Self Observation & Inneraction

Two virtual reality installations based on participants' biofeedback

Diplomarbeit

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Fachhochschule St. Pölten, **Masterklasse Experimentelle Medien**

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Declaration

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Kurzfassung

Diese Arbeit beschäftigt sich mit neuen Möglichkeiten aufkommender Virtual Reality Technologien. Die Arbeit beschäftigt sich dabei vor allem mit interdisziplinären Methoden wie dem Gebrauch von Biofeedback basierend auf diversen Körpersignalen. Des Weiteren stellt diese Arbeit neue Möglichkeiten immersiver Medienkunst basierend auf aktuellen State-of-the-Art Praktiken.

Zwei interaktive Virtual Reality Installationen, *Self Observation* und *Inneraction*, basierend auf den Biofeedbackdaten der Teilnehmer wurden entwickelt und evaluiert.

Self Observation ist eine spiegelähnliche Installation die versucht, der Nutzerin oder dem Nutzer eigenen Körpervorgänge mithilfe des Biofeedbacks in Echtzeit leicht verständlich zu vermitteln.

Im Gegensatz dazu verwende Inneraction eine sehr ausdrucksstarke, experimentelle visuelle Sprache. Die entstandenen Visualisierungen basieren hauptsächlich auf den Biofeedbackdaten der Nutzerinnen und Nutzer.

Das Feedback der Teilnehmer für beide Installationen war positiv, speziell aber für die Installation *Self Observation.* Für besondere Aufmerksamkeit sorgte ein mit Körperschallwandlern ausgestatteter Stuhl der das Biofeedback der Teilnehmer als Vibrationen spürbar macht. Generell fühlten sich alle Teilnehmer schnell in der präsentierten virtuellen Umgebung wohl und begeisterten sich vor allem für die Visualisierungen basierend auf deren Biofeedbackdaten.

Abstract

This thesis aims at envisioning new possibilities of upcoming virtual reality technologies using the interdisciplinary approach of biofeedback sensing as well as introducing new ways of immersive new media art based on current state-of-the-art practices.

Two interactive installation, *Self Observation* and *Inneraction* based on participants' biofeedback have been developed and evaluated:

> *Self Observation* is a mirror like, quasi-educational installation representing audiences' participator's personal physiological processes of their body in an easily understandable way.
>
> *Inneraction* uses an expressive and experimental visual language, based on an algorithmic interaction between generative visualizations and sound entirely driven by the biofeedback data stream of the participant.

The opinion has been positive for both installations, and especially for *Self Observation*. The aspect that caught the attention of the audience the most has been the vibration of the audio reactive chair, considered as an innovative and interesting element. In general, participant felt easily familiar to the virtual environment and enjoyed controlling the animation through their bio inputs.

Table of Content

1 Introduction

This thesis aims at envisioning new possibilities of upcoming virtual reality technologies using the interdisciplinary approach of biofeedback sensing as well as introducing new ways of immersive new media art based on current state-of-the-art practices.

Therefore, this work is allocated in the subject areas of virtual reality, sensor development, signal processing, biofeedback and psychophysiology as well as media art, related to the contemporary artistic practices of new media and interactive arts.

Two interactive installation, *Self Observation* and *Inneraction* based on participants' biofeedback have been developed and evaluated:

> *Self Observation* is a mirror like, quasi-educational installation representing audiences' participator's personal physiological processes of their body in an easily understandable way.
>
> *Inneraction* uses an expressive and experimental visual language, based on an algorithmic interaction between generative visualizations and sound entirely driven by the biofeedback data stream of the participant.

Referring to the previous described proceeding, the research question is formulated as follows:

> How do biofeedback signals, experienced through a virtual reality environment, affect the user's personal perception and physiology in an educational and artistic context?

To answer the above-mentioned research questions, the resulting installations were presented to 20 students from the media department of the University of

Applied Science, St. Pölten. Each student experienced both installations (*Self Observation* and *Inneraction*) for five minutes each and filled in a questionnaire afterwards. The completed questionnaires were evaluated and discussed.

The structure of this work is characterized by two main parts, a theoretical fundament as well as an experimental part. The first part includes chapter 2 and 3. Chapter 2 gives an overview on fundamental physiology and biofeedback. Chapter 3 presents past and present state of the art practices using biofeedback technologies in new media, interactive art and virtual environments.

The experimental part of this thesis includes chapter 4, 5, 6 and 7. This part provides information about the process that lead to the experimental phase, the experiment itself. Chapter 4 gives an overview of the used hardware and software, explains the methods for data acquisition and illustrates the final setup for both installations, *Self Observation* and *Inneraction*. The auditory and visual displays of the Installations itself as well as the approach of signal processing are described in chapter 5.

Chapter 6 deals with the description of the experimental setup and the final results summing the feedback of participants completed questionnaires. Finally, the conclusion that can be drawn from this work are stated in chapter 8.

2 Theoretical background

This chapter gives a brief introduction in the terminology and history of *biofeedback* and its influences on Western medicine and body imaging, followed by recent and past state of the art biofeedback art installations and performances.

2.1 Biofeedback

The term *biofeedback* was first mentioned in 1969 at the inaugural meeting of the Biofeedback Research Society, Santa Monica, California, USA [1]. The term is used as a shorthand for processes involving external psychophysiological feedback, physiological feedback, and in some cases augmented proprioception. In their book, “Biofeedback: A practitioner’s guide”, Schwartz and Olsen (1995) suggest that clinical biofeedback’s emergence as a field is best understood as a convergence of several traditionally separate research areas:

- Instrumental conditioning of autonomic nervous functioning
- Psychophysiology
- Behaviour Therapy and Behavioural Medicine
- Stress research and stress-management methods
- Biomedical engineering
- Consciousness, altered states of consciousness and electro-encephalographic (EEG) feedback
- Cybernetics and
- Broader cultural factors including the popularization of eastern body-mind practices and the emergence of ‘preventative health’ and ‘wellness’ as public health and education issues.

Several researchers supported the validity of biofeedback training in the late 1960’s. John Basmajian demonstrated in 1967 that almost anyone could, with properly given biofeedback, gain control of a single motor unit of a muscle within a brief period of time. The first demonstration of humans’ learning to switch alpha brainwave rhythms on and off was given by Joe Kamiya.

As a process, applied biofeedback is a group of therapeutic procedures that utilizes electronic or electromechanical instruments to accurately measure, process and 'feed back' to persons information with reinforcing properties about their neuro-muscular and autonomic activity, both normal and abnormal, in the form of analogue or binary, auditory and/or visual feedback signals. Best achieved with a competent biofeedback professional, the objectives are to help persons develop greater awareness and voluntary control over their physiological processes that are otherwise outside awareness and/or under less voluntary control, by first controlling the external signal, and then with internal psychophysiological cues [1].

2.2 Electrocardiography (ECG)

While the cardiac impulse passes through the heart, electrical current spreads from the heart into the adjacent tissues surrounding it. A small amount of current spreads all the way to the surface of the body. The electrical potentials generated by the current can be recorded by placing electrodes on the skin on opposite sides of the heart. This recording is called electrocardiogram [2].

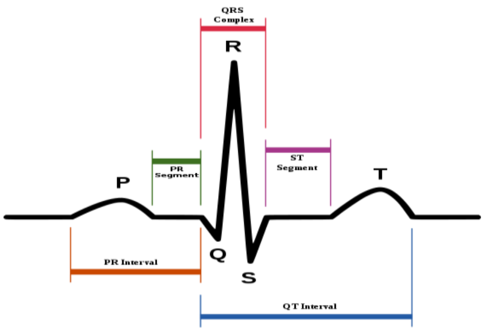

Figure 1: ECG of a usual heart beat [3]

Kommentiert [Office1]:

2.3 Electromyography (EMG)

Electromyography (EMG) is a method of studying the electric activity of muscles. The electromyogram, or EMG signal, is the electrical signal generated by contracting muscle fibres. It can be detected using electrodes placed on the skin surface above the muscle of interest, or with indwelling intramuscular or subcutaneous electrodes. The flow of current across the membrane produces an electric field that can be detected as a change in the electric potential or voltage at an electrode located in the surrounding tissue.

2.4 Electrodermal activity (EDA)

Electrodermal activity (EDA) is one of the most popular methods of measuring arousal, attention and orientation. It is present in fields such as psychology [4], emotion recognition [5] and psychophysiology [6]. It is defined measure of neutrally mediated effects on sweat gland permeability. It is observed as changes in the resistance of the skin to small electrical current, or as difference in the electrical potential between different parts of the skin. The EDA signal reflects the action of sympathetic nerve traffic on eccrine sweat glands [7].

Sympathetic neural activity in skin is closely correlated to changes in mental state. In constant conditions (temperature and rest state), EDA indexes change in attention and cognitive and emotional states of arousal [8].

Sympathetic skin response (SSR) can be recorded from palmar or plantar skin versus dorsal skin of hand of foot using AgAgCL-electrodes [9]. Figure 2 shows a typical electrodermal activity signal.

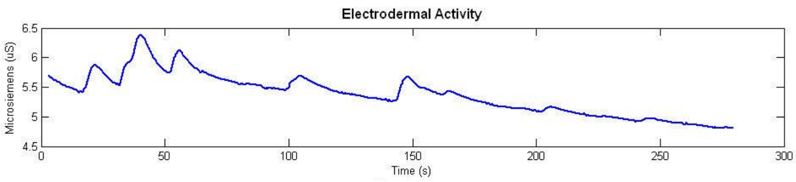

Figure 2: Electrodermal Activity signal

2.5 Electroencephalography (EEG)

The method of electroencephalography (EEG) represents moment-to-moment electrical activity of the brain, usually measured using electrodes on the scalp surface near the ear. It is produced by the summation of synaptic currents that arise on the dendrites and cell bodies of billions of cortical pyramidal cells that are primarily located a few centimetres below the scalp surface [10].

An EEG can be recoded using at least two electrodes which detect electrical potentials in a specific scalp region with respect to a reference electrode usually located in areas with low muscular activity. Nowadays EEG procedures use a variety of EEG helmets with up to 256 electrodes build into the helmet [10] [11]. Figure 3 shows a typical example of an EEG signal.

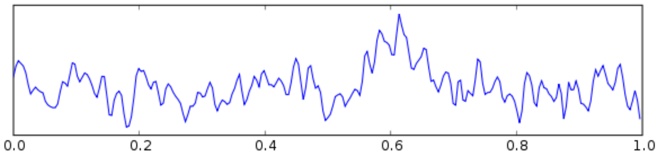

Figure 3: Typical raw EEG signal [12]

3 State of the Art

Music for Solo Performer (1964) by Alvin Lucier can be mentioned as the first artwork using biofeedback as a control source for live performances. In his performance, he was wearing a headband fitted with EEG electrodes to detect the performer's brainwave activity (alpha waves). The resulting brainwave patterns were used to resonate a collection of percussion instruments which have had speakers attached underneath or directly onto them. These live sounds were achieved by short bursts of pre-recoded and pitched-shifted brainwave material stopping and starting according to the alpha-frequency brainwave amplitudes [13]. Figure 4 shows Alvin Lucier performing his piece *Music for Solo Performer*.

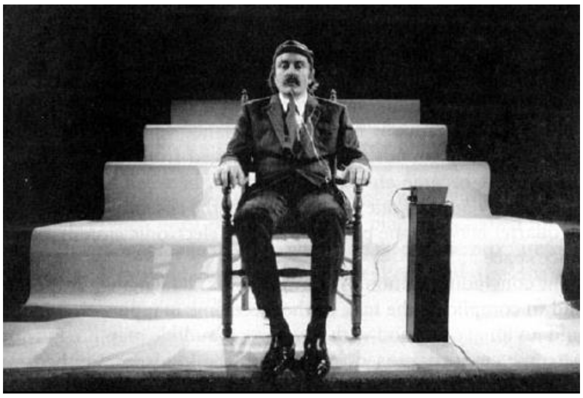

Figure 4 Alvin Lucier performing Music for Solo Performer. Photo by Phil Makanna (Lucier, 1976).

Alvin Lucier describes his approach to the development of *Music for Solo Performer* in the following Statement published in *David Rosenboom's* anthology "*Biofeedback and the Arts: Results of early experiments"*:

> From the beginning, I was determined to make a live performance work despite the delicate uncertainty of the equipment, difficult to handle even under controlled laboratory conditions. I realized the value of the EEG situation as a theatre element and knew from experience that live

> sounds are more interesting than taped ones. I was touched by the image of the immobile if not paralysed human being who, by merely changing states of visual attention, can activate a large configuration of communication equipment with what appears to be power from a spiritual realm. I found alpha's [brainwave-rhythm's] quiet thunder extremely beautiful and instead of spoiling it with processing, chose to use it as an active force in the same way one uses the power of a river [14]. (Lucier, 1976)

According to virtual reality, Charlotte Davies is one of the first artists that used biofeedback in a virtual environment. In her virtual world *Osmose* (1995) the participants' breath and balance are used to navigate through virtual scenarios: "*a boundless ocean abyss, shimmering swathes of opaque clouds, passing softly glowing dewdrops and translucent swarms of computer-generated insects, into the dense undergrowth of a dark forest" [15]*. Her work uses a tilt sensor for measuring the participants body position and a chest mounted strain gauge to measure changes in their breath rate. Figure 6 shows a participant wearing the breathing/balance interface vest [16] [15].

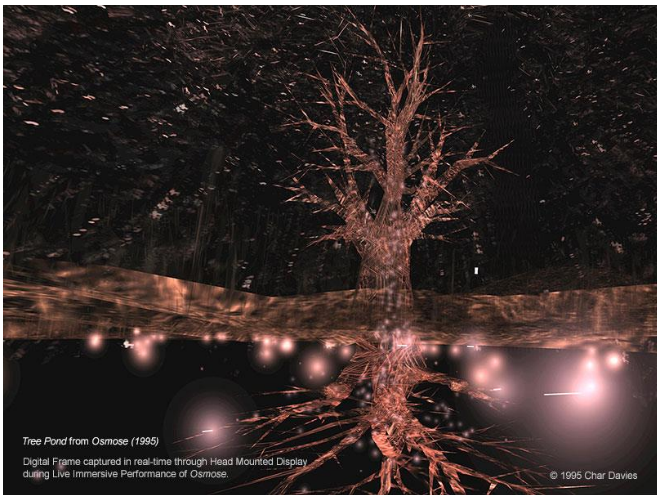

Figure 5. Tree Pond from Osmose (1995) – Digital frame captured in real-time through a head mounted display during a live immersive performance of Osmose

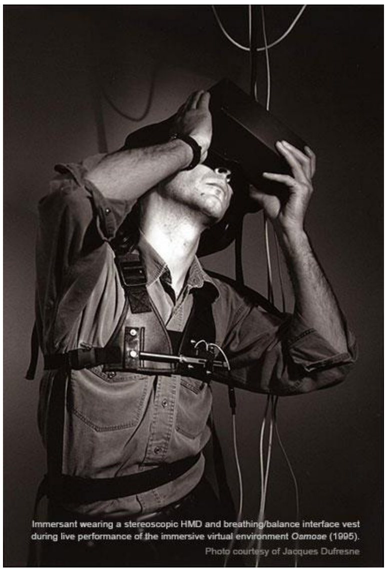

Figure 6. Immersant wearing a stereoscopic HMD and breathing/balance interface vest during live performance of the immersive virtual environment Osmose (1995).

George Poonkhin Khut, an artist and interaction-designer, describes in his doctoral exegesis the role of biofeedback in artworks focussing on self-experiences, such as self-sensing, self-moving, self-knowing. In his work, he focusses on immersive, meditative artworks based on individual’s heart rate and breathing [13].

4 Hardware and software implementation

In this chapter, hard- and software implementations will be described. In both interactive works the same hard- and software fundaments are used. Table 1 gives an overview on the used hard and software while the key part in hard- and software will be described in the following sections.

Table 1: Used hardware and software for both interactive, biofeedback installations (Self observation & Inneraction)

Hardware	Software
Oculus Rift CV1 by Oculus VR	BluetoothOCSBridge (self developed software)
BITalino Refolution Plugged Kit by Plux Wireless Biosignals S.A. (bluetooth microcontroller and sensors)	Derivative Touchdesigner 099
Renkforce MP-2000 PA power amplifier	
Reckhorn Limited Bass Shaker BS-200i	
Laptop – OMEN by HP – 17-w101ng	
OLYMP 3000 – Styling Chair	

4.1 Hardware

4.1.1 Oculus Rift CV1

Oculus Rift CV1 is the first commercially available head mounted display (or Virtual Reality (VR) Headset developed and manufactured by Oculus VR. It is a fully immersive providing 360° field of view as well as transcendent sound [17].

4.1.2 BITalino Revolution Kit

BITalino Revolution Kit, is a low/cost vital sign reading platform for prototyping and educational purposes. It provides sensors for sensing vital signs as EMG, ECG, EDA, EEG. The device transmits sensed bio signals via Bluetooth to a computer or another mobile device.

The following sections describe the used sensors for the installations in terms of technology and applications:

4.1.2.1 Breathing sensor

The breathing sensor is based on piezoelectric film technology provided with an elastic chest strap to secure it in placement. It is used for respiratory analysis in applications such as, thoracic or abdominal respiration analysis, respiratory cycles measurement or sleep studies. It is equipped with a localized sensing element measuring displacement variations induced by inhaling or exhaling [18].

Figure 7 shows *BITalino's* breathing sensor and an example of the use on the chest.

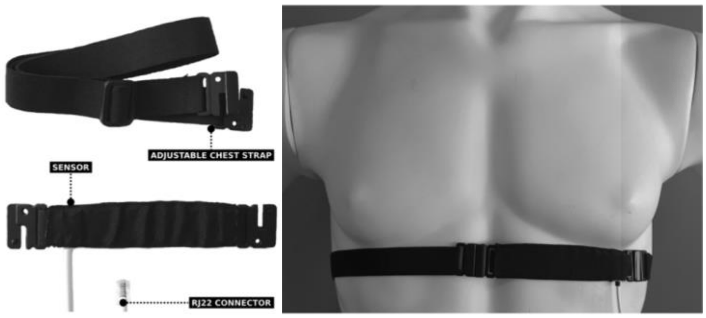

Figure 7: Breathing sensor (left), example of respiration sensor used on the chest (right) [18]

4.1.2.2 ECG sensor

BITalino's ECG sensor measures electrical potentials generated by the heart using three electrodes (positive, negative and reference). The sensor allows data acquisition on chest as well as on hand palms [19].

Figure 8 show an example of a two electrode placement (left) as well as an exmaple of three electrodes placement (right).

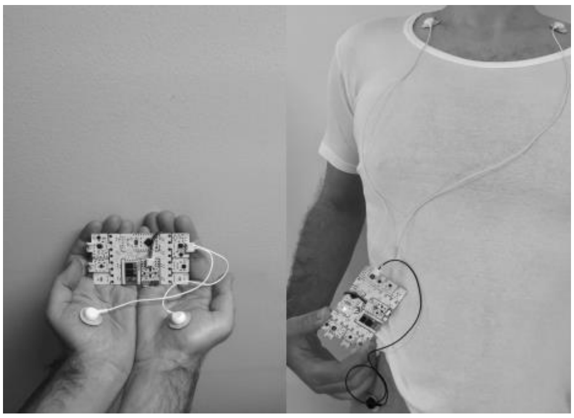

Figure 8: Example of a 2 electrodes placement at hand palms (left) and a 3 electrodes placement at the chest (right)

4.1.2.3 EMG sensor

Muscle activity is triggered by bioelectrical signals of very low amplitude sent from the motor control neurons on our brain to the muscle fibres. The sensor is designed for surface electromyography, which means it measures these bioelectrical signals on the surface of skin. It is equipped with three electrodes (positive, negative and reference), where the positive and negative electrodes should be placed on the muscle belly and while the reference electrode should be placed in a bone region. EMG signals can for example be used for physiology studies, robotics and cybernetics, biomechanics or muscle reflex studies [20].

Figure 9 shows the EMG sensor and its electrodes placed on the forearm. Positive and negative electrodes are placed approximately 20mm apart over the muscle belly while the reference electrode is placed on the elbow.

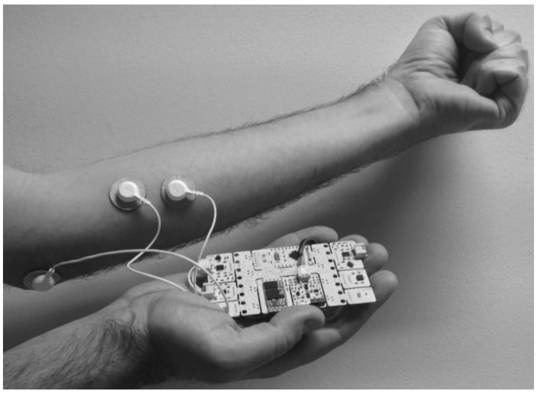

Figure 9: EMG sensor placed on the forearm [20]

4.1.2.4 EDA sensor

The EDA sensor measures skin resistance affected by sweat glands secretion which is associated to the sympathetic nervous system activity of the human body. Emotional arousal (e.g. nervousness) changes the resistance of the skin, especially on palms of hand and feed. The most common uses for EDA sensors are emotional mapping and the polygraph test (lie detector) [21].

Figure 10 shows the EDA sensor as well as the typical placement of positive and negative electrodes on the palm of the hand.

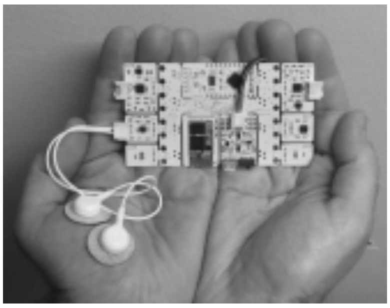

Figure 10: BITalino's EDA sensor and electrode placement [21]

4.1.3 Audio reactive chair

A vintage styling chair was modified by placing two 100W sound pressure transducers (Reckhorn Limited Bass Shakers BS200i) were mounted on the backrest of the chair. The aim of this modification was to apply vibrations in low frequencies through the chair to participants of the installation.

Figure 11 shows a photograph of the developed audio reactive chair including the two sound pressure transducers.

Figure 11: Audio reactive chair

4.2 Software

4.2.1 TouchDesigner 099

The entire application for the present installations was implemented using Derivative©'s visual, node-based development platform *TouchDesigner 099*. It can be defined as node-based programming language, which means that instead of opening text documents and typing lines of code, TouchDesigners's graphical interface is used to create application out of nodes (called Operators within the software) [22].

TouchDesigner is commonly used for real-time projects such as interactive 3D art, multi-screen interactive experiences, museum exhibitions, data visualisations, architectural projections as well as live visual performances and rapid-prototyping purposes [23].

4.3 Data acquisition and communication

Bio signals provided by BITalino Revolution was acquired using the API (application programming interface) provided by Plux© [24]. Using this API for Microsoft's Programming language *C#,* a simple command line application was developed in order to receive bio signals via Bluetooth from the microcontroller and communicate the signals to Derivative's TouchDesigner application where further signal processing is implemented.

The communication from the developed C# application to TouchDesigner is achieved via OSC (open sound protocol), a protocol for real time communication among computers, sound synthesizers and other media devices optimized for modern networking technology [25].

Listing 1: C# code for reading bio signals from BITalino via Bluetooth and transferring it via OSC to the TouchDesigner application

```
dev.read(frame);
Bitalino.Frame f = frame[0];
var message = new SharpOSC.OscMessage("/BITalinoTouchdesigner/",
                                       (Int32)f.analog[0],
                                       (Int32)f.analog[1],
                                       (Int32)f.analog[2],
                                       (Int32)f.analog[3]);
var sender = new SharpOSC.UDPSender("127.0.0.1", 1313);
sender.Send(message);
```

Listing 1 shows the essential code of the developed command line application. dev.read(frame) reads the Bluetooth stream and stores it in the Bitalino.Frame variable f, which includes all readings from the BITalino device. The readings of each frame (100 per second) are then sent via the *SharpOSC* (a weightleight OSC library for *„.NET 3.5*") [26] sent to the local network address 127.0.0.1 on port 1313 from which the OSC data stream can be accessed using TouchDesigner's OSC interface.

Figure 12 shows the acquired biosignals in the TouchDesigner environment. The raw real time signal can be seen on the right side in the following order:

- RED – respiration signal
- YELLOW – electrocardiography signal
- GREEN – electromyography signal
- BLUE – electrodermal activity signal

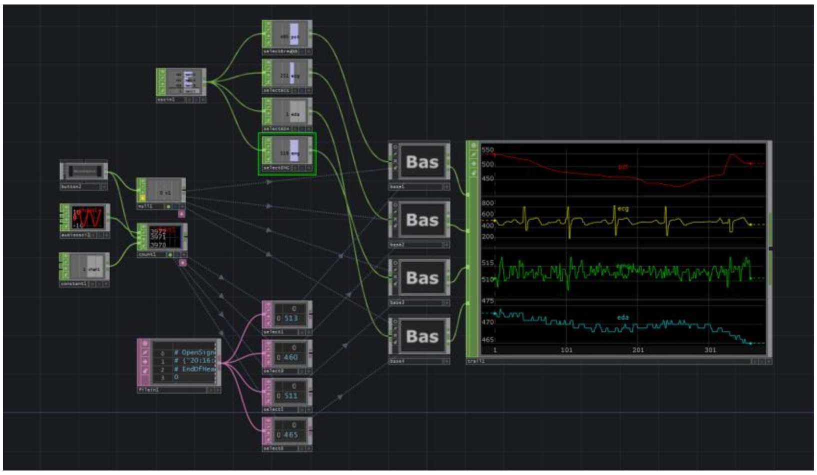

Figure 12: Acquired bio signals in the TouchDesigner environment using open sound protocol (OSC)

4.4 Final hardware and software setup

The flow-chart below, (Figure 13) shows the basic hardware and software setup for both interactive biofeedback installations, *Self Observation* and *Inneraction*. Light blue rectangles indicate used software while dark blue rectangles indicate hardware.

The origin point of each installation is the individual subject (yellow rectangle). Vital signs (breathing, ECG, EMG and EDA) of the individual are sensed using the *BITalino Revolution* microcontroller, which transmits the signal via Bluetooth connection to the computer. A simple program receives the Bluetooth signal and sends it via the OSC network protocol to the *TouchDesigner* application where the bio signals are processed and the visual as well as the sound representation are implemented.

Fehler! Verwenden Sie die Registerkarte 'Start', um Heading 1 dem Text zuzuweisen, der hier angezeigt werden soll. Fehler! Verwenden Sie die Registerkarte 'Start', um Heading 1 dem Text zuzuweisen, der hier angezeigt werden soll.

The audio feedback is separated into two parts in order to send them to two hardware destinations. One signal is sent to 100W sound-pressure transducers which cause vibrations on the audio reactive chair, while the second signal is sent to the to the headphones of the *Oculus Rift.*

The visual feedback is sent directly to the *Oculus Rift*, where it can be perceived by the individual participant.

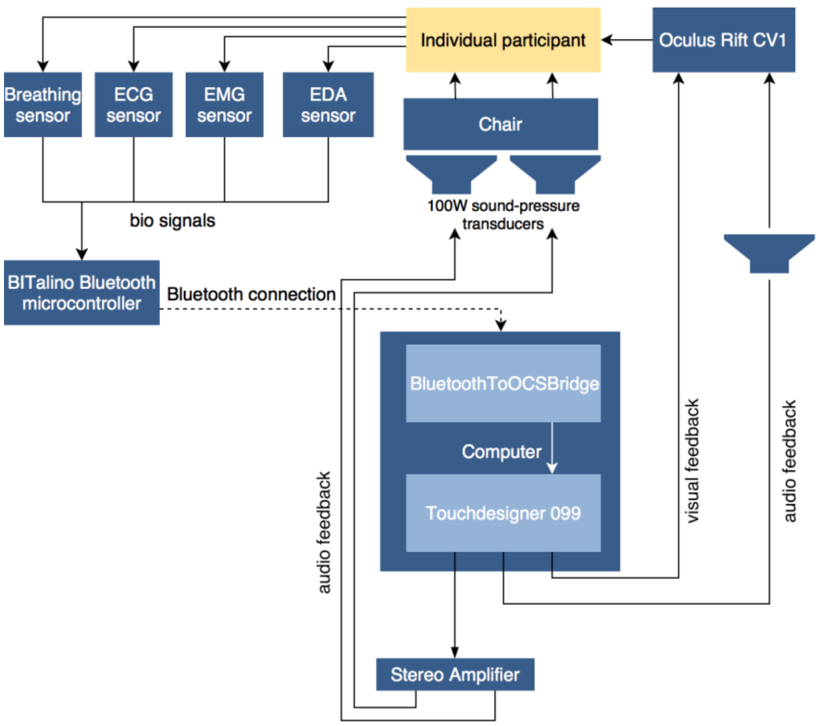

Figure 13: Data flow-chart for both installations – Self Observations & Inneraction

5 Installations

This chapter details the development of the two interactive virtual reality installations, *Self observation* and *Inneraction*. Both works are documented in terms of visual and audio design and sonification.

The fundament of both installations is, one hand the hardware and software stated in chapter 4, as well as participant's four essential bio signals:

- Breathing,
- Heart rate
- Muscle activity and
- Electrodermal activity

Even though the two above-mentioned installations have the same origin in vital signs, different approaches in terms of visual and auditory representation were chosen.

5.1 Self Observation

5.1.1 Introduction and aim

Self Observation is a mirror like, quasi-educational installation representing audiences' participator's personal physiological processes of their body in an easily understandable way.

Participants equipped *BITalino* sensors watch the own breathing, heart rate, muscle activity and their level of arousal in a fully immersive 3D environment. For each vital sign, 3D objects representing the corresponding organ were presented. Heart rate and breathing can be observed as due to realistic 3D objects of heart and lungs in real time.

While the animation of the heart contraction in the virtual environment was based on the ECG signal, the extensions of the lungs were originated from displacement variations of participant's chest induced by inhaling or exhaling. Muscle activity could be observed as simulation of flash lightings.

Figure 14 shows three rendering of Self Observation though the five-minute experience. The left rendering shows the representative 3D objects from a distant perspective during the first minute of the installation. The centred rendering illustrates the participant's vision from closer distance (during the second minute) while the right rendering demonstrates the field of view from the inside of the heart object (during the last minute). It can be seen that the participant's vision is slowly approaching towards the heart object. Once reached the inside of the heart, this marks the endpoint of the *Self Observation*.

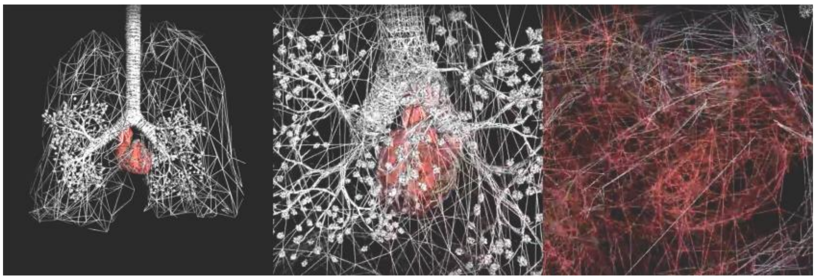

Figure 14: Self Observation renderings through time; left – first minute, middle – second minute, right – last minute

5.1.2 Biofeedback & audio-visual aesthetics

In the following subsections, each of the audiences' biofeedback signal will be discussed in terms of signal processing as well as approaches in the design of audio-visual feedback.

5.1.2.1 Heart rate

The heart can be seen as the core element in *Self Observation*. Therefore, it has the most prominent representation in this VR installation.

5.1.2.1.1 Visual representation and animation

The human heart is represented as a realistic, coloured, wireframe 3D object. The animation is based on the real-time ECG signal of the subject trying to simulate realistic contractions of the heart muscle. A flowchart describing the filtering process and can be seen in Figure 15.

Figure 15: Flowchart of heart's animation signal processing

The first step in terms of signal processing was the normalization to scale the signal from the original one. To achieve harmonic heart animations, the signal needed to be smoothed using a Gaussian filter. The amplitude of the smoothed signal had to be mathematically manipulated (e.g. by multiplication) in order to accomplish realistic heart animation in the right scale. Figure 16 shows the visualization of the heart (a), an extended heart (b) as well as the applied signal processing on the raw ECG signal (c, d, e) including the post processed signal applied for animation (e).

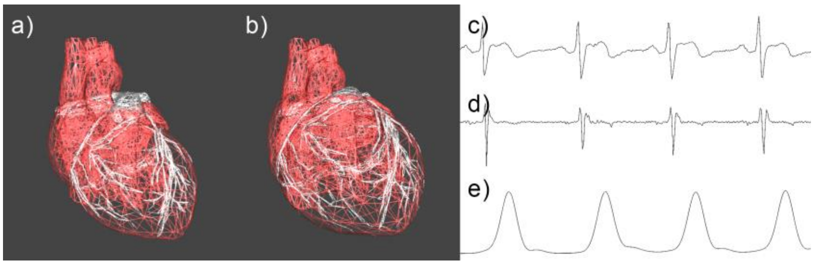

Figure 16: a) heart, b) extended heart, applied signal processing: c) raw signal, d) bandpass filtered signal, e) Gaussian filtered signal (= post processed signal)

5.1.2.1.2 Audio (and physical response)

The same importance given to the heart, in terms of visualization and animation, has been given to this organ in terms of audio and physical response. The ECG signal was processed in a similar was as for the animation with the difference of triggering an audio oscillator on low frequencies in a range from 5 to 15 Hz.

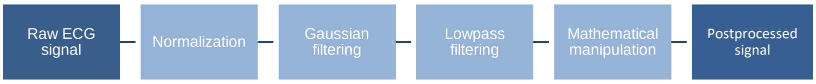

Figure 17: Flowchart of heart's audio signal processing

The signal was amplified and sent to the audio reactive chair mentioned in section 4.1.3. The two sound pressure transducers vibrate and transfer those vibrations to the chair and therefore giving physiological response to the subject as well as sound feedback caused by these vibrations. Using Oculus Rift's transcendent sound implementation, the caused vibration and sound feedback depends on the position of the head mounted display. Therefore, vibrations get stronger depending on participants' position in the virtual environment, e.g. stronger vibrations and sound when closer to the heart object and vice a versa.

5.1.2.2 Breathing

After the heart, the breathing is the second strong represented biofeedback signal.

5.1.2.2.1 Visual representation and animation

Breathing is represented as a white wireframe 3D object of human lungs in *Self Observation*.

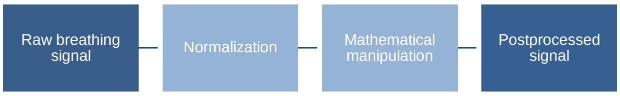

Figure 18: Flowchart of lung's animation signal processing

The raw breathing signal derived by the piezoelectric respiration sensor. The signal was normalized and mathematically manipulated to fit the extension of the lungs. Figure 19 shows the lungs object during exhaling (a) and inhaling (b) as well as the signal processing.

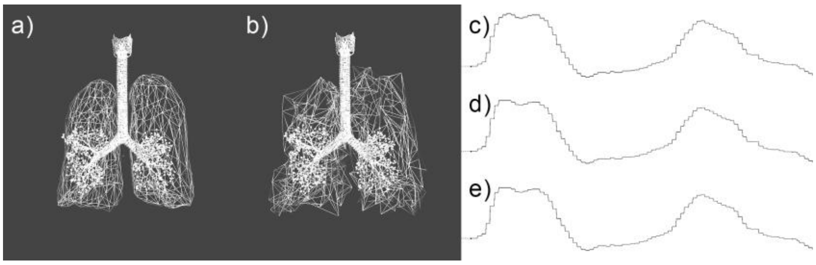

Figure 19: a) lungs, b) extended lungs, applied signal processing: c) raw signal, d) normalized signal, e) Gaussian filtered signal (= post processed signal)

5.1.2.2.2 Audio response

Lung's audio design was achieved in modulating the amplitude of a filtered noisy sound signal (white noise) depending on the extension of the elastic strap placed on the participant's chest.

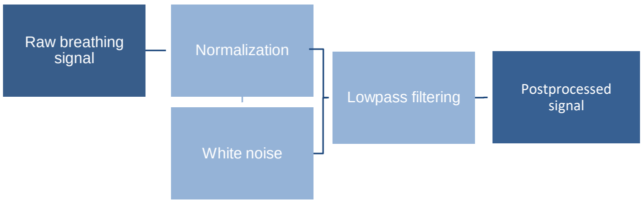

Figure 20: Flowchart of lung's audio signal processing

Figure 20 shows the steps of the audio signal processing for the lungs object. After normalizing the signal, it modulates the amplitude of generated white noise. A low-pass filter eliminates high frequencies to imitate the sound of flowing air.

5.1.2.3 Muscle activity

The bio signal for muscle activity is sensed on the participant's biceps. Lightning bolts represent the muscular activity in the virtual environment.

5.1.2.3.1 Visual representation and animation

The raw signal, depending on the muscle activity was normalized, and mathematically manipulated. To trigger the lightning bolts' animations, a threshold was set. If the EMG signal reaches this threshold (during muscle tension), lightning animations start and end as soon as the derived signal decreases. Figure 21 shows the signal processing for the above described procedure while Figure 22 shows a rendering of a resulting lightning animation and the characteristics of the processed muscle activity signal.

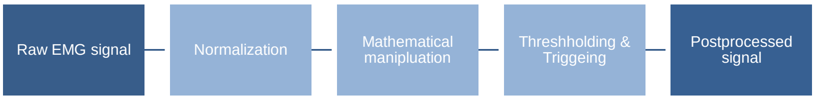

Figure 21: Flowchart of muscles' animation signal processing

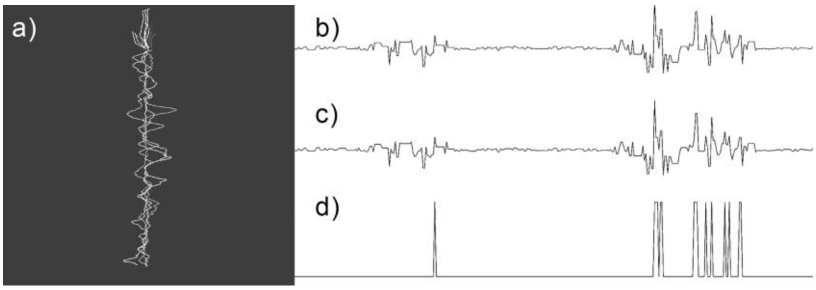

Figure 22: a) lightning animation, applied signal processing: b) raw signal, c) normalized signal, d) “triggering” signal (= post processed signal)

5.1.2.4 Electrodermal activity (EDA)

In contrast to the other mentioned vital signs, Electrodermal activity is a changing very slowly. Therefore, a different approach in manipulating participants’ entire field of view is used.

5.1.2.4.1 Visual aesthetics

Electrodermal activity was visualized using render effects. A rise in the EDA feedback affected changes in the participant’s vision. Therefore, a Gaussian blur filter was applied on the rendering shown in the Oculus Rift.

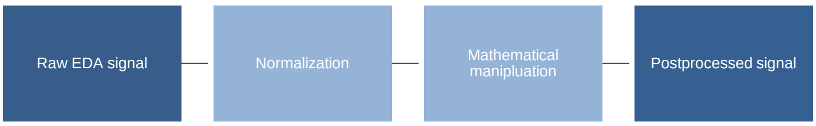

Figure 23: Flowchart of EDA animation signal processing

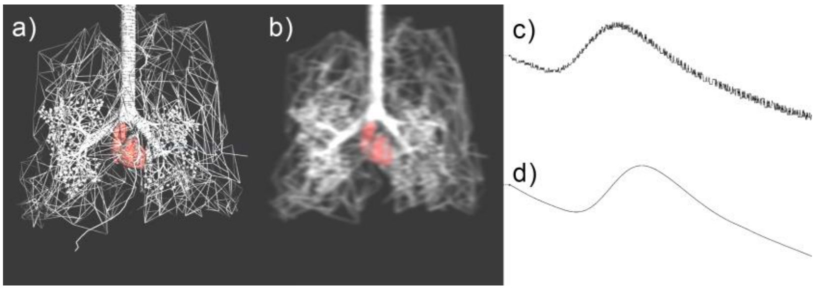

Figure 24: a) normal vision, b) blurred vision: c) raw signal, d) normalized and filtered EDA signal (= post processed signal)

5.2 Inneraction

As mentioned earlier, *Inneraction* uses the same biofeedback signals as *Self Observation,* although the concept differs significantly.

5.2.1 Introduction and aim

Inneraction uses an expressive and experimental visual language, based on an algorithmic interaction between generative visualizations and sound entirely driven by the biofeedback data stream of the participant. After the first minute of the five minutes long experience, a certain "intense event" in the visual and auditory display occurs. This event, is the initial moment where biofeedback signals are interacting and manipulating each other.

While biofeedback signals were well separated in *Self Observation*, *Interaction*'s aim was to slowly fuse the perceived biofeedback signals as time passes, especially after the above mentioned "intense event". This approach was inspired by the natural interaction of physiological processes in the human body.

The flowchart illustrated in Figure 25 shows the above-mentioned process of the interaction and manipulation of biofeedback signals among each other. As in *Self Observation* the origin of this installation is based on the four biofeedback inputs (Breathing, ECG, EMG and EDA). Within the first minute, each 3D object (waves, spheres and particles) is manipulated based on one biofeedback signal. Those manipulations of the objects can include changes in appearance and shape as well as changes in colour and light.

The full lines from the biofeedback signals to the 3D objects indicate their mapping within the first minute while the dashed lines show their additional influence starting from the earlier mentioned "intense" event. This procedure should be stated in a short example:

Within the first minute, the sphere is based on only one biofeedback signal, namely the ECG signal. After the "intense event", the breathing signal influences the signal derived by the sphere changing the amplitude.

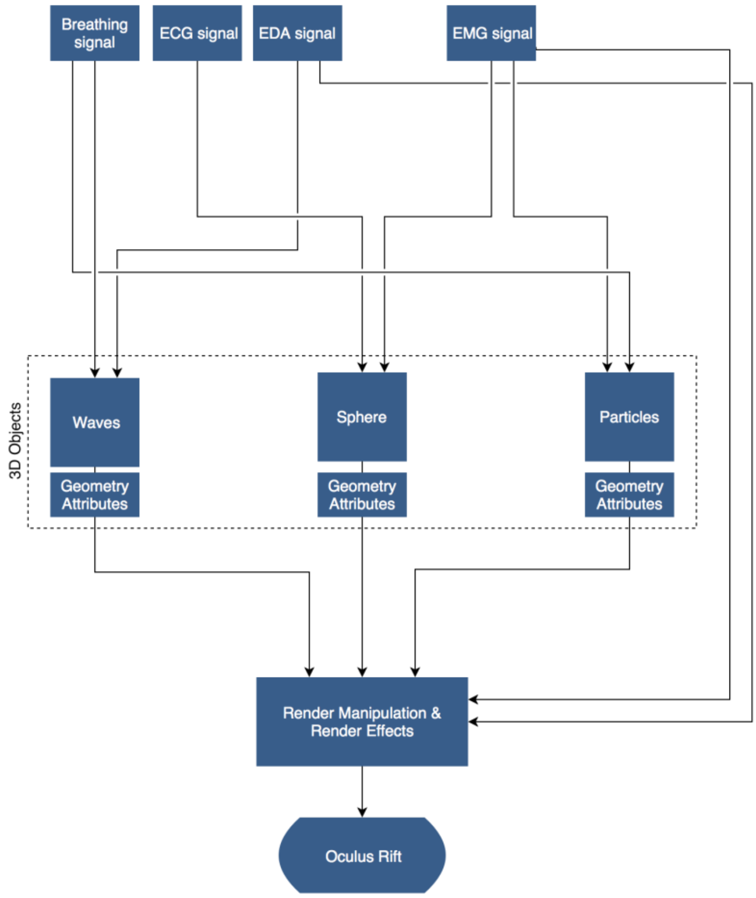

Figure 25: Inneraction - signal mapping flow chart

Due to the reason of the influences within the biofeedback signals, the following subsections will not describe processes of the visual and auditory display of each element within *Inneraction*. Instead some key aspects of this installation will be mentioned in more detail.

6 Testing & Evaluation Results

6.1 Experimental setup

The project was presented at the St. Pölten University of Applied Science to 20 students of the faculty of media technologies. The audience is, therefore, generally aware of the VR technology and its operation. Each student experienced both installations (*Self Observation* and *Inneraction*) for five minutes each and filled in a questionnaire afterwards. Participants were requested to be seated in the audio reactive chair (see 4.1.3) and to place the required, self-gelled, Ag/AgCl electrodes of the sensors as instructed. The following list describes the instructed placement of used electrodes and sensors:

- **ECG electrodes**
  - Positive electrode: under right "clavicular (under the right collar bone);
  - Negative electrode: under left "musculus pectoralis major" (under left pectoral muscle);
  - Reference electrode: under left clavicular (under the left collar bone).
- **Respiration chest strap**
  - The chest strap of the respiration sensor was placed on the thorax of the individuals.
- **EMG electrodes**
  - Positive and negative electrodes were placed on the muscle belly of the biceps (aligned with the muscle fibers) while the reference electrode was placed on the bone on the elbow.
- **EDA electrodes**
  - The positive electrode was placed on the index finger while the negative electrode was placed on the middle finger.

The questionnaire has been designed to have a feedback from the audience about the experience and suggestion for further developments. The structure of the questionnaire includes four sections: demographic information, questions regarding to the *Self Observation mode*, question regarding *Inneraction* mode and final considerations. Questions require different sorts of answers:

- Rating on a scale from 1 to 5, where 1 corresponds to a low agreement to the statement and 5 to a high agreement;
- Positive or negative feedback, namely "YES" or "NO";
- Open answers or short comments.

Moreover, talking to the participants allowed a better understanding of their feedback and their comments. For the questions 13-16 and 27-30, which require an open answer, the most common responses have been listed, as well as the feedback received talking to the participants after their experience.

6.2 General questions

Table 2: Evaluation of general questions and demgraphic data

1) Gender	**Female**				**Male**		
	7				13		
2) Age [years]	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Number of answers	2	1	5	7	1	1	2
Mean [years]	23.05						
Standard deviation [years]	1.99						

3) It was my first experience with VR applications.	**Yes**			**No**	
Number of answers	4			16	
4) I got easily familiar with the virtual environment. [rating]	1	2	3	4	5

Number of answers	0	0	2	6	12
Mean [rating]	4.5				
Standard deviation [rating]	0.69				

6.3 Self Observation

Table 3: Evaluation of Self Observation

5) I like how the visualizations look like.	1	2	3	4	5
Number of answers	1	1	4	5	9
Mean [rating]	4				
Standard deviation [rating]	1.17				
6) I felt the changes in my heartbeat reflected the changes in the heart animation. [rating]	1	2	3	4	5
Number of answers	0	0	4	8	8
Mean [rating]	4.2				
Standard deviation [rating]	0.77				
7) I felt the changes in my respiratory rhythm (intensity, frequency) reflected the changes in the lungs animation. [rating]	1	2	3	4	5
Number of answers	0	0	4	8	8
Mean [rating]	4.2				
Standard deviation [rating]	0.77				

8) I felt the changes in my muscular activity provoked changes in the animation. [rating]	1	2	3	4	5
Number of answers	0	2	3	5	10
Mean [rating]	4.15				
Standard deviation [rating]	1.04				

9) I felt my biofeedback affected the perceived sounds. [rating]	1	2	3	4	5
Number of answers	0	2	5	6	7
Mean [rating]	3.9				
Standard deviation [rating]	1.02				
10) I felt easy to control the visualizations depending on my bio inputs. [rating]	**1**	**2**	**3**	**4**	**5**
Number of answers	0	1	4	7	8
Mean [rating]	4.1				
Standard deviation [rating]	0.91				
11) I enjoyed using the application. [rating]	**1**	**2**	**3**	**4**	**5**
Number of answers	1	2	5	5	7
Mean [rating]	3.75				
Standard deviation [rating]	1.21				

12) It was disturbing/stressful to use the application. [rating]	**1**	**2**	**3**	**4**	**5**
Number of answers	2	7	6	4	1
Mean [rating]	2.75				
Standard deviation [rating]	1.07				

13) **What was the most interesting aspect of your experience?**

The majority of participants stated the ability of observing their own physiological processes as the most interesting aspect of their experience. Furthermore, most participants enjoyed the physical feedback of the audio reactive chair.

Four participants documented interesting changes in the heart animation as well as stronger sound when they contracted muscles to trigger animations for the EMG biofeedback.

14) **What connections between your body and the sound and/or visuals did you find most interesting?**

The chair vibrations generated based on the ECG biofeedback signal was the most interesting aspect for participants. They reported similarities to massage chairs.

Several (three) individuals mentioned that the sound triggered by their breathing was relaxing.

Two participants stated that they found interesting in the animation of the lungs object while they were holding their breath.

15) Were there any aspects you did not enjoy about the application? If yes, which aspects did you not enjoy?

Yes	No
4	16

Four over 20 participants mentioned that they did not enjoy some aspects of the installation. Two stated that the increasing vibrations of the chair as well as the increasing sound during the final minute of the installation was too intense.

Other two participants mentioned that the animation and sound of the lungs were delayed and not synchronised with their actual breathing.

16) Do you have any suggestions for how this work might be developed further in the future?

Ten out of 20 participants explained that they expected a better representation of the EDA biofeedback or they did not realise changes depending on that signal.

Sound representation for the EMG biofeedback as well as for the EDA signal was suggested for further future developments.

6.4 Inneraction

Table 4: Evaluation of Inneraction

17) I like how the visualizations look like. [rating]	1	2	3	4	5
Number of answers	2	3	6	7	2
Mean [rating]	3.2				
Standard deviation [rating]	1.15				
18) I felt the changes in my heartbeat reflected the changes in the heart animation. [rating]	1	2	3	4	5
Number of answers	2	3	6	6	3
Mean [rating]	3.25				
Standard deviation [rating]	1.21				
19) I felt the changes in my respiratory rhythm (intensity, frequency) reflected the changes in the lungs animation. [rating]	1	2	3	4	5
Number of answers	2	3	6	6	3
Mean [rating]	3.25				
Standard deviation [rating]	1.21				
20) I felt the changes in my muscular activity provoked changes in the animation. [rating]	1	2	3	4	5
Number of answers	6	5	5	3	1
Mean [rating]	2.4				
Standard deviation [rating]	1.23				

21) I felt my biofeedback affected the perceived sounds. [rating]	1	2	3	4	5
Number of answers	3	3	6	5	3
Mean [rating]	3.1				
Standard deviation [rating]	1.29				
22) I felt easy to control the visualizations depending on my bio inputs. [rating]	**1**	**2**	**3**	**4**	**5**
Number of answers	1	2	8	5	4
Mean [rating]	3.45				
Standard deviation [rating]	1.10				
23) I enjoyed using the application. [rating]	**1**	**2**	**3**	**4**	**5**
Number of answers	1	2	5	5	7
Mean [rating]	3.75				
Standard deviation [rating]	1.21				

24) What was the most interesting aspect of your experience?

As in *Self Observation* the majority stated the, participants found it the generative visualizations driven by the biofeedback data stream the most interesting.

The majority of participants found it interesting to see visualizations of slightly different content for the left and the right eye.

The “intense event” of “frightening” was stated as most prominent experience from six individuals.

25) What connections between your body and the sound and visuals did you find most interesting?

As in question 28, participants state the different visualizations as most interesting aspect. The majority enjoyed the visualization of the sphere depending on the Breathing, ECG and EMG biofeedback data stream.

17) Were there any aspects you did not enjoy about the application? If yes, which aspects did you not enjoy?

Yes	No
7	14

Seven over twenty participants mentioned, that they did not enjoy some aspects of the installation. Two stated that the increasing vibrations of the chair as well as the increasing sound during the final minute of the installation was too intense. (= same answer as for *Self Observation*)

Four individuals described some visualizations as stressful in contrast to the approach in *Self Observation*.

26) Do you have any suggestions for how this work might be developed further in the future?

The majority of participants mentioned improvements of sounds, specially in smoother changes.

Nine individuals suggested to transfer the installations in an audio-visual performance.

6.5 Final considerations

Table 5: Evaluation of final considerations.

27) This experience helped me to better understand my physiology. [rating]	**1**	**2**	**3**	**4**	5
Number of answers	2	3	6	7	**2**
Mean [rating]	3.2				
Standard deviation [rating]	1.15				
28) I felt my body involved in the virtual environment. [rating]	1	2	3	4	**5**
Number of answers	2	3	6	6	**3**
Mean [rating]	3.25				
Standard deviation [rating]	1.21				
29) This application can be a tool to incorporate biofeedback, art and virtual reality environments. [rating]	1	2	3	4	**5**
Number of answers	2	3	6	6	**3**
Mean [rating]	3.25				
Standard deviation [rating]	1.21				

7 Discussion

This chapter discusses the key findings of the feedback given by the twenty participants after their experiences in both installations, *Self Observation* and *Inneraction*.

7.1 Self Observation

The majority of participants gave generally positive feedback on the visual representations. They felt easily familiar with the environment and enjoyed interacting with their biofeedback signals. Participants could understand easily the connection of their biofeedback and the perceived animations and sounds. That aspect lead to a high level of awareness regarding how to experience changes in their bodies within the virtual environment.

The vibrations of the audio reactive chair were generally stated as the most interesting aspect, which makes it the key element of both installations. This could result from bringing physical feedback “inside” a virtual environment which probably result in a higher level of immersion.

Negative feedback was given by four individuals due to delayed animations of the lungs object as well as a too high intensity of vibrations. In regarding to delayed lungs animation, this is a result of limitations of the chest-strap sensor. The subjective feeling of breathing and the sensed expansion of the chest can differ from each other. Additionally, signal processing, especially filters can cause a slight delay between the extension of the participant’s chest and the animation. Too intense vibrations could be solved by implementing a way to manually lower the intensity, e.g. implementing a button on the arm rest which lowers the amplitude of perceived vibrations.

7.2 Inneraction

The feedback given on *Inneraction* was generally not as positive as the feedback on *Self Observation*. This could result due to the better understanding of participants' biofeedback signals. While within Self Observation, the biofeedback signals were well separated and mapped to single 3D objects and sounds, the influences of biofeedback among each other seemed to cause the deliberately provoked confusion.

The visualisation of slightly different content for the left and the right eye initiated by the "intense" event of "frightening" was mentioned as the most interesting aspect during participants' experience. The majority found this aspect interesting due to the reason that they could not really understand what triggers those events.

Nevertheless, it is a difficult task to exactly evaluate the perception of each individual and therefore it is challenging to draw conclusion on subjective perceptions.

The most positively mentioned visualisation was the 3D object of the sphere based on ECG, breathing and EMG signal. This possibly resulted in the easier understanding of EMG and breathing biofeedback signals, which can be more actively triggered.

Negative feedback given by seven individuals focussed on the deliberately provoked confusion. Four participants described the achieved visualizations as stressful, especially in contrast to *Self Observation*.

Suggestions made for *Inneraction* mostly focus on the perceived audio due to smoother changes in the audio layer. This resulted from limitations in the used software *Touchdesigner 099*. For future project an additional use of software tools should be considered regarding to audio design and audio processing. Furthermore, it should be considered to transform *Inneraction* additionally in a audio-visual performance context.

8 Conclusion

Two interactive virtual reality installations, *Self Observation* and *Inneraction*, based on participants' biofeedback signal were developed and evaluated. The aim of these installations was to enable individuals to reflect and observe their own physiologies using the technology of biofeedback interaction.

The installations have been presented to 20 individuals for five minutes each. Each participant filled in a questionnaire after the experience, giving feedback and comments.

The opinion has been positive for both installations, and especially for *Self observation*. The aspect that caught the attention of the audience the most has been the vibration of the audio reactive chair, considered as an innovative and interesting element. In general, participant felt easily familiar to the virtual environment and enjoyed controlling the animation through their bio inputs.

Negative feedbacks have been collected especially in regarding to some animations, considered stressful. Additionally, the sound and the reaction of some visuals were perceived by the audience as delayed and that was due to and- and software limitations.

The development of this work might go, therefore, in the direction of the improvement of the sound design, by using an alternative and additional software dedicated to this purpose, and reviewing the design of some animations. Moreover, a performance context could be also considered for this work.

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Appendix

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