956, in various forms [1]. Typically biosensors involve the user wearing some type of a receptor that tracks data from their life functions. The main benefit of biosensors is obtaining instant, accurate biometric data in a digital form from a user in a live situation which means the testing conditions and events of interest can easily be pinpointed from the gathered data. Biosignals are physiological signals in the human body that often shift during changes in the emotional state [2]. Heart rate and Galvanic Skin Response (GSR), which is used for detecting changes in the skin conductance when a person experiences emotional moments such as joy or stress [3], are examples of biosignals that are widely used for analysis of a human behaviour.

This chapter will explain some of the biosensors available for studies related to virtual reality and the biometric data or biosignals that can be collected with them. Biometric platforms that are needed to synchronize and analyse biometric data are discussed in chapter 3.

1.1 Eye-tracking

As the VR technology has evolved, eye trackers have become increasingly popular for analysing eye movements and pupil dilation in correlation with human behaviour. In a recent study about commercial eye-tracking VR glasses, Varjo VR-1 was found to be suitable for gaze-contingent experiments due to its relatively low eye-tracking delay of 35ms to 36ms, scoring better than HTC Vive Pro Eye and just behind Fove-0 [4].

However, Varjo has a huge advantage over any of its competitors in its extremely high resolution due to Varjo’s ability to combine two displays together. The peripheral display covers a wide field of view with a lower resolution while the focus view covers a much smaller area but with a very high pixel density. Combining these two displays causes the player to see everything in a much higher resolution than would otherwise be possible. [5.]

According to a review of the highest-end tier VR headsets, Varjo VR-3 has the best visual clarity, detail and immersion on the VR market [6]. The best alternative to Varjo glasses is the HP Reverb G2 Omnicept Edition headset, which can not quite produce the visual detail of Varjo VR-3, but has integrated eye-tracking sensors from Tobii as well as an integrated heart rate sensor and a face camera [6, 7].

VR-1 hit the market in 2019 and while it is not the newest edition of VR glasses provided by Varjo anymore, the headset had cutting-edge technology at its release, including an eye-tracking technology that is very suitable for research purposes [8]. One VR-1 headset was readily available to be borrowed from the client for this study..

The direction and duration of the look as well as how the pupils react and whether the user blinks many times are all measurable data that can be interpreted to mean various end-results about the gaze. Pupil size and blink rate can both be measures of cognitive effort. The pupil size is known to increase and the blink rate is suggested to decrease in cases of extreme focus or increased workload. [9]. Extreme focus or increased workload could be interpreted to be signs of elevated stress levels. It has been suggested that in stressful situations the eye fixation, or in other words, the duration of a person’s gaze on a target, in around their central area of view on objects could last longer and their ability to remember these objects was better than in less stressful situations. [10].

Heat maps have been found to be an easy way to visualize the areas of eye fixation. These maps show the visual relation between areas that have greater density in fixation versus those that have a lesser density [11].

1.2 Galvanic Skin Response (GSR) and heart rate

Emotional arousal is state of heightened physiological sensitivity such as feeling of fear or excitement [12]. The amount of sweat someone releases affects their GSR or skin conductance and is known to change slightly as their emotional arousal level changes, which can be caused by experiencing emotional shifts such as sudden happiness or stress [13].

A rapid change in GSR, as well as elevated heart rate, can be signs that the user has entered into a stressful situation [14]. Stress is only one of the possible causes of emotional arousal that could cause sweating but it is commonly used in research papers to explain the spikes in the GSR data.

Companies such as Shimmer, BIOPAC and Empatica have all manufactured their type of a wrist-held GSR device which are all compatible with the iMotions biometric platform. All of these devices can be used to evaluate the GSR and heart rate values of a user. In this thesis, Shimmer3 will be the utilized product as it was available to be borrowed from the client.

Along with feet, fingers were found to be among the best areas in a human body to obtain high skin conductance response values to show up in emotional situations [15]. Since movement should usually be minimized for the area where the electrodes are attached, the index and middle fingers from either hand are good places to put the electrodes onto for a user who plays with a VR headset and with only one controller. Heart rate can either be measured from the pinky finger of the same hand where GSR electrodes are attached to or from the user's auricle, or in other words, the outer ear.

1.3 Electroencephalography (EEG)

Electroencephalography (EEG) is a method to measure changes in electromagnetic impulses in the brain by placing electrodes along the scalp. EEG devices can offer valuable input into the mental states of a person as well as their thoughts and imagination, which is why they are utilized by professionals in various areas of expertise. [16.]

Analysing EEG data is often considered very difficult due to the many technical steps needed to fully process the data. Even just preprocessing to remove non-physiological and physiological artefacts cannot be fully automated as the artefacts can vary greatly in different experimental conditions [17]. The end data analysis for EEG seems to also be cumbersome as signals do not always automatically indicate one emotion, such as happiness or fear, but they often have to be interpreted deeply before further conclusions can be made.

The EEG data can show emotional signals in the brain but to confirm what kind of emotional arousal the signals represent, the confirmation has to be made by cross-referencing EEG with other data, namely additional biometric data or surveys.

Traditional EEG caps do not easily fit under a VR headset and while such a solution could still be feasible, issues can arise with the wires and pressuring of the attached EEG sensors, especially if the user has to move during the play session [18]. The difficulty of mounting the EEG cap under the VR headset as well as the complexity of the analysis are the reasons why the idea of utilizing EEG data for this thesis was discarded. Some new VR headsets such as DSI-VR300 already have an integrated EEG cap in them which could make analysing VR EEG data more manageable.

1.4 Facial Expression Recognition systems

Facial Expression Recognition (FER) systems are used to categorize human emotions, such as anger, fear and happiness, based on the facial expressions they make. Most FER systems, such as iMotions Affectiva Facial Expression Analysis, use an optical camera to detect the user’s facial expressions. This method is problematic in cases where the user must wear a VR headset because multiple facial components such as the eyes, eyebrows, mouth, nose and cheeks, would all have to be detectable by the camera to be accurately recognized as facial expressions. [19.] Since most VR headsets cover at least some of these facial parts, the results for the facial expressions utilizing an optical camera and a VR headset would likely be inconclusive.

There is some research about successfully using EMG or facial electromyogram along with a VR headset to be able to read the user's facial expressions [20], but since the technology is still being experimented on and it requires attaching several electrodes on the face of the user, which can make it uncomfortable for them, neither an EMG nor any other FER system was included in this thesis.

3 Biometric research platforms

It would be extremely difficult and cumbersome to synchronize and analyse biometric data from several biosensors without a biometric platform. There are at least a few other noteworthy platforms that are reviewed below. Since there were two serious games focused on the cognitive mental state of the players utilized in this thesis, the focus of the reviews will be on the platforms designed to be used for research with brain-related applications.

1.5 iMotions

Currently, iMotions is one of the leading biometric research platforms in the scientific field in giving researchers and businesses easy access to analyzing human behaviour by being able to synchronize biometric data from a selection of over 50 biosensors with little effort [21]. For example, the eye-tracking data alone from a single play session with a Varjo VR-1 lasting a minute saves thousands of rows of data in a CSV file. IMotions allows for easy analysis of the most important aspects of this raw data in both a numerical pattern, such as the amount and duration of blinks, as well as in a graphical form, namely for example heatmaps that show with simple colours where the user or users have fixated their eyesight during the session the most and the least.

Besides eye tracking, with iMotions, it is possible to analyse multiple other types of biosignals, including EEG, heart rate, GSR and facial expressions. All of these biosignals can be viewed as graphs or as plain numbers.

In addition to being able to process and analyse several different types of raw biometric data, one of the main benefits of using iMotions over other biometric research platforms is that the biometric data that is collected from different biosensors during the one session can be imported into the same study and synchronized to make it possible to compare such data easily in one timeline. That is possible even if the biosensors, such as the Varjo VR-1 glasses with its eye-tracking technology, are not directly linked with the iMotions software during the recording of the session. This allows for more freedom in selecting the methods and tools for a biometric research.

1.6 NeeuroOs

NeeuroOs, developed by Neeuro, is a biometric platform that can be used to gauge human cognitive mental states from EEG signals. The platform uses machine learning to conclude what emotions each spike in the EEG signal data most likely means.

Developers outside the company itself are encouraged to build brain-related games and other mobile and desktop applications for the platform, and for that, the developers only need Neeuro’s Software Development Kit and the SenzeBand 2, a wireless headband device [22]. Cogoland, for example, which was developed for the NeeuroOs platform, is a training application for children with ADHD and has already gone through clinical trials where it was found to improve the attention span of the children with ADHD [23].

The benefits of choosing NeeuroOs as the biometric platform over other similar ones are that the machine learning algorithms can do most of the analysis of the mental states from the EEG raw data which means the developers do not have to spend resources on developing their own AI learning system and can spend more time on developing the applications for the platform instead. Another benefit is the unintrusive mobile hardware solution that is used to collect the raw EEG data, SenzeBand 2. The device is quick and easy to fit on a user’s head and it works with a Bluetooth connection so it does not require any wiring. However, since SenzeBand 2 does not fit under a VR headset, the NeeuroOs platform is unavailable for VR applications.

1.7 MindMotion

MindMaze, a company estimated to be worth over 1,5 billion dollars, offers a variety of solutions for different types of neurological and other healthcare issues such as Parkinson’s disease, Alzheimer’s disease, patients recovering from a stroke and many others.

MindMotion is one of these solutions and it is designed for both clinical and home use. MindMotion includes 17 games that, along with optical sensors, can help patients with neurological issues to recover their motor functions and mobility. The program has full-body motion capture with real-time feedback on the quality of movement. [24.]

The benefits of using MindMotion over other similar applications are that it uses cutting-edge technology, is fully approved by FDA for both clinical and home use and takes only a few minutes to set up. The downside is that there is still relatively little detailed public information available about MindMotion.

4 VR games dealing with memory impairment diseases

1.8 Sea Quest Hero

Sea Quest Hero, which can be considered both an entertaining memory game and a tool for dementia research, was developed for mobile platforms in 2016 by an independent game development company Glitchers in partnership with Alzheimer's Research UK, University College London, University of East Anglia and Deutsche Telekom, and was relaunched in 2017 to be playable also with VR headsets. [25].

Even though a mild decline of spatial orientation or sense of direction happens to everybody over time, a rapid decline in the ability to navigate in 3D spaces is said to be one of the first signs of a memory impairment disease [26]. The purpose of Sea Quest Hero was for researchers to be able to gather valuable research data from the player base about how they manage wayfinding in 3D areas to help diagnose early phase dementia, and to possibly even find a treatment for it. During the data collection period, the game was played by over 4,3 million individuals for over 117 years of total playtime [27], giving researchers a vast quantity of anonymous but valuable spatial recognition data from people ranging from every spectrum of age, gender and race, making it the largest dementia study in history. While the data collection has already finished, the game is still available for free in the iOS and Android app stores.

In the game, the player takes control of a boat which they must navigate through multiple levels with an escalating difficulty in wayfinding. Before each level begins, the player is presented with a map of the zone that they must memorize in order to find all of the checkpoints in it. The first levels are easy with only one or two checkpoints and a straightforward route to memorize.

As the player progresses through the game, they will encounter many different types of environments including snowy arctic regions as well as tropical areas. In the later levels, the memorization and navigation tasks become much more difficult as the number of checkpoints increases and the routes become more complicated.

The navigation tasks in the mobile version of the game were compared to similar tasks in real life, and there was a clear correlation between how the users performed in the real world and the virtual environment regarding their wayfinding skills. The longer the tasks became, the stronger the correlation between the real and virtual world navigation tasks came to be. [28.] This means that orientation exercises are an excellent method to replicate in a virtual environment setting to screen users for an early phase of dementia or Alzheimer's disease.

1.9 Dementia: First Hand

A photorealistic VR game Dementia: First Hand was developed by a game development studio Galactig from North Wales in 2019 to increase awareness of dementia in people. The player has the option to play the game in either English or Welsh. For people from Wales, the Welsh version gives an opportunity to speak about or experience personal and challenging issues in their own language which can be important when dealing with as personal an issue as dementia.

Along with the photorealistic 3D models in the game, the developers also used 3D stereoscopic footage from a real actress as a conversation partner in one of the scenes (Picture 3).

Picture 1. 3D stereoscopic video footage from a real actress is inserted inside the virtual environment along with 3D models [29].

The game follows the everyday life of an elderly person with dementia through a few scenes showing the player how difficult and tragic it can be to live with a memory impairment disease. The player can hear the player character muttering in a confused manner, just like a real person with dementia would speak or think to themselves, as they try to complete their daily tasks. The monologues and dialogues are available in either English or Welsh, depending on the player’s preference.

Recently, awareness of dementia was tested among a group of people and nearly 50% of them saw dementia as something that cannot be prevented with different life choices [30]. However, it has been found that there are several healthy living behaviours, such as physical exercise, cognitive activities and blood pressure control, that have a clear impact on preventing dementia [31]. Since many aspects of dementia are a mystery to almost half the population, games such as Dementia: First Hand with its immersive graphics and narrative, as well as the bilingual support, can spread knowledge of the disease to some new people better than traditional methods.

1.10 A Walk Through Dementia

Much like Dementia: First hand, A Walk Through Dementia is a VR simulator game made to raise awareness of dementia. The game was developed with the help of people who had different forms of dementia and who wanted to share their experiences of living with the disease. A Walk Through Dementia was tested on a group of health care assistants from two nursing homes, and it was found to improve their understanding of dementia as well as to make them more sensitive to patients who are suffering from the disease [32].

The game will take the player through three scenarios: At the Supermarket, On the Road and At Home. Each scene has its purpose in telling the player different facts about dementia through the eyes and ears of a dementia patient.

The scene at the supermarket portrays the anxiety a dementia patient can have when confronted by a stranger in a social situation as well as their struggle with the short-term memory and spatial memory. Even reading simple texts and calculating can often be overwhelming for a person with dementia.

The scene On the Road explains to the player how easily dementia patients can confuse strangers with close relatives and how wayfinding even in familiar surroundings can often become a struggle. Unlike the supermarket scene which was fully built from 3D models, the whole scene of On the Road was shot with a 360 camera (Picture 4).

Picture 2. The scene On the Road was shot with a 360 camera making the surroundings very realistic.

The final scene, At Home, the player character struggles to make tea for guests which shows the player how dementia patients can suffer from many difficulties even while in a completely safe and familiar environment like home. The scene represents symptoms like the difficulty of remembering a list of things as well as the weakening eye-sight and hand-eye coordination that people with dementia and Alzheimer’s disease often encounter.

5 Utilized VR serious games

Two virtual reality serious games, A Day to Remember and Perception of Memory Impairment in Alzheimer's Patients, were designed for screening memory impairment diseases.

The virtual environments in both games were developed using the Unity 3D engine. Since PMIAP was not initially designed to be used with Varjo HMD, the Unity version of the project was upgraded from 2019.4.16f to 2020.3.32f to allow the use of the same Varjo SDK and settings that were used in the project A Day to Remember.

1.11 A Day to Remember

A Day to Remember was funded by Business Finland as a BEE project and developed by a research group called Future Interactive Technologies in association with medical health care professionals from Turku University Hospital.

The purpose of the game was to be able to discover possible symptoms of early dementia in the players and to screen for potential dementia cases. The game tests both the short and long-term memory of the user and since the VR can simulate the environments and routines of the user's daily life, it was found to be more engaging for the users than the traditional pen-and-paper tests that are traditionally used for screening dementia. [33.]

5.1.1 The House

At the beginning of the game, the player finds themselves waking up from their virtual bed as an alarm clock starts ringing. The player must first turn off the alarm clock and read to the note next to it for instructions on what to do next. Tasks include finding the keys and wallet from the kitchen table, the packed lunch from the refrigerator and an invitation to a TV event, which is locked into a safe. The four-digit code to open the safe is on the fridge door (Picture 5)

Picture 3. The code that opens the safe is on the fridge door and is easy to miss when playing the first time.

5.1.2 The Path

After the player has found their keys, wallet, packed lunch and the invitation to the TV event, they must make it through the woods to the bus stop from which they can take a bus to the TV station. On their path through the woods, the player will find two minigames, animal recognition minigame, where the player must try to recognize animals based only on their sound, and a memory card game.

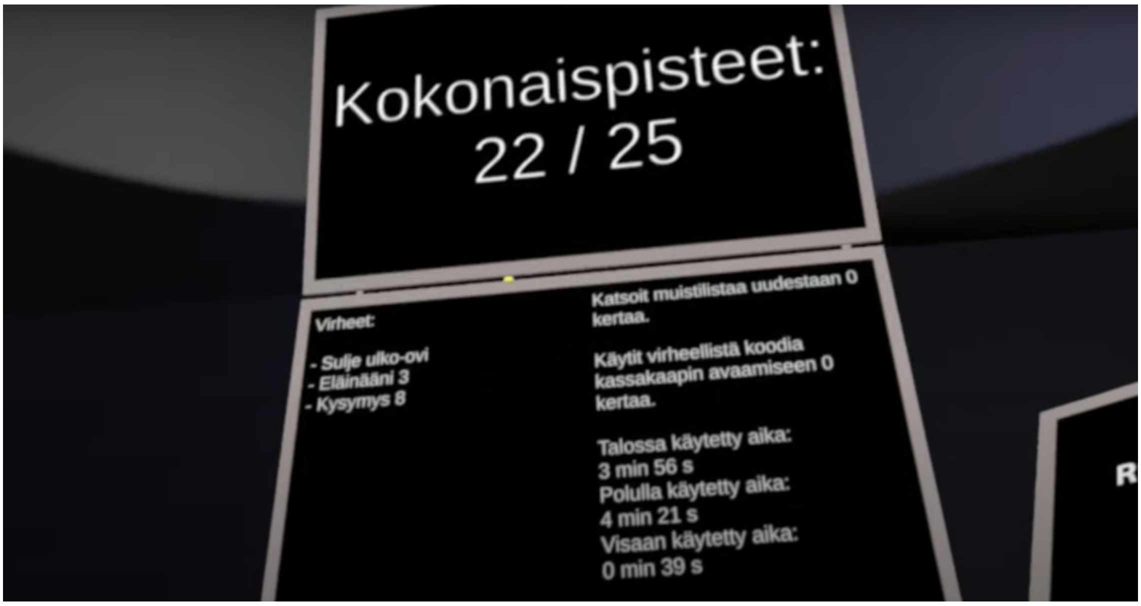
The memory card minigame, which is the only part of A Day to Remember that is used for testing in this thesis, consists of eight cards which make a total of four pairs. At first, the cards are placed with their picture side faced down and the player has to touch one card and turn it upside down, in other words, to open it, to see its picture side. After that, the player will open another card and if the two cards match, they will remain open and the player can try to find another pair. If the cards do not match, they will turn back and the player will have to try another combination of cards to see if they would match. The game is completed when all four pairs of cards are turned around. Above the game board, the player can see how attempts they have needed so far during the task (Picture 6), which could be a source of slight stress if the user does not complete the game as quickly as they had expected.

Picture 4. The player has at this point already attempted to turn around 6 pairs of cards.

After the two minigames, the player will find themselves at the bus stop where they must wave at the bus with the correct number.

5.1.3 The TV Show

After taking the bus the player will reach the last part of the game, the TV Show. There the player's long term memory is tested as they are asked several questions about their journey to the TV studio and are evaluated immediately after the questionnaire (Picture 7).



Picture 5. The player has completed the questionnaire at the end and received a score of 22 out of 25.

1.12 Perception of Memory Impairment in Alzheimer’s Patients

Perception of Memory Impairment in Alzheimer’s Patients was developed for detecting early phase Alzheimer’s disease as a part of an international student project called IC-xR-P, which was funded by a German funding agent Baden-Württemberg Stiftung.

The game was developed by a group of six students from three different universities and countries. Three students were from Germany, two from Tunisia and one from Finland. The author of this thesis was the Finnish student and contributed to planning the project as well as both coding and graphical design of the game. The goal that the international student group was asked to pursue in the project was to create a virtual reality game to detect early-phase Alzheimer’s disease.

Dementia is one of the main symptoms of Alzheimer’s disease, which is why the game will mostly focus on testing the short and long term memory of the user with various cognitive tasks replicating daily activities the user might have in real life. While most of the content in the game is unique, A Day to Remember was used as an inspiration for its development which means there can be found some similarities such as that players will start both games in a home-like environment and that both games have a memory card minigame as one activity to test the player’s memory.

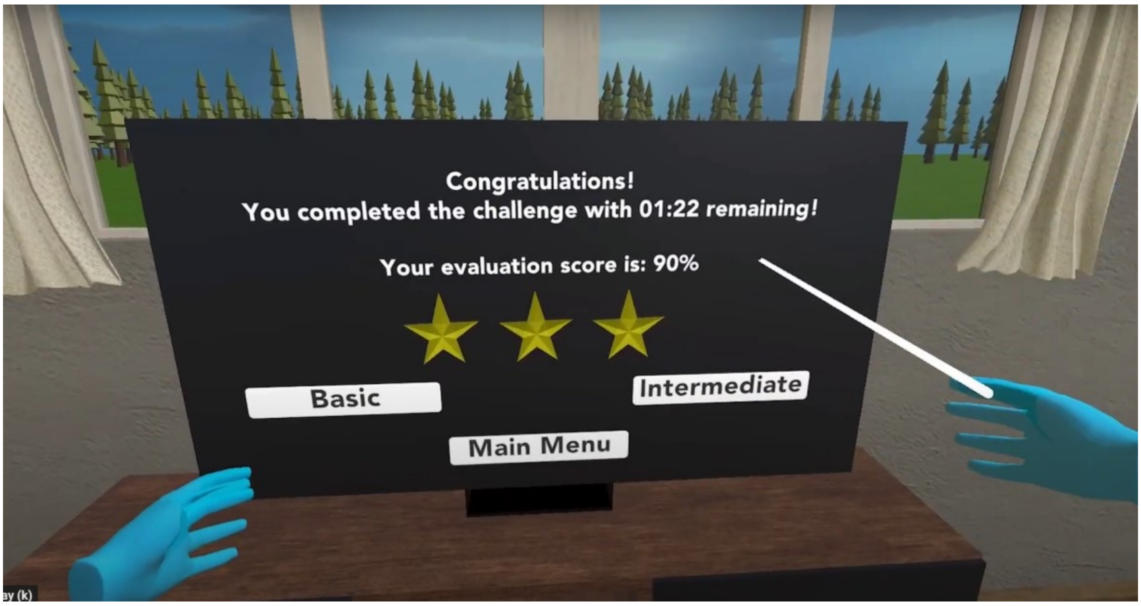
5.1.4 Orientation exercise

Orientation exercise is the main application in the game to test the player’s ability to move around the house as well as their short and long term memory. The player is given instructions on how to locate four pieces of a painting from around the VR house environment, which includes a bedroom, living room, bathroom and a garden, and to bring the pieces back to the empty frame in the bedroom to make the painting complete again (Picture 8).

Picture 6. The Player has to find four pieces of a painting around the house.

There are three different difficulty levels – easy, medium and advanced – to test the user’s ability to remember progressively more difficult tasks. In the easy level, the player is given video instructions on how to locate the next piece of painting after each one they have found. In the medium level, the video instructions on how to find all four pieces are played at the very beginning of the level and the player has to remember the order in which the pieces were shown in the video and to find them around the house and garden in that order. The advanced level offers the instructions at the beginning of the level in a similar fashion as the medium level but instead of fully animated video instructions, there will be only a few sentences describing the locations of the pieces of the painting.

Again, the player has to remember the locations in order and to bring the pieces back to the bedroom to assemble the painting. A timer is present in all scenes during the tasks and the player is evaluated at the end of each round based on the time they spent completing the task (Picture 9).

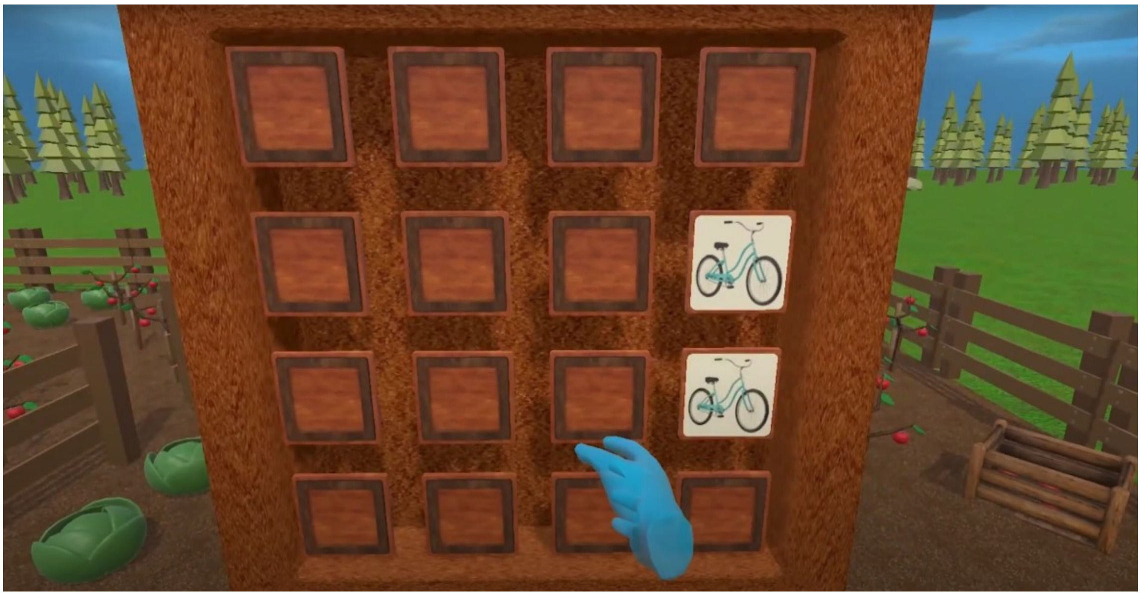


Picture 7. Evaluation of player performance based on the time they spent finding the paintings.

5.1.5 Memory card game

The memory card game is the only part of PMIAP that is used for testing in this thesis. Like in any traditional memory card game, the purpose of the game is to find all the matching pairs of cards by flipping them over.

At the beginning of the game, in the initial position, the picture side of all of the cards is faced away from the player and once the player touches any card, it will turn around, or open,.showing its picture side. The player must then proceed to open another card by touching one and if the pictures of the two opened cards match, they will remain open and the player can continue the game by trying to find the next matching pair of cards (Picture 10).



Picture 8. The player has found the first matching pair of cards.

If the picture sides of the cards do not match the cards are turned back around after a 1,5s delay. The player will proceed to turn around the cards until all of the matching pairs are found or until the player runs out of time.

The game uses a timer visible to the player (Picture 11) to evaluate the player’s performance. The player performance evaluation is based on their time spent.

Picture 9. The player can easily see the time remaining for the task.

There are three difficulty levels: easy, medium and advanced with 8, 12 and 16 cards respectively to challenge the player's memory. The medium level with 12 cards will be used in this thesis. It has four more cards than the version in A Day to Remember which, along with the short one-minute timer, can cause some additional stress on the players.

5.1.6 Other activities

PMIAP offers four other activities besides the two main minigames that were explained above. The remaining activities were made to stimulate memory or to feel the sense of going through daily routines such as cooking, but there is no player performance evaluation in any of them.

In the cooking memory game, the player is shown instructions in a text form of which ingredients to put into which cooking pot and in which order. The player must recognize the difference between a tomato, a potato and a carrot and remember in which order they were instructed to put the ingredients into the cooking pots. The minigame has three difficulty levels but no evaluation for player performance.

The animal recognition game tests the player's ability to recognize a variety of animals by their looks and sound. A choice of three different answers is given from which the player has to choose the correct one by assessing the species by its looks or by the sound it makes. There are a total of five different questions the player must answer.

Making-a-hamburger minigame was designed mostly just as a curiosity and a leisure activity inside the game. The purpose is to pile up six different ingredients to create a hamburger. During the game, the player is given clear instructions to grab the ingredients one by one and to take them on top of the empty plate on the table. Should a green box lights up on the plate, the ingredient the player is holding is the correct one in the sequence and if they let go of it, the ingredient will snap onto its place in the hamburger on the plate, whether it's the bottom bun or tomatoes or something else.

Karaoke was designed for elderly users with memory impairments who could benefit from being able to listen to and sing along to songs from their youth to possibly trigger and enhance old memories. The idea was to be able to customize the song selection based on the patient's personal history or at least their nationality. In the end, this idea was not fully realized, but rather eight placeholder songs were left in.

6 Testing

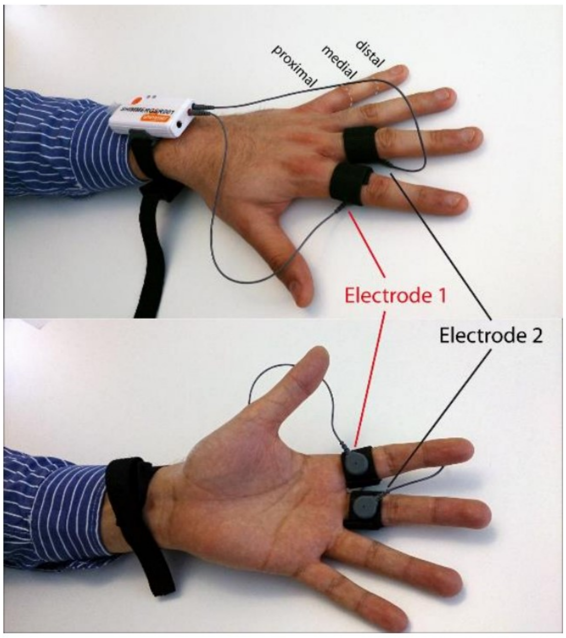
This thesis aimed to determine whether iMotions can be easily utilized for analysing biosensor data from VR serious games.

1.13 Testing scope

The tests were conducted with 10 test subjects aged 20-38 who played through the memory card games in A Day to Remember and PMIAP. Only one participant had prior experience with Varjo headsets and a few testers had very little experience with VR in general.

The card game in the game A Day To Remember had no timer but the players were shown the number of attempts they had used in the game while playing. After finishing the first game the players were assigned to play a similar minigame inside PMIAP but before the session the players were told about the short timer of 60 seconds and that they would be told when there were 30 seconds, 15 seconds, 10 seconds and 5 seconds remaining – if they had not found all the matching pairs of cards before those time marks.

The test subjects had electrodes from a Shimmer3 sensor unit attached to their index and middle fingers (Picture 12) to track their Galvanic Skin Response and another electrode attached to their auricle to monitor their heart rate. Shimmer3 was linked through Bluetooth into a laptop in which the iMotions software was running. The testers were given approximately 60 seconds with the electrodes attached to their fingers and ear before the recording for the first game was started.

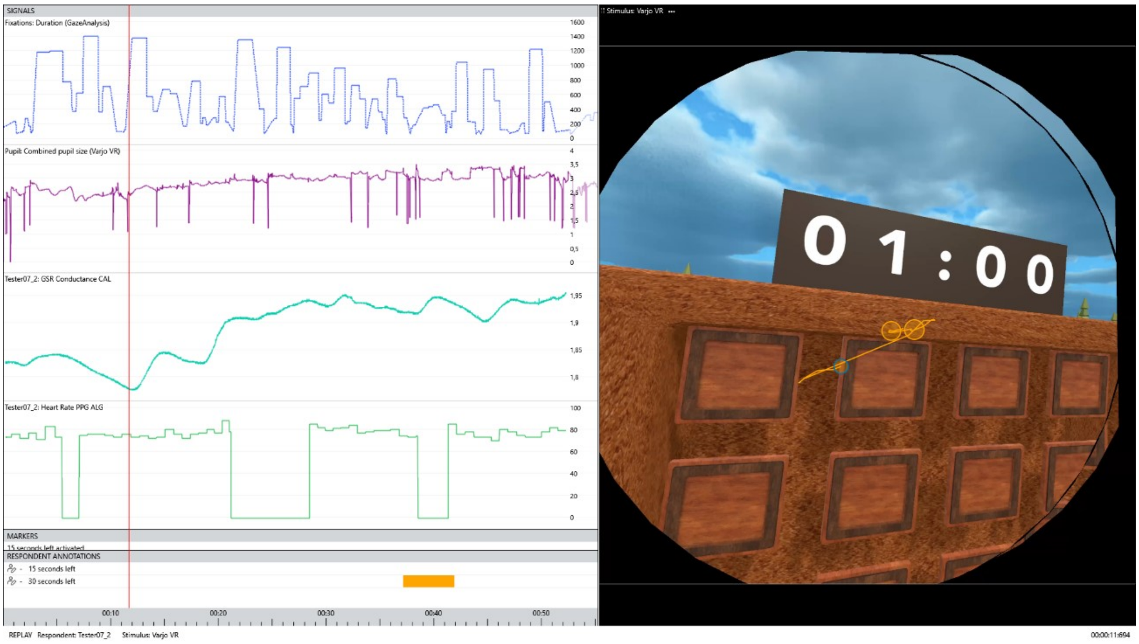


Picture 10. Shimmer3 electrode placements on the index and middle fingers.

Varjo VR-1 headset was linked to a separate desktop computer while the tests were conducted. Varjo Base and SteamVR were required software to be installed on the PC for the tested games to be playable on the Varjo headset. A separate CSV file and an mp4 video file were recorded with Varjo Base from each test subject from each game. These files were required for the eye-tracking analysis.

The clocks on the laptop and desktop were synchronized and one button was pressed from each device at the same time when the testing sessions began to record data from both Shimmer3 and Varjo VR-1 simultaneously. After the tests had concluded, the CSV and mp4 files were transferred to the laptop and imported into the same study with the GSR and heart rate data that were acquired from the Shimmer3 sensor unit.

This thesis focuses mainly on the visual analysis of the collected biosignals that were deemed relevant [11-15] for measuring stress levels. IMotions offers a visual analysis tool where the user can handpick their preferred signals to view them in the same timeline. The stimulus – in this case, the test subject's view while playing the game with the Varjo VR-1 headset – is shown next to the biosignals. The four signals that were chosen to be presented as graphs for this study were gaze fixation duration, pupil size, GSR conductance and heart rate (Picture 13).



Picture 11. Four signals from top to bottom: Gaze fixation duration, pupil size, GSR conductance and heart rate. The stimulus, in this case, footage from PMIAP, is shown on the right side.

The longer a test subject fixated their eyes on a single point in the game, the taller and wider the pillar for gaze fixation is on the graph. The pupil size graph tracks the combined size of the left and right pupils. Sudden spikes in the pupil size graph are usually caused by erratic eye movements or blinks, short moments when the eye tracker fails to recognize the eyes.

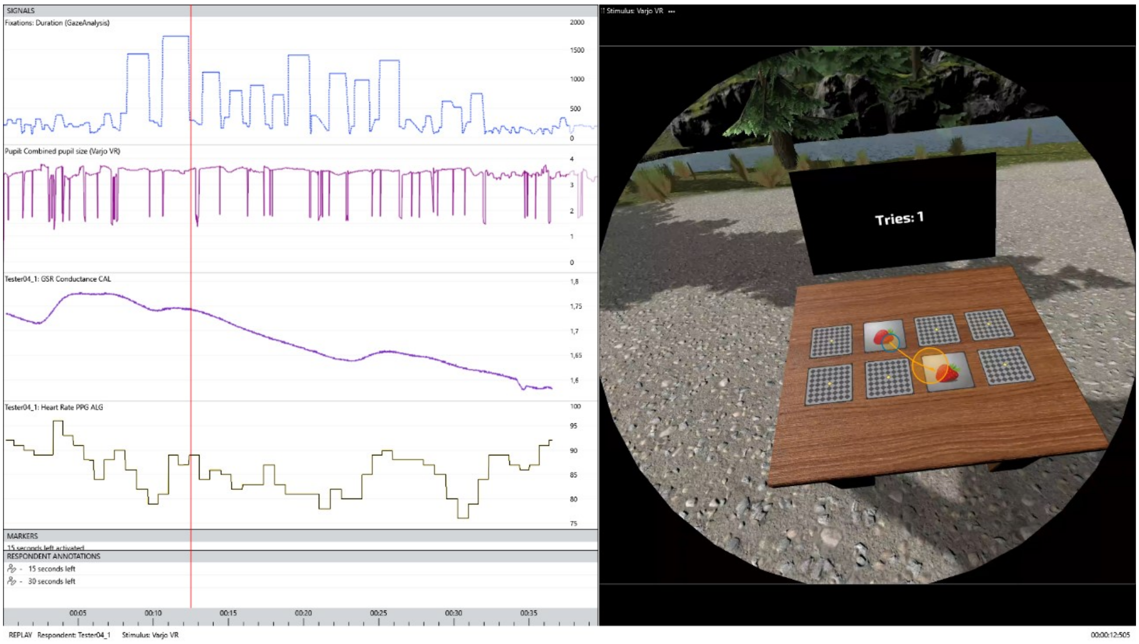
GSR values show the test subject’s skin conductance. Clear spikes show changes in the user’s emotional arousal which are usually delayed by a second or two compared to the stimulus due to human physiology. The heart rate graph is self-explanatory as it just tracks the user’s heart rate. The heart rate was measured from the outer ear of the test subjects, and in the measurements there often occurred artefacts, which are visible from the analysis graphs as sudden drops to zero beats per minute, leaving portions of the heart rate data unavailable for analysis. The portions of data with artefacts will be disregarded for this study.

1.14 Results

6.1.1 Heart rate

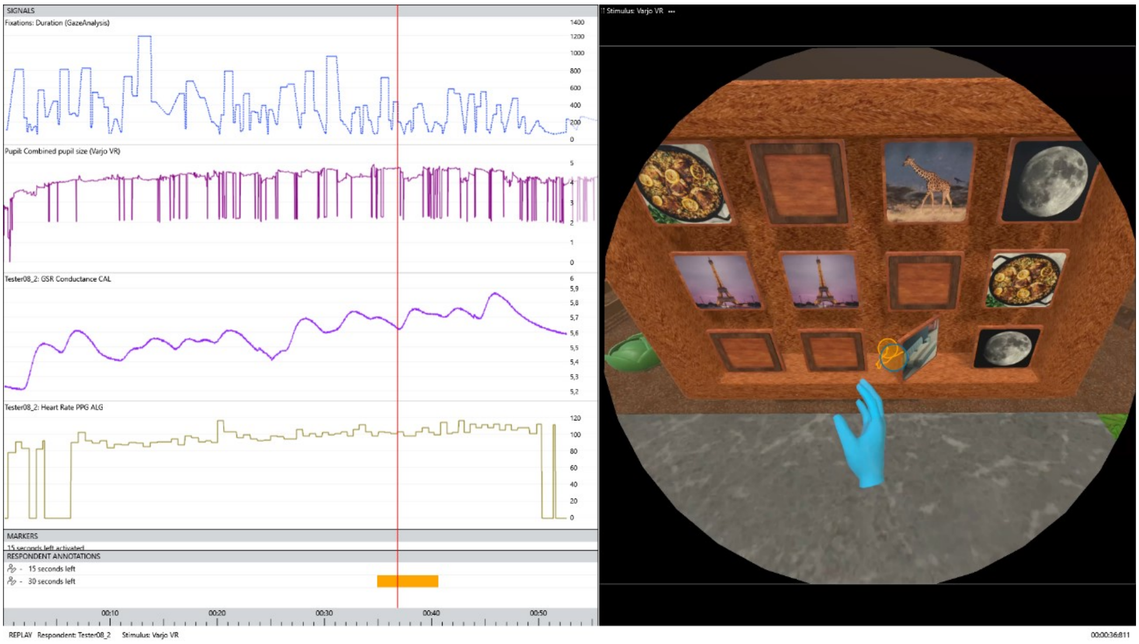
The heart rate values of the participants were examined at the beginning, the middle and the end of each play session as well as any additional moments of interest such as when 30 or 15 seconds were remaining in PMIAP. The middle part of the play session means the approximate chronological middle point of the session.

The results showed that while playing A Day to Remember, 7 of the 10 testers started the game with an elevated heart rate. For each of those seven testers, the heart rate dropped by at least 10 beats per minute (BPM) by the middle point of the session and for four of them, it rose back up close to the starting values at the end of the session (Picture 14). Three of the 10 participants showed slightly more elevated heart rate (8-20 BPM) during the middle point of the session than at the start or end. The average BPM from all of the participants at the start point was 84, at the middle point 74 and the end 79.



Picture 12. The bottom figure shows how the participant's heart rate was elevated at the start of the session, at a noticeably lower point during the middle part and elevated again at the end.

The participants’ heart rate values while playing Perception of Memory Impairment in Alzheimer’s Patients followed a slightly different but still similar pattern as to when they were playing A Day to Remember. The average heart rate at the beginning of the PMIAP sessions was 85 BPM, at the middle it was 78 BMP and at the end of the game it was 90. This means that the average heart rate values of the participants were very similar between the two games at the beginning and the middle of the levels (1-4 BPM), but they showed a noticeable difference of 11 BPM higher average heart rate values at the end of PMIAP than at the end of A Day to Remember. Only two participants had their heart rate elevate noticeably after they had been told they would have only 30 seconds left to finish the task (Picture 15).

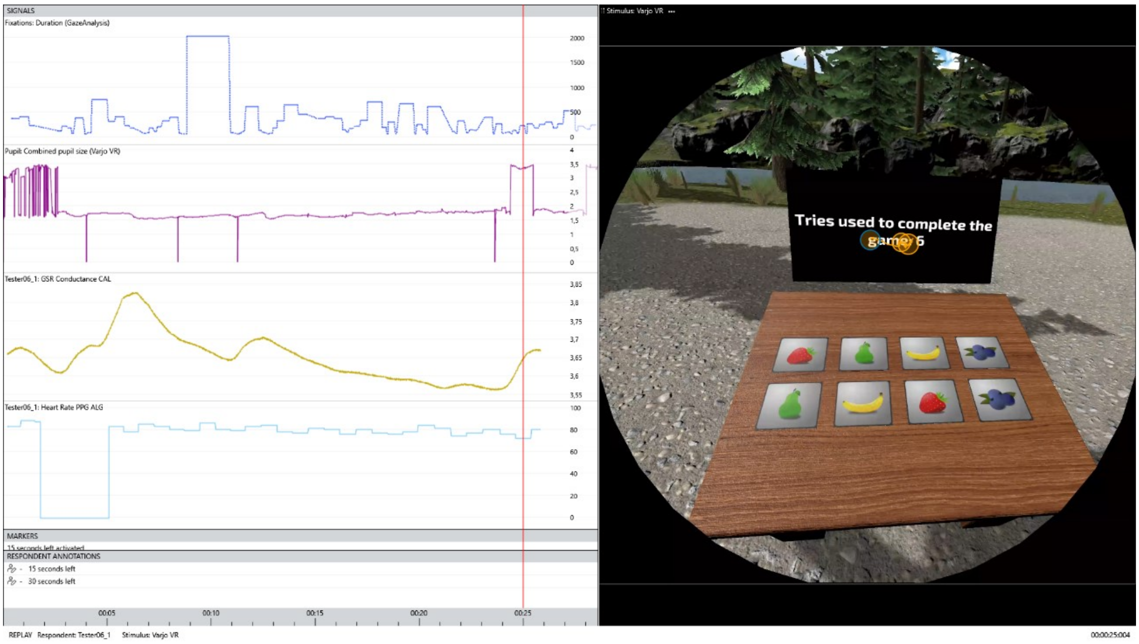


Picture 13. The heart rate (bottom graph) of a tester elevates slowly throughout the game session from 90 BPM to 110 BPM. The audio clue (the orange bar below the graphs) given at 30 seconds remaining had no visual effect on HR.

Only two participants out of 10 played the game long enough to reach the 15-seconds-remaining audio cue. They showed a slight elevation in their heart rates after that moment

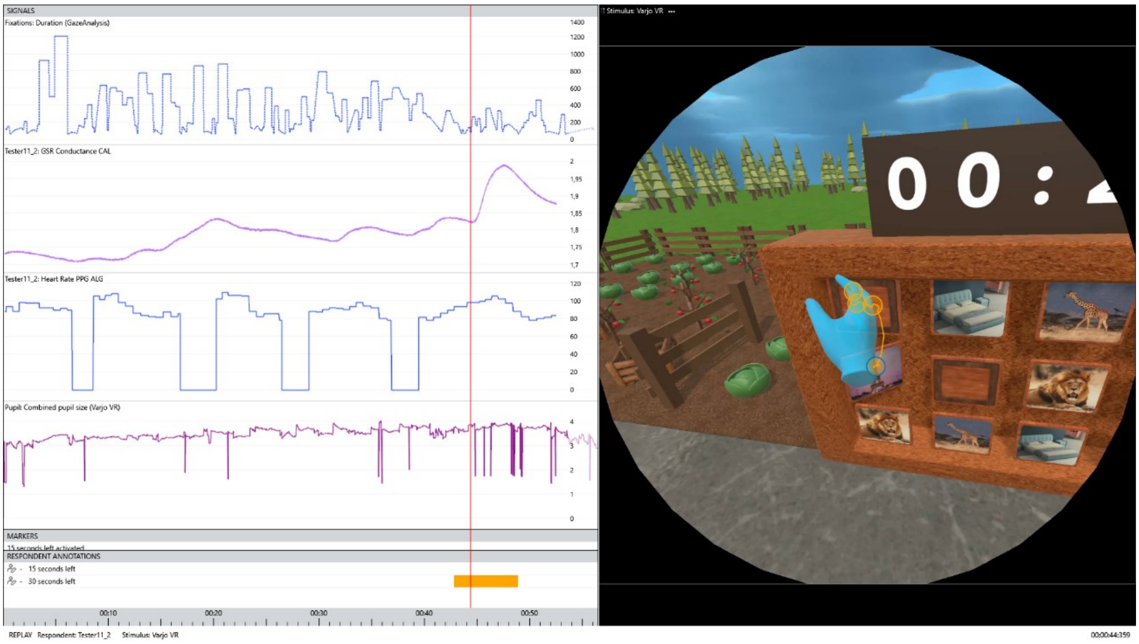
6.1.2 Galvanic Skin Response

GSR values on most of the participants playing A Day to Remember had often a spike at the beginning of the game when the player was told that they can start playing and, for some, one at the end of the game (Picture 16).



Picture 14. Two clear spikes are visible in the GSR graph (third graph from the top) for many testers while playing A Day to Remember – one at the beginning and one at the end.

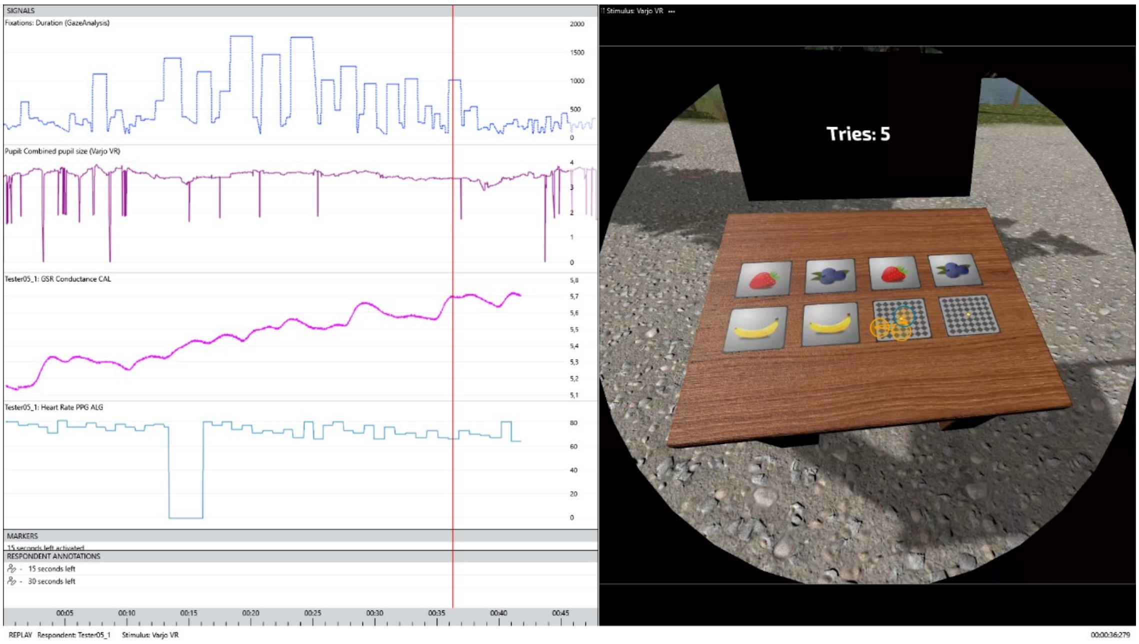
The GSR graphs recorded during the play sessions in PMIAP were more dynamic, meaning there were more and higher spikes in the graphs, than the ones taken from A Day to Remember. Some players also responded visibly to the 30-second audio cue (Picture 17).



Picture 15. GSR graph (2nd from the top) spiking after the player had been given a notice of 30 seconds remaining.

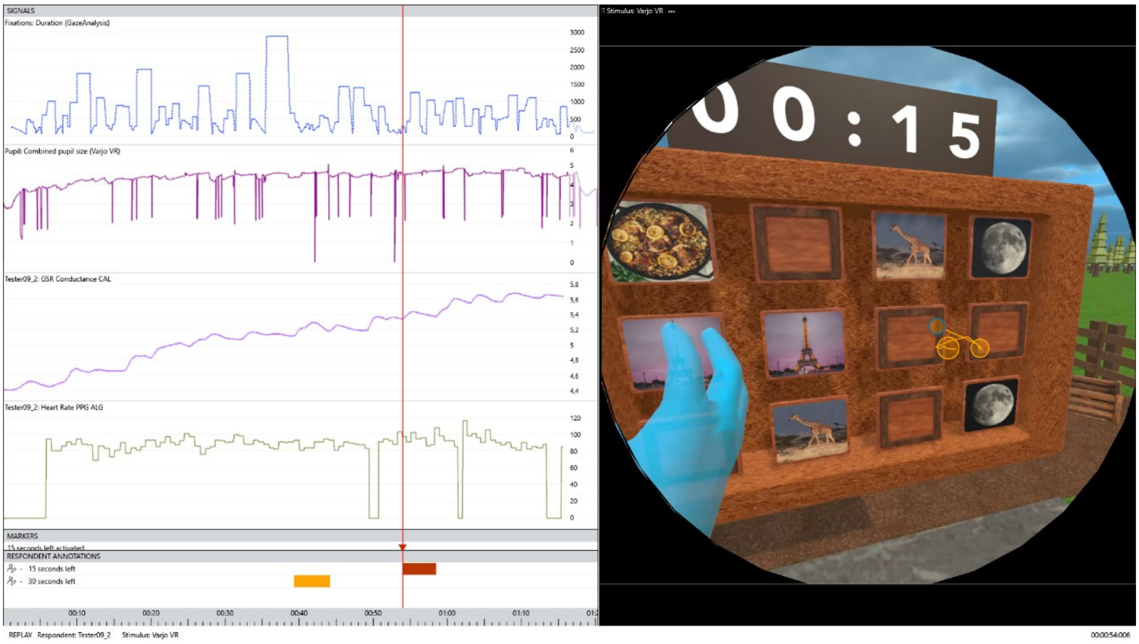
6.1.3 Eye movements and pupil size

The eye fixation duration and the pupil size of the participants did not fluctuate much during the playthrough of A Day to Remember. Players usually fixated their eyes on locations for slightly longer at the beginning than at the end but the difference was not huge for any participant. Eye fixation duration and pupil size also did not seem to correlate with the heart rate and GSR graphs (Picture 18).



Picture 16. Eye fixation duration (top) and pupil size graph (2nd from the top) do not show much fluctuation over time.

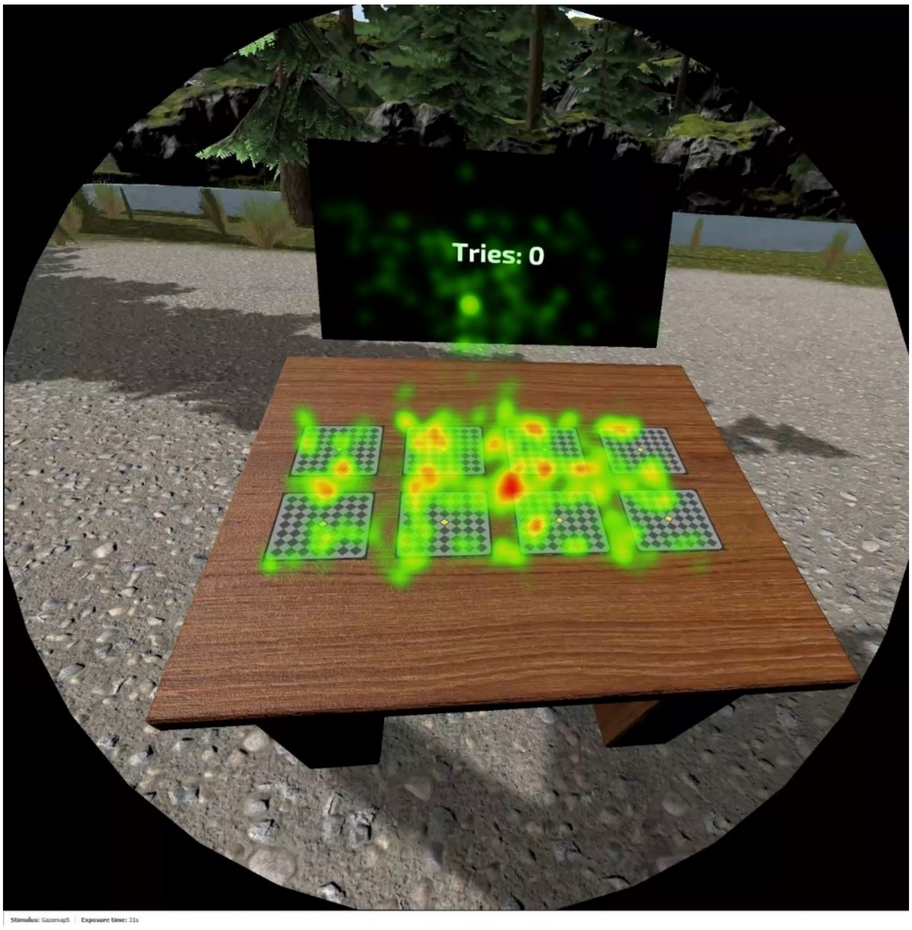
In contrast to the session of A Day to Remember, while the participants were playing PMIAP, every participant had their eyes dilate after the beginning of the game until they had finished the game after which they contracted back to their original size again (Picture 19).



Picture 17. Pupils dilate for the duration of the memory card game and contract back after the game is finished (second graph from the top).

Eye fixation durations were similar to the ones that participants got while playing A Day to Remember, and no clear conclusion could be drawn from them.

A heatmap from the eye fixations of the participants from each game was created to visualize where the players directed their gaze during the play sessions. The heatmaps are similar for both games in that they show how the testers focused their eyes almost completely on the gameboard while the games were in progress. After playing A Day to Remember the players looked at the scoreboard to see how they had performed (Picture 20).



Picture 18. The participants focused their gaze mostly on the cards on the table and usually at the end at the "scoreboard" to see how many tries they had needed to complete the game.

in PMIAP the players again focused on the cards. The game had a visible timer on top of the gameboard but it received relatively few glances (Picture 21).

Picture 19. According to the heatmap, players took only a few glances at the timer while playing PMIAP.

1.15 Discussion

The participants started the first game with a seemingly elevated heart rate most likely because they were not sure what to expect from the tests and some of them had not had much experience with VR devices before. The heart rates stabilized to lower values after a short while after the testers had become used to the VR environment and managed to find their first pair of matching cards in the memory game. The GSR values also often spiked at the beginning, meaning that the players encountered some emotional arousal, most likely stress when they first started playing the game. Pupils did not dilate for long on any participant during the playthrough of the first game.

When playing the second game, the participants seemed to give more attention to the game as their pupils dilated right after the start and contracted back after finishing the game, which can be a sign of extreme focus or an increased workload. However, pupil dilation can also be caused by other sources such as fluctuation in lighting conditions since the players tested two different games. For optimal results the two tested games should be exactly the same in every way except for an additional stimulus such as a timer in one game.

The heart rates also ended up being noticeably higher at the end of the second game compared to the values at the end of the first one. The GSR graphs were also more dynamic, meaning there were more sources of emotional arousal in the stimulus when the testers played the second game.

Heatmaps were similar for both games as the players rarely, if ever, focused their gaze outside the gameboard where the cards were located. The only exceptions were the scoreboard in the first game, where the players checked how many tries they had needed to complete the game, and the timer in the second game. The timer received surprisingly little attention, probably either because its position was poor or because the participants were not properly notified beforehand that there would be a visible timer in the game. Instead, they were informed that they would be told when the time was running out.

Psychology PhD student Suvi Holm was interviewed briefly about the findings of the study. Holm has used measures of GSR and EMG [35] as well as eye movements [36] in her studies on videogames. According to Holm, even though 10 test subjects are not enough to draw statistically relevant conclusions, the test results were rational and in line of what could be expected from a pilot study about the subject. She added that while the tests in this study focused on comparing biosignal values at the beginning, middle and end of the play sessions, in similar studies a baseline measurement is often conducted on the test subjects before the actual tests to obtain base values from the testers’ biosignals. These base values can then be compared to the values that are gathered during the play sessions.

Holm also mentioned that, even though the two tested games in this thesis were relatively similar, to obtain more accurate test results and to remove most doubt about different conditions in tests, there could be two versions of the same game. An additional stimulus such as a timer could then be added to one of the versions.

7 Conclusion

This thesis aimed to find out whether different biosensors can be utilized together with the iMotions biometric platform for easy analysis of play sessions of VR serious games. The author of this thesis had very little prior knowledge of biosensors or the health technology in general but the tests for this thesis with biosensors and iMotions were completed successfully with some help from the TUAS personnel and the online material from the iMotions help desk.

The tests indicated that the game with the timer and more cards caused the players to focus more intensively on the task at hand than the game with fewer cards and no timer. Apart from the beginning of the first game when the players entered the virtual reality, signs of stress were also more visible in the sessions of the second game.

This thesis could have been improved in a few ways as there were a couple of issues. First, the time management became a problem as devising the thesis topic took much longer than expected, leaving less time to work on the thesis than would have been preferred. This could have been avoided by choosing a thesis topic from the list of topics rather than by trying to come up with a new one.

Second, some of the differences in the compared data could be explained with the differences in the tested games. Rather than to have had two separate games for tests, the tested games should have been two nearly similar versions of only one game to minimize doubt about different testing conditions. Also, to produce even more reliable testing results, each tester should have had a baseline measurement conducted for their biosignals before playing the games. This could have been achieved by attaching biosensors to the players for a few minutes before the play sessions until their metrics normalized.

Third, most of the testers did not spend even 45 seconds of their one-minute timer on the second game, meaning they may not have experienced much stress from the lack of time. This issue could have been solved either by reducing the amount of time or by increasing the number of cards.

The tests in this thesis were conducted using only the eye-tracking technology of Varjo VR-1 and Shimmer3 to track the GSR and heart rate. For future research about biosensors and VR, options to include EEG or Facial Expression Recognition by utilizing EMG as well as HP Reverb G2 Omnicept Edition, which has integrated eye-tracking sensors from Tobii as well as a heart rate sensor and a face camera, could be explored further.

References

[1] Bhalla N, Jolly P, Formisano N, Estrela P. Introduction to biosensors. Essays in Biochemistry. 2016 Jun 30;60(1):1–8.

[2] Antoniou PE, Arfaras G, Pandria N, Athanasiou A, Ntakakis G, Babatsikos E, et al. Biosensor real-time affective analytics in virtual and mixed reality medical education serious games: Cohort study. JMIR Serious Games. 2020;8(3).

[3] Villarejo MV, Zapirain BG, Zorrilla AM. A stress sensor based on galvanic skin response (GSR) controlled by ZigBee. Sensors (Switzerland). 2012;12(5).

[4] Stein N, Niehorster DC, Watson T, Steinicke F, Rifai K, Wahl S, et al. A Comparison of Eye Tracking Latencies Among Several Commercial Head-Mounted Displays. Iperception. 2021;12(1).

[5] Varjo. Introducing bionic display: how Varjo delivers human-eye resolution in virtual reality. [Internet]. Helsinki (FI): Varjo; [cited 2022 June 22]. Available from: https://varjo.com/blog/introducing-bionic-display-how-varjo-delivers-human-eye-resolution/

[6] Circuit Stream. High-End VR Headsets Comparison: Pimax, Varjo, Xtal, StarVR, HTC Focus 3, and HP Reverb G2 Omnicept. [Internet]. Alberta (CA): Circuit Stream; [Updated 2022, cited 2022 June 22]. Available from: https://www.hp.com/us-en/vr/reverb-g2-vr-headset-omnicept-edition.html

[7] HP.Development Company, LP. Reverb G2 VR headset Omnicept-Edition. [Internet]. Dallas (US): HP Development Company, LP; [Updated 2022, cited 2022 June 22]. Available from: https://www.hp.com/us-en/vr/reverb-g2-vr-headset-omnicept-edition.html

[8] Jesse Damiani. The Varjo VR-1: Everything you need to know about the highest-end VR headset in the world. [Internet]. New Jersey (US): Forbes; 2019 [Updated 2019, cited 2022 June 22]. Available from: https://www.forbes.com/sites/jessedamiani/2019/02/19/the-varjo-vr-1-everything-you-need-to-know-about-the-highest-end-vr-headset-in-the-world/?sh=6cc4ee365b91

[9] Meghanathan RN, Ruediger-Flore P, Hekele F, Spilski J, Ebert A, Lachmann T. Spatial sound in a 3D virtual environment: All bark and no bite? Big Data and Cognitive Computing. 2021;5(4).

[10] Hirt C, Eckard M, Kunz A. Stress generation and non-intrusive measurement in virtual environments using eye tracking. Journal of Ambient Intelligence and Humanized Computing. 2020;11(12).

[11] Akuma S. Eye Gaze Relevance Feedback Indicators for Information Retrieval. International Journal of Intelligent Systems and Applications [Internet]. 2022 Feb 8;14(1):57–65. Available from: https://www.mecs-press.org/ijisa/ijisa-v14-n1/v14n1-5.html

[12] Allen Richards. Understand Emotional Arousal, Heal Your Relationships. [Internet]. Utah (US): Sunrise Residential Treatment Program, an Embark Behavioral Health program; 2015 [cited 2022 June 22]. Available from: https://sunrisertc.com/emotional-arousal-and-relationships/

[13] Ness D, Calabrese P. Stress effects on multiple memory system interactions. Vol. 2016, Neural Plasticity. 2016.

[14] Salgado DP, Rodrigues TB, Keighrey C, Flynn R, Naves ELM, Murray N, et al. A QoE assessment method based on EDA, heart rate and EEG of a virtual reality assistive technology system. In: Proceedings of the 9th ACM Multimedia Systems Conference, MMSys 2018. 2018.

[15] van Dooren M, de Vries J, Janssen JH. Emotional sweating across the body: Comparing 16 different skin conductance measurement locations. Physiology and Behavior. 2012 May 15;106(2):298–304.

[16] Soufineyestani M, Dowling D, Khan A. Electroencephalography (EEG) technology applications and available devices. Vol. 10, Applied Sciences (Switzerland). 2020.

[17] Michel CM, Brunet D. EEG source imaging: A practical review of the analysis steps. Frontiers in Neurology. 2019;10(APR).

[18] Tauscher JP, Braunschweig Fabian Wolf Schottky T, Braunschweig Steve Grogorick T, Braunschweig Paul Maximilian Bittner T, Braunschweig Maryam Mustafa T, Magnor M, et al. Immersive EEG: Evaluating Electroencephalography in Virtual Reality.

[19] Cha HS, Choi SJ, Im CH. Real-time recognition of facial expressions using facial electromyograms recorded around the eyes for social virtual reality applications. IEEE Access. 2020;8.

[20] Cha HS, Im CH. Performance enhancement of facial electromyogram-based facial-expression recognition for social virtual reality applications using linear discriminant analysis adaptation. Virtual Reality. 2022;26(1).

[21] Imotions. Platform. [Internet]. Copenhagen (DK): Imotions; [cited 2022 May 22]. Available from: https://imotions.com/platform/

[22] Neeuro. Neeuros. [Internet]. Pasir Panjang (SG): Neeuro; [updated 2022, cited 2022 May 22]. Available from: https://www.neeuro.com/neeuroos

[23] Duke-NUS Medical School. IMH, Duke-NUS, A*STAR and Neeuro Pilot Home-Based Brain-Training Game to Help Children with ADHD. [Internet]. (SG): Duke-NUS; [updated 2019, cited 2022 May 22]. Available from: https://www.duke-nus.edu.sg/allnews/media-releases/imh-dukenus-and-neeuro-pilot-home-based-brain-training-game-to-help-childrenwith-adhd

[24] MindMaze. Digital therapies for neurorehabilitation. [Internet]. Lausanne (CH): MindMaze; [updated 2022, cited May 22]. Available from: https://www.mindmaze.com/digital-therapies-for-neurorehabilitation/

[25] Deutsche Telekom AG. Deutsche Telekom presents innovative new mobile game Sea Hero Quest. [Internet]. Bonn (DE): Deutsche Telekom AG; 2016 [cited May 22]. Available from: https://www.telekom.com/en/media/media-information/archive/deutsche-telekom-presents-innovative-new-mobile-game-sea-hero-quest--363198

[26] Gazova I, Vlcek K, Laczó J, Nedelska Z, Hyncicova E, Mokrisova I, et al. Spatial navigation-A unique window into physiological and pathological aging. Frontiers in Aging Neuroscience. 2012;4(JUN).

[27] Big Think Plus. Urban rural divide navigation. [Internet]. Big Think Plus; [updated 2022, cited May 22]. Available from: https://bigthink.com/thinking/urban-rural-divide-navigation/

[28] Coutrot A, Schmidt S, Coutrot L, Pittman J, Hong L, Wiener JM, et al. Virtual navigation tested on a mobile app is predictive of real-world wayfinding navigation performance. PLoS ONE. 2019 Mar 1;14(3).

[29] Galactig. Dementia First Hand featured on BBC Click. [Internet]. Caernarfon (GB): Rondo Media Group; 2019 [updated 2019, cited June 22]. Available from: https://galactig.com/dementia-first-hand-on-bbc-click/

[30] Cations M, Radisic G, Crotty M, Laver KE. What does the general public understand about prevention and treatment of dementia? A systematic review of population-based surveys. Vol. 13, PLoS ONE. Public Library of Science; 2018.

[31] Heger I, Deckers K, van Boxtel M, de Vugt M, Hajema K, Verhey F, et al. Dementia awareness and risk perception in middle-aged and older individuals: Baseline results of the MijnBreincoach survey on the association between lifestyle and brain health. BMC Public Health. 2019;19(1).

[32] Aicken C, Hodgson L, de Vries K, Wilkinson I, Aldridge Z, Galvin K. 'This Adds Another Perspective': Qualitative Descriptive Study Evaluating Simulation-Based Training for Health Care Assistants, to Enhance the

Quality of Care in Nursing Homes. International Journal of Environmental Research and Public Health. 2021;18(8).

[33] Alzheimer's Research UK. A Walk Through Dementia. [Internet]. Granta Park (GB): Alzheimer's Research UK: [cited June 22]. Available from: https://www.awalkthroughdementia.org/

[34] Dulau E, Botha-Ravyse CR, Luimula M, Markopoulos P, Markopoulos E, Tarkkanen K. A virtual reality game for cognitive impairment screening in the elderly: a user perspective. 10th IEEE International Conference on Cognitive Infocommunications 2019.

[35] Holm, S. K., Kaakinen, J. K., Forsström, S., & Surakka, V. Self-reported playing preferences resonate with emotion-related physiological reactions during playing and watching of first-person shooter videogames. International Journal of Human-Computer Studies, 155, 102690. 2021.

[36] Holm, S. K., Häikiö, T., Olli, K., & Kaakinen, J. K. Eye Movements during Dynamic Scene Viewing are Affected by Visual Attention Skills and Events of the Scene: Evidence from First-Person Shooter Gameplay Videos. Journal of Eye Movement Research, 14(2). 2021.