Biofeedback Integration in Virtual Reality Applications

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MASTERARBEIT

eingereicht am
Fachhochschul-Masterstudiengang

Interactive Media

in Hagenberg

im Januar 2020

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Hagenberg, January 22, 2020

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Contents

Abstract

Stress is a major problem all around the globe. However, research on this topic is mostly done by developing new strategies to prevent stress from manifesting. Hence, this paper strives to combine two concepts dating back to the middle of the 20th century to counter stress in a modern manner. The integration of biofeedback in virtual reality applications is a topic that is rarely researched. Modern health and lifestyle applications mostly integrate biometric data by acquiring vital signs data sets via smartwatches. This data, however, is not precise enough to make an accurate assumption about the user's mental state. The goal for this thesis project is to integrate biometric sensors in a VR application for wireless realtime biofeedback, as well as evaluating captured biometric data with research-grade bio sensors in combination with a questionnaire, which the participants fill in directly after capturing their biometric data. This data is later utilized to evaluate the application itself, as well as the used sensors. Furthermore, approaches for implementing biofeedback integration and concepts for a virtual reality relaxation application are discussed in this thesis.

Kurzfassung

Stress ist ein großes Problem auf der ganzen Welt. Aber die Forschung zu diesem Thema erfolgt vor allem durch die Entwicklung neuer Strategien, um zu verhindern, dass sich Stress manifestiert. Die Kombination von zwei Konzepten, die beide auf die Mitte des 20. Jahrhunderts zurückgehen, wird genutzt um Stress in einer modernen Art entgegenzuwirken. Die Integration von Biofeedback in Virtual-Reality-Anwendungen ist ein Thema, das nur selten erforscht wird. Moderne Gesundheits- und Lifestyle-Anwendungen integrieren meist biometrische Daten, indem sie biometrische Daten über Smartwatches erfassen. Diese Daten sind jedoch nicht genau genug um eine präzise Annahme über den psychischen Zustand der Benutzer zu treffen. Das Ziel dieses Projektes ist es biometrische Sensoren in eine VR-Anwendung für drahtloses Echtzeit-Biofeedback zu integrieren. Zusätzlich wird die Auswertung der erfassten biometrischen Daten mit biometrischen Sensoren in Kombination mit einem Fragebogen, den die Teilnehmer direkt nach der Erfassung ihrer biometrischen Daten ausfüllen, abgehalten. Diese Daten werden später zur Auswertung der Anwendung selbst sowie der verwendeten Sensoren verwendet. Darüber hinaus werden in dieser Arbeit Ansätze zur Implementierung von Biofeedback-Integration und Konzepte für eine Virtual-Reality-Relaxationsanwendung diskutiert.

Chapter 1

Introduction

Reading human vital signs data sets with biometric sensors and evaluating captured data or visualizing data via biofeedback is practiced by doctors, therapists and clinicians all around the globe. The topic of biofeedback is not a new one. It dates back to the 1970s, when guidelines and practice areas were determined. These guidelines for biofeedback in physical therapy and psychotherapy were created by John V. Basmajian, a professor for Medicine and Anatomy from McMaster University, Ontario, Canada [2]. Looking back, biofeedback in the late 70s and early 80s was mostly electromyography, visualizing muscle activity in the treatment of cramps or headaches. Nowadays, biofeedback is used in a variety of areas, reaching from incontinence to sleeping disorders and other forms of fibromyalgia. As new areas for biofeedback were developed, technology became increasingly more reliable and processing power skyrocketed. With new technology such as combined sensor kits with home-ready EEG and ECG sensors and revolutionizing technologies like virtual reality (VR), new ways to utilize biofeedback arose. The goal of the corresponding thesis project is to incorporate biofeedback in a virtual reality relaxation application and to start testing new ways of utilizing biofeedback in application areas like work-environment-stress and relaxation. Additionally, evaluation of the relaxation effect of the tested relaxation application is conducted through a questionnaire, which is held after the execution of three relaxation exercises inside the virtual world. Furthermore, evaluation of the acquired sensor data is done by means of comparison of the captured data and provided data from the seller of the biometric sensors.

1.1 Thesis structure

This thesis is structured into five main chapters. In chapter 2, Embodiment and Presence in VR, biofeedback methods of modern times are provided and biofeedback systems are inspected. Furthermore, this chapter provides an overview of modern virtual reality systems and combinations of different areas of application for virtual reality. As the last part of this chapter, current papers are analyzed, summarized and a conclusion showing what can be learned from these papers is given. Chapter 3 provides insights into the concept behind the virtual reality relaxation application and on different rendering styles utilized in virtual reality applications. In chapter 4, the implementation of the corresponding thesis project is shown and code as well as strategies are provided. In

chapter 5 acquired vital signs data sets are evaluated and the results of the conducted questionnaire are presented. As a conclusion, chapter 6 focuses on findings and the accumulated knowledge which was acquired during this thesis project. Furthermore, future problems regarding biofeedback data for assumptions about the human relaxation level are presented.

Chapter 2

Embodiment and presence in VR

Improving virtual experiences has been the goal of many researchers and scientists in the past 60 years. In the beginning, being immersed in a virtual world started by utilizing computer screens and haptic input devices such as mice and keyboards.

2.1 Immersion through visual stimuli

One of the first researchers to develop a method to immerse users further into a virtual world was Ivan E. Sutherland, a professor at Harvard University, with the help of his student Bob Sproull. They began working on what they called "the ultimate display", resulting in the first head-mounted three-dimensional display. In his paper, Sutherland describes that stereoscopic display is not as important as the kinetic depth effect to make a virtual scene appear to be 3D. The kinetic depth, as described, is that moving perspective images appear strikingly three dimensional without stereo display. Having created the first virtual reality head-mounted display (HMD, see fig. 2.1) Sutherland was already considering eye tracking inside of a virtual reality HMD but considered it to be too difficult and expensive at his time, in perspective of not needing it for rendering because rendering was only dependent on head position and rotation. Today, eye tracking inside an HMD is becoming increasingly popular, which shows that this technology and idea has existed for a long time, but was stalled by technological difficulties. As a result, Sutherland's project birthed the augmented reality HMD named "the Sword of Damocles". This project was given this name because it was suspended from the ceiling, enabling stationary use without having wiring blocking the floor and opening weak points, such as technical failure due to unplugged cables [24].

As the first cornerstone for three-dimensional rendering inside a virtual reality headset was set, research steadily improved rendering techniques and rendering quality and as the next step, scientists and companies began to research new ways to improve immersion into a virtual environment by means of audio technologies. In 1989 *Crystal River Engineering Inc*, a company founded by Scott Foster after being contracted by NASA, that was focusing on head-related transfer function for realtime applications, which was acquired by *Aureal Semiconductor* in 1996, developed the first realtime binaural 3D audio processing unit for NASA's VR Workstation Project VIEW [28]. VIEW (The Virtual Interface Environment Workstation) is a head-mounted stereoscopic dis-
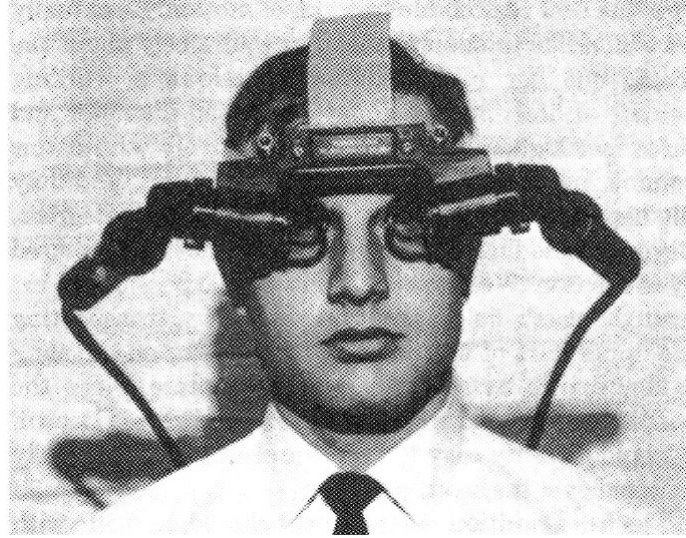
Figure 2.1: Mini-CRT Displays combined into a head-mounted display [24]

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play system in which the display is either an artificial computer-generated environment or a real environment relayed from remote video cameras. The operator can "step into" this environment and interact with it. Not only focusing on 3D audio to enhance immersion, NASA also developed a haptic interaction device, the DataGlove, and full-body tracking, the DataSuit, for users of VIEW (see fig. 2.2). The DataGlove has a series of fiber optic cables and sensors that detect any movement of the wearer's fingers and transmit the information to a host computer; a computer-generated image of the hand will move exactly as the operator is moving his gloved hand. With appropriate software, the operator can use the glove to interact with the computer scene by grasping an object. The DataSuit is a sensor-equipped full-body garment that greatly increases the sphere of performance for virtual reality simulations by reporting the motions, bends, gestures and spatial orientation of the wearer to the computer [53]. This project included many technologies to greater immersion and enabled users to interact with virtual environments, which are still in use in today's consumer state-of-the-art virtual reality devices. But at that time, projects of this extent were connected to large financial expenses, which could only be carried out by big companies and were by far not ready for commercial use. The first virtual reality headset that made it to the market shelves was called VFX1 by Forte Technologies, which was released in 1995. The pricing was set at nearly the same level as modern consumer virtual reality headsets at USD 695 and it was shipped with an external input device, designed especially for virtual reality interaction. The VFX1 consisted of a VR headset, which had adjustable focus and adjustable interpupillary distance, a haptic input device called "Cyberpuck", which tracked pitch and roll of the device itself, and an external interface which the headset and the computer were connected to. Around the same time, Paul Milgram introduced the "Reality-Virtuality Continuum" (see fig. 2.3) and renewed the definition of the term "Mixed Reality" (MR). This term acts as a superordinate concept for the terms "Virtual Reality" (VR), "Augmented Reality" (AR) and "Augmented Virtuality" (AV) and was introduced because the term MR

Figure 2.2: NASA employee using VIEW [53].
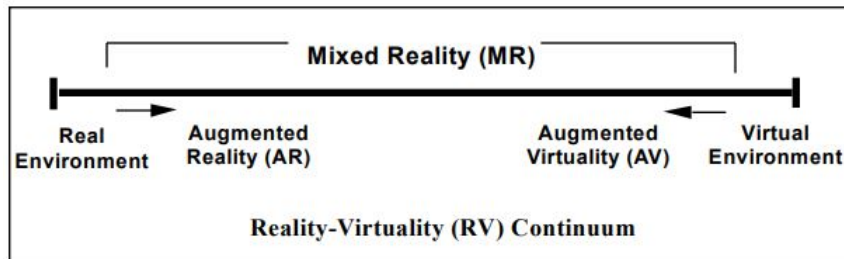
Figure 2.3: The "Reality-Virtuality Continuum" by Paul Milgram [14].

was constantly misapplied. The "Reality-Virtuality Continuum" defines a scale for MR applications, ranging from entirely real environments to completely computer-generated ones, to clarify the definition of AR, VR and AV [14]. Years from that, little commercial projects were available, but research on greater immersion into virtual environments continued. A turning point for commercial VR was the creation of a Kickstarter campaign for a revolutionary commercial VR headset. In 2014, *Oculus*, a company acquired by *Facebook* in the same year, produced the world's first consumer-ready virtual reality head-mounted display. The company had started as an ambitious Kickstarter campaign and quickly evolved into one of the biggest VR headset companies on the current market.

After presenting their first prototype at E3, *Oculus* was quickly acquired by *Facebook*. With affordable hardware and high-resolution displays, *Oculus* revolutionized the Virtual Reality business and created a big hype around the topic by also addressing the general public. The release of the device started the so-called "virtual reality revolution" and opened the gates for various fields of application for virtual reality systems beyond the domains of gaming and entertainment [33, 48]. Early research utilizing commercially available VR headsets was done in gastrointestinal endoscopy training regarding cost efficiency, availability and novice education. The future of endoscopy heavily relies on virtual endoscopic simulators with now two simulator kits ready for purchase. Especially novice trainees can benefit from virtual simulators as they enhance their training procedures for upper and lower gastrointestinal endoscopy [25]. With *Oculus* opening the market and showing the newly gained potential for consumer VR headsets, *HTC*, a company formerly known for their mobile phones and creating the first smartphone running *Android* OS, partnered with *Valve*, a company known for their gaming platform "Steam", created a revolutionizing virtual reality system, which was released in 2016 and elevated immersive VR experiences to the next level. With the *HTC Vive*, not only affordable hardware with high resolution displays were combined, but room-scale VR in combination with tracked motion controllers with haptic feedback was introduced to the public, too. Room-scale VR allows its user to move freely in a limited space while being tracked by the virtual reality system. The technology enabling room-scale tracking are the so-called *Valve Lighthouse* sensors. In contrary to many other tracking solutions, *Valve's Lighthouse* trackers do not rely on optical tracking. Inside a *Lighthouse* tracker is a laser system that floods the play-area with non-visible light. The main idea behind *Valve's* tracking solution are photosensors. A *Lighthouse* sensor sends out a non-visible flash and the VR system counts how long the lasers take to reach the photosensors on the tracked devices. This way, the exact 3D positions of the headset and the controllers can be calculated. As the first VR system with room-scale capability, the *HTC Vive* additionally ships with motion controllers that utilize vibration as haptic feedback to its user. This includes yet another sense to further immersion into virtual environments. With this technology, moving freely while playing VR games was made possible. As with VR itself, this revolutionary adaptation to VR systems opened the gates for even more fields of application.

One of the most nameworthy fields is psychotherapy. Fighting against phobias can be a difficult journey to master for a patient and his or her psychologist. Therefore, companies have specified themselves on fighting phobias with the help of virtual reality systems. An exceptionally good example is fighting Acrophobia with VR training. Acrophobia, most commonly known as the fear of heights, prevents people suffering from it, from being able to function normally when being on elevated terrains. With virtual therapy, patients will not have to climb mountains or have to have a psychotherapist on their side when they tackle their phobia.

In 2018 a study led by Professor Daniel Freeman, from the Department of Psychiatry at the University of Oxford, enlisted 100 volunteers with clinically diagnosed acrophobia. Of those 100 volunteers, 49 were able to complete the two-week virtual reality therapy, the other 51 were volunteers served as the control group. During this treatment, volunteers used a VR headset to meet with a virtual coach that led them through six therapy session, each 30 minutes long. Volunteers were confronted with real-

life scenarios, ranging from climbing a tree to crossing over a considerable height on a rope bridge. Between the sessions, participants were encouraged to expose themselves to real-life heights. After the virtual reality therapy, 34 of the 49 volunteers expressed that they no longer suffer from Acrophobia. All of the volunteers in the control group had no change in their fear of heights.

This study demonstrated that virtual reality treatments have a valid right to exist in the psychotherapeutic field of application and this study is going to lead to more research in virtual reality treatment, which is exceptionally important for patients that suffer from severe mental health problems and cannot leave their home [5, 44]. Exposing participants to virtual worlds with the intention of helping them overcome phobias or traumatic events is called "Virtual Reality Exposure Therapy", short "VRET". In this area, a growing number of applications is being tested. Research on the topics like arachnophobia, the fear of spiders, aquaphobia, the fear of water, and Post Traumatic Stress Disorder in soldiers suggests that on-site exposure is no longer needed in the treatment of patients and can be replaced by "VRET" [12, 15, 60].

Another relevant field of application for virtual reality systems with room-scale capabilities is physical health. The American company *Black Box* and the Swiss company *Virtual Reality Fitness* have both specialized in fitness studios supported by virtual reality. While *Virtual Reality Fitness* focuses on training with pre-made software and using virtual worlds to train their customers, *Black Box* uses a different approach. *Black Box* has custom software in which users can compete and even fight against each other in virtual worlds. Workout stations rigged with sensors allow its users to control actions inside a virtual environment, pushing users to their limits with challenging either real-life opponents or specifically designed non-player enemies. To enhance the quality of immersion of VR experiences, an old concept that was mentioned before comes into play. As Sutherland already imagined in 1989, eye tracking is the newest adaption to virtual reality HMDs. Being very processor intensive, processors in 1989 were not efficient enough to track eye movement while tracing head position and orientation. With processor development and more processing power, eye tracking is the new state-of-the-art technology inside VR headsets. Outside of HMDs, eye tracking can be realized by utilizing external eye tracking devices, such as the *Tobii Eye Tracker 4C* (see fig. 2.4 a). External eye trackers work in a similar way like built-in versions. The external devices emit near infrared light and track the reflection patterns of the eye (see fig. 2.4 c). Utilizing HMDs, the eye is not visible to an external device, so a built-in version is the most pragmatic solution. Eye tracking inside of a VR headset works similar to external tracking. The near infrared light emitters are positioned around the eye of the user and cameras placed between the emitters capture the eye's reflection (see fig. 2.4 d). Tacking the eye position is not only important for measuring points of interest from application users, but it also increases immersion and performance. VR headsets only render images sharp and clear in the middle of the screens inside the HMD and blur the outsides to decrease rendering load. As a result, only head movement influences which part is rendered sharply and therefore immersion is not as deep because normally, users would not move only their head and look straight forward, but also move their eyes to look around. Utilizing eye tracking, the sharply rendered part of the images inside the VR headset can be rendered according to the position the users look at. This technique is called "foveated rendering". Therefore, the system increases performance by not

(a)

(b)

(c)

(d)
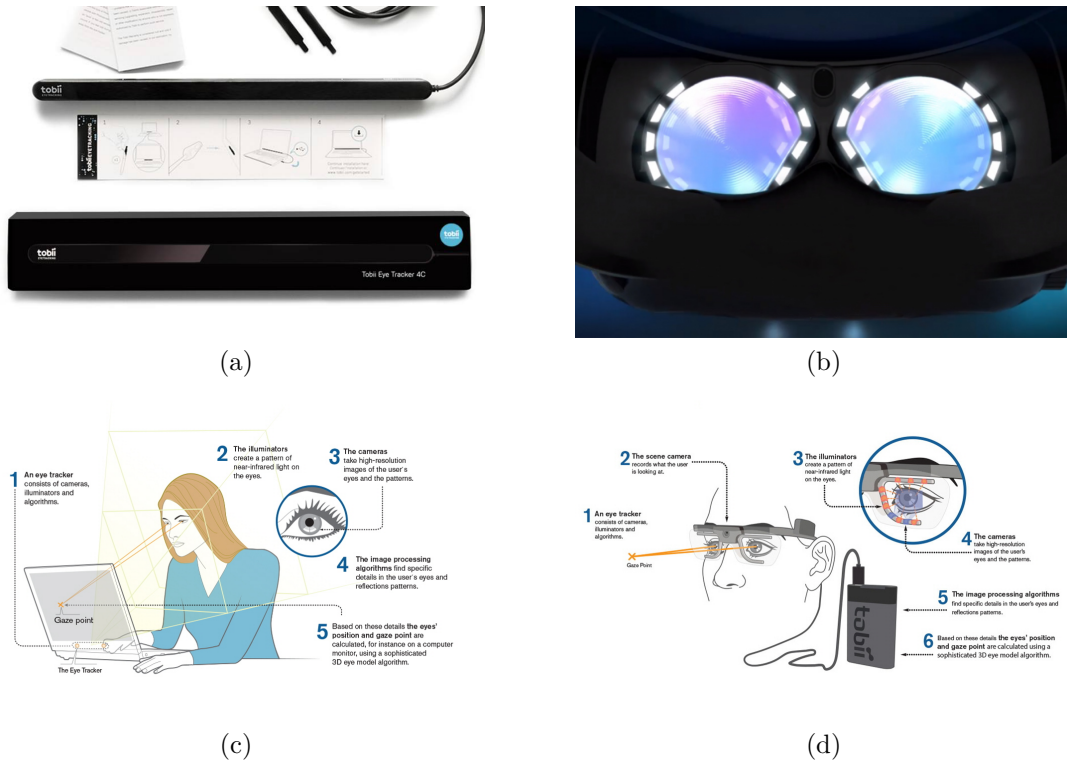
Figure 2.4: This figure depicts two different approaches for eye tracking. *Tobii Eye Tracker 4C* [43] (a), the insides of a *Vive* Pro Eye [31] (b), an explanation graphic for external eye tracking (c) and an explanation graphic for internal eye tracking [54] (d).

having to render a whole sharp image and it also increases immersion by allowing the user to focus on an object not only by head movement, but also by moving their eyes. Additionally, this feature for VR systems enhances immersion especially in multiplayer applications because the eye movement of users in the same virtual space are tracked and represented accordingly by their virtual avatar. State-of-the-art technologies for eye tracking not only include out of the box eye tracking included in consumer hardware, but are also systems that are separately developed and sold by third-party vendors. A built-in out-of-the-box solution is included in the newest version of the *HTC Vive*, the *HTC Vive Pro Eye* (see fig. 2.4 b), which is shipped with the latest built-in eye tracking solution by *Tobii Gaming*, a company founded in 2001 and since then, a leading developer in eye tracking solutions.

Opening VR up to eye tracking also increases the use cases in therapy. A study about virtual eye rotation vision exercises [29] shows that training participants that suffer from binocular vision disorder with 12 one hour treatments with the specifically developed application VERVE showed clinical success in seven out of nine participants and the remaining two participants reported serious improvement in both eye-accuracy and holding on to a target. As virtual reality was adopted into the gaming scene, concepts for immersion from 2D screen games were adopted to virtual reality, including, amongst other things, vital signs data sets used for biofeedback and realtime changes

to the environment. For increased immersion in virtual reality environments vital signs data sets of the user are measured with biometric sensors to assume the user's psychological state and thus, change the virtual world according to the user's data. To understand why vital signs data sets and biofeedback are used to enhance immersion, the following chapter will elaborate the term biofeedback, biometric data acquisition and demonstrate one way of evaluating biometric data.

2.2 Enhancing immersion quality

By including biometric data to change virtual worlds and by extending the user's senses inside a virtual world, virtual reality applications become increasingly realistic and immersive. This does not only have entertainment purposes, but finds its integration in modern medicine. Nowadays, stress can be a major problem in working environments and private life. Stress is one of the main issues that lead to mental illness such as burnout and anxiety. Treating and countering stress and other psychic or physical illnesses and especially treating chronic illnesses biofeedback has a high status in the medical field. In general, biofeedback is a scientific method or a learning process that teaches users to control their unconscious body functions. Biofeedback is utilized by doctors, psychologists and other therapists to teach their patients to control their unconscious body functions by displaying their vital signs data and elaborating the changes their body is undergoing when, for example, under stress. As with many illnesses, easing pain and restoring a normal course of life are the most important parts in the treatment. Medication, especially in the field of attention-deficit or hyperactivity disorder, often has unwanted side effects and on top of that medication for this psychological illness contains substances that are cardiovascularly toxic. This poses a considerable problem to treating illnesses and biofeedback is able to relieve pain and treat those illnesses without side effects, making it a very safe treatment. However, taking biofeedback as some kind of all-curative treatment, which cures illnesses without the need of medication or other precautions, is far from reality. It is well documented that biofeedback is able to help patients to relax and that it is able to treat certain psychological and physiological illnesses, but in some fields of medicine inconclusive results are displayed. In case of fecal incontinence in women test results show that only half of the patients in this study were showing signs of improvement of their rectal and vaginal squeeze pressure and it is yet to be discovered, why biofeedback was only effective for 50 percent of these patients [6, 16]. Other fields of application of biofeedback are supervised, not only by doctors but by trainers, coaches and even by private individuals in a variety of areas like sport- and fitness training, entertainment, mental training and concentration training.

2.2.1 Relaxation with biofeedback support

Learning about one's own body is the main purpose of biofeedback. Physiological responses to stress can be detected and countered by employing relaxation techniques like meditation or visualization. Visualization of biofeedback data mainly supports the concept that a patient receives realtime output of his or her physical qualities and deficiencies to portray, if the utilized exercises are effective against stress. By learning how to counter stress more effectively and efficiently, time consumption of employing relaxation

exercises constantly declines. Because stress is a main trigger for psychological illness, countering stress as it is still underway, helps to prevent illnesses from manifesting.

Research on relaxation with biofeedback support was predominantly conducted in the field of medicine. Treating headaches with biofeedback supported relaxation training has proven to be a reliable countermeasure. In one study, during the time span of four weeks, baseline data were collected from 98 patients with chronic headaches ranging from 18 to 68 years in age. After receiving a ten-session relaxation regimen, patients who did not show significant headache reduction were given a twelve-session relaxation regimen with biofeedback support. This biofeedback therapy led to a significant reduction in all patients who received this therapy. Within this study, the effectiveness of relaxation therapy with biofeedback support to counter chronic headaches was demonstrated [4].

2.2.2   Biofeedback as means for immersive experiences

Utilizing biofeedback to immerse users into a virtual world can be seen as an extension of the user's senses. Biometric data is collected via sensors that are attached to a participant and this data is sent to a computer for further processing. In the case of immersive experiences, virtual reality plays a big role, but standard 2D games, which are playable on a simple screen, are modified to be immersive using biofeedback as well. Applicability of biofeedback is found in many different genres of games. The spectrum ranges from, on one side, biofeedback used in relaxation applications to support users with their data to accelerate the relaxation process and on the other side, horror games use biofeedback to intensify the user's experience. In modern relaxation applications, users are immersed into a relaxing virtual surrounding or are presented 360 degree videos captured at beach sides or in forests. In combination with soothing audio and biofeedback to better control the user's level of relaxation, the following applications support relaxation for users at home without medical supervision.

Provata VR by *StayWell*

As mentioned on *StayWell's* website [30, 59], this application was developed focusing on the economic impact stress has on our current generation. Being able to push declining amounts of workload because of mental stress, which can lead to burnout, is an important field worth tackling. Including consumer market smartwatches with built-in biometric sensors such as *Applewatch* or *Fitbit watch*, users can utilize cost-efficient biometric sensors. In *Provata VR*, 360 degree videos are presented to its user and biofeedback data is captured to detect which exercise and day of time are best for its user's level of relaxation (see fig. 2.5 a). Seen from a user's perspective, *Provata VR* lacks variation in 360 degree videos, boring its users after a few sessions. Additionally, this application only captures heart rate as biometric data. The human heart rate is highly dependent on other factors such as the current respiration rate and age of the user. Capturing additional biometric data to increase the accuracy of relaxation detection increases measuring precision and evaluation potential.

SoundSelf by *Orpheus Self-Care Entertainment*

In this application, the user's voice acts as biometric input data. By detecting sound from its user, the application alternates between different abstract environments (see fig. 2.5 b). For this application, it is best to use it lying down because each session lasts for one hour [58]. A major point of criticism on this application is its long session duration. Being inside a virtual environment for an hour is exhausting, especially for inexperienced users. Furthermore, having only one interaction possibility for one hour will bore the user and will decrease user retention.

Deep VR

This application utilizes abstract underwater 3D scenes and an innovative control system to guide its user to a substantial relaxation level (see fig. 2.5 c). The project is developed in collaboration with scientists at the Radboud University and the Games for Emotional and Mental Health Lab. In *Deep VR*, users control their in-game movement with their breathing rate. The game's environment encourages the player to take deep long breaths by giving its users a visual representation of their respiration rate [40].

2.2.3 Intensifying experiences with biofeedback

Contrary to relaxation applications, horror games intend to scare their users. How frightening a game is perceived is strongly dependent on the user's experience with horror themed media. As inexperienced players tend to be frightened a lot more than experienced players, some games might be either too terrifying for beginners, or not terrifying enough for professional players. Developers of horror games have to keep in mind the target group of players and fans of horror games are split up into different groups, which minimizes the targeted fans and with that, the estimated income the game will bring back to the studio. This problem is tackled by the studio called *Red Meat Games*. With their game *Bring to Light*, artificial intelligence assisted with biofeedback data decides on whether their game has to be more or less frightening, depending on the user's heart rate [55].

The development of applications that utilize biometric sensors for data visualization after sessions or for realtime changes to the application itself is gaining popularity, especially in combination with VR technology. However, only capturing vital signs data sets and using this data is not enough to make generally valuable assumptions about the mental state of a user. Vital signs data sets greatly vary from person to person, not only in their experience of stress or relaxation, but also because of their physiology. Age, Gender and other health factors are influencing the captured data. To be able to extract certain elevations in captured biofeedback data, a baseline has to be acquired, which shows vital signs data sets of the user's normal state. Normal meaning, neither relaxed nor excited.

2.2.4 Establishing a baseline

A baseline is comprised of the expected values or conditions against which all performances are compared. A baseline is a fixed reference point. A baseline in medicine is information found at the beginning of a study or other initial known value which is

(a)

(b)

(c)
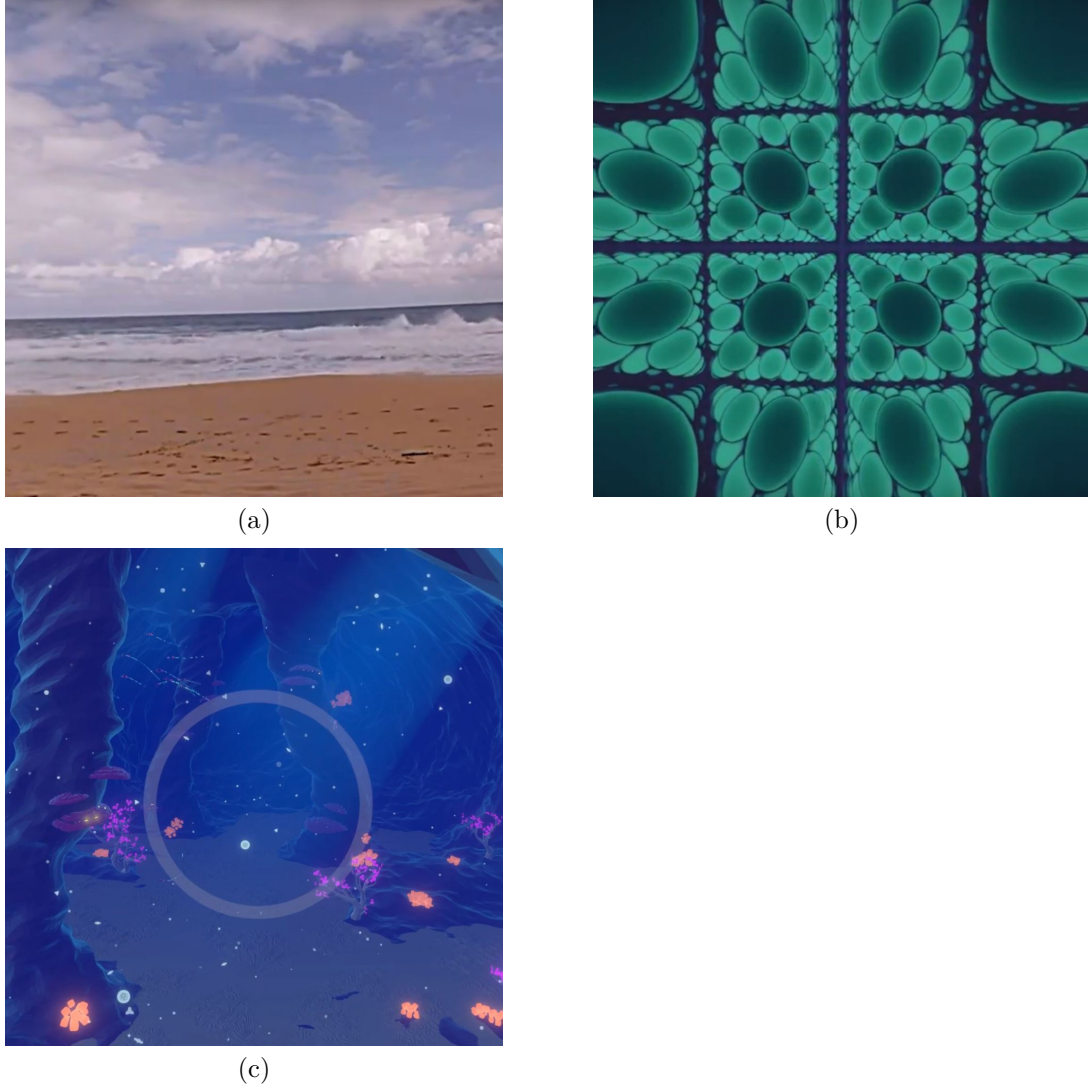
Figure 2.5: *Provata VR* (a) [30], *SoundSelf* (b) [58] and *Deep VR* (c) [40] are commercially available VR-based relaxation applications.

used for comparison with later data. The concept of a baseline is essential to the daily practice of medicine in order to establish a relative rather than absolute meaning to data.

Baselines can be found in many fields of application. As a rule of thumb, the more baseline data points are captured, the more accurate the data to compare against. The general approach to evaluate if values contain a significant deviation is the calculation of the confidence interval. The calculation of the confidence interval requires certain calculations before utilizing the final equation. For easy understanding of the calculation of the confidence interval, an example with a specified data set is presented. In the following example, the sample size n is 3 with the samples $x_1 = 100$, $x_2 = 150$ and $x_3 = 200$, resulting in an *arithmetic mean* of 150. To calculate the standard deviation *sd*,

which is a measure of variation of data in the data set,

$$sd = \sqrt{\frac{\sum_{i=1}^{n} \overline{x} - x_i}{n-1}},$$

which is 50 in the specific example. To calculate the standard error (*se*), which is an estimate of how far the sample mean is away from the population mean,

$$se = \frac{sd}{\sqrt{n}},$$

the standard error is 28.9 for this example. To calculate the upper confidence interval limit the *T-value* for 95 percent confidence for $n-1$ degrees of freedom is looked up in a T-table. For this example a *T-value* of 4.303 for 2 degrees of freedom is multiplied by the *standard error* resulting in 124.35. This is added to the *arithmetic mean*, showing that values over 274.35 are significant deviations from the baseline. To calculate the lower confidence interval 124.35 is subtracted from the *arithmetic mean*. This results in a confidence interval ranging from 25.65 to 274.35 [62].

Baselines for biometric data for this thesis project

In the corresponding thesis project, a baseline for every captured participant was acquired before testing the actual application. Having tested twelve participants, not enough data for stochastic evaluation was acquired, so the data was compared to timestamps. The detection of large differences between baseline data and captured data hints to timestamps, which are crucial for the application. The identification of relaxation is very important in this project, but detecting stressful moments and being able to prevent them from happening is of even greater importance.

Lie detectors

A use-case for baselines in biofeedback which is encountered rather rarely by the public is lie detectors. A project that tries to solve border control with lie detectors is AVATAR [42]. The "Automated Virtual Agent for Truth Assessment" is currently being tested by the Canadian Border Service Agency and combines Artificial Intelligence Lie detection with fully automated border control kiosks. The virtual agent determines whether a traveler is truthfully stating his motives for crossing the border or the traveler has undisclosed intentions. AVATAR is comparable with a self-checkout at a grocery store. The AVATAR kiosk interviews the traveler and detects physiological or behavioral changes. This system is able to detect changes in eyes, voice, gestures and posture. This way, the system can tell if the traveler is truthful or might pose a risk. To create values the software can compare against the kiosk first asks harmless questions to establish a baseline, to single out values which are heightened due to outside factors like fear of flying. When the system detects a risk in a traveler, he or she is flagged for further human security checks. This system has a success rate of about 85 percent and was only tested under laboratory conditions. Only relying on AVATAR to distinguish whether a traveler is a risk or not is impossible with a success rate of only 85 percent. Further testing under real conditions has to be done to provide data that is representative.

2.2.5 Data acquisition

To capture biometric data, many different sensors in different price ranges are available, ranging from commercial use at home to medical use in hospitals. In par with the scope of the project, a sensor kit at a low price range was chosen to be utilized. This sensor kit contains the most commonly used biometric sensors that are used in biofeedback data acquisition.

BioSignalsPlux Kit

The company BioSignalsPlux produces high-performance but at the same time low-budget sensors that can be acquired in bundles. For this project the Explorer Bundle, which lets the customer select four different sensors from their repertoire, was chosen. To gather the biofeedback data which was needed for this project, the four most common sensors in stress detection were selected. In conclusion of the research, which was started before the thesis project, EDA, ECG, Resp and Temp (see fig. 2.6) were found to be the most commonly used sensors in stress detection.

- Electrodermal Activity (EDA): This sensor measures changes in the electrical properties of the human skin. Mostly positioned on the participant's hand, where the sweat gland density is high [26, 35].
- Electrocardiography (ECG): An ECG sensor records the electrical heart activity. Abnormalities in duration and amplitude are used for diagnosis by trained physicians. The heart rate gives a good representation of the stress experienced by the participant, as a study on pilots has shown [19, 34].
- Respiration sensor (RSP): The piezoelectric respiration sensor measures displacement of the diaphragm induced by inhaling and exhaling. A downside of a strap based respiratory sensor is testing is only accurate for participants with a body mass index (BMI) of under 25 [18, 37].
- Temperature sensor (TMP): The Negative Temperature Coefficient Thermistor is a resistance-based sensor that conducts more electricity the warmer the sensor becomes. As researched, acute stress leads to rapid drops in skin temperature, measurable only at distal body parts like fingers and hands. Regions in the vicinity of the heart remain unchanged in skin temperature. However, the core temperature of the human body uniformly rises when the body is put under stress [27, 38].

Collecting data to detect participant's mental state is a delicate task. The following chapter will give an insight into the definition of stress, the different kinds of stress, signs of stress and how to counter stress.

2.3 Stress

Stress is a topic that affects many people in their workplaces, studies or in their private lives. Countering stress is an increasingly important task, considering studies have repeatedly shown that increasing stress leads to lower workload capability and illness. A rising number of people complain about stress levels that they cannot handle anymore and in some people, this increasing amount of stress leads to burnout or other illnesses. For students, stress is on the daily timetable and there is little time to deal with it. In

(a)   (b)

(c)   (d)
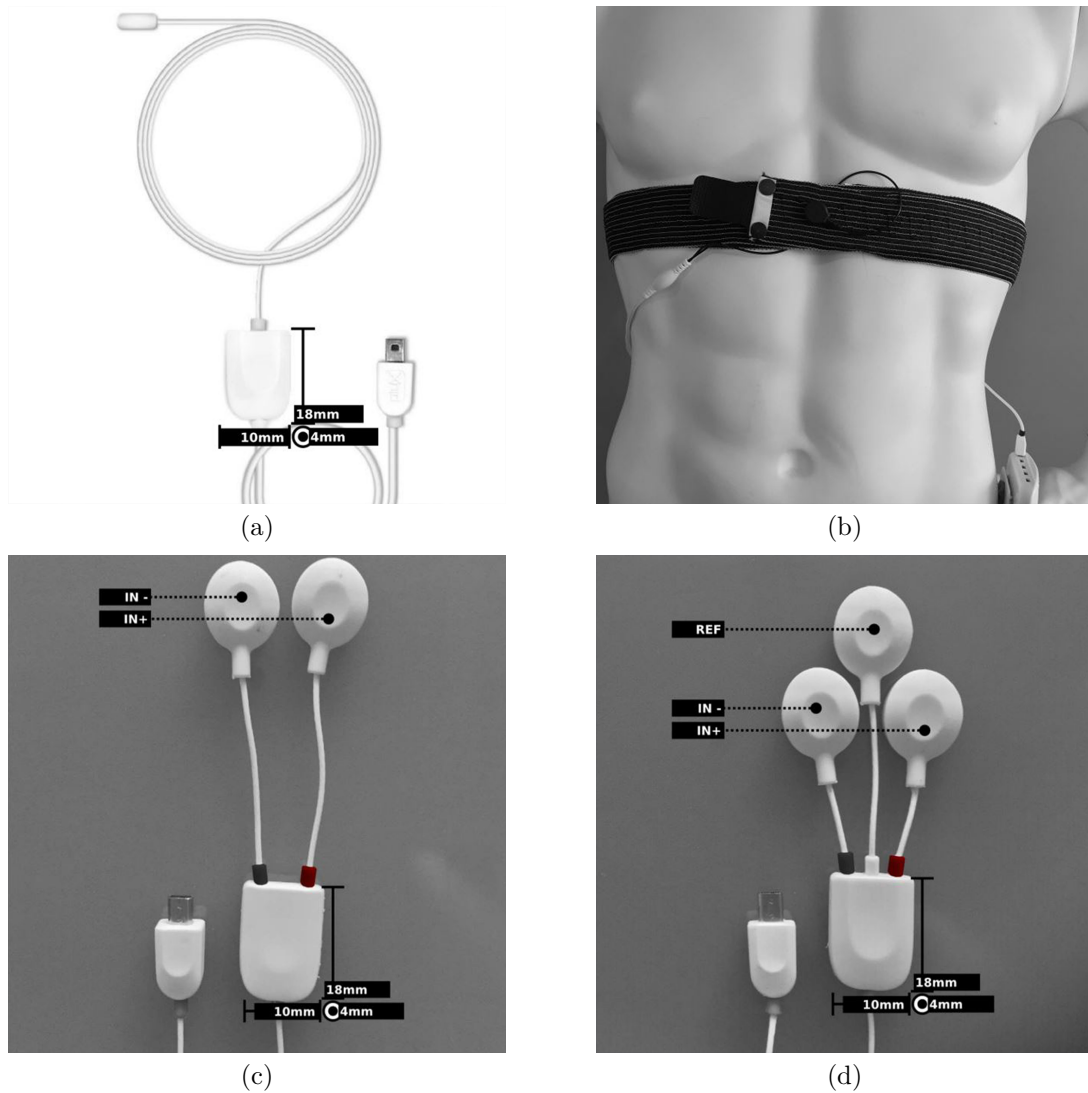
Figure 2.6: The sensors used for this thesis project include a temperature sensor (a) [38], respiration sensor (b) [37], electrodermal activity sensor (c) [35] and electrocardiography sensor (d) [34].

2015 the dropout rate in America's high schools was at around 6 percent [32], where low-income families had a higher average than normal income ones. As reported in 2015, pupils from low-income families have missed out three or more schooldays in the past month due to lack of transportation, crime, drug use or pressure from other pupils. This is leading to the conclusion that stress factors at school and at home cannot be handled any longer by the peers and dropout is their only option. There have been studies suggesting that children suffering from stress early on will develop illnesses like heart diseases or obesity later in life [3]. Understanding what stress is and where it comes from are the most basic questions that have to be answered, to understand how to counter it. The following chapter will tackle the topic of stress in general, the effects of stress

on the human body and how to counter stress.

2.3.1   Definition of stress

Stress is a broad field with many concepts describing it. On a basic level, one can differentiate between four stress concepts: the stimulus concept, the reaction concept, the transactional concept, and the discrepancy concept. Emphasis is largely put on situational conflicts and events that set the stimulus concept. This approach describes certain stimuli as stressful in every individual. Stressful stimuli include accidents, time pressure and conflicts at work. Nonetheless, the stimulus concept is disputable because every individual reacts in different ways to certain stimuli. The reaction concept is built on the fact that every individual suffering from stress shows a specific reaction pattern. Coping efforts and other outside influences are not considered to be relevant in this approach, leading to altered data due to different reactions in different people trying to cope with stress. Another approach is the transactional concept. This concept takes the person and the situation into account when defining stress. According to this concept, stress results from a transaction between a person and the environment. For empirical validation of this concept, researchers rely on spoken reviews and vital signs data sets, which both implicitly lead back to the application of the reaction concept. As the last concept, the discrepancy concept describes stress as the incongruence between an individual's desire and the environment [23].

Conceptualizing stress is a task still researched today, but for capturing biofeedback data to evaluate the state of an individual, the reaction concept is steadily applied. But taking into consideration that "good stress" (eustress) and "bad stress" (distress) may both lead to the same reactions inside a human body.

2.3.2   Eustress vs distress

Eustress is frequently referred to as "good stress". This term was defined by Selye in 1987, where he defined stress as a response of the body to anything that happens to it. Per his definition, stress is subdivided into eustress, "good stress", and distress, "bad stress". At that time, eustress and distress were both a subsection of stress but later split up into separate areas due to their fundamental differences. Distress, as defined by Selye, occurs when the demand placed on a human exceeds their capability of fulfilling this demand. By this definition, stress can be broken down into either eustress or distress, where distress is represented by too much or too little demand, and everything in between is eustress [9]. This definition describes a vital part of stress detection. Stress is not always negative, but the body reacts in the same way for both good stressors and bad ones. Research hints to a distinction between eustress and distress on a cellular level, but this is non-relevant for this thesis [1].

2.3.3   Effects of stress on the human body

In the human body, different system come into play when the human body is put under stress: on the one hand, the Central nervous system, which moves skeletal muscles and is responsible for logical thinking, and on the other hand, the peripheral nervous system, which, amongst other things, is responsible for gland activity and heart rate.

Central Nervous System

The Central Nervous System (CNS) consists of the brain and the spinal cord. It is the most protected and complex part of the human body. The human brain controls the release of hormones, gross motor movements, memories, emotions and many more. By releasing certain hormones, the brain controls, for example, the body temperature. Brain regions such as the "Medula Oblongata" are responsible for uncontrolled actions like breathing and blood pressure regulation. The spinal cord is responsible for relaying signals to the brain from the peripheral nervous system (PNS), as well as controlling certain reflex reactions, such as muscle movement. These responsibilities make the CNS the origin of measurable body reactions. But without the PNS, the CNS is not able to detect stimuli to which it has to react to [20, 61].

Peripheral Nervous System

All neurons that are not classified to be in the CNS compose the PNS. As described in the section above, one responsibility of the PNS is the pathway from sensory nerves to the spinal cord. The PNS is divided into two subsystems. The somatic nervous system (SNS) and the autonomic nervous system (ANS). The SNS is the connection from the CNS to the sensory organs. The ANS is responsible for relaying impulses which regulate the human body, such as gland activity, heart activity and smooth muscle activity, like urine bladder contraction. Measurable signs of stress triggered by the SNS [20] are for example increased heart rate and an increase in contractility of the heart muscles. Additionally, the bronchial tubes dilate (open up), resulting in increased oxygen intake, sweat glands are stimulated, resulting in an increased amount of sweat production and the adrenaline medulla secrets adrenaline and noradenaline. Furthermore, the mucosa, which is a protective layer on internal organs, constricts which can result in for example low protection of the stomach from the stomach acid.

2.3.4   Countermeasures against stress

Coping, how taking measures against stress and stimuli is called by many researchers and therapists, is a topic in close connection with the concept of the corresponding thesis project. As there are many different concepts of defining and classifying stress, there are many options in how to cope with stress. Varying from sufferer to sufferer, different techniques appear to be differently effective.

   A well-known relaxation technique is meditation. Traditionally, meditation is believed to come from India, but has found its way into relaxation all around the globe. The most modern way of meditation is guided meditation through apps and audio streaming. A very well known app is "Headspace" [45]. This app uses guided meditation as means to relaxation for all age groups. To improve the relaxation experience, vital signs data sets may be captured and analyzed with medically trained personnel to decide which technique and which time of the day works best. Another technique for countering stress is not about relaxation; it is about countering stress. Mentoring in students, especially in nursing and medical staff students, is a very important field. There have been studies, finding mentoring in students by students in higher semesters can minimize their stress and lead to better performances [22]. Stress in students is omnipresent.

But stress is not only a problem of students; it nearly affects everybody working or studying. Because of this development of modern society, the United States Center for Disease Control and Prevention (short CDC), built a list of prevention techniques which applies to nearly everybody across the board [41].

2.4 Summary

In this chapter, the history of virtual reality is described, to show that the concept of the newest technological advances in virtual reality were already considered by Sutherland at the beginning of the creation of this technology. Every new technological adaptation to the current state brought more senses of the human body to the virtual world. Integrating eye tracking, which is the current state-of-the-art technology inside VR headsets, is an adaption to the currently existing thesis project, which enables the integration of eye relaxation exercises, which track eye movement and not only head movement. Examples of modern relaxation applications that utilize biometric data are described, as well as modern biometric data sensors kits are evaluated. Most modern relaxation applications utilize a limited amount of biometric and have little interaction or evaluation of the captured data. The corresponding thesis project tries to incorporate many different biometric data to have a precise assumption of the body's state and the VR relaxation application incorporates relaxation exercises that find little use in current relaxation applications. Furthermore, stress and its countermeasures as well as measurable body reactions are described in this chapter, to show how measuring biometric data can give a precise assumption about the human body's state. In the next chapter the implementation of countermeasures against stress into relaxation exercises as well as communication between different parts of the thesis project will be described.

Chapter 3

Biofeedback and Relaxation Techniques

Monitoring the market for relaxation applications, one can see that a multitude of already existing applications use the same approach. Focusing on one relaxation technique or utilizing no interactive environment, many of those applications are targeted at a specific group. For this project, other target groups of relaxation are the main focus. While monitoring the market, several relaxation techniques appear to be neglected.

3.1 Neglected relaxation techniques in existing relaxation applications

Often utilized in therapy sessions, but rarely seen in relaxation applications, is Jacobson's muscle relaxation. The lack of guided meditation and relaxation in many applications is a topic which is focused on in this project. Other applications force the user to do nothing for a fixed amount of time, which is only applicable for a few users because not every relaxation type is suited for relaxation by doing nothing. As a solution to this predicament, the resulting relaxation application focuses on gameplay elements to keep its user engaged. To keep the user interested in the application itself, visual appearance is a key feature which has to be designed to be visually appealing to a majority of users. Praised by many media outlets and on forums, photorealistic rendering is the rendering technique that sounds appealing to a large user base which is not engaged in the computer games scene. However, games utilizing photorealistic rendering require large teams working on one virtual scene because, while photorealistic rendering appeals to a majority of users, a visually unappealing scene may be the result. The uncanny valley is a term used to describe a sense of visual dissonance, for example an environment looks the same as in the real world, but small things are off. As studies have shown, these small deviations can affect the user in negative ways by destroying immersion. Another approach to photorealistic rendering is photogrammetry. This approach utilizes 3D scanned environments and objects to appear as realistic as possible. This technique applies to big structures with low-level details. Both techniques are not applicable in this project because the uncanny valley effect poses a risk that has to be bypassed and a high level of detail is needed for the planned scene. The next approach that many applications utilize is 360-degree video background. This approach features a high level of realism, but as testing has shown, many users feel elevated inside a 360-degree video and miss the feeling of being grounded, which hinders relaxation. To bypass both prob-

lems, an abstract representation is the chosen solution. The last approach this project focuses on, which is targeted by few available applications, is biometric data storage and biofeedback integration. Measuring relaxation progress through biometric data suggests to the user, which relaxation techniques in combination with daytime, result in the best relaxation level. Additionally, real-time integration of vital signs data sets to enhance immersion into a virtual scene, which is commonly known as biofeedback, helps its users to feel like a part of the virtual scene. The following sections accurately elaborate on the decision which concepts are applied in this project.

3.2   Progressive Muscle Relaxation

Dr. Edmund Jacobson developed a relaxation technique which progressively teaches its users which muscles are in tension and how to relax these muscles. Through alternately flexing and relaxing every muscle group after one another, patients develop awareness of their bodies in a new way, and learn how to counter muscle tension. This therapy is set on a two-week schedule with two daily executions of the relaxation technique [7]. Progressive relaxation typically follows a specific order of steps:

1. Strongly clench both fists until the feeling of exhaustion arises in the fists and in the forearms. Then relax.
2. Bend both elbows upwards and clench both biceps. Stay relaxed in both hands. Then relax.
3. Stretch both arms to the front and flex both triceps. Then relax.
4. Pull both shoulders on each side to the ear on the same side. Then relax.
5. Pucker the whole body and raise both eyebrows. Then relax.
6. Pinch cap. Then relax.
7. Tighten the jaw while keeping the lips tight. Then relax.
8. Push the tongue against the top of the mount. Feel the tension in the jaw. Then relax.
9. Tilt your head back as far as it is possible. Then relax.
10. Press the chin against the chest. Then relax.
11. Lift the shoulders to the ears. Then relax.
12. Take a deep breath, completely fill the lungs, hold your breath, exhale and relax.
13. Pull shoulder blades together. Then relax.
14. Clench stomach muscles. Then relax.
15. Clench buttocks. Then relax.
16. Flex thighs. Then relax.
17. Push the feet into the floor. Then relax.
18. Lift the toes and push up. Then relax.
19. Breathe calm and regularly into the stomach. Take seven breaths and with each exhale, let your body fade like a rag doll and focus on the word "Relax".

This technique is implemented in one exercise of the corresponding thesis project (see section 3.5.5). To achieve muscle relaxation, this pattern of flexing and relaxing muscles

is supported by visual aids for understanding which muscle group has to be flexed and afterwards relaxed.

Originally, Jacobson's technique resulted in high time consumption, as the therapist could focus on any muscle group in detail, resulting in therapy sessions up to nine hours. In 1948 Joseph Wolpe modified Jacobson's instructions and reduced therapy time down to twenty minutes per session, but still resulting in the same amount of relaxation as Jacobson's approach. In addition to this whole-body relaxation, which splits the body in 16 different muscle groups, there are other approaches that divide the body into seven or four different muscle groups. For the exercise in this thesis project, the amount of muscle groups and the succession of muscles can be freely modified via a configuration file, resulting in a mixture of approaches in this exercise and not only focusing on Jacobson's relaxation technique [13].

3.3 Visual appeal of virtual environments

There are several different approaches to rendering a virtual scene. The decision which technique is utilized is often influenced by subjective matters. Recent developments in successful entertainment media [46] suggest cell shading or cartoony art styles as commonly accepted by the public. However, specific rendering techniques are not applicable for every environment and target group. Additionally, sequentially released entertainment media commonly never switches rendering techniques from one release to the next. The section below will elaborate on different rendering techniques, which were discussed in context with this project.

3.3.1 Photorealistic rendering

For inexperienced users, photorealistic rendering (see fig. 3.1 a) immerses users faster than scenes rendered with another technique. Testing has shown that the rendering technique of a scene is mostly responsible for destroying immersion, rather than enhancing it. So it is not of importance which rendering technique is utilized, rather than how well the virtual environment plays together with the setting of the experience. A major problem with photorealistic rendering is the aforementioned "Uncanny Valley effect" (see fig. 3.1 b). Photorealistic rendering works as long as it is an exact representation of the real world. The moment a user detects a slight difference between the rendering and the real world, it transfers a feeling of discomfort. In respect of the uncanny valley, utilizing photorealistic rendering is a risk for relaxation applications because discomfort hinders the human mind from relaxation. To represent an exact copy of the real world in a virtual world, another method of creating 3D objects can be considered. Photogrammetry uses 3D scans of real-world objects and creates highly realistic 3D models.
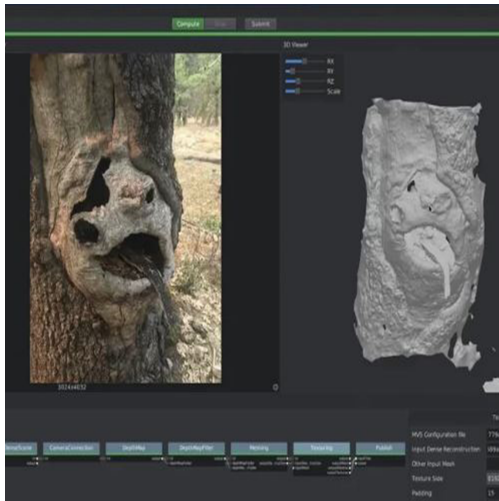
3.3.2 Photogrammetry

Scanning real-life objects and creating 3D models based on the scanned data is called photogrammetry (see fig. 3.1 c). This technique is mostly utilized by companies based in the field of rendering and game development. For photogrammetry, special scanners are needed, which scan surfaces and textures from real-world objects and map them to

(a)

(b)

(c)

Figure 3.1: This figure depicts different rendering techniques applied in different media formats. Photorealistic rendering in an architectural visualization (a) [57], the "Uncanny Valley effect" in the animated movie "Polar Express" (b) [56] and photogrammetry performed in *AliceVision's* "Meshroom" (c) [51].

3D models. A major problem of photogrammetry is high-level of detail in 3D topology. Textures are scanned to a very high level of detail, but a complex 3D topology such as bushes and trees, exceeds the capabilities of photogrammetry. In the concept for the 3D scene of the relaxation application are 3D objects, which do not translate from the real world to the virtual world using photogrammetry. A high level of detail in virtual scenes is not exclusive to 3D environments. Another technique which is utilized by applications available on the market is 360-degree video background.

3.3.3 360-degree video background

Capturing a real-world scene with a 360-degree camera is state of the art for many fields of application. 360-degree video support on *YouTube* and other social networks indicates a trend toward market acceptance of 360-degree videos. Capturing clear 360-degree images and videos for use in virtual reality, high resolution has to be accomplished. Filling a virtual scene with a 360-degree video transmits a feeling of presence at the captured scene, but simultaneously, the user has a feeling of hovering inside the scene. The feeling of being grounded inside the environment is lost in capturing a 360-degree video and filling a virtual scene with it. To counter the problems mentioned above, another approach of rendering was chosen to be suitable for this project.

3.3.4 Abstract representation of the real world

Immersing a user in a virtual world is not exclusively conveyed by the rendering technique. If the setting of the experience fits the art style, immersion is not hindered by rendering techniques other than photorealistic rendering. For this project a cartoony art style was chosen. Mistakes in photorealistic rendering leading to the Uncanny Valley can be neglected, given the fact that cartoony environments excuse more mistakes because the human brain is not expecting certain routines from the real world. As presented above, a cartoony art style is commonly accepted by the public. But this is not the only reason why this rendering technique was chosen. Relying on 4K textures to achieve a realistic look results in high performance consumption. The target platform for the corresponding thesis project is the *Oculus Go* with no external graphics card, resulting in limited rendering power. For this reason, a cartoony art style is commonly utilized to be able to port an application to as many platforms as possible. Furthermore, the setting is at night, to have low light, which has to be calculated for every 3D object in the scene. This is especially important for the included water surface, because integrating many different lights in the water simulation would not have been possible with the internal processing power of the chosen VR device. Another reason to have the relaxation setting at night is the conscious utilization of light. In a dark scene, the attention of the user is easily manipulated by brightening certain parts of a virtual scene, such as a campfire, being a main part of the virtual scene that influences the surroundings.

A feature that is rarely seen inside relaxation applications is vital signs data integration. As physicians present, vital signs data describe the mental state of a person at a certain point in time. This leads to assumptions on the effectiveness of certain relaxation techniques.

3.4 Biometric sensor integration

Integrating biofeedback data into a relaxation application is one key element of this project. Not only is biofeedback data a scientifically established means to evaluate a user's mental state, it is also a means to evaluate the relaxation application itself and how effective each exercise is. The availability of smartwatches leads to increasing integration of those gadgets as means to acquisition of biofeedback data. As tests have shown, vital signs data captured by smartwatches is often incoherent and not accurate enough to give an exact estimation on the mental state of the user. For this project,
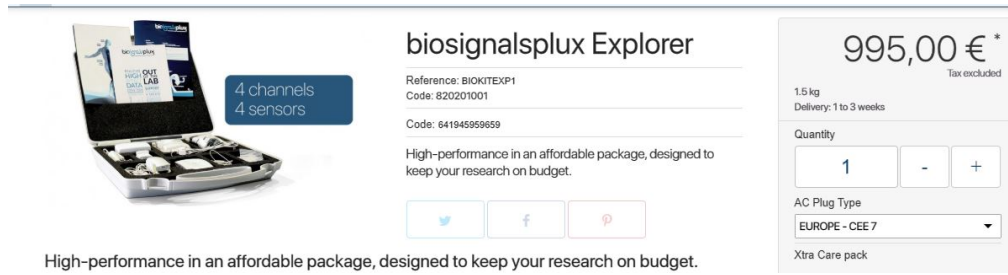
Figure 3.2: BioSignalsPlux Explorer Kit [36].

the accuracy of the captured biometric data is an important cornerstone, eliminating the option of smartwatch integration for biometric data acquisition. Medical equipment found at hospitals or ordinations is costly, yet very accurate. Purchasing medical equipment was outside the scope and budget of this project, leading to a different approach. For this project a data acquisition kit was acquired, which is both very accurate and cost-effective. The following section will elaborate different data acquisition kits from different price categories and will introduce the data acquisition kit which was used in this project especially.

3.4.1 Smartwatch biometric data

The multitude of smartwatch devices on the market leads to rising integration of these devices into relaxation applications. These gadgets, however, have error margins that have been scientifically evaluated. As stated in a paper, the heart rate accuracy from smartwatches in respect to a medical grade sensor in average diverges 18.4 bpm. The *Apple Watch* captured data with a difference in bpm of 8.73, the *LG Urban* captured a difference of 17.78 bpm and the *Samsung Gear S2* captured data with a difference of 28.69 bpm. According to conducted research [11, 17], usage of these sensors is not suitable for accurate biofeedback data acquisition.

3.4.2 Medical-grade sensors

For this thesis project, purchasing medical-grade equipment would be far beyond the available project budget. As presented on their website *Co-Med* sells medical-grade ECG sensors with compatible patches for around 4,000 Euros [49, 50].

3.4.3 Chosen sensor kit

BioSignalsPlux produces sensors with high accuracy for research purposes. Their sensors are cost-effective because they are not medically certified. For this project the BioSignalsPlux Explorer kit (see fig. 3.2) was chosen, which costs about 1,000 Euros.

Utilizing biometric sensors to capture biofeedback data from users inside a VR application leads to estimations of the user's mental state at a certain point in time. Through this procedure all exercises proposed in this project can be evaluated. This project incorporates five different exercises which foster relaxation in the users of this application. The following section will elaborate all five exercises, their concept and their realization.

Figure 3.3: Free mind exercise

3.5   Exercises

The intent of this application is to counter stress in its users. Five different exercises cover most of the common relaxation techniques in combination with Jacobson's muscle relaxation routine. A relaxing virtual environment combined with soothing sound effects immerse the user in a virtual environment in which relaxation is the main focus. The following sections will give further insight into the different relaxation exercises.

3.5.1   Free mind

This exercise applies Jacobson's muscle relaxation technique through repeatedly squeezing one's fist, relaxing one arm and hand of the participant. The visual representation of squeezing the fist are Chinese lanterns (see fig. 3.3) lighting up by pressing the motion controller and flying away when the controller is pressed for a fixed amount of time.

3.5.2   Breathing

Respiration rate is tightly connected to the heart rate in the human body. Calming down the respiration in a user immediately leads to a more relaxed state. Breathing in and out deeply is visualized by a circular animation (see fig. 3.4), dictating the inhale and exhale time. This exercise is commonly known and used by smartwatches to calm down its user.

3.5.3   Eyes

In this exercise, the user is given the task to follow a light source with his or her eyes (see fig. 3.5). This releases tension in neck musculature and is also a well-known relaxation technique for the eye musculature. Tracing different patterns, the user experiences relief

Figure 3.4: Breathing exercise

Figure 3.5: Eye exercise

of tension in their eye musculature. Other than with existing relaxation techniques, this exercise keeps the user focused because many eye relaxation techniques require the participant to close their eyes and stare into nothingness.

3.5.4   Fireflies

The fourth exercise combines head movement with Jacobson's muscle relaxation technique. Fireflies are scattered throughout the scene and by pressing the motion controller, the fireflies form into symbols in the sky (see fig. 3.6). Through focusing on different

Figure 3.6: Fireflies exercise

symbols, the attention of the user is kept on the exercise, preventing the user from feeling bored.

3.5.5   Muscle Relaxation

The last exercise fully incorporates Jacobson's muscle relaxation technique by guiding the user through a progressive muscle relaxation routine and visualizing which part of the body has to be flexed. The visualization of the human body is presented through a star constellation on the sky, highlighting the body part which has to be flexed (see fig. 3.7).

Measuring the relaxation level of a user while actively using the relaxation application is done by capturing vital signs data sets and storing it on a computer. For realtime visualization of biometric data, a wireless connection from the computer to the *Oculus Go* has to be established.

3.6   Commonly occurring problems

When developing VR applications, several problems tend to reoccur in projects. Keeping these problems in mind while developing eases the development in many ways. Having worked on different projects with different teams, a list of commonly occurring problems was developed.

3.6.1   Time consumption

Several relaxation applications on the market tend to consume a large amount of time, causing the user to feel bored. Taking up too much time causes the user not to use the application frequently, leading to less effectiveness of the relaxation application.

Figure 3.7: Muscle relaxation exercise

3.6.2   Presenting effectiveness

As different studies have shown, presenting the user progress keeps the user motivated to use the application more often. This can be seen in many applications such as computer games and mental health apps for mobile phones.

3.6.3   Motion sickness

Moving the virtual camera without intention of the user tends to cause motion sickness in the user. Having a continuously attached virtual camera keeps the user immersed and minimizes the chance of causing motion sickness. Movements through the scene in a forward or backward direction, even if intended by the user, can lead to motion sickness mostly because of simulated body movement, which is not happening in real life. Upwards and downwards movements lead to less motion sickness.

3.6.4   Loading times

Keeping the user immersed in the virtual scene is the number one priority when developing VR applications. Breaking immersion through many scene changes or few scene changes with high loading times are to be minimized. In perspective of relaxation, immersion is vital to keep the user focused on the application itself. Considering the different exercises in the corresponding thesis project, a way to incorporate all five exercises into one scene had to be found.

3.6.5   Time pressure

Pressuring the user to finish certain tasks, not only in VR but in the real world as well, tends to lead to an elevated level of stress in the user while executing a specific task. Avoiding this is essential in perspective of a relaxation application.

3.6.6   User attention

Many different relaxation applications do not guide the user through a meditation routine. These application force the user to focus on nothing to relax. Testing has shown that this is not applicable for many users and keeping the user focused on tasks inside the VR application leads to better relaxation results across the board.

3.7   Summary

This chapter focuses on relaxation techniques that find little implementation in modern relaxation applications and describes Jacobson's progressive muscle relaxation technique in detail, which is implemented in the corresponding thesis project. Additionally, this chapter describes different rendering techniques, which find their application in modern applications and presents arguments, why the chosen rendering technique is the best suited one for the thesis project. Furthermore, the different relaxation exercises of the corresponding thesis project are described and why they were implemented. This section is followed by a small section describing commonly occurring problems during development of virtual reality application. In the next chapter, the implementation of the described relaxation techniques will be described in detail, and certain choices during development will be evaluated.

Chapter 4

Implementation

This thesis includes a use case for realtime integration of biofeedback into a virtual reality relaxation application. To integrate realtime biofeedback into a virtual reality application, a number of programming pieces and the *Unity3D* game engine had to be combined into one working application. The following chapter describes the individual pieces of this project and how to combine them into one working application. The following section shows the overall structure of this thesis project.

4.1   Overall structure

As described earlier, this project consists of different programming components, a VR application developed in *Unity3d*, biometric sensors and a sensor-reading application. An essential part of this project was the selection of biometric sensors. On the one hand, the sensors should be accurate enough to make correct assumptions about the state of its user, on the other hand, the device had to be rather affordable and easy to use. This decision was made by the AIST Lab from Hagenberg. This lab played an important role in this project; they developed an application that will be explained later on. The biofeedback sensors that were chosen are from *BioSignalsPlux*. Their sensors are affordable because they have no medical license, but they are specifically designed for prototyping medical applications and because of that, measurements of biometric data are exact. These sensors can be bought either sensor by sensor or they are sold in sets. For this project, a set was ordered which consists of an EDA sensor, an ECG sensor, a temperature sensor and a respiration sensor. Handling all different sensors is made possible by *BioSignalsPlux* itself. They provide its users with a sensor hub. This sensor hub is connected through wires with all sensors at once and it is also connected wirelessly to the user's computer via Bluetooth. This makes it possible to read data from the hub that is worn on the body of the sensor's user, making the user setup simple and giving the participant no to little movement restriction. On the connected computer, a tracking software has to be installed and running. The software is developed by *BioSignalsPlux* and it is called *OpenSignals*. This software makes it possible to detect which sensors are connected, at which rates those sensors perform and to record sensor sessions.

Having chosen the sensors to work with, an application by AIST Lab was devel-
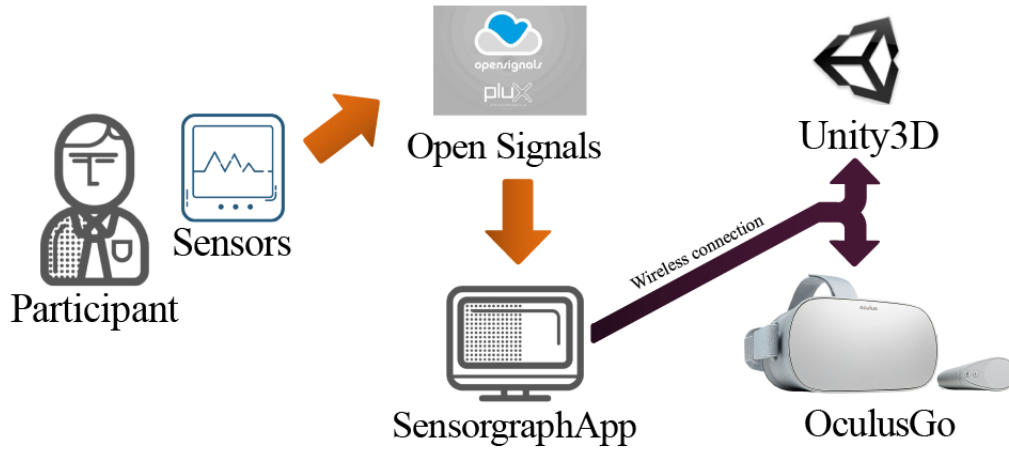
Figure 4.1: Project overview

oped. This application makes it possible to record all sensors at once and draws a corresponding realtime graph for each sensor. Even though it is possible to record with OpenSignals, this code made it possible to easily access the sensor data sent by the sensors in realtime. Data access is a key point of this project. Now able to easily access sensor data, a bridging software had to be made that connects the piece of software from AIST Lab to the virtual reality application, which will be described in a later section.

As the VR application is designed for the *Oculus Go*, which is a mobile VR headset, data had to be sent wirelessly either via Bluetooth or via WiFi. Having experienced common Windows and Bluetooth problems, which will be discussed later, the decision to use web technologies was an easy one. The bridging software utilizes sockets and the HTTP protocol to send data from a computer to the VR headset for realtime translation to visual output. These data sets are formatted for easy use inside *Unity3D*. To receive data inside of *Unity3D* a webclient had to be implemented. The already built virtual reality relaxation application *VIRE* from *Playful Interactive Environments* (PIE) Lab in Hagenberg that features five different relaxation minigames that should help its user to relax faster and better, did not have a webclient integrated, but after receiving the corresponding Unity project with access to all files, a webclient was implemented (see fig. 4.1). With all these components up and running, the VR application with biofeedback integration was ready for testing. More to the testing and evaluation in the chapter Evaluation. In order to be able to sense biometric data from participants, sensors have to be attached.

4.2 Participant setup

Detecting biofeedback data can be a lot of work when using a stationary biofeedback data acquisition system. For this project, a mobile biofeedback data sensor kit is used, to be able to use it everywhere for testing and to be quick in putting it on and taking

it off the participant. For the participant, it is most important to be calm because the application that is tested on its capability to relax a participant. For this, the participant has to be in a neutral state for testing to begin and having him come to a big facility with many people can induce stress all on its own. Furthermore it is more convenient for the user to be able to try the application at home, where he is inside his comfort zone. To capture data that is valuable, the data has to show if it tells something about the user. To be able to analyze data and tell if it is significant, it has to be tested against another value. This value that it is tested against is the baseline. This baseline is acquired when the participant is in his neutral state to be able to tell whether there was change in his vital signs data when stress is induced or if the induced stress reduces. To capture the most accurate data, all sensors have to be mounted onto the participant's body correctly.

4.2.1 Sensor Setup on the participant

For this project, several different sensors were in use. For measuring the heart activity, an ECG is placed on the participant's body. For every sensor, there are specific parts on the body where they have to be placed. Depending on the sensor, the sensing equipment has to be mounted either directly on the skin with a sticky patch, strapped on to a finger or put on the chest. Depending on the data that is needed, there are different levels of invasion into the privacy of the participant. On the one hand, strapping a clip on the participant's finger, is very non invasive, on the other, sticking sensors on the participant's chest is one of the most invasive actions to take on the participant (see fig. 4.2). The following section will show the different sensors that were used and how to attach them to the participant and the resulting complications.

Respiration Sensor

The respiration sensor consists of a strap that is pulled over the head and attached to the chest or the diaphragm, measuring chest cavity expansion. Underneath the strap there should be thin to no clothing to capture the best sensor results. Depending on the sensor, there is a certain threshold of how much the sensor value on breathing in and out should vary at a minimum (further described in section 2.2.5).

Temperature Sensor

To measure the skin temperature of the participant's hand, a wire is strapped around his or her fingers. This sensor is connected to the BioSignalsPlux hub (further described in section 2.2.5).

ECG

Electrocardioraphy is an essential part of the sensor setup. Ventricular and atrial arrhythmias can be triggered by stress responses of the human body [8]. Detecting arrhythmias is as important as measuring the heart rate with an ECG sensor to make assumptions about the participant's mental state. However, the heart rate is highly dependent on other factors than stress, such as body fat, respiration rate and age. To

Figure 4.2: Participant Setup

correctly acquire results from testing, sensor patches have to be mounted onto specific parts of the participant's body (further described in section 2.2.5).

EDA

An electrodermal activity sensor measures the variation of electrical properties on the human skin. To capture data with an EDA sensor, two electrodes have to mounted onto one palm of the participant (further described in section 2.2.5). To access the acquired vital signs data set in realtime with the BioSignalsPlux sensors, AIST Lab wrote an application that made the data easily accessible.

4.3 Sensor Graph Application developed by AIST Lab

For capturing real-time data, the *BioSignalsPlux* Hub has to be connected via Bluetooth to the computer that runs the sensor graph application. The first step in capturing data is opening up *OpenSiganls* and making sure the *BioSignalsPlux* Hub is connected properly and all the channels have the right sensor assigned. Opening up Sensor Graph,
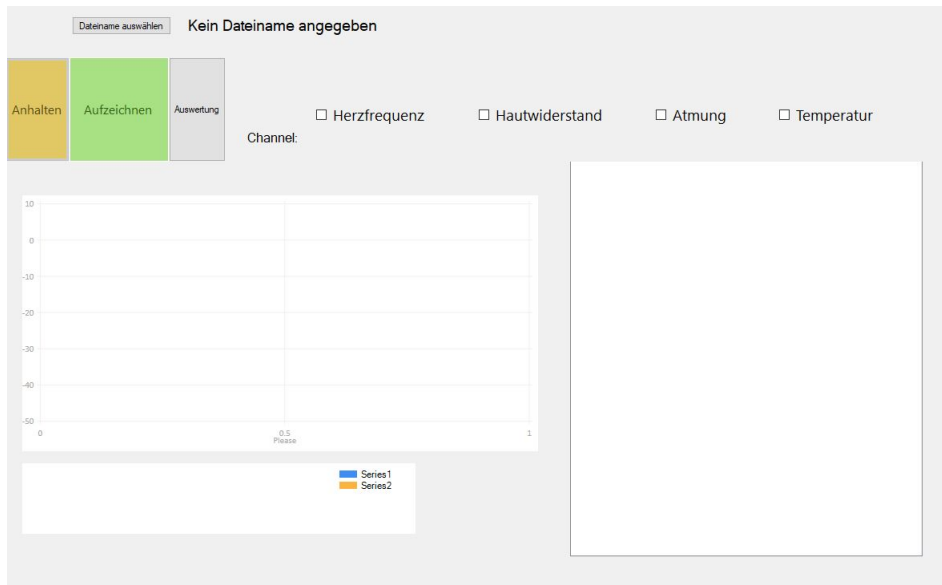
Figure 4.3: Sensor Graph Interface

there is a form with all necessary settings to capture and plot realtime data (see fig. 4.3). The sensors have to be selected in the order they are connected to the hub. Naming the file and selecting if it is either a baseline capture or an intervention, meaning while performing certain tasks, is done in a prompt popping up when pressing the "Change filename" button. Having everything set up this way, pressing the "Record" button will change the application view to a realtime graph that measures vital signs data in realtime and displays it simultaneously. After pressing the "Stop" button, the file will be saved to the bin/Debug folder in the project hierarchy of the *Visual Studio* project.

For exporting data from Sensor Graphs to *Unity3D* in realtime, a simple web server was implemented. Through this server, data distribution was managed. This server was implemented inside an own visual studio project and a standard IP was designated to host the server. This server receives data from Sensor Graphs and pipes it through to the virtual reality application. Below is a code snippet, showing a simple web server sending sensor data to a client, if requested.

```
HttpListenerRequest clientRequest = ctx.Request;
string url = clientRequest.Url.ToString();
string[] componentsOfUrl = url.Split('/');
if (componentsOfUrl.Length > 1)
{
    string command = componentsOfUrl[componentsOfUrl.Length-1];
    if (command == "data")
    {
        recData = componentsOfUrl[componentsOfUrl.Length - 2];
    }
}
string rstr = _responderMethod(clientRequest);
recDataDouble = Convert.ToDouble(recData);
byte[] buf = Encoding.UTF8.GetBytes(recData);
ctx.Response.ContentLength64 = buf.Length;
```

```
ctx.Response.OutputStream.Write(buf, 0, buf.Length);
HttpResponseMessage response =client.GetAsync(interpretedValue.ToString()+"/data").
    Result;
```

The data coming from sensor graphs is raw and not formatted. To give a small example, below is one line of raw sensor data.

```
0,128644;-3,84521484375;25,983377876652;-0,12945556640625;0,01220703125
```

Sending data in a not formatted way is possible, but makes it harder to work with it later on. For the purposes of this project, data with only two decimals were accurate enough. To work with formatted data, a small amount of code had to be added to the existing project.

```
if (chartList[i].Name == "Atmung")
        {
        interpretedValue = ValueInterpreter.
        InterpretRespiration(args.ReceivedData[i]);
        interpretedValue.ToString("#.##");        //rounding
        }
```

To transmit formatted data, a client for receiving data had to be implemented inside of Unity for further processing of the received data. Below is a code snippet showing the client inside Unity.

```
var url = new System.Uri(L_url +"/"+ command);
        HttpClient client = new HttpClient();
        StringContent content = new StringContent("");
        Debug.Log("EnteredSendCommand");
        StringContent stringcontent = new StringContent("");
        client.GetString(url, (r) =>
        {
            if (r.Data!=null) {
                n1 = System.Double.Parse(r.Data, culture);
                Debug.Log(n1 + " PARSED DATA");
                if (!double.IsNaN(n1)) //parse to double
                {
                    handleT.calculatedValue = n1;
                }
            }
        }
```

For real-time display of the received biometric sensor data, an application was developed by *Playful Interactive Environment* (PIE) in Hagenberg. This application is developed to run on the *Oculus Go* and serves as the visual representation for realtime data visualization.

4.4 VIRE

Virtual Interactive Relaxation Environment (VIRE) is a virtual reality relaxation application consisting of several relaxation exercises. Every exercise incorporates another relaxation technique. Adding to relaxation triggered by the relaxation techniques, a cartoony 3D environment surrounds the user inside the virtual world. To enhance the relaxation process, soothing audio is played on the VR headset while using the relaxation application. The next sections will present all different relaxation techniques

and configurations that can be done to the config file to customize the virtual reality experience.

4.4.1 Free mind

This exercise serves the purpose of introducing the participant to the virtual world. In this exercise, lanterns fly from the sky down to the sea and when the trigger button is pressed, one lantern at a time flies up into the sky. When the trigger is pressed, a random lantern is picked and brightens over time while the trigger is pressed. If the trigger is released before the lantern has lifted up into the sky, the light vanishes and the lantern is put back to its neutral state. After a fixed amount of lanterns has moved into the sky, this exercise is over and the next one is initiated. Below is the code that chooses the lantern and lights it up.

```
if (Interaction.Instance.TriggerChanged)
{
//init  light  lantern when trigger pressed
    if (Interaction.Instance.TriggerPressed && mindIndex < mindCount)
    {
        getNearest();
        mindIndex++;
        lanternPressTime[mindCount - mindIndex] = Time.time;
    }
//stop  light  lantern when trigger  released  bevor  full  lighten
    if (!Interaction.Instance.TriggerPressed)
    {
        if (!isLanternLighten(mindCount - mindIndex))
        {
            lanternPressTime[mindCount - mindIndex] = 0;
            mindIndex--;
        }
    }
}
```

4.4.2 Breathing

Inhaling and exhaling are part of most meditation and relaxation routines one is able to find online and in books dedicated to relaxation. It is a core part to transfer the body into a relaxed state. In this exercise a ring that is split into two halves leads the breathing speed. As one half is highlighted, the user is inhaling, as the other half is highlighted, the user is exhaling. This exercise is customizable through a config file, establishing the inhalation and exhalation times.

```
<config>
<initTime>10</initTime>
<breathingCount>8</breathingCount>
<breathingIntervalLength>10</breathingIntervalLength>
```

4.4.3 Eyes

Moving the head and the eyes is really important in order to become more relaxed, especially if the user works in front of a computer screen and stares straight at the

monitor for long periods of time. This exercise is composed of a particle system that the user has to follow with his head. The particle movements are predefined into five different move sets.

```
if (particleAnimator.isActiveAndEnabled)
{
    var animationState = particleAnimator.GetCurrentAnimatorStateInfo(0);
    if (animationState.IsName("eyesUp")) actState = EyeExercise.lookUp;
    else if (animationState.IsName("eyesRightLeft")) actState = EyeExercise.lookSide
    ;
    else if (animationState.IsName("eyesUpDown")) actState = EyeExercise.lookDown;
    else if (animationState.IsName("eyesEightLeft")) actState = EyeExercise.
    eightLeft;
    else if (animationState.IsName("eyesEightRight")) actState = EyeExercise.
    eightRight;
}
return actState;
```

4.4.4   Fireflies

Combining head movement with muscle activation, this exercise presents the user with a particle system that is scattered all around the scene. By pressing the trigger button, the particles move to predefined locations into predefined symbols. The following code shows how the distance between the actual particle and the destination in the symbol is calculated.

```
for (int i = 0; i < particleCount; i++)
{
    //calculate distance between the actual position and the goal position
    var distance = Vector3.Distance(morph_particles[i].position,
    destination_particles[i].position);
    //calculate smooth interpolation between start distance and goal. Calculate actual value
    of smoothing.
    var maxDistanceDelta = Mathf.Abs(Mathf.Sin(distance / start_distance[i] * Mathf.
    PI)) * Interaction.Instance.Intensity() * 2 + 1;
    //adjust the value for noise calculation
    distance /= 300f;
    if (distance > 1) distance = 1;
    if (distance < 0.1f) distance = 0;
    //calculate a noise value for each direction to genate a natural movement from point A
    to B for each firefly
    var noiseX = getNoise(destination_particles[i].position.x, distance);
    var noiseY = getNoise(destination_particles[i].position.y, distance);
    var noiseZ = getNoise(destination_particles[i].position.z, distance);
    //calculate new position for the firefly
    morph_particles[i].position = Vector3.MoveTowards(morph_particles[i].position,
    destination_particles[i].position, maxDistanceDelta) + new Vector3(noiseX,
    noiseY, noiseZ);
}
```

4.4.5   Muscle Relaxation

As an essential part of this project, guided muscle relaxation from Jacobson is implemented in this exercise. Following a config file, particles move through the scene, showing

the user which muscles to flex. This exercise is highly customizable though a config file, which lets the developer decide which procedure this exercise follows. Below there is a snippet of the config file, allowing customization.

```
<progressive-muscle-relaxation>
<time-flow time="00:00:00" part="Breath" state="tight" />
<time-flow time="00:00:35" part="R Forearm" state="tight" move="0/1" movePart="child
    " rotate="90" highlightBone="2" />
<time-flow time="00:00:45" part="R Forearm" state="relax" />
<time-flow time="00:01:11" part="R Forearm" state="tight" move="0/1" rotate="90" />
<time-flow time="00:01:24" part="R Forearm" state="relax" />
<time-flow time="00:01:36" part="R Elbow" state="tight" rotate="120" highlightBone="
    1" />
<time-flow time="00:01:46" part="R Elbow" state="relax" />
<time-flow time="00:02:01" part="R Elbow" state="tight" rotate="120" />
<time-flow time="00:02:11" part="R Elbow" state="relax" />
```

4.5 Prototyping and hurdles encountered during development

As with many software projects, delays are nothing out of the ordinary. This projects consists of several different parts, developed by different people in different organisations. By the time this project was started, a crucial part, sensor reading, was not fully developed, leading to the development of a system for reading presaved data for testing.

4.5.1 Reading dummy data

BioSignalsPlux, the company that produces the sensor kit used in this project, provides its developers with dummy data from their website. This data was then used to substitute realtime acquired data. Below, dummy data from the *BioSignalsPlux* website [39] for respiration sensors is shown.

```
# OpenSignals Text File Format
# {"00:07:80:3B:46:61": {"sensor": ["CUSTOM/0.5/1.0/V"], "device name": "00:07:80:3B
    :46:61", "column": ["nSeq", "DI", "CH1"], "sync interval": 2, "time":
    "16:6:8.872", "comments": "", "device connection": "BTH00:07:80:3B:46:61", "
    channels": [1], "date": "2017-1-17", "mode": 0, "digital IO": [0, 1], "firmware
    version": 772, "device": "biosignalsplux", "position": 0, "sampling rate": 100,
    "label": ["CH1"], "resolution": [16], "special": [{}]}}
# EndOfHeader
0 0 32564
1 0 32538
2 0 32550
3 0 32544
4 0 32576
5 0 32572
6 0 32630
7 0 32664
8 0 32728
9 0 32754
```

This dummy data was processed inside *Unity3D* and read from a file inside the *Unity3D* project. Reading in dummy data from a file was made possible through the use of the *Microsoft* Streamreader. Below is code from the official *Microsoft* documentation for the class Streamreader [52].

```
// Create an instance of StreamReader to read from a file .
// The using statement also  closes  the StreamReader.
using (StreamReader sr = new StreamReader("TestFile.txt"))
{
string line;
// Read and display lines from the  file   until  the end of
// the  file  is  reached .
while ((line = sr.ReadLine()) != null)
    {
    Console.WriteLine(line);
    }
}
```

4.5.2   Utilizing *GitHub* with *Unity3D*

Working on software projects goes hand in hand with utilizing version control. A commonly known version control is *git*. For this project *GitHub* was utilized as a means to control which version of the project is the most up to date one and which changes have been made in the past. Utilizing git, a repository is needed, which is saved on a local machine and in the cloud. To lower the down- and uploading sizes, git introduced the `GitIgnore` file. Because not every file is needed by everybody working on the same project, setting this ignore list correctly can save much time.

Uploading a whole Unity project into a repository is a convenient way of handling backups and version control. Because *Unity3D* projects tend to be very large, a correct `GitIgnore` file is advantageous. For this project the `GitIgnore` file was set incorrectly and the "StreamingAssets" from Unity could not be assigned correctly. As a quick fix to this problem, the *Unity3D* project was put on a USB-drive and handed over. Alternatively, adjusting the `GitIgnore` file would have fixed the problem as well.

After modifying the *Unity3D* project, building the application and pushing it onto an *Android* device was the next task.

4.5.3   Building to an *Android* device utilizing ADB

Building a *Unity3D* project for the *Oculus Go* is no different from building to any *Android* based device. After installing the *Android* SDK on the computer running Unity, building an `.apk` file is done by building the project for any Android device inside Unity. The difference of the *Oculus Go* to an *Android* phone is moving the built `.apk` file to the device. On an *Android* phone, simply moving the .apk file into the phone's storage is enough to be able to run it on the desired device. Running a `.apk` file on the *Oculus Go* requires one more step. For moving the `.apk` file to the *Oculus Go*, the "Android Debug Bridge" (ADB) is needed. After installing the ADB on the computer used for moving the file, the `.apk` file has to be moved to the root folder of the ADB installation. When the file is moved to the correct location, typing `adb install [filename]` into the *Windows* command line will move and install the specified `.apk` file to the connected device.

4.6   Changing connection protocol

To stabilize the quality of connection from the Sensor Graph Application to Unity3D, another protocol was chosen to be better suited. The User Datagram Protocol (UDP) is a connectionless network protocol that is included in the transport layer of the internet protocol family. By utilizing sockets it is possible to send datagrams, enclosed and independent data units, over an IP based network.

4.6.1   Socket connection

A socket is an object provided by the operating system that serves as a communication endpoint. A program uses sockets to exchange data with other programs. The other program can be located on the same computer (interprocess communication) or on another computer accessible via a network. Communication via sockets is usually bidirectional, i.e. data can be both received and sent via the socket.

4.6.2   UDP

Having chosen UDP as the suitable protocol is due to its capability of transmitting data faster than most other protocols. Packets are sent without the need of a "handshake" or agreement of the receiver, therefore speeding up the communication process. Ordering and error checking are features, which UDP does not support, making it unreliable and error prone, but it also speeds up the communication between the endpoints. UDP is used when losing packets is less important than time consumption. For the corresponding thesis project, dropping a packet with biometric data is not as important as visualization speed. For real-time visualization every vital signs data set is visualized inside a VR application. Because of the speed of communication, a user of this software will not notice a dropped packet. But the user will notice a delay from waiting on a missing data set. This makes UDP a better communication protocol for the corresponding thesis project.

4.6.3   UDP Implementation

The implementation of the User Datagram Protocol consists of a client that sends biometric data and a receiver that receives this data and that is processing it further inside of *Unity3D*. To send data from a client, there are two key elements that have to be specified. A port number and an IP address, which allow the client to send data to a specific port in a network. To have high compatibility with the application, the port and IP are variable. At startup of the application the user is prompted to fill in the IP address and a free port.

```
private static void GetInfo()
      {
          Console.Write("IP: ");
          ip = Console.ReadLine();

          Console.Write("Port: ");
          port = Convert.ToInt32(Console.ReadLine());
      }
```

Socket connections can only communicate by utilizing byte arrays. In this thesis project, there were four different values that had to be sent to the VR application. Having clarified which sensor data comes after another, there was no conversion needed for optimal further processing. Strictly following the structure of heart rate, temperature, ECG and EDA made it possible to have a small packet sent to the port.

```
private static bool Send()
    {
        byte[] dataArray = sensoryData[];//Hz, Tp, ECG, EDA
        IPEndPoint ep = new IPEndPoint(IPAddress.Parse(ip), port);
        Socket sock = new Socket(AddressFamily.InterNetwork, SocketType.Dgram,
ProtocolType.Udp);
        try
        {
            sock.SendTo(dataArray, ep);
            return true;
        }
        catch (SystemException saysex)
        {
            return false;
        }
    }
```

To receive the sent data, a receiving endpoint inside of *Unity3D* was created. A *Unity3D* application is currently updated by the *Update* function. This update rate is bound to the frame rate of the application that is currently running. To avoid receiving data only as fast as the frame rate, a separate thread was created to pull data from the port into the *Unity3D* application. To be able to receive data from a client, the same port number as in the client has to be specified. In this case, this application receives data from any IP address that is sending to this port, which could be further specified to improve the security of the implementation.

```
private void init()
    {
        port = 904
        receiveThread = new Thread(
            new ThreadStart(ReceiveData));
        receiveThread.IsBackground = true;
        receiveThread.Start();
    }
    private void ReceiveData()
    {
        client = new UdpClient(port);
        while (true)
        {
            try
            {
                IPEndPoint anyIP = new IPEndPoint(IPAddress.Any, 904);
                byte[] data = client.Receive(ref anyIP);//data[0-3]sensordata hz,tp,ecg,
eda
                byte[]recD = data;
                print(">> " + recD[1]);
            }
            catch (Exception err)
            {
                print(err.ToString());
```

```
            }
        }
    }
```

4.7 Summary

This chapter describes the overall structure of the corresponding thesis project, which consists of biometric data sensors, a data capturing software, a bridging software that pipes data from the capturing software to the VR application that was developed in *Unity3D*. Switching from HTTP to UDP for data transmission is discussed in detail, but it boils down to the fast transmission capabilities of a socket connection, in respect of lost packets, which do not effect the thesis project. This leads to a fast connection and a good visualisation quality. While testing the VR application, the participants were connected to biometric sensors that sent data to a PC, which saved the data for further processing. This data was then evaluated and plotted into graphs for better visualization. Code examples are presented in this chapter for better understanding of how this project was realized. The next chapter describes the evaluation process and evaluates the captured data to the point, if the captured data is able to represent the participants state. Furthermore, the next chapter will discuss the results of a survey that was held right after the testing of the application with every single participant, to see if the sensor values correspond with the captured biometric data.

Chapter 5

Evaluation

Stress is an increasingly important problem that affects people around the globe, independent from work environment or age group. Affecting workload capability in workers and even affecting private life, stress rises to be a major problem in work environments, but also at universities. Suicide rates in students are rising, which makes it a modern and important topic, leading to research done for treating stress and relieving personal load from students and enabling a healthy lifestyle and creating a healthy university environment. Research on this topic is done by finding papers on this topic and by testing a relaxation application with quantitative measures on a small scale. The acquired biometric data are used to describe the capabilities of the sensor kit and if this sensor kit is suitable for further testing of this application. This means that the acquired data are not used to describe the relaxation capabilities of the application itself, but the capability of these biometric sensors for conducting testing on a larger scale.

5.1 Methodology

Considering the scope of this thesis, large-scale quantitative testing was not an option because of lack in participants and time. To test relaxation techniques, data was acquired utilizing a questionnaire that was filled out after testing the virtual reality relaxation application. Standard methodology in this field often relies on large-scale quantitative testing, by doing surveys for identifying patterns, to generalize findings, which are to be assumed to be true for a larger group of people. Testing relaxation applications is somewhat of a delicate venture because testing whether a participant is stressed or relaxed requires a trigger to stress the participant and this may cause problems with people which cannot handle stress very well – presenting an ethical predicament.

5.1.1 Ethical aspects of stress testing

To be able to discuss what is ethical and what is not, a definition of ethics has to be given. Defining ethics is a delicate field. Ethics are not hard facts, which can be seen as wrong or right. The ethics of a person strongly depend on their personality, their upbringing, their religious beliefs and many more factors. This proposes a problem to finding guidance to what is ethical, to what is right. Two different people may see one ethical question in two opposing ways. However, there are basic rules, which most people cannot neglect. On

top of all rules is the natural law, known as the principle of non-maleficence. Commonly explained as doing no harm. But this rule opens a new question. Defining harm is, however, problematic, as different people will classify different interventions as harmful, creating a dilemma. Immanuel Kant developed the "Categorical Imperative", which he dubbed the supreme principle of morality. Freely interpreted, this principle includes that any action that can coexist with everyone's freedom is right and it is only right, if it can be applied to everyone else [47].

When applying these beliefs to human testing, the freedom of each participant cannot be restricted and it is only morally right, if this testing can be done on everybody without restricting any participant's freedom. Defining ethics is an objectively hard task, but breaking it down to basic rules helps with understanding what is right and what is wrong on a basic level. To give an answer if something is ethical cannot be done by one person alone. Hence, there are ethics committees all around the globe, discussing if research is justified or unethical. A modern and standard approach is to obtain informed consent from participants. Per definition, individuals that are not able to give informed consent, such as children or mentally disabled individuals, can not take part in any kind of research. Informed consent is the agreement of the participant and the researcher - after being informed on the commonly expected outcomes of the research - on whether the testing can be performed on the participant or not. While in this research human subjects were tested, no physical or mental harm was inflicted on the participants. For further testing on the relaxation application, whether it is able to counter stress, stress has to be inflicted on the participants. It has to be discussed if this is ethical or not, but for this research, ethical questions did not arise [21].

5.2 Data acquisition

The acquired data consists of data from four different sensors and a questionnaire. Collecting vital signs data was realized by connecting an ECG, an EDA, a respiratory sensor and a temperature sensor to twelve different participants. While capturing the data, the participants were left alone in a room minimizing outside influences. After completing the virtual reality relaxation application, the participants were disconnected from the sensors and were presented with several questions regarding their experience. This questionnaire consists of seven statements, which had to be rated on a Likert scale and three open questions, which were recorded on a mobile device [10]. The questionnaire was created utilizing *Google Forms*, which is easy to use for the creation of the questionnaire. Testing took about 20 minutes, consisting of five minutes for sensor connecting and baseline acquisition, ten minutes for VR application testing and five minutes for answering the questionnaire.

5.2.1 Participants and set up

In total, there were twelve participants, consisting of six females and six males, with an age range between 20 to 25. Five of the participants were from Austria and are students at the University of Applied Sciences Upper Austria Campus Hagenberg. The remaining seven participants were Erasmus students coming from Portugal, Sweden and Poland.

The location of the test was a computer laboratory at the University of Applied

Sciences Upper Austria Campus Hagenberg, which was air-conditioned and kept at a steady temperature.

5.3   Acquired vital signs data sets

The biometric data that was collected during the completion of the virtual reality relaxation application was captured by using an ECG, an EDA, a respiratory sensor and a temperature sensor. Those sensors were mounted onto the participant as explained in each data sheet of the sensor from the sellers website. The ECG was placed on the left side right on the upper rib. The EDA was attached to the right arm of the user with sticky patches on the index finger and on the ring finger. Temperature sensing was done by wiring the remaining fingers from the right hand of the participant with the temperature sensing wire. Lastly, the respiration sensor strap was put around the abdomen of the participant, with the sensing part of the strap being over the diaphragm. At first, there was a baseline acquisition, which took two to three minutes, depending on how long the sensor connection had taken. While acquiring the baseline, the participants could see the realtime output of their biometric data.

After baseline acquisition was done, the participants were handed the *Oculus Go* with the application already booting up. With help, the participants put on the virtual reality headset and waited for the application to start. Meanwhile, the biofeedback data acquisition was already capturing data, even without already executing relaxation exercises. For the duration of the relaxation application users were left alone in the testing room, but they would have been able to call for help. The testing room was connected to another empty room, were other participants were waiting in silence.

When participants were finished with the application, they called for help and were taken out of the virtual environment. The next step was to unmount the biofeedback sensors from the participants and to start the questionnaire. The questionnaire was held directly after experiencing the virtual reality application and was held in person. The participants were presented with statements and presented answers according to a Likert scale. After giving a an explanation to all seven statements, three open questions were asked, which were audio recorded with the consent of the participant.

5.3.1   Biofeedback data evaluation

The point of biofeedback data evaluation for this project is not to evaluate how well the relaxation application relaxes a user. For this kind of evaluation, a much larger number of participants would have been needed. This research was conducted to determine if it is possible to execute a large-scale quantitative evaluation with the current sensor setup. In the next section, the biometric data acquired by one person will be evaluated to the extent, of an IT student's knowledge and not of the knowledge of a trained physician.

Evaluating biometric data on the example of one participant

While acquiring biofeedback data from participants, no personal data, apart from age and gender, were captured. The randomly chosen participant is male and is 24 years old. The acquired biofeedback data were captured into text files and plotted via *Google* ta-

bles. The following section presents the detailed evaluation of captured biofeedback data of one participant. First, the baseline data will be evaluated, afterwards, the intervention data will be evaluated. The participants are labelled as participant01 to participant12. participant01 to participant06 are male and the remaining participants, participant07 to participant12, are female.

participant01 data

Elaborating if data is significant or not is done by comparing acquired data with data provided by the company that sells the utilized sensor kit. The following section will present the data acquired while testing the virtual reality relaxation application and the data provided by *BioSignalsPlux*.

ECG

Comparing the different ECG diagrams (see fig. 5.1), the most prominent finding is the difference in sampling rate. Having utilized *BioSignals'* software *OpenSignals* to configure all sensors with predefined presets by *OpenSignals* itself, the sampling rate was set too low. When looking at the same time step, it can be seen that the provided diagram (see fig. 5.1 a) is sampled at a much higher rate. However, the captured data is sampled frequently enough to give estimates about the participant's heart activity. For heart rate arrhythmia detection for suddenly occurring jumps in the heart activity, the standard sampling rate for this sensor might be too low. If an arrhythmia lasts shorter than a sampling step the whole spike can be lost when it occurs in between two sampling steps.

EDA

Having compared the different EDA diagrams (see fig. 5.2), there is no major difference in sampling rate from the provided diagram [35] to the captured data, by using the preset from *OpenSignals*. The single difference is that the acquired data (see fig. 5.2 b and c) has far more noise, disturbing the sensor values. Small spikes every second are disturbing the overall average value of the EDA values, but a clear trend in EDA values can be detected.

Temperature data

The different temperature data diagrams show the raw captured data of the sensor (see fig. 5.3 b and c) with a polynomial trend line and the provided sensor data (see fig. 5.3 a) after applying the corresponding transfer function (transferring the measured resistance to degree) and applying the same trend line without raw sensor data [38]. The accuracy of this sensor seems high and the response time on the skin is about 2 seconds, as accurately stated in the data sheet.
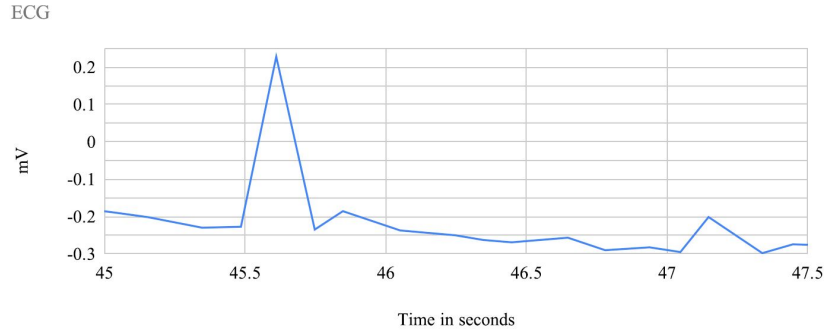
Respiration data

The captured data compared to the example data looks very similar with clear inhaling and exhaling values. Noise captured in the raw data (as seen in fig. 5.4 b and c) was
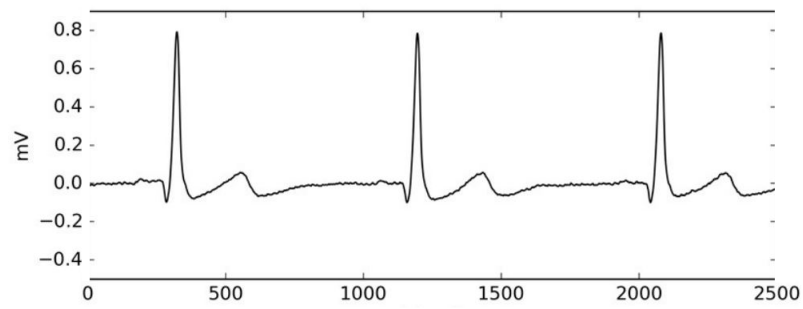
(a)
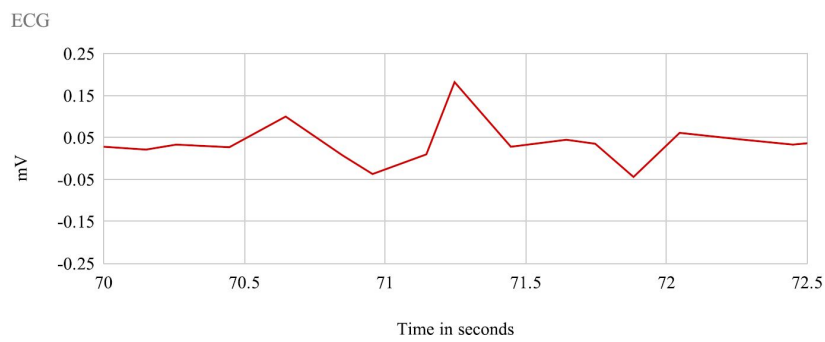
(b)

(c)

Figure 5.1: This figure depicts sample heart rate from *BioSignalsPlux* [34], as well as the heart rate of participant01. *BioSignalsPlux* sample signal (a), intervention data from participant01 (b), baseline data from participant01 (c).
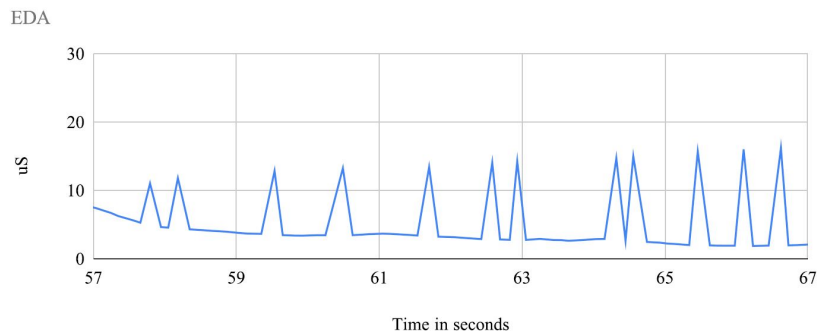
filtered out by *BioSignalsPlux* in their diagram (see fig. 5.4 a). There are appropriate filtering techniques for smoothing out sensor values such as exponential filtering or running average. This data gives an accurate representation of the participants respiration rate and can be used for further testing.
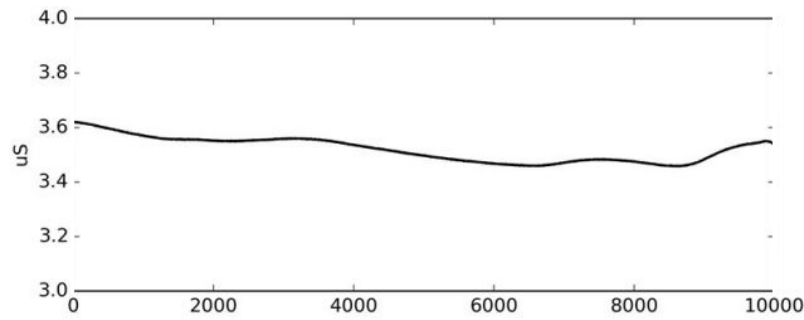
(a)
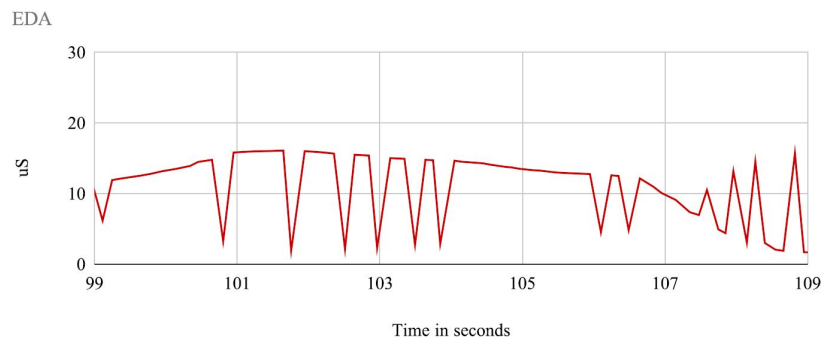
(b)

(c)

Figure 5.2: This figure depicts sample EDA values, as well as captured EDA intervention and baseline data from participant01. Sample data from *BioSignalsPlus* (a) [35], intervention data from participant01 (b), baseline data from participant01 (c).

Significant findings

While comparing different diagrams, there was one finding that was significant. The hand temperature of women is on average higher than the hand temperature of men. One female participant peaking at between 31 and 32 degree hand temperature was the highest value captured (see fig. 5.5 a). In connection with body temperature, EDA sensor values (see fig. 5.6 b) of another female participant maxed out the sensor capacity, which
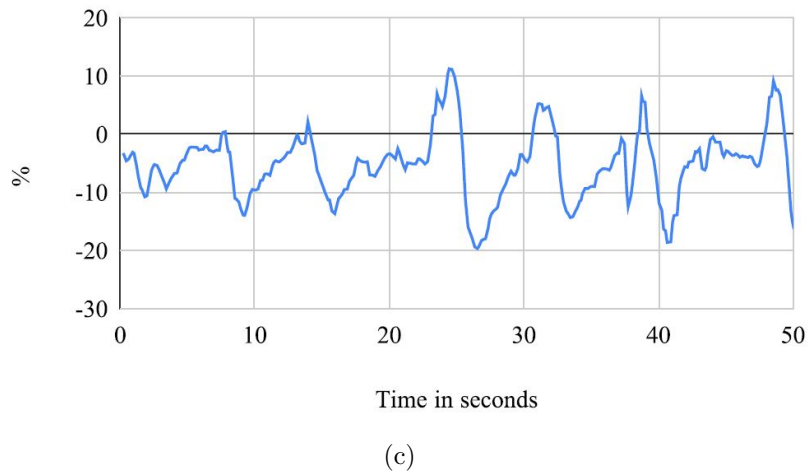
(a)

(b)
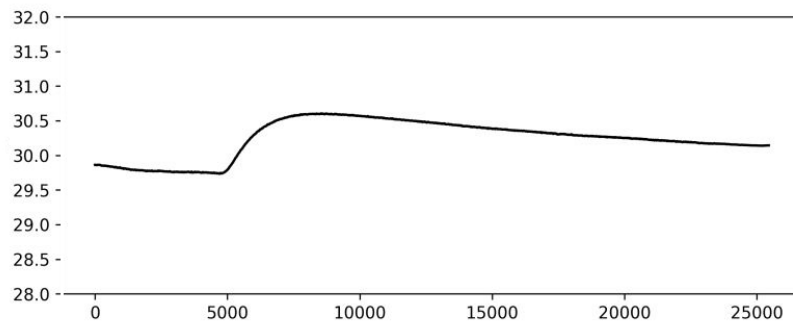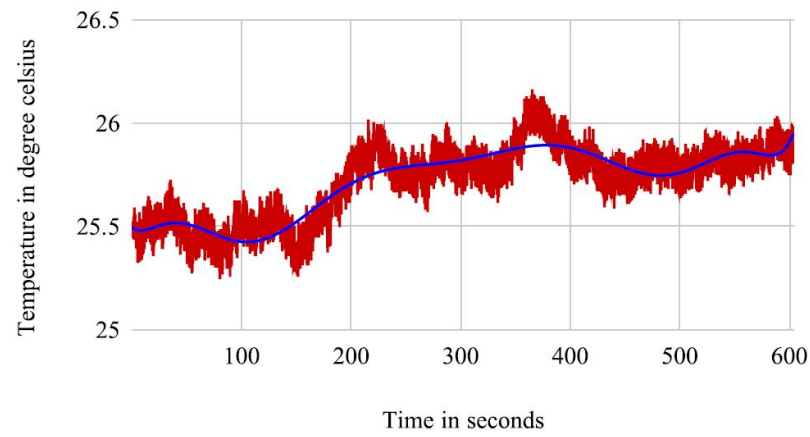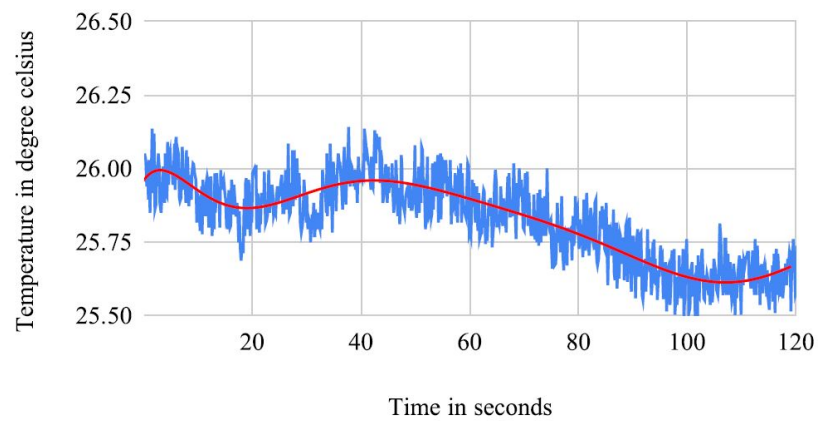
(c)

Figure 5.3: This figure depicts sample temperature sensor data, as well as intervention and baseline temperature data from participant01. Sample data from *BioSignalsPlux* (a) [38], intervention data from participant01 (b), baseline data from participant01 (c).

(a)

(b)

(c)
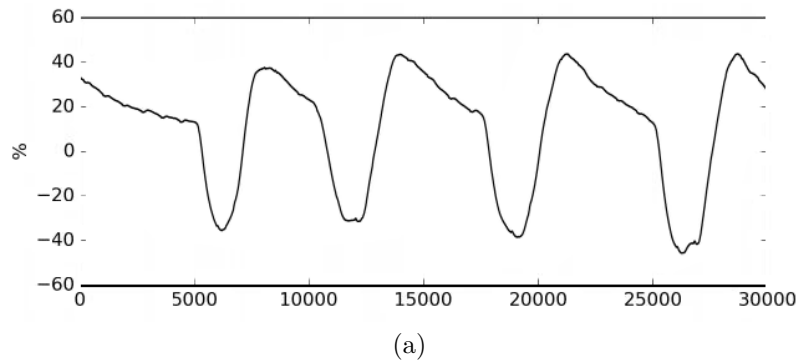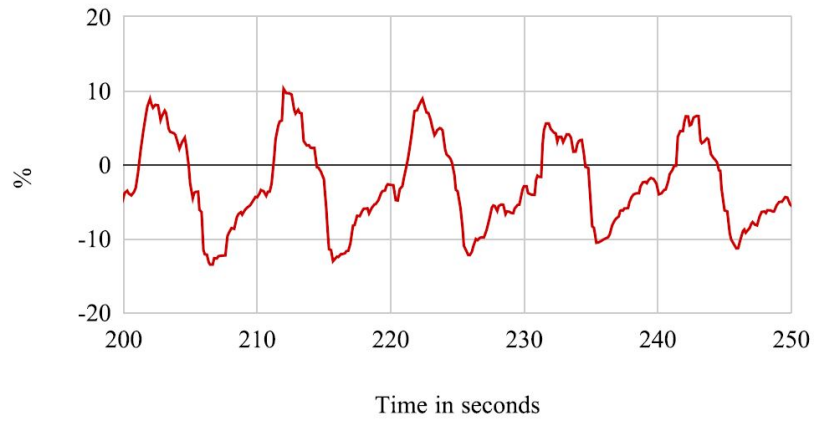
Figure 5.4: This figure depicts the sample data provided by *BioSignalsPlux*, as well as the intervention and baseline respiration data from participant01. Sample data (a) [37], intervention data from participant01 (b), baseline data from participant01 (c).

can hint to the connection between hand temperature and sweat gland activity, but it might also be a wrongly attached sensor. Bad sensor placement may be ruled out because in her baseline data, body temperature (see fig. 5.5 b) is lower than during the testing and she has high EDA values already (see fig. 5.6 a). With a rise in body temperature, a rise in sweat gland activity can be expected, increasing the values detected by the EDA.

5.3.2   Questionnaire

The statements for this questionnaire were constructed in close consultation with Houston Rodrigues, a PhD student from Brazil which is currently at the *University of Applied Sciences Upper Austria Campus Hagenberg*, and Jeremiah Diephuis, BA MA. The questionnaire was conducted after the vital signs data set acquisition was finished. The participants were presented with seven different statements, which they had to rate on a 5-point Likert scale. The rating options included:

- I totally disagree.
- Partially disagree.
- Doesn't matter.
- I partially agree.
- I totally agree.

The questionnaire consists of seven statements:

- The concept and application of the software is easy to understand.
- It is easy to learn how to use the software.
- I felt comfortable using the software.
- I felt relaxed after using the software.
- The relaxation exercises proposed by the application are effective against stress.
- By using the software, I achieved a satisfactory level of relaxation in less than 10 minutes.
- I would recommend this relaxation application to friends and family.

 These seven statements were followed by three open questions:

- Did you feel different using this application?
- At any point in time, did you feel stressed during the application?
- Is there anything you would add to the application or anything you would modify?

The answers to these open questions were recorded by mobile phone and typed down after the participants left the testing room.

5.3.3   Questionnaire results

The questionnaire was conducted utilizing *Google Forms* which presented easy further processing of the data. The acquired data are presented in form of histograms.

   The results of the first statement (see fig. 5.7 a) "The concept and application of software is easy to understand" presented that the majority of participants felt that the use of the application is clear. No participant felt that the application was unclear. This leads to assumptions about the visual environment and exercise design. In the open
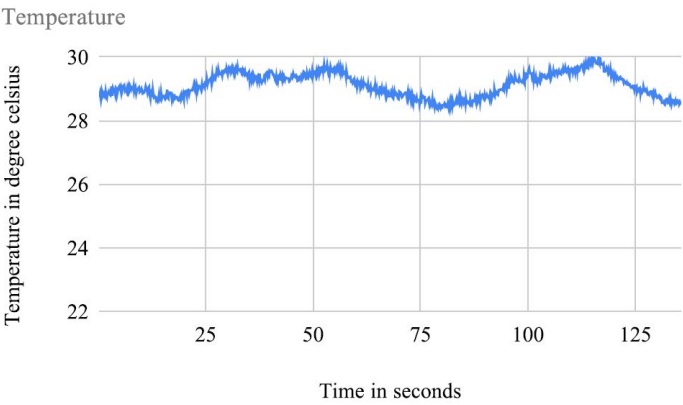
Temperature

(a)

Temperature

(b)
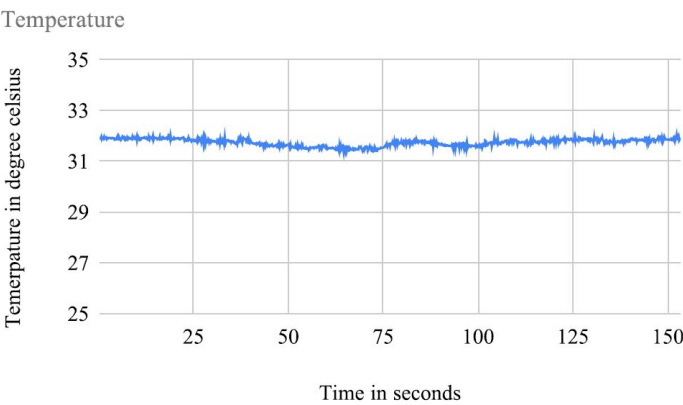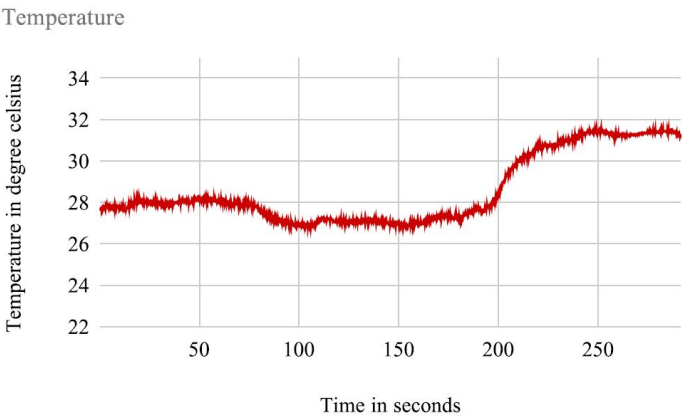
Temperature

(c)

Figure 5.5: This figure depicts the captured baseline temperature data of a female participant, as well as the captured intervention and the baseline temperature data of another female participant. Captured baseline data of a female participant (a), captured intervention temperature data of another female participant (b), baseline temperature data of a female participant (c).

EDA
uS
Time in seconds

(a)

EDA
uS
Time in seconds

(b)
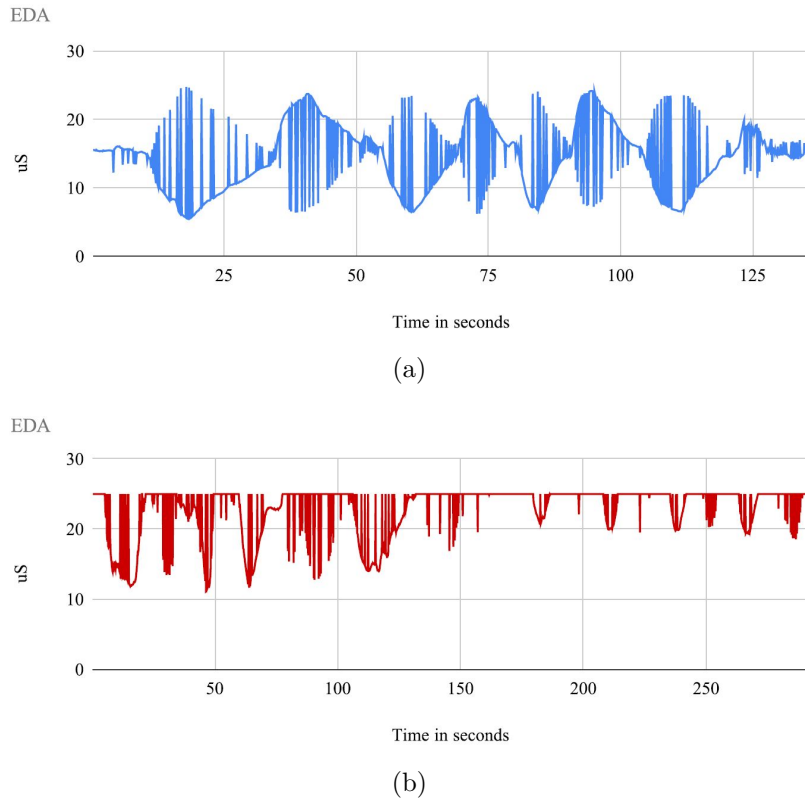
Figure 5.6: This figure depicts intervention and baseline EDA data from a female participant. Baseline EDA data from a female participant (a), intervention EDA data from a female participant (b).

questions many participants talked about the relaxation in the visual representation of the virtual world. With only the visual representation and the exercises provided inside the virtual world it became clear what the purpose of this application is. Additionally, a majority of the participants were positively influenced by the audio of the application, making the purpose even clearer.

The results of the statement (see fig. 5.7 c) "It is easy to learn how to use the software" presented that only one participant partially agreed to the software being easy to use. The rest of the participants totally agreed. This leads to assumptions about the game design of the application. There was no explanation at the beginning and only sparse use of text inside the virtual world. Nonetheless, the majority of participants had absolutely no problem using the application. This hints to clear designed exercises and perfectly used text elements. Hence, executing every task inside the virtual world with few instructions was no problem.

The results of the third statement (see fig. 5.7 b) "I felt comfortable using the software" presented that the participants overall felt that the application is comfortable to use. The results of this statement are mixed, but overall positive. This result is due to a beautiful visual representation of the virtual world, exercises designed with slow movements and a well chosen time limit for every exercise. As stated in the open
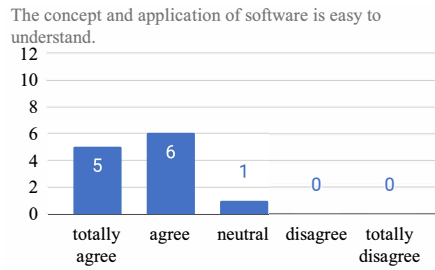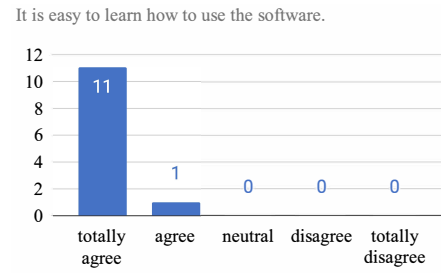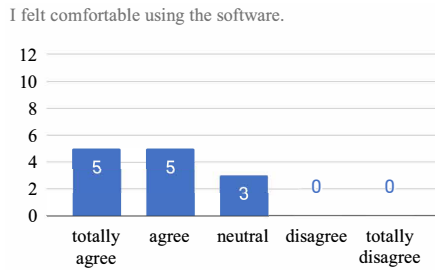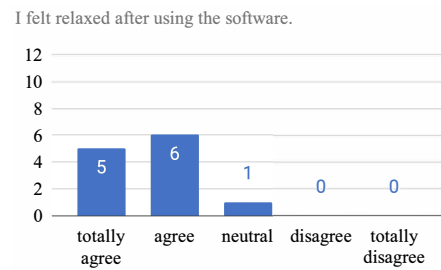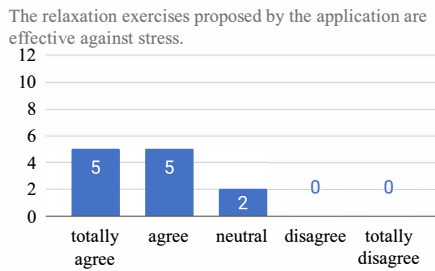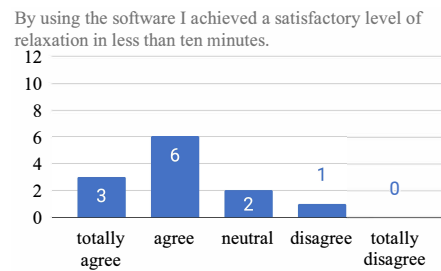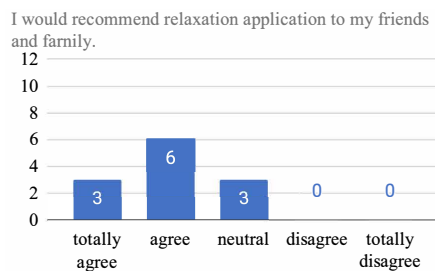
Figure 5.7: This figure depicts the evaluation diagrams for the participant survey. Selections for the statement "The concept and application of software is easy to understand" (a), selections for the statement "It is easy to learn how to use the software" (b), selections for the statement "I felt comfortable using the software" (c), selections for the statement "I felt relaxed after using the software" (d), selections for the statement "The relaxation exercises proposed by the application are effective against stress" (e), selections for the statement "By using the software, I achieved a satisfactory level of relaxation in less then 10 minutes" (f), selections for the statement "I would recommend this relaxation application to friends and family" (g).

questions, this was the first time participants used a virtual reality device and it is widely known that even 30 seconds of a badly designed virtual reality application can lead to motion sickness.

The results of the statement (see fig. 5.7 d) "I felt relaxed after using the software" presented, that the majority of participants felt partially relaxed after the relaxation application. As stated by some participants, the relaxation level before the exercise was already very high, leading to no further increase of their relaxation level. Another participant stated to be highly relaxed after the execution of the exercises. This participant had an elevated level of stress when entering the virtual world and left the virtual environment in a relaxed state.

The results of the fifth statement (see fig. 5.7 e) "The relaxation exercises proposed by the application are effective against stress" were similar to the results in statement three (see fig. 5.7 c). Overall the participants felt that the application proposed effective exercises against stress. This leads to good design of the exercises proposed inside the virtual world. Even the participant that stated to be on the same relaxation level as before assigned the exercises an overall positive score. One participant had a high level of relaxation after using the software, hinting to a successful stress reduction with help of the VR relaxation application.

The results of the statement (see fig. 5.7 f) "By using the software, I achieved a satisfactory level of relaxation in less then 10 minutes" presented that the majority of participants felt that the application partially raised their relaxation to a satisfactory level. One participant disagreed with this statement and elaborated his concern about one particular exercise in the open questions. One relaxation exercise encourages the user to move his head around. This exercise led to a feeling of discomfort in this user because the participant did not see any meaning in this exercise. This disbelieve in the exercise led to a feeling of discomfort.

The results of the last statement (see fig. 5.7 g) "I would recommend this relaxation application to friends and family" presented that the majority of participants would recommend this application to family and friends. This leads to the last statement: most of them were answered only positively or neutral. This suggests a high rate of theoretical recommendations. The overall average for this questionnaire is between the statements "I totally agree" and "I agree", hinting to an overall successfully designed relaxation application. The aspects of visual representation of the virtual world, exercise design and audio composition were discussed with the participants and were overall accepted in a highly positive way.

5.3.4   Findings in the open questions

The open questions were answered overall positively with no participant feeling stressed during the use of the application. One participant felt discomfort during one exercise because of his/her disbelieve in the effectiveness of this exercise. This exercises encouraged the user to follow a blue light with their eyes and move their head accordingly. The majority of participants felt really immersed into the virtual world, completely blending out the real world. Four participants praised the music inside the virtual reality application, mentioning that they felt truly immersed due to the music. The greater number of participants stated that the visual representation was working together with the audio

composition very well, which immersed them deep in the virtual world. The last open question was answered by half of the participants in a way that they would not modify or add anything to the existing application. The other half of the participants stated their disbelief in one single exercise. The exercise that caused one participant to feel discomfort was accepted the least by the participants. The "Eyes" exercise, which encourages the user to follow a blue light with their eyes and move their head accordingly, has to be reviewed and modified.

5.4 Summary

In conclusion, this chapter tackled ethical problems that may result in human testing and why human testing has to go through an ethical committee. The corresponding thesis project was not under ethical supervision because no stress factor was introduced in testing with human participants, resulting in a non invasive relaxation testing. Additionally, the participant acquisition and the testing setup was briefly discussed, to give an overview of the setup that was utilized to acquire biometric data. Furthermore, captured biometric data was evaluated as well as the results of the participant survey were discussed. The results of the captured data in respect to the data given by the producers of the sensor present data that is usable to detect relaxation in participants. The raw data from the used sensors incorporate a considerable amount of noise, but presents a clear view of the trend, if a participant gets more stressed or more relaxed. The survey's results clearly hint that the VR relaxation application is calming the participants down and has an impact on the state that he or she is in before testing the relaxation application.

Chapter 6

Conclusion

Biofeedback integration into virtual relaxation applications is a new and exciting topic. Through visualizing the user's biometric data, the user has more control over his own body and feels more immersed in the virtual world. Many applications on the market propose pseudo biofeedback by integrating smart devices like smartwatches, which are much too inaccurate in representing the current mental state of the user. By utilizing more expensive hardware, a reasonably precise assumption about the user's mental state can be made. This assumption is limited to the precision and clearness of the utilized sensors and to the amount of testing that is done with one participant to receive a clear vision how the user's body reacts to distress. A problem detecting stress and mental state of a user is the differentiation of eustress and distress. The difference in biometric data from experiencing stress or excitement is very hard to decipher without a therapist or communication with the user.

While evaluating biofeedback data is a crucial part of detecting stress in users, communication with the user in a face to face conversation can give a vital insight into the mental state of the user. Biometric sensors detect every small change in body function. While this is very useful for capturing biofeedback data and evaluating this data, real-time visualization is bound to cause a negative feedback loop. There has to be a distinction in what biofeedback data to visualize and what biometric data to store for a later conversation with support of a trained physician.

Detecting differences in biometric data is dependent on many different factors, not only the mental state of the user. Gender, level of training, body fat and many other factors play into the captured data. While making general assumptions is still possible, making accurate assumptions about the mental state of the user is near to impossible without capturing a baseline to compare to. Capturing data alone is not enough to make accurate assumptions. Having no data to test the biometric data against makes the biometric data less useful. For measuring the effectiveness of a relaxation application, the key data cannot consist of biofeedback data itself. In combination with biofeedback data, survey data is very important. To match survey data with biofeedback data and to detect discrepancies between what participants feel and what the biometric sensor detects is critical to develop a system that helps the user learn how to relax in the best manner for their personal needs. Hence, generalizing relaxation for every user is not possible.

In addition, biofeedback data not only consists of changes in body function, but also

time stamps of when changes occur in the user's body. Time stamps provide useful data for comparing the perceived stress level with the recorded vital signs data sets. This allows physicians to evaluate the tested application to see if there were any interfering factors, and also provides insight into the user's different reaction patterns to certain events that occur within the virtual world.

In conclusion, developing a virtual reality relaxation application that utilizes biofeedback data to enhance relaxation effectiveness is presented to be a good way of integration. With further development and in combination with trained physicians, the collected biofeedback data can be accurately interpreted and this data will help users understand their own relaxation needs.

6.1 Future work

The evaluation of the biometric sensors in combination with a questionnaire is only the first step in testing the VR relaxation application. Further testing has to be done to evaluate if the application induces relaxation in its users. To get a better understanding of heart rate and biometric data sets, stratified random sampling for participants would be a very good idea. Differentiating participants in age groups will lead to a better understanding of how age affects the heart rate and the captured biometric data set. With biometric sensors capable of capturing data that is readable and reliable, a large-scale quantitative survey could be started. Capturing data from a large number of participants will lead to statistically relevant findings, which can be compared against surveys which have already been conducted. A date has already been set for evaluation of the captured biofeedback data with trained physicians.

Appendix A

CD-ROM/DVD Contents

A.1   PDF-Files

Path: /

ThieleThesis.pdf . . . .   Thesis PDF

A.2   Project-Files

Path: /

ProjectSources.zip . . .   *Unity3D* and *Visual Studio* Projects

A.3   Online-Sources

Path: /

OnlineSources.zip   . . .   Online Sources

A.4   Questionnaire

Path: /

Questionnaire.zip . . . .   Online Questionnaire

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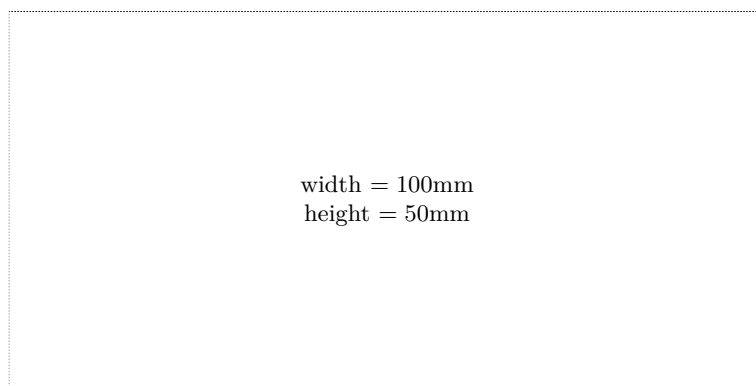
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