HEARTSPACE VR

A practise-led research project
exploring the creative application of
VIRTUAL REALITY
in conjunction with
BIOFEEDBACK

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Statement of Authorship

This is to certify that this paper has not been previously submitted for a degree or diploma in any university. To the best of my knowledge and belief, the exegesis contains no material previously published or written by another person except where due reference is made in the work itself. This exegesis has received professional editing services.

Signed ……………………………………………………………

Nina Rath – S5074978

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Abstract

This exegesis concerns itself with the development of a Virtual Reality (VR) experience designed for composure and wellbeing enhanced by the modalities of biofeedback. First, it provides a brief introduction into the underlying principles of VR and biofeedback and illustrates existing biofeedback VR applications (initial and contemporary, Clinical and non-Clinical, immersive and non-immersive) and their various forms of aesthetic and conceptual expression. Then it describes the process of creating an immersive biofeedback VR prototype with an existent biofeedback device focusing on the heart measurements to provide feedback of the user's heart activity via audio-visual stimuli in near real-time in VR. The research has found that technological conditions of VR hardware, software and biofeedback devices highly influence the process of imagining and creating new art practice paradigms. Aesthetic and conceptual VR approaches in conjunction with biofeedback can provide a far-reaching and complex research domain for a contemporary screen practitioner to demonstrate the close links between physical condition, mental activity, emotion and variations in heart rate with the instruments of immersive media.

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1. Introduction

Immersive Virtual Reality (VR) transports an individual into a multisensory, three-dimensional environment viewed through a Head Mounted Display (HMD). At the onset of Virtual Reality in the 1970s, devices and experiences were mainly developed in medicine, aviation, flight simulation, automobile design and the military (Grau, 2003). Since the mid-1990s, scientific research has emerged around the concept of Clinical Virtual Reality to utilize VR as a therapeutic tool across a wide range of clinical health conditions (Anderson et al., 2001). In this context, VR has been applied diversely in the treatment of:

- specific phobias (Garcia-Palacios et al., 2002, 983-93),
- post-traumatic stress disorder (Rizzo and Shilling, 2018),
- anxiety and depression (Zeng et al., 2018),
- acute pain reduction during wound care and medical procedures (Hoffmann et al., 2011),
- improvement of body image disturbances of people with eating disorders (Keizer et al., 2016),
- reduction of discomfort during cancer treatment (Chirico et al., 2016),
- physical rehabilitation (Kallmann et al., 2015)
- and the treatment of other cognitive functions (e.g., improvement of memory, attention span, spatial awareness, etc.).

Deepak Chopra, a world-renowned speaker and pioneer in the field of mind-body healing, argues, "In a few years, this [VR] will replace traditional pharmaceuticals. You go to a doctor, he will tell you to go for a VR session." (HTLS, 2016)

Today, there is also an increasing quantity of VR applications focusing on relaxation, wellbeing and mindfulness-based stress reduction for Clinical and non-Clinical purposes. These apps can either be used with a trained clinician or autonomously at home. Some of these applications incorporate biofeedback into the VR experience. Biofeedback is a process using electronic monitoring of a normally automatic bodily function (e.g., skin temperature, muscle tension, brainwave function, heart rate) to train someone to acquire voluntary control of that function. Therefore, biofeedback rapidly ‘feeds back’ information to the user about his or her physiological conditions. The visualisation of this information can support these conditions' self-regulation and lead to sought changes in thinking, emotions, and behaviour. Over time, these changes can endure without continued use of biofeedback instruments.

The central question addressed in this exegesis is how Virtual Reality can be applied from an aesthetical and conceptual perspective for stress-reduction, composure, and wellbeing supported by biofeedback modalities. The research has identified an existing biofeedback device from the Institute of HeartMath (HeartMath, 2018) currently used by more than twenty-five thousand healthcare practitioners in over one hundreds counties. Yet there is no immersive Virtual Reality experience designed to illustrate the recorded data artistically so far. There are currently only two-dimensional applications such as games and animations for users to experience via laptop or computer screen interaction. Therefore, this project aims to fill the gap by creating a prototype of an immersive biofeedback VR experience using the emWave Pro device. The practice of this exegesis was only concerned with the development of this prototype - named *HeartSpace VR* - and issue-related scientific research. The effects of this application on the user has not been investigated as part of this exegesis.

HeartSpace VR illustrates a journey through outer space towards a heart-shaped star. To navigate towards that star, the participant has to influence the signals emitting from the heart using breath control to move through space. The user-interface utilises a headset (head-mounted display) and a biofeedback sensor attached to the participant's earlobe to record signals from the heart (e.g. heart rate, heart-rate- variability, coherence) and integrate this data into an immersive VR environment in near real-time. These signals then influence the imagery and soundscape of the VR experience. The more the participant is able to attain a state of inner ease and composure, the more the virtual environment reacts.

In addition to building this prototype, the research investigated artistic visualisation techniques of early and contemporary biofeedback VR applications to gain a deeper understanding of interactive VR aesthetics. Contemporary examples of Clinical (e.g., The Virtual Meditative Walk(2015)) and Non-Clinical (e.g., Unyte, 2018), immersive (e.g., STRATA, 2017) and non-immersive (e.g., Portals of Care Visualiser, 2017) biofeedback VR experiences have been outlined to contextualize the presented work within the existent body of research.

Conclusively, the exegesis describes the practitioner's journey of creating the final artwork and reveals the project's technological, experiential, and conceptual outline. The research has found that biofeedback VR experiences can provide an intuitive approach for visualising and understanding complex forms of physiological data in ways that leave room for personal interpretation and curiosity. They provide an experiential space for embodied enquiry and aesthetically engaging self-exploration. However, reading from the literature (Khut, 2006, 190) indicated the underlying concepts of heart-based biofeedback could, in some cases, be too confusing for the participant (i.e., 'what is heart rate variability?' and 'what does this tell me about the state of my body and my mind?). Therefore, a comprehensible implementation of biofeedback in Virtual Reality provides a highly complex learning ground for a contemporary screen practitioner and visual artist to create a VR experience for composure and wellbeing with immersive media instruments.

2. Methodology

The main methodology used in developing this practice-led research and its related body of works refers to a broad spectrum of conversations, methods, contexts and practices. Graeme Sullivan has defined this approach as *Visual Arts Knowing* in his publication *Art Practice as Research* and introduced it to distinguish between creative arts research and qualitative research. "Artists emphasize the role of the imaginative intellect in creating, criticising, and constructing knowledge that not only is new but also can transform human understanding." (Sullivan, 1951. 2010) Graeme Sullivan characterises this procedure of *Visual Arts Knowing* as a braid-like structure in which a variety of tightly bundled strands are continuously unravelled, critically sorted and re-braided. Through this process, new 'ropes' of creative practice and analysis are woven together from existing discourse, application, examination and critique (ibid).

Furthermore, the methodology has been informed by the work of Donald A. Schön and his publication *Reflective Practitioner: How Professionals Think in Action* (Schön, 1995;2017). Instead of working through a predetermined set of assertions, this approach investigates how 'reflection-in-action' works and how this procedure is a vital part of creativity relying less on pre-existent formulas and assumptions than on the kind of improvisation learned in practice (ibid).

The practical part of this exegesis involved developing a biofeedback VR experience named *HeartSpace VR* and issue-related scientific research. The effects of *HeartSpace VR* on the user have not been researched as part of this project. The practice was only concerned with building a prototype. However, *HeartSapce VR* has been presented and tested by 15 people as part of the Master Show Case at Griffith Film School, on Sunday, October 28, 2018.

Limitation of this research: The integration of this biofeedback device in this practice-led exegesis is not intended to diagnose, treat, cure, or prevent any disease. It is neither used as a medical tool in this context, nor should it be considered a medical instrument in assessing this exegesis. It is exclusively applied as a tool for art practice and research.

3. Background and Personal Motivation

Parallel to my studies at Griffith Film School, I worked for Immerse Enterprise; a Virtual Reality, Augmented Reality and 360° Imagery company, owned by Lex Van Cooten (Immerse Enterprise, 2018). I was employed as the director's assistant and learned a lot about the business-side of VR. I mainly worked in administration, marketing and strategic planning. I also produced 360° image films for the company but no VR content at that time. We mainly collaborated with companies, governmental and educational institutions, NGOs and Non-for-Profit organisations.

During that time, I lived in a Hinduism-based Yoga monastery with two monks to learn about the effects of Yoga, meditation and mindfulness on the body and the mind. The monastery offered daily classes for Yoga and Meditation to the public, and I could see the positive effects on others and myself. Regularly, people told me, through this practice, they experienced a significant increase in the ability to focus, make decisions, feel more positive and maintain a state of inner ease and calmness, even while exposed to stressful or challenging life situations. Since I observed these effects within myself as well, I wondered how I could bring ancient mindfulness-based practises and Virtual Reality together for the purpose of composure and wellbeing.

Before coming to Australia to do my studies in film, I also participated in Biofeedback training (Biocybernaut Institute, 2018). In this training, I sat in a dark chamber for 3-4 hours each day for 7 consecutive days and listened to my own brainwaves in the form of musical sounds. I had eight electrodes attached to my skull, recording the different parts of my brain's electrical signals. These signals were analysed and amplified by a computer program and fed back to me in the form of sounds in real-time. This training aimed to learn how to increase alpha-brainwave activity. Alpha waves are neural oscillations in the frequency range of 7.5–12.5 Hz (Gerrard and Malcolm, 2007, 349-64) and are associated with meditative states. By getting a musical feedback-loop about these alpha brainwaves' occurrence in my own brain in real-time, I could learn how to optimise my meditation practices in a very rapid way. If there was more alpha activity in the brain, the sounds became louder. If there was less alpha activity, the sounds became quieter.

To explain all the insights and revelations I gathered throughout this training would go beyond this exegesis's scope. Still, in essence, I became extremely intrigued by the idea of creating a self-reflective Virtual Reality experience in which people could observe visual content informed by the condition of their bodies. Throughout the course of my exegesis, I discovered a form of biofeedback not focusing on measuring brain activity but on the heart's activity to provide feedback. Since it would have been too complicated to measure brainwave activity whilst wearing a VR headset, I decided to apply this heart-based method for my VR project. Instead of measuring brainwave activity, this approach focuses on measuring heart rate, heart rate variability, heart rhythm patterns and coherence to provide feedback about these conditions to the person in real-time. This feedback aims to help people attain a state of composure and coherence - as defined later in this exegesis.

Conclusively, due to my background in film/media, meditation/mindfulness and my experience with biofeedback, I became highly motivated to develop an interactive artwork that engages the participant in a mirror-like process of self-reflection, observation, and correlation. The following section outlines this exegesis's conceptual frameworks to familiarize the reader with Virtual Reality and biofeedback and its far-reaching fields of application.

4. Conceptual Framework

This section provides an overview of key areas of enquiry that have emerged as a framework for the aesthetical and conceptual development of an immersive biofeedback VR experience documented in the chapter *Practise* of this exegesis. It outlines a short definition of immersive and non-immersive Virtual Reality and provides a brief historical review. Consequently, it illustrates how Virtual Reality has been applied experimentally by early pioneers in the field. The section investigates, in particular, Char Davies’ work and how she has extended the medium of Virtual Reality with the modalities of biofeedback to alter virtual environments.

4. 1 Virtual Reality

An overarching definition of Virtual Reality has been debated amongst many scientists and researchers over the last decades. Back in the 1980s people argued about the terminology and used words like “virtual environments”, “synthetic reality”, “artificial presence” and “consensus reality” to describe a new form of media interaction (Lanier, 2017, 305). The exact origin of Virtual Reality has been subject to dispute due to the difficulties of formulating a distinct definition for the concept of experiencing and engaging with alternative, virtual worlds. VR was birthed by a long parade of scientists and entrepreneurs. One of the early pioneers in the field was the cinematographer Morton Heilig (Lanier, 2017, 56). In the 1950s he envisioned an “Experience Theatre” that could involve all the senses of a person and draw the spectator into the screen content. In 1962 he built a prototype of this idea in the form of a multisensory machine entitled "Sensorama" (Steinicke, 2016, 25), which combined smells with stereoscopic images. Five films were screened inside the machine accompanied by sensual stimulation (e.g. vibrations, head movements, sounds, and rushes of wind).

Figure 1 Sensorama simulator patented by M. L. Heilig (1962). This invention is widely credited as being the first simulator designed to stimulate multiple senses.

In 1969, Ivan Sutherland built a head-mounted display that he referred to as “the ultimate display,” so that the spectator could see a world sustained by computer programs from within the world (Lanier, 2017, 56). From 1970 to 1990, Virtual Reality devices and experiences were mainly developed in medicine, aviation, flight simulation, automobile design and the military (Grau, 2003). Pioneers like Scott Fisher, Jaron Lanier, Michael Naimark, Tom Zimmerman, and Brenda Laurel, worked on developing various VR-related technologies. By the 1980s, the term ”Virtual Reality” was defined by Jaron Lanier (Lanier, 2017, 233) and through the 1990s, this form of media-practise became more publically known.

In the initial times, many technical obstacles needed to be resolved before this emerging technology could become available to the general public. The resolution of 3D graphics was very primitive, interface devices were very complex and non-intuitive to operate, the costs of development and applications were very high, and HMDs(head-mounted-displays) were very voluminous, heavy and unconformable to wear. Furthermore, the tracking speed, field of view, and graphic resolution were very limited. Therefore, the public awareness became disappointed with the inefficient “expectation-to-delivery” ratio and viewed VR commonly as failed technology around 1995. Even though VR reached its lowest point in the mid-1990s, pioneers in the field continued their research and pursuit of further development. Due to the technological advancements over the last two decades, including the increase of computational speed, the improvement of computer graphics, the development of tracking sensors, the intuitive and easy-to-use application of user-interfaces, panoramic videos and the progression of software programs, VR has shifted from an experimental technology to an everyday experience for many people around 2015. Companies like *Samsung* and *Oculus* (purchased by *Facebook*) introduced a new phase in the cultural reception of VR.

In general terms, VR has been classified as a way of visualising, manipulating, and interacting with extremely complex data and as a sophisticated form of human-computer interaction (HCI).[1] The user is thereby interacting within synthetic computer-generated virtual environments. VR is not specific to any

[1] HCI is a field of design research and information technology concerned with the study and development of interactions between humans and computational systems.

particular type of technology, neither in terms of hardware nor software to create or present virtual simulations. Though VR has various forms of expression, the user's ability to navigate/manipulate a world other than the one they are objectively located in is included in all forms. VR can be developed and experienced with a broad range of technological components, interaction devices, sensory display systems, and computer interfaces. It is important to note VR does not imply 360° imagery. 360° photo or video content is recorded with a multi-lens camera (e.g., Insta 360 pro) and the recordings from the individual lenses are stitched together in postproduction so that the user can watch the content with the use of a head-mounted display (HMD) in 360° field of view. In regards to VR, there is a clear distinction between non-immersive an immersive VR content.

4.1.1 Non-immersive Virtual Reality

In non-immersive Virtual Reality, the content is presented on a two-dimensional (2D) computer monitor or television screen without excluding the outer world. The user engages with three-dimensional (3D) computer simulations via mouse or keyboard interfaces or particular interface devices such as gamepad or joysticks.
Historically, this form of media practise was established in the 1940s and 1950s when people started experimenting with computer-animated content and various computer graphics forms. One of the early pioneers in this field was John Whitney (Bendazzi, 2015, 253). Since the 1960s new ways for innovative computer-animated design and implementation emerged, since digital computers had become widely established and more accessible to the general public.

4.1.2 Immersive Virtual Reality

Here, the user interacts with three-dimensional (3D) computer graphics with a head-mounted display that excludes the external environment. This approach can include body tracking sensors and specialised interface devices. The information from the user’s position and body movement can be tracked accurately using a laser-based positional tracking system (e.g., Lighthouse) (Yang et al., 2017, 1). This enables the users to move around and re-orientate themselves in any position within the tracking system's range. The audio-visual information from the user's experience updates in real-time according to his or her head position (via the head-mounted display) or body movement (via controllers or body tracking sensors) to create the illusion of being "immersed" in virtual space.

4.2 Early Experimentations of Virtual Reality and Biofeedback

In the early beginnings of VR in the 1970s, scientists, researchers, programmers and artists started experimenting with the medium itself, to explore and expand its technological and conceptual limitations. Visual artist Char Davies started to discover VR as an arena for artistic expression and envisioned how Virtual Reality could shift the habitual perception of mundane reality. In 1995 Davies created an immersive virtual environment named Osmose (Davies, 1998, 65-74), where she combined 3D visual imagery and spatially localised sound with human-computer interactions based on breath control and balance. The following photo illustrates how the user experienced Osmose.

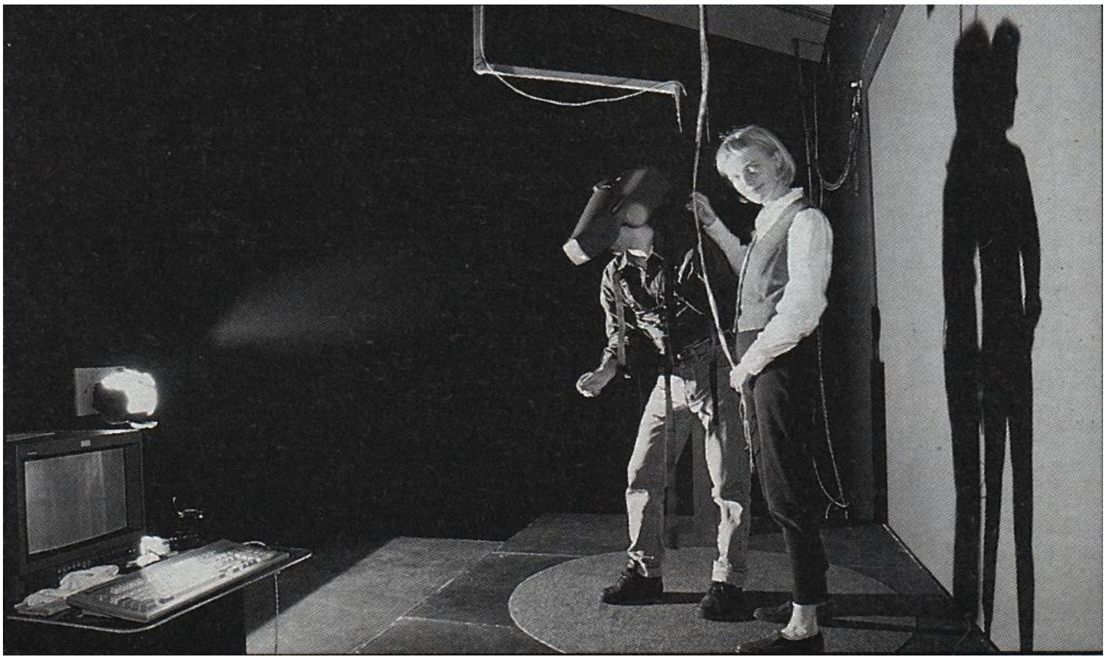

Figure 2 Char Davies (right) with Georges Mauro (left) in the projection room of the Montreal Museum of Contemporary Art by Jean-Franqois Lenoir (1995)

The next photo illustrates what the person was looking at within the headset.

Figure 3 *Forest Grid* still image captured during interaction in *Osmose* by Char Davies (2006)

The journey of *Osmose* illustrates twelve different abstract sceneries that reflected "metaphorical aspects of nature" (Nelson, 2009, 262).
The participant wore a head-mounted display and a body vest to monitor breathing and balance to interact with nature-based visualisations whilst manoeuvring through an artificial spatial environment. Breathing in allowed the spectator to flow upwards, breathing out guided the movement downwards; leaning forwards and backwards, the participant initiated a gentle change in directions (Davies, 1996, 25-28).

> I wanted to subvert the visual and behavioural conventions associated with VR technology at the time. And, in doing so, I wanted to prove that this new spatiotemporal medium was capable of enabling experiences that could reaffirm our embodied being in the world, rather than distracting and distancing us from it. (Davies, 2017)

Davies' work suggests VR and immersive environments have the potential to dissolve boundaries and collapse the dichotomy and distinctions between interior and exterior worlds. This utopian perspective warrants further extrapolation in consideration of the origins of VR.

Since VR originated in the military and western science (Lele, 2013,17-26), Davies elaborated that VR not only reflects but also re-enforces the western worldview, particularly in terms of domination and control and it upholds a very dualistic perspective of looking at the self embedded in the world (Davies, 1998, 73). First-person shooter games in VR can be seen as a representation of that; an attempt to subdue the virtual world and dominate it whilst overpowering other creatures and avatars to ensure victory. Davies' work was designed to transform these conventional technological and ideological paradigms through establishing a sense of self-awareness and feeling of embodiment within her artwork. Breath control and the adjustment of balance – which she often uses in her art installations to navigate through virtual space - indicated, that the user has to be aware of his or her own body, and what the body is doing whilst experiencing the audio-visual stimuli. In this regard, the concept of "control" can be seen as sovereignty over the self, rather than domination over others. In 1998, she founded the company Immersence, Inc., intending to create and provide software for 3D virtual environments (Davies and Harrison 1996, 25-8). To this day, her work is exhibited in museums and art institutions worldwide, and she is considered one of the early pioneers of biofeedback VR.

Conclusively this section has provided a brief introduction into the field of Virtual Reality. Further, it has highlighted Char Davies' work and its underlying principles of using body measurements like breath and balance to navigate a computer-generated virtual environment. Her work has been referred to as biofeedback VR. To familiarise the reader with some underlying concepts and terminologies, the next section will provide a brief introduction into the field of biofeedback.

4.3 Biofeedback

From its early beginnings, biofeedback connected very diverse fields of scientific research including internal medicine, neurology, humanistic and transpersonal psychology, psychology, neuroscience, sport, coaching, nursing, physical therapy, and studies of consciousness (Schwartz and Andrasik, 2003). The Biofeedback Certification International Alliance states (Logo, 2010, 146):

> Biofeedback is a non-invasive form of treatment. The therapist attaches sensors or electrodes to the body and these sensors provide a variety of readings--*feedback*--which is displayed on the equipment for the patient to see. The signals typically measure skin temperature, muscle tension and/or brainwave function. With this information, patients can learn to make changes so subtle that at first they cannot be consciously perceived. With practice, however, the new responses and behaviors can help to bring relief and improvement to a variety of disorders.

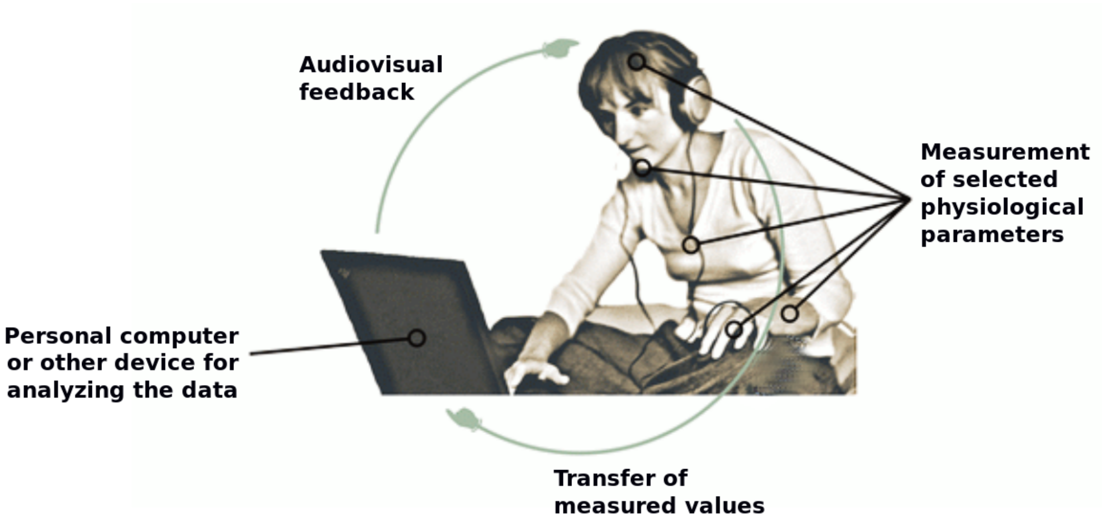

Figure 4 Illustration of a Biofeedback Circle by Medline Plus [D001676] (2013)

The graphic above illustrates a bio-feedback-cycle practised on a two-dimensional screen. Specific physiological parameters (e.g., skin temperature, muscle tension, brainwave activity, heart rate) are measured through non-invasive sensors and transferred to the computer. The computer then analyses these signals and translates them into audio-visual feedback. The audio-visual feedback content depends on the indented effect on the person and the methodologies applied to generate this effect. Since there are very different methodologies of measuring and interpreting physiological data, the following section will only provide a brief overview of the functionalities of the selected biofeedback device (named emWave® Pro) applied in this exegesis, to familiarize the reader with its key principles. Because this research has been written in the context of screen production and media analyses, the following section will be kept short and simplified.

4.3.1 Heart Rate Variability

The old scientific paradigm considered the heartbeat, much like a metronome, beating in a steady, regular rhythm. However, this has been proven wrong. Scientist and physicians today know that the interval between consecutive heartbeats is continually changing. The heart doesn't beat monotonously but slightly irregular. This occurs naturally, and the variation between heartbeats is called heart rate variability (HRV). (Schaffer et al. 2014)

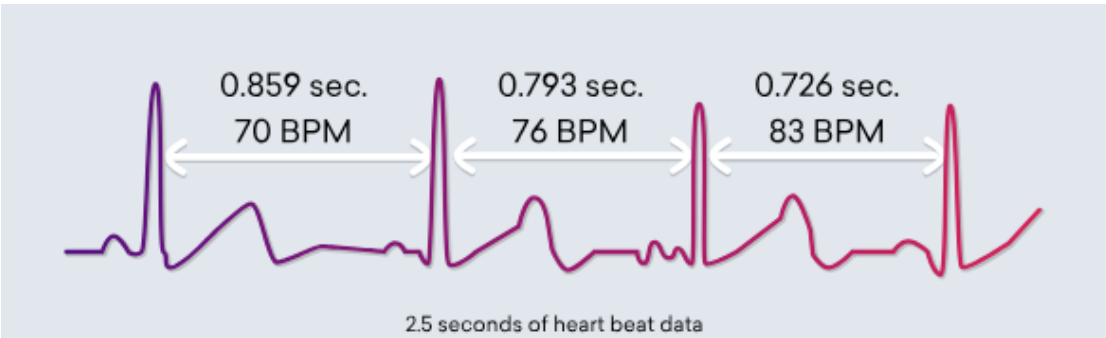

Figure 5 This diagram shows three heartbeats recorded on an electrocardiogram (ECG) graphic obtained from the Institute of HeartMath (2014)

Heart rate variability (HRV) can assess the activity of the autonomic nervous system (ANS), which controls the body's internal functions including heart rate, gastrointestinal tract and secretions of many glands, respiration, and it interacts with immune and hormonal system functions. The ANS has two branches - the sympathetic branch acts to accelerate heart rate and the parasympathetic branch slows it down and therefore cause a normal variability to occur. Both branches interact with each other consistently to ensure an optimal reaction under changing external and internal conditions. Many factors influence ANS activity, also influencing HRV such as physical exercise, breathing patterns and even thoughts and emotions (McCraty et al., 2009, 7). When the variation of the heart rate is recorded and plotted over a period of time, the emerging shape of the waveform illustrates the heart rhythm pattern.

4.3.2 Heart Rhythm Pattern

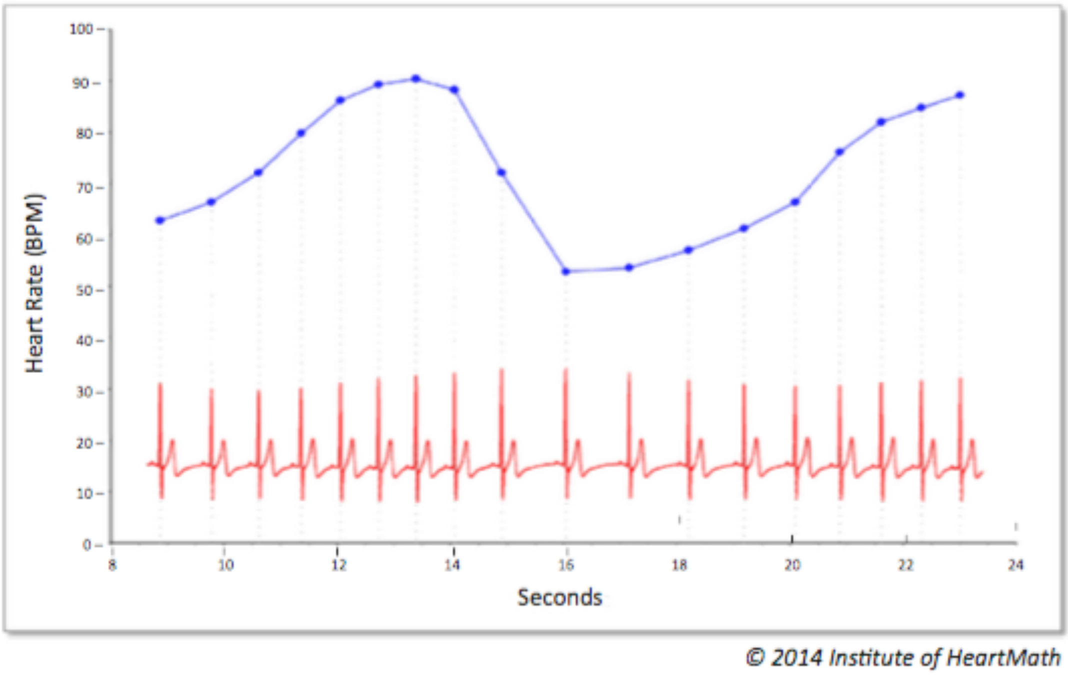

Figure 6 Illustration of a heart rhythm pattern recorded over 24 seconds. Institute of HeartMath (2014).

Mental and emotional states directly affect the ANS activity, and this can be observed in the heart rhythm patterns (McCraty et al. 2009, 7). A heart rhythm pattern in a jagged and irregular waveform indicates emotions like stress, anger, anxiety and frustration. This is called an *incoherent* heart rhythm pattern. Whereas a heart rhythm pattern appearing in an ordered, harmonious, sine wave-like pattern indicates positive emotions such as love, care, compassion, kindness, joy or gratitude. This is called a *coherent* heart rhythm pattern. In this fluctuation, the activity in the sympathetic and parasympathetic branches of the ANS operates more orderly and efficiently in conjunction with the body’s systems (McCraty et al. 2009, 20).

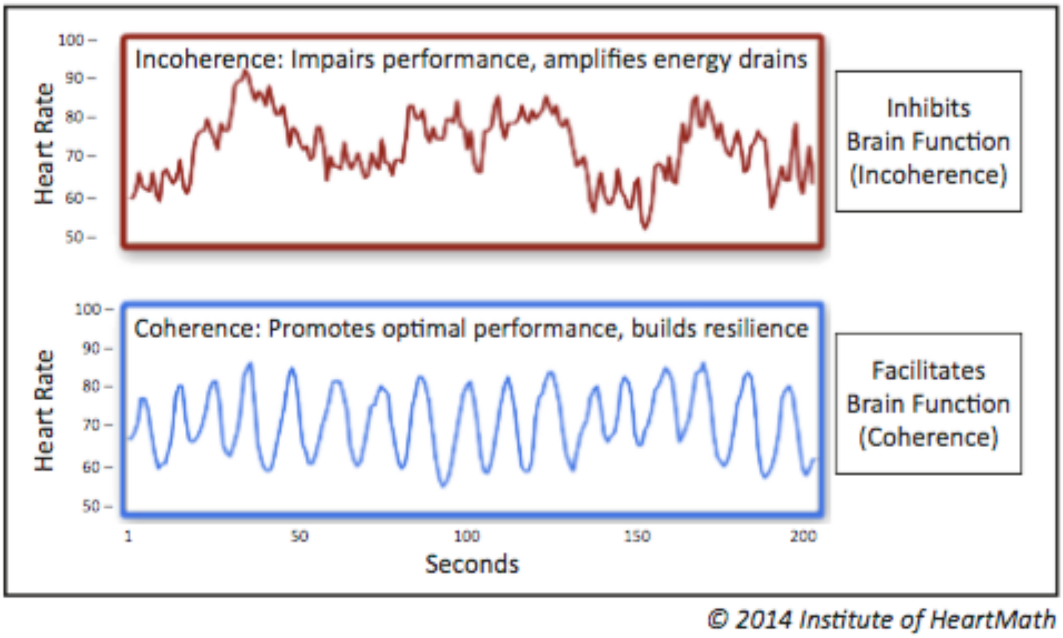

Figure 7 Heart rhythm patterns during different emotional states. These graphs show examples of real-time heart rate variability patterns (heart rhythms) recorded from the same individual experiencing different emotions. Graphic obtained from the Institute of HeartMath (2014)

4.3.3 Coherence

HeartMath Institute's research demonstrates prolonged positive emotions generate a body-wide shift that can be measured scientifically.
This state is called *psychophysiological coherence* because it increases harmony and order in the physiological (body) and in the psychological (mental/emotional) aspects of the body (McCraty et al., 2009, 15).
Physiological coherence has been related to a general sense of wellbeing and improvements in health and physical, social, and cognitive performance.
Studies have indicated that *psychophysiological coherence* can significantly improve brain function and lead to an increased ability to focus (Lloyd et al., 2010), increased ability to self-regulate emotions and produce higher test scores (Bradley at al., 2010) and an increased ability to learn (McCraty, 2005).

This specific pattern – termed *heart rhythm coherence* – is measured and quantified by the biofeedback device emWave® Pro. The device calculates and reflects the heart rhythm pattern by detecting a pulse from the earlobe with an electronic sensor. It monitors the slowing down and speeding up of the heart rate and calculates the heart rhythm pattern according to the degree of smoothness or jaggedness of the patterns and computes a coherence score with a patented algorithm. Furthermore, this coherence score can be sent to a VR application to transform the data into audio-visual expressions. The coherence score has been selected as the main parameter to influence VR imagery and sound in this exegesis's practical component.

4.3.4 The Power of Breath

The heart rhythm can be regulated through breath control and particular breathing exercises. Therefore, an individual can shift into a coherent heart rhythm pattern by breathing slowly and regularly at a 10-second rhythm (5 seconds on the in-breath and 5 seconds on the out-breath). (Mejía - Mejía et al., 2018, 6) This method has been implemented into the VR experience – as stated in the *Experiential Outline* in the chapter *Practise.*

To sum up, this section has providence a brief overview of biofeedback and its fields of application and introduced the key modalities and functionalities of the biofeedback device applied in this exegesis. The research now looks at the difference between Clinical and Non-Clinical biofeedback VR applications to identify the project's adequate affiliation within the existent body of research.

4.4 Clinical Vs. Non-Clinical Biofeedback VR

Ever since the initial experimentations of biofeedback in conjunction with VR by Char Davies in the 1990s, VR informed by the user’s body measurements has continuously increased its field of application. Nowadays, there is a clear distinction between non-Clinical biofeedback VR applications available to the general public and Clinical biofeedback VR applications developed for medical treatment and scientific research.

4.4.1 Clinical Biofeedback VR

Clinical biofeedback VR experiences follow strict scientific methodologies, procedures and assessment and can only be executed with the supervision of a qualified scientist, psychologist or psychiatrist. This approach has been applied for example in the field of physical rehabilitation, to provide patients with the opportunities to improve muscle activity and increase self-control of movement during specific training tasks (Ma et al., 2010). It has also been researched by a group of scientists at the Simon Fraser University, Canada. In response, a Virtual Reality game for chronic pain management has been developed for the assessment of a randomised, controlled study. The participants had to walk through a foggy virtual forest whilst their skin conductance levels were measured. The more the person was able to shift into a state of deep relaxation or Mindfulness-based stress reduction (MBSR), the more the virtual fog lifted, revealing an idyllic wilderness scene. The researchers concluded that VR intervention with MBSR and biofeedback invoked better results in reducing chronic pain than MBSR techniques alone (Gromala et al., 2015).

Figure 8 Screenshot from ”The Virtual Meditative Walk” by Diane Gromala (2015)

Figure 9 Screenshot from “The Virtual Meditative Walk” by Diane Gromala (2015). As patients approach an inferred meditative state, the fog begins to dissipate (left to right), and sounds become more audible.

4.4.2 Non-Clinical Biofeedback VR

Non-Clinical biofeedback VR experiences can be used privately without the backing of a trained clinician. There is a growing number of these autonomous biofeedback VR experiences available on the market today. The majority of these products are currently non-immersive and can only be practiced on a two-dimensional screen. Yet, there is an emerging quantity of immersive biofeedback VR designed for the general public. These devices and products (e.g. *Unyte Health Inc,* 2018), provide the user with the opportunity to learn and practice basic biofeedback techniques independently at home in order to recognise and control the body's internal states whilst receiving personal physiological information in real-time – visually or aurally –and applying it in preparation for challenging life situations – such as school and work environments or particular social situations.

Conclusively, the previous section has provided a distinction between Clinical and Non-Clinical biofeedback VR to contextualize the practical part of this exegesis and has engaged the second approach as a starting point for the creative practice. Whilst Clinical biofeedback VR can be very costly and inaccessible to many people, non-Clinical biofeedback VR can deliver an affordable and engaging self-care technology to provide guidance and support for the user in the preparation of challenging life situations. Even though it might lack scientific accuracy and protocols, it can still open a doorway for daily practises of self-awareness and mindfulness-based techniques. To understand the visual and conceptual frameworks of contemporary biofeedback VR applications, the following section will outline how existent visualisation techniques are applied in the field.

4.5 Aesthetical Styles of VR and Biofeedback

The following section outlines a brief overview of aesthetical styles and includes screenshots of contemporary examples in the field of biofeedback VR. This aims to deepen understanding about the diversity of illustrating psychophysiological data and contextualise this exegesis's practical component accordingly.

4.5.1 Non-Immersive Approaches

The following two references can only be experienced on a two-dimensional computer screen using a biofeedback sensor attached to the user's earlobe, which records physiological data and calculates a coherence score that influences the computer-simulated animation.

Balloon Game (2017)

This biofeedback experience invites the user to take a trip on a hot air balloon. The velocity and hight of the balloon changes according to the user's coherence score. Visually it interlinks simplified, cartoonish animations with naturalistic, schematic scenery and a bright colour spectrum.

Figure 10 Screenshots from Balloon Game in low coherence (left) and high coherence (right) by emWave® Pro (2018)

Portals of Care Visualiser (2017)

This scene adjusts the colour space and the intensity of light beams emitting from the centre of a planetary depiction according to the user's coherence score. An increase in coherence results in more light radiating out at a higher frequency. It is characterized by smooth, feminine curves and waves that blend seamlessly into each other.

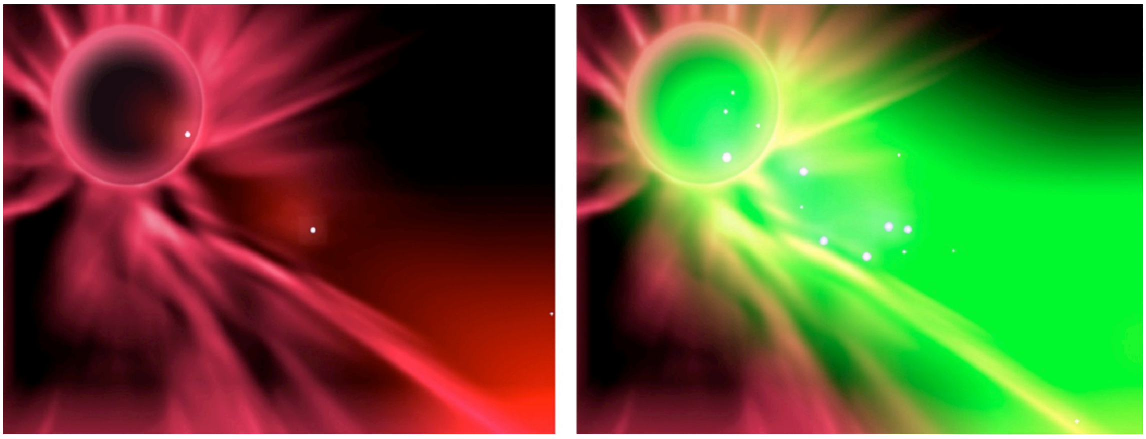

Figure 11 Screenshots from in Portal of Care Visualiser in low coherence (left) and high coherence (right) (2018)

4.5.2 Immersive Approaches

Unyte (2018)

The following immersive biofeedback VR application has been created by the company *Unyte Inc*. and applies religiously oriented imagery in conjunction with numerical cues that indicate the user's performance level. These cues illustrate heart rate in beats per minute (bpm), a resonance score, the remaining time interval of the experience and a breath indicator. Visually it merges complex textures, shades and lightning patterns with ancient symbolism. *Unyte Inc.* has created an extensive digital library in conjunction with their biofeedback device *iom2*. The library includes guided meditations, games, and VR games, specially designed to optimize the user's meditation experience with biofeedback modalities (Unyte, 2018).

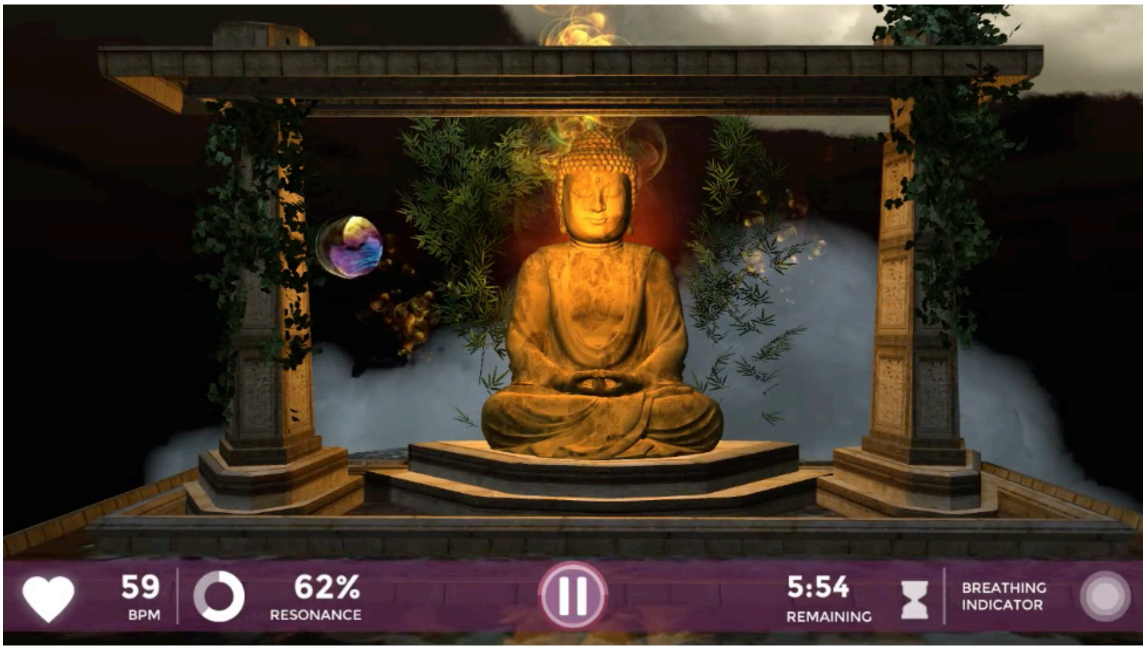

Figure 12 Screenshot extracted from Unyte (2018)

Deep (2016)

Deep is a meditative VR game controlled by the user's breathing patterns. The participant is wearing a Virtual Reality headset and a custom-build biofeedback device to measures diaphragmatic expansion and contraction to measure deep breathing patterns. This data is recorded and analysed by a connected computing system and reflects this information back to the user in visual cues, such as changes in velocity, colour or sizes of objects. Aesthetically it reveals mysterious underwater worlds with gently floating, abstract shapes and edges, accompanied by surrealistic symbolism (Deep, 2016).

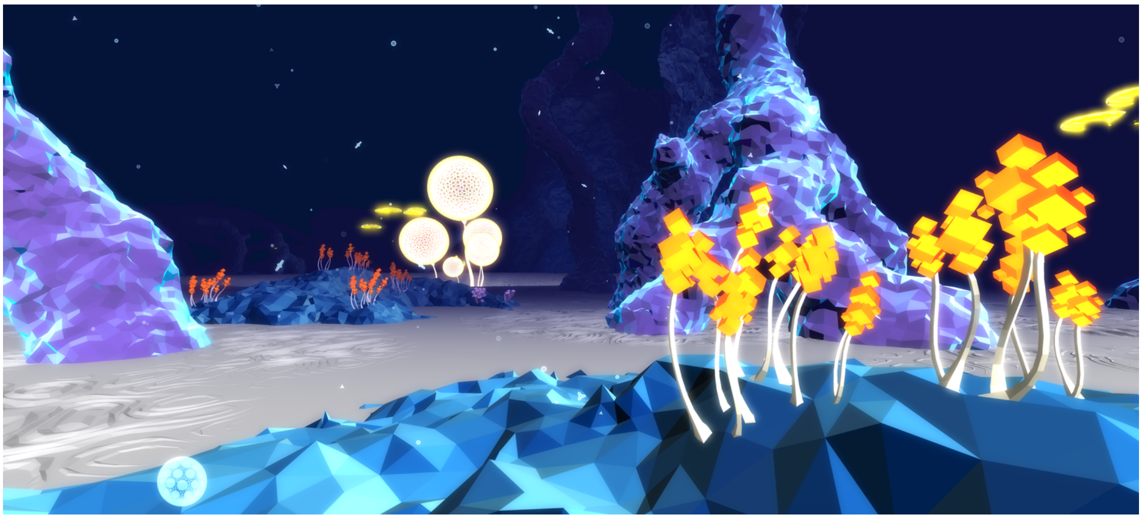

Figure 13 Screenshot extracted from Deep (2016)

STRATA | A Biometric VR Experience (2017)

STRATA incorporates multiple streams of biofeedback information (e.g. heart rate, brainwaves activity and breathing patterns) that enable the user to float within virtual simulations according to their emotional states, level of focus or relaxation. Visually it encompasses five floating worlds that illustrate nature-inspired alterations of supernatural territory including a subterranean lake, a meadow, floating islands, and a distant nebula (STRATA, 2017).

Figure 14 Screenshot extracted from STRATA | A Biometric VR Experience (2017)

To sum up, the exemplified, aesthetic scope of biofeedback-enabled VR applications has informed and enriched the creative choices of the practical design aspect of this exegesis. It has identified the style of STRATA with its multi-layered, overlapping spheres in the midst of galactic territories as the most appealing artistic research domain. The following section provides an in-depth explanation of the creative practises applied throughout this exegesis.

5. Practice

This section provides an overview of this exegesis's practical research component, which incorporated the development of a biofeedback VR experience entitled *HeartSpace VR.* As mentioned earlier, the main methodology was informed by the concept of *Visual Arts Knowing* by Graeme Sullivan. The artist has the responsibility of exploring diverse fields of research that can be referred to symbolically as “the tightly bundled strands”, to continuously unravel them, critically sort what is relevant for the practise and then re-braid these findings in a way that has never been done before (Sullivan, 1951. 2010). The British film producer, David Terence Puttnam, referred to this concept during one of his lectures[2] at Griffith Film School as a series of continuously collecting *hunches*. These *hunches* or insights appear to be very disconnected in the beginning. They just indicate a direction, a field of interest, and they have a very strong attractive power on the researcher. Throughout the research practice, these insights become interwoven in a web of knowledge and start to take shape.

Yet, the artist has to navigate through this process partially blindfolded until all these pieces eventually connect and reveal the bigger picture of the puzzle. Therefore, the following section is based on the *practitioner's hunches* throughout the research in order to make the artwork more understandable in its entirety. The practitioner chose the self-referential writing style since it appeared to be the most authentic and comprehensible form of expression. This choice has been informed by the work of Donald A. Schön in his publication *Reflective Practitioner: How Professionals Think in Action* (Schön, 1995;2017).

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[2] Name of the course: “Producing for Screen and Society in the 21st Century.” Examining the relation between the screen production industry and society. Attended at Griffith Film school in 2017.

Figure 15 Idea of creating a VR Heart-set by Nina Rath (2018)

Early on in the research for my exegesis, I discovered an aphorism that said: “If you change the way you look at things, the things you look at change.” (Author unknown) As discussed earlier, Immersive Virtual Reality is typically viewed through a headset (head-mounted-display) to explore and engage with virtual environments. Whilst working on my exegesis, I became fascinated by the idea of creating a heart-set in addition to the headset, to view the presented content “through the eyes of my heart.” But the big question was, how could I possibly do that? It appeared to be more like a vague daydream rather than a concrete possibility. The first *hunch* appeared in my life when I discovered that the Institute of HeartMath in Boulder Creek, America had already built heart-based biofeedback devices for professional treatment and private usage. I contacted the Director of Research, Rollin McCraty, PhD, to see if the Institute would be willing to donate one of these devices to my research project. He agreed and confirmed to send me one of these devices (emWave® Pro). But then the question arose: How can I find a VR developer to build the project with me? I had never created any computer-generated games or VR content myself before, so I clearly needed assistance. I asked my colleagues and friends from the VR scene about with whom I could best work. A week later, I found two candidates who were interested in the project.

Jonno Ament and Patrick Hoffmann had experience in building VR projects. Jonno Ament had built VR content for multiple industries for more than four years, and Patrick Hoffmann was doing his *Bachelor of Games and Interactive Environment* at the *Queensland University of Technology*. Due to Jonno's advanced expertise, he became the lead VR developer, and Patrick became the assistant VR developer. That was when I realised: my role was to be the producer and director of this project. I became responsible for creating an aesthetic and conceptual structure of the VR experience and Jonno and Patrick for programming in the VR software. The next question was, how can I find someone who is specialized in biofeedback to combine the technology of HeartMath with the VR environment? Fast forward to the next *hunch*.

I received a phone call from a friend. He said I should get in touch with Mic Black from Sunshine Coast because he is highly skilled with bringing different wearable devices and biosensors and rare, new, experimental technologies together (Black, 2018). I contacted him and told him about my research project, and he agreed to help me instantly. A week later, he extracted the device's data and wrote a basic instruction in a document[3] for Jonno to start working with these values in the VR software *Unreal Engine*. The next problem arose: What does the software emWave® Pro actually do and how can this data be translated into a virtual experience? In simple terms, how could we cast these graphs, scores and numbers in a visual mould? And what do they mean anyway?

[3] Added to Appendix D

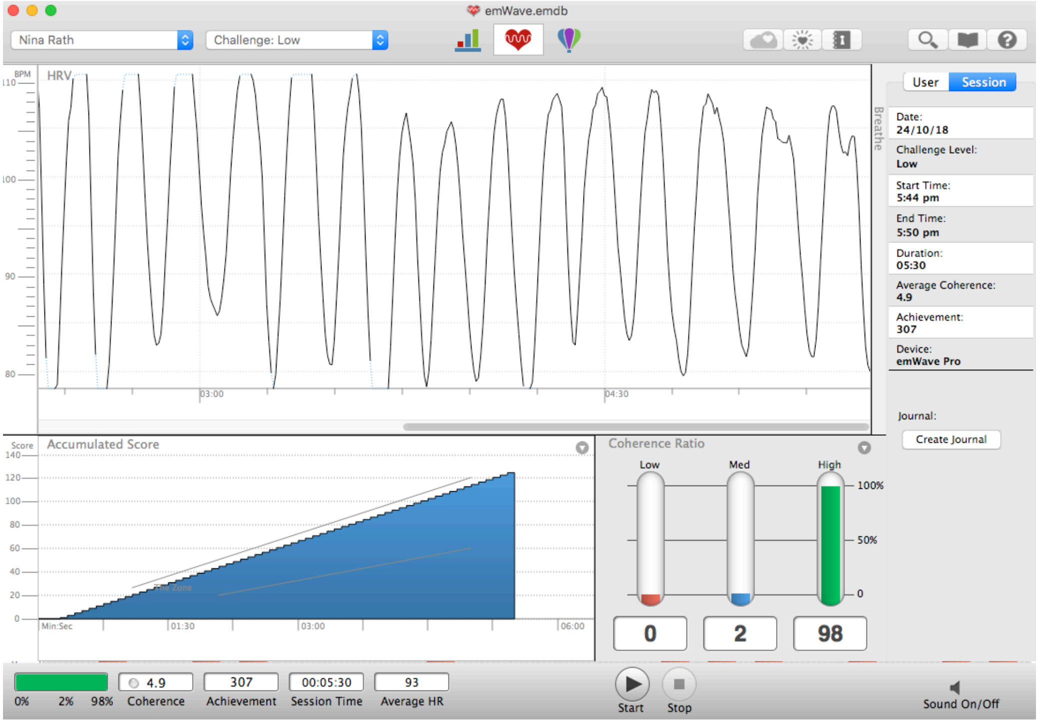

Figure 16 Screenshot from a recording of emWave® Pro (2018).

To answer these questions, Mic and I started to experiment with the emWave® Pro hard- and software in his laboratory at the Sunshine Coast, Australia.

Figure 17 Nina Rath testing the technology of HeartMath in the workshop of Mic Black (2018)

Figure 18 Mic Black in his workshop at Sunshine Coast; Australia (2018)

To gather more *hunches*, I enrolled in the 6-week online “HeartMath Coach/Mentor Program” to better understand the software's practical applications. Additionally, I studied peer-reviewed publications about how the heart rhythm directly affects physical and mental performance and about the significance of psychophysiological coherence (Edwards 2015, 367-374), (McCraty et al., 2009). Additionally, I examined how biofeedback has been applied in gameplay to enhance gameplay experience (Ambinder, 2011).

Parallel to the literature review and scientific research of VR and biofeedback, I started drawing pictures, drafting and analysing meditative VR content (e.g., Satori Sounds VR (Satori Sound, 2018)) and thought about bringing ancient mediation practises and visualization techniques into contemporary VR applications. Initially, I wanted to build a VR experience based on violet flames. In ancient esoteric teachings, violet flames/fire were considered supportive in helping people to release traumatic memories from the past, simply by imagining burning these memories in the flames. When we actually started to program these flames and fire, it appeared too extreme, too violent and dreadful to me, almost like sitting in the midst of a pyre.

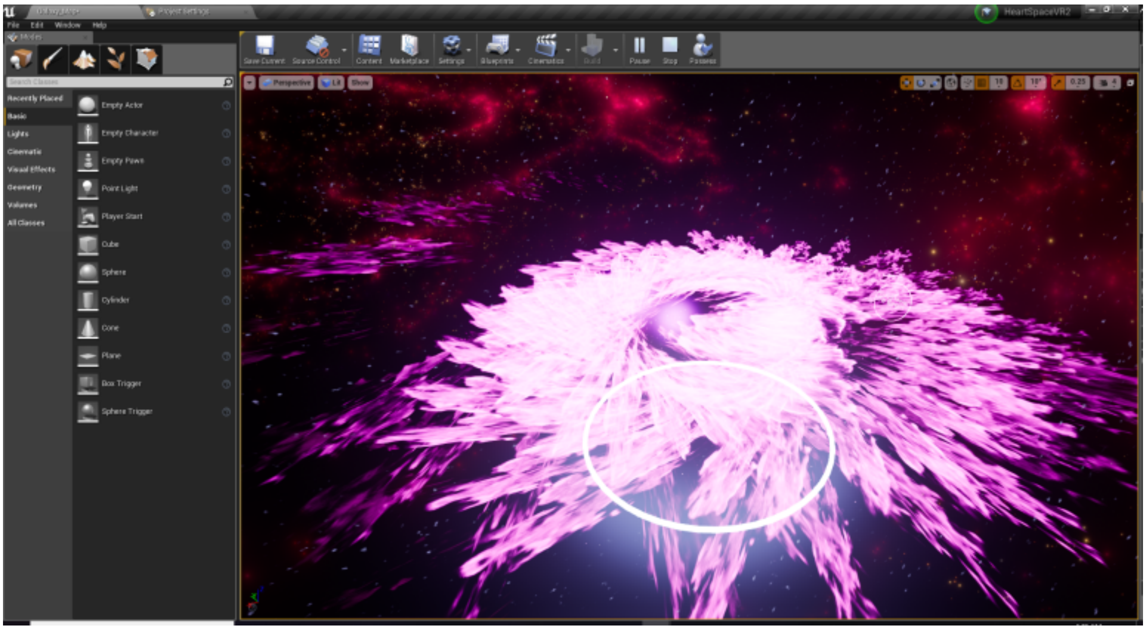

Figure 19 Violet Fire Simulation in Unreal Engine (2018)

Regarding the creative process, Jonno, Patrick and I had individual VR set-ups installed in our homes. I was providing instructions and visual reference of how the experience should look. Jonno and Patrick then started to build these ideas in *Unreal Engine*. We exchanged the latest version of the project via GitHub (a software development platform) to review and discuss the changes online via discord (a digital communication platform designed for video gaming communities) or Skype (a telecommunications application for video and voice calls). Jonno was responsible for programming the overall structure of the environment. Patrick was responsible for specific subareas for the application (e.g., the heart-shaped cluster of particles – mentioned in the chapter *Practise* under *Experiential Outline*).

Disenchanted by the early experimentations, I started to familiarise myself with imagery from the medical context (e.g., anatomy and cardiology). But I was not satisfied with my findings from an aesthetic point of view. These images appeared to be too analytic, distant and clinical to me. Then I discovered an illustration of the heart's electromagnetic field that a magnetometer can measure,[4] according to the HeartMath Institute.

[4] A magnetometer or magnetic sensor is an instrument that measures magnetism—either the magnetization of a magnetic material like a ferromagnet, or the direction, strength, or relative change of a magnetic field at a particular location.

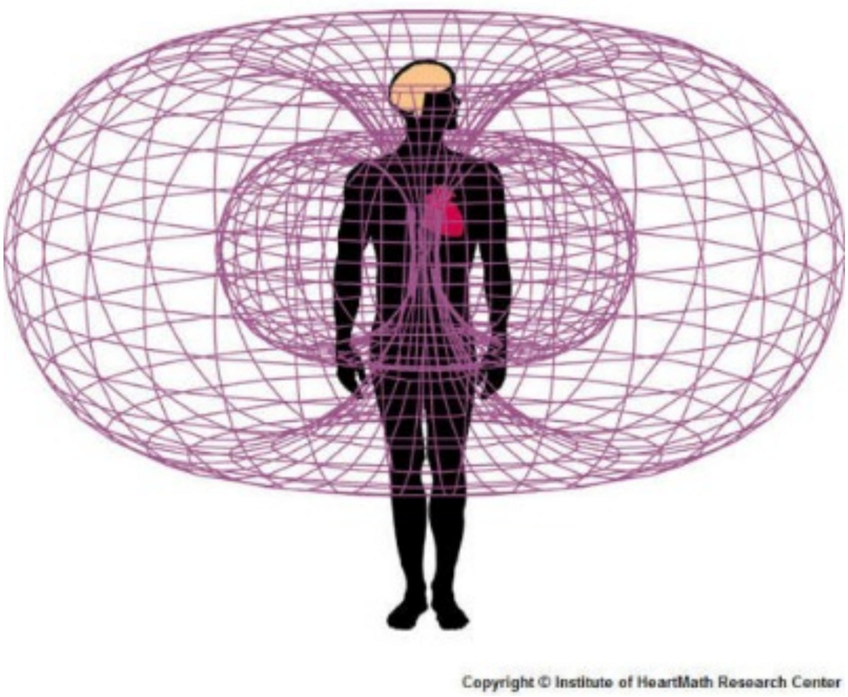

Figure 20 Illustration of the electromagnetic field of the heart by the Institute of HeartMath Research Center (2015)

Below our early experimentations of working with this idea.

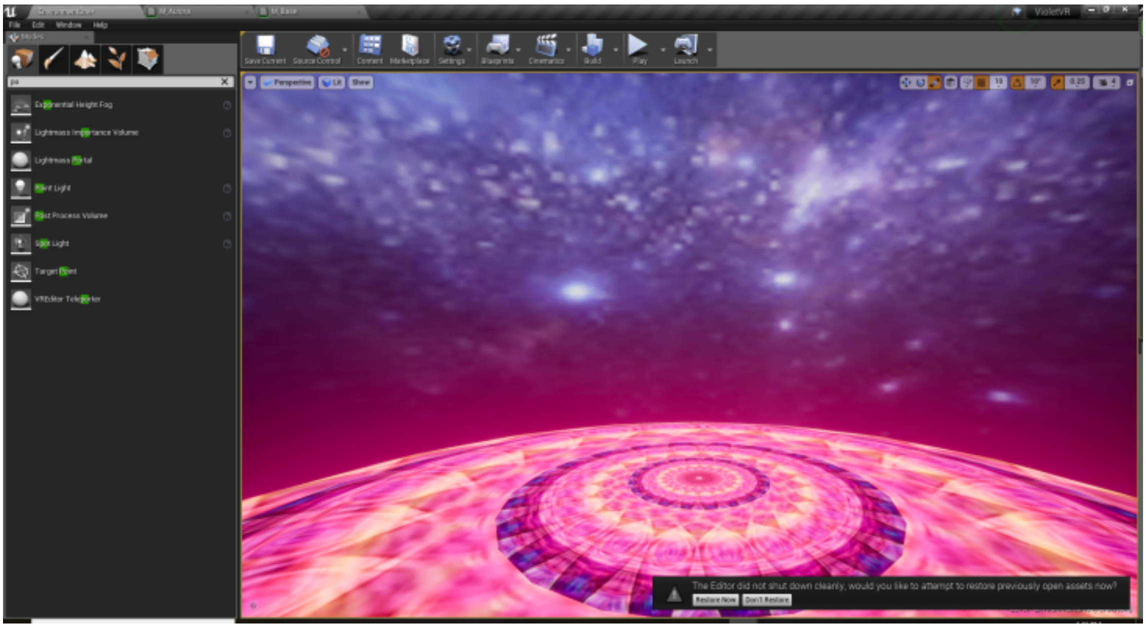

Figure 21 Surface of VR environment based on kaleidoscope and mandala patterns (2018)

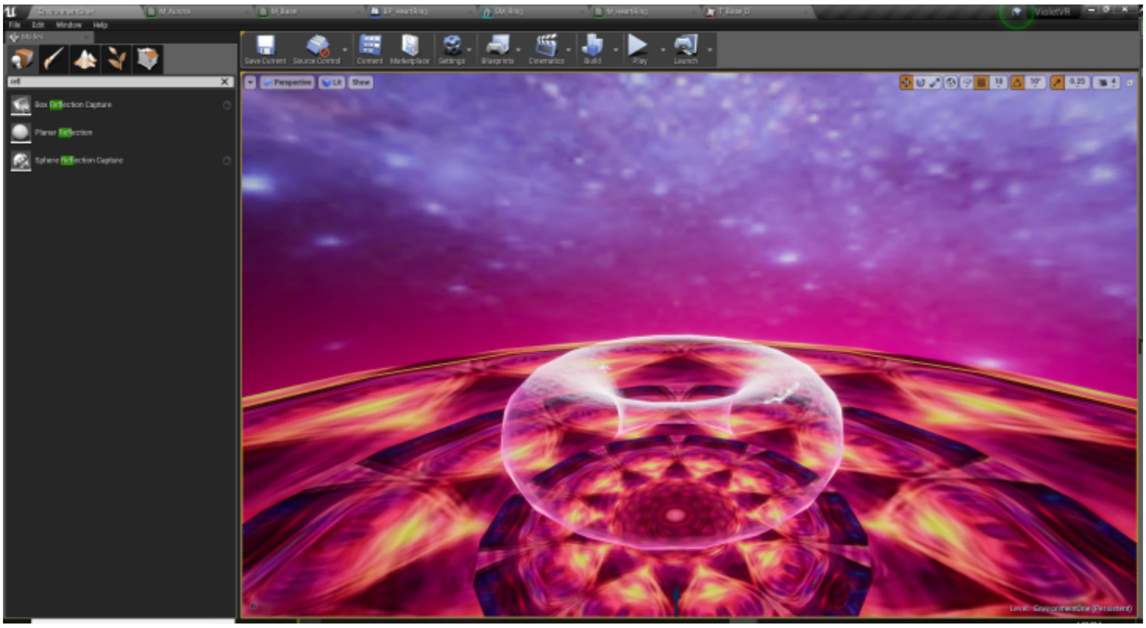

Figure 22 Visualisation of a doughnut-shaped electromagnetic field (2018)

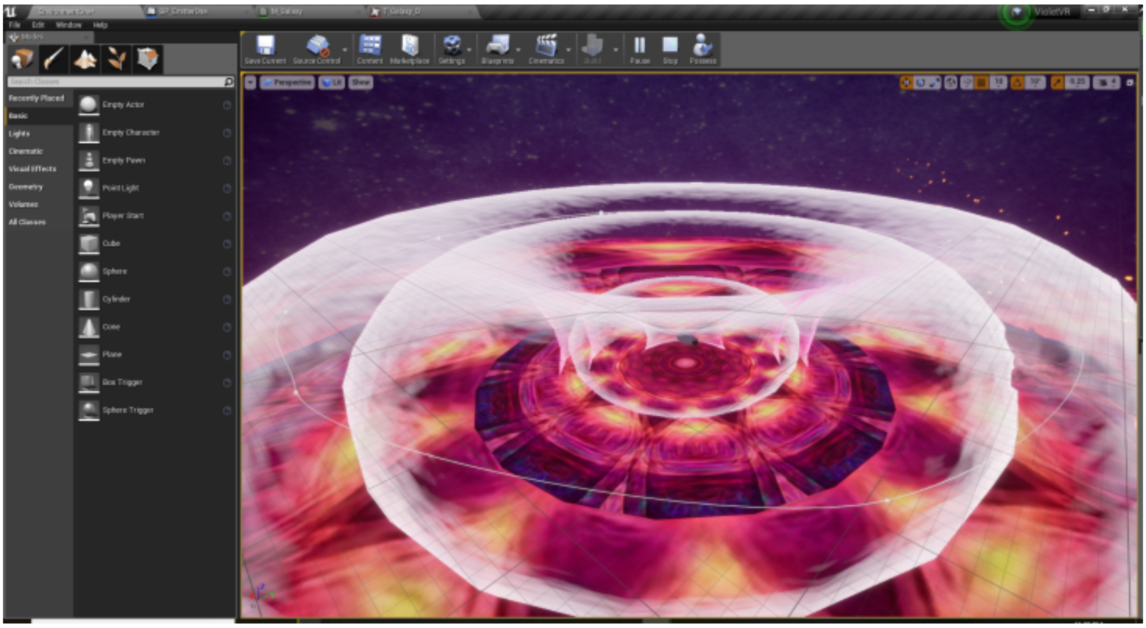

Figure 23 Simulation of multiple electromagnetic fields nested into each another (2018)

I was pleased by the early drafts on a two-dimensional screen, but the movements, shapes, and textures appeared disjointed and disturbing when I looked at them through the VR headset. There was no gentle movement and flow within the experience. It seemed to be too clipped and jerky. To get more *hunches* about improving this simulation, I invited Jonno and Mic to my house for dinner. With the help of salad, pasta, gong-sounds mediation and Michael Jackson's "Man in the Mirror" we came up with the final draft of our biofeedback VR experience. Below is the original draft we painted together that night.

The octopus unicorn did not become part of the final VR experience but was just an expression of joy and creative freedom.

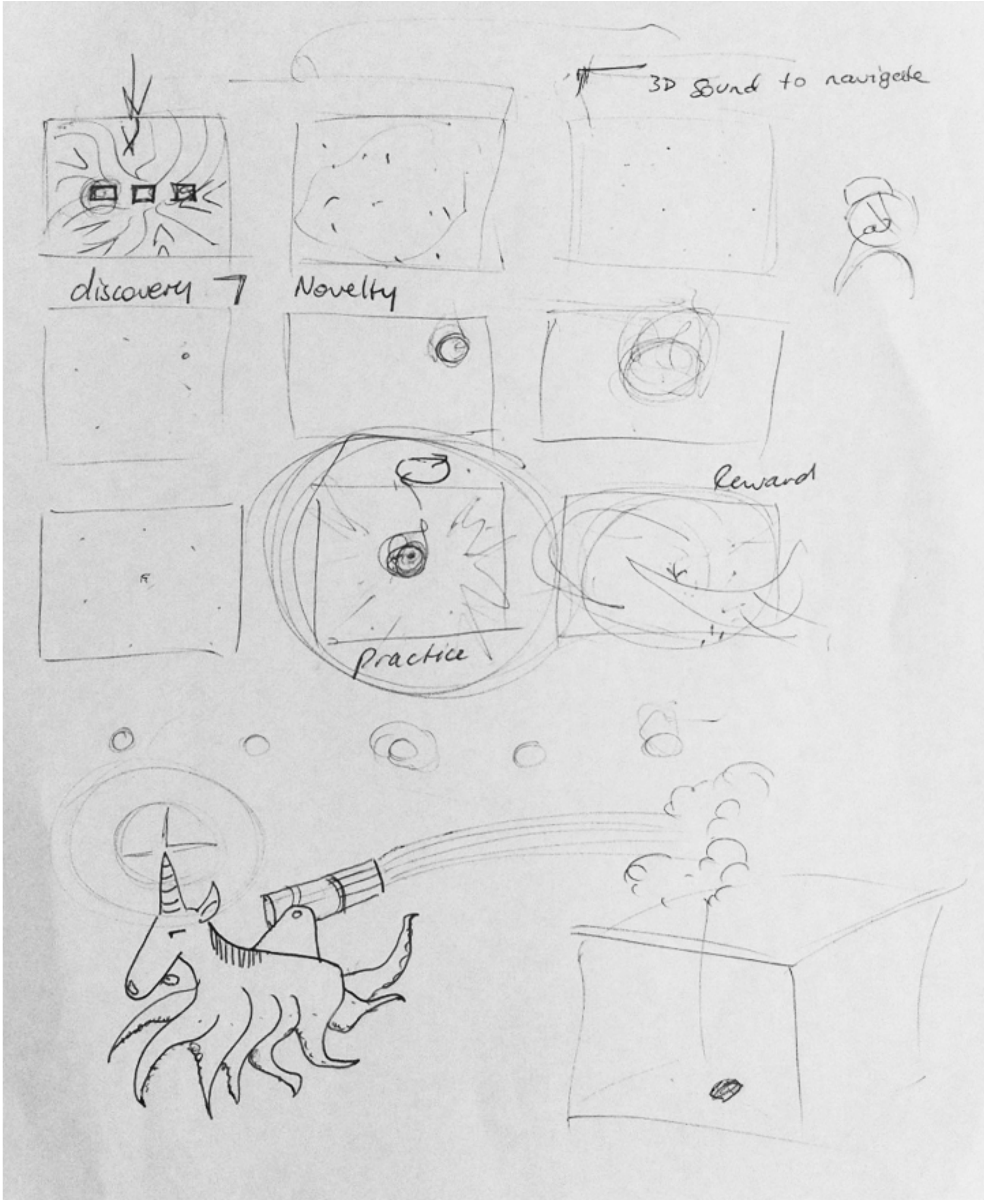

Figure 24 Original draft of *HeartSpace VR* (2018)

The following sections provide a technical, experiential and conceptual outline of the final biofeedback VR experience named *HeartSpace VR.*

5.1 Technical Outline

Figure 25 Technical Set-Up for experiencing *HeartSpace VR*: Nina Rath wearing a head-mounted display and a biofeedback sensor attached to the earlobe (2018).

The user-interface is based on HTC-Vive head-mounted display (headset) and the biofeedback device emWave® Pro (heart-set). The latter is placed on the participant's earlobe and plugged into the computer via the USB port. The accompanying software of emWave® Pro records and analyses physiological data and sends it to the VR application. The VR application integrates selected values from the data and translates these values into audio-visual stimuli. Specifically, the VR application extracts two values from the incoming data:

1. EP - Entrainment Parameter: a computed physiological measure reflecting the coherence score of the user[5]
2. IBI - Interbeat interval: the time interval between individual beats

The EP is converted in the VR application into a low, medium and high coherence score to influences the imagery and the soundscape.
The IBI is implemented between a pre-recorded audio file of a heartbeat, making the user’s actual variation in heart rate audible.
In-depth explanations of technical details and implementation strategies have been added to the appendices of this exegesis.

[5] Additional information can be found in the Appendix C of this exegesis.

5.2 Experiential Outline

Figure 26 Starting point of the *HeartSpace VR* intergalactic flight session (2018)

The participant is visually located in outer space and has to navigate towards a star in the distance that looks like a heart-shaped cluster of particles in a galactic nebula. Sound-wise, the user is listening to a heartbeat, based on his own heart rhythm. Only if the user is looking into the right direction of the heart-shaped star, the heartbeat becomes audible.

Figure 27 Screenshot extracted from the experience of moving through stardust and violet nebula (2018)

To navigate towards this heart-shaped star, the person has to influence the coherence score via breath control. The coherence score can be increased using a 10-second breath cycle (5 seconds in and 5 seconds out). A semi-transparent circle is introduced into the scenery with a 5-second contraction and 5-second expansion, providing visual guidance to help the user modulate breathing patterns.

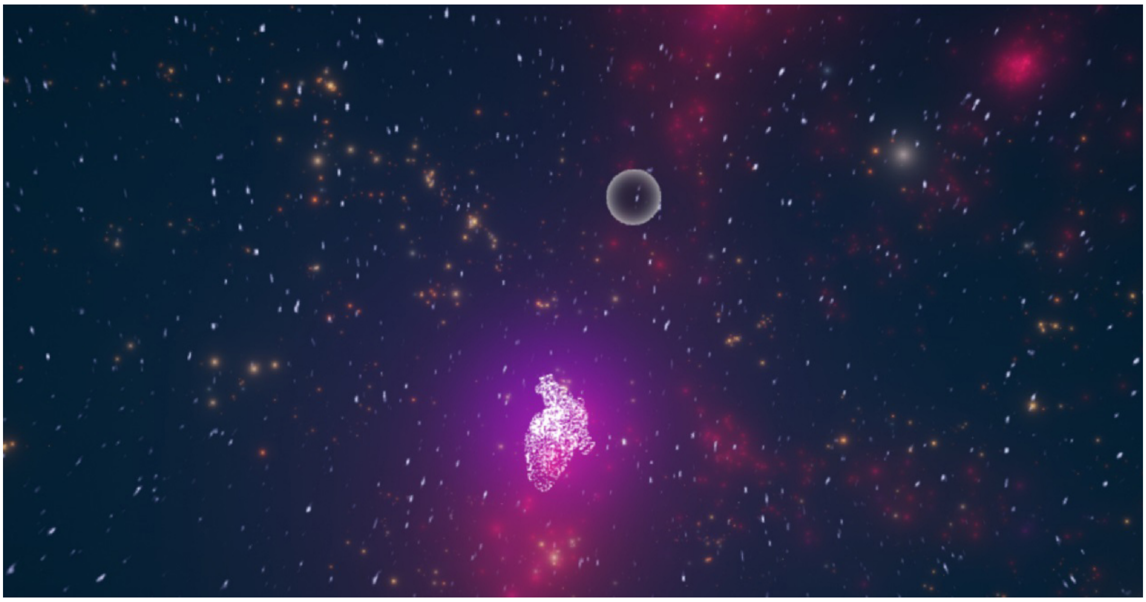

Figure 28 Approaching the heart-shaped star with the use of breath control (2018)

In outer space, the velocity and the sound-sphere changes according to the coherence level of the person. In a state of high coherence, the participant flies through cosmic violet-coloured fog patches with increased speed. In a state of low coherence, the user starts to slow down, and the galactic environment becomes stagnant. Acoustically this is accompanied by wind sounds that change according to the coherence score and enhance the sensation of flying.

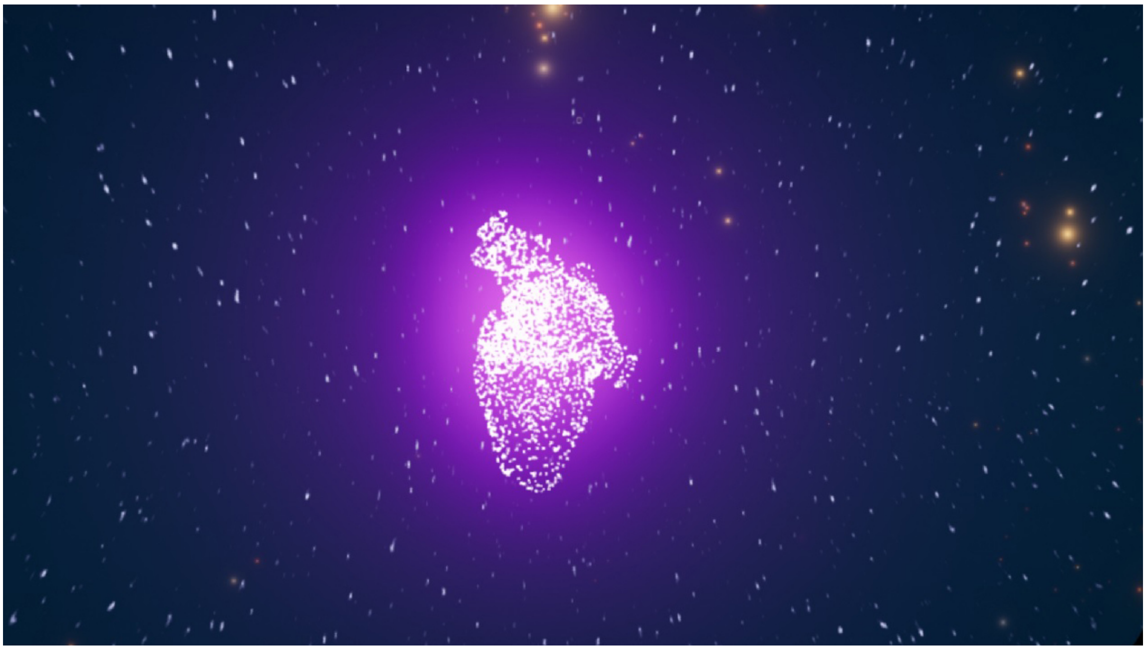

Figure 29 Violet aura surrounding the heart-star (2018)

Once the person has reached the heart-star and manages to navigate into the centre of it, the heart-shaped cluster transforms into a particle simulation and surrounds the user by 360 degrees. If the person is in a state of high coherence, many cheerful, active particles move in and out from the centre of the user's chest and extend into the environment.

Figure 30 Particle simulation of high coherence score (2018)

If the person is in a state of low coherence, fewer particles fly chaotically in and out from the chest area with randomized and slow dynamics.

Figure 31 Particle simulation of low coherence score (2018)

At the end of the experience, all of the elements within the galaxy gradually dissipate and fade to black. Amid complete darkness, only the gently pounding sound of a heartbeat remains.

Figure 32 Last part of *HeartSpace VR*; Complete darkness accompanied by the sound of the user's heartbeat (2018)

The final part is designed to build a smooth transition from one reality (VR) to another reality (earth) and is inspired by the following quote of Jaron Lanier:

> Virtual reality was and remains a revelation. And it's not just the world external to you that is revealed anew. There's a moment that comes when you notice that even when everything changes, you are still there, at the center, experiencing whatever is present. (Lanier, 2017, 65)

To deepen an understanding of the experiential outline, the following section elucidates the artwork's underlying conceptual aspects.

5.3 Conceptual Outline

The conceptual approach of HeartSpace VR is designed to dissolve culturally learned boundaries and habitual perceptions about the separation between interior and exterior, mind and body in a virtual-self-explorative way. This experience aims to connect the immersed person not merely to a virtual representation but rather to the depths of his or her inner state of embodiment and physical presence within an immersive VR experience. The concept of dominance, violence and control - represented in most current VR games - is replaced by the idea of sovereignty over the self. In traditional VR, the body is often reduced to interact through physical movements and manually based interface techniques such as joysticks and controllers. In *HeartSpace VR*, the activity of the heart acts as the primary interface with the virtual environment. Therefore, the user must become familiar with the concept of controlling the outer environment (biofeedback-informed Virtual Reality) though the inner environment (psychophysiological conditions of the heart). Readings from the literature have indicated that biofeedback artworks can in some cases be too complicated or confusing to understand for the participant (i.e. 'what is heart rate variability?' and 'what does this tell me about the state of my body and my mind?)(Khut, 2006, 190). Therefore, it is very challenging for the visual artist to translate these conditions into imagery to make it intuitive and easy to understand for the user.

The conceptual outline of the acoustic design implies the following semantic equation: 1. The heart is an organ 2. An organ is an instrument. 3. If the user can influence a piece of music with a heart-based interface device, it would indicate that he or she can listen to the heart (organ) whilst simultaneously being the instrument (organ). The VR software solution for this comparison took a pre-built musical composition by Mic Black and altered the music with a lowpass filter[6] in conjunction with the coherence score. The lowpass filter limits the audible bandwidth of the signal and therefore the music becomes more “pristine” or “clear” in high coherence or more “hollow” or “muffled” in low coherence.

The practise of this exegesis was only concerned with the development of a prototype - named *HeartSpace VR*- and issue-related scientific research. However, *HeartSapceVR* has been presented and tested by 15 people as part of the Master Show Case at Griffith Film School on Sunday, October 28, 2018.

Figure 33 A young woman experiencing *HeartSpace VR* at the Master Showcase at Griffith (2018). Nina Rath (second from the left) observing the coherence score in conjunction with the participant’s breathing pattern.

[6] A low-pass filter (LPF) attenuates the music above a cutoff frequency, allowing lower frequencies to pass through the filter.

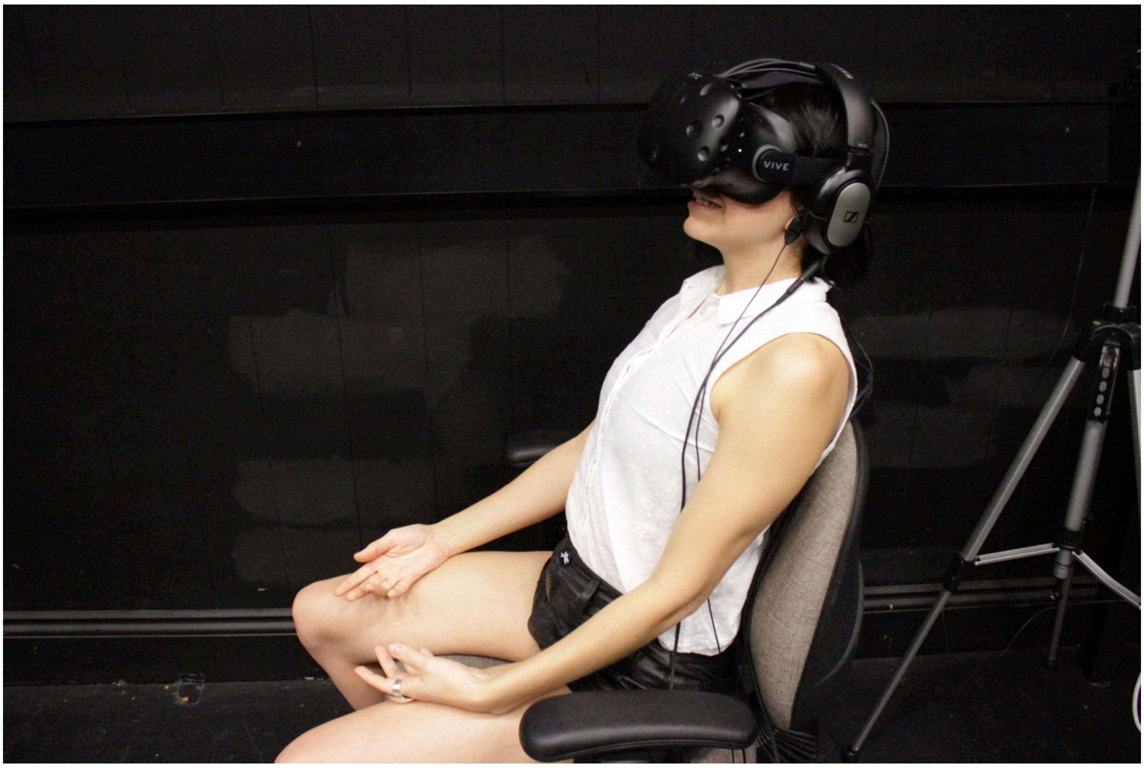

Figure 34 Violate Rodriguez practising deep breathing exercises whilst engaging with *HeartSpace VR* at the Master Showcase at Griffith Film School (2018).

A video recording of Violeta Rodriguez's feedback after experiencing *HeartSpace VR* can be found in Appendix H.

Since the final artwork can only be experienced using emWave® Pro hardware and software, an additional version has been created to review the content on any given HTC- Vive VR-station using an artificial coherence score. Additionally, a two-dimensional screen recording of the experience has been created. Both of these references have been added to the appendices of this exegesis.

6. Conclusion

Due to this exegesis's complex nature, the final section is divided into a research-based and *hunch*-based conclusion.

Research-based Conclusion

The research and artworks documented in this exegesis have provided the groundwork for developing a biofeedback VR experience named *HeartSpace VR*. In combining the conceptual and practical aspects of this exegesis, *HeartSpace VR* can be classified as a non-Clinical, immersive, biofeedback VR experience using abstract visualisation techniques influenced by the user's heart signals in near real-time. This invites the person to think and reason outside of the confined frameworks of sensory awareness and habitual perception. It is important to evaluate these interactive media not merely as externally focused audio-visual artwork, but rather as an extension of one's own intrinsic psychological and physiological conditions. Biofeedback VR experiences, in general, can provide an intuitive approach for visualising and understanding complex forms of physiological data in ways that leave room for personal interpretation and curiosity. They provide an experiential space for embodied enquiry and aesthetically engaging self-exploration. These interactive art practices invite the participant to look at the artwork in a mirror-like self-reflection process, observation, and correlation. They can act as models for understanding and evaluating, internal emotional, physiological and psychological conditions through external audio-visual stimuli.

The maturity of VR hardware and software has drastically increased over the last 25 years and become more affordable and accessible to the general public than ever before. Affordable design tools (e.g., Unity 3D, Unreal Engine) and VR hardware are leading to an enlargement in popularity of VR in schools, universities, companies, independent research institutions and private individuals. Since the financial threshold of working with VR has drastically decreased, the present momentum is inspiring a whole new generation of VR developers to build completely novel VR applications and evoke new ways of looking at the medium itself as well as its content. Technological conditions of VR hardware, software and biofeedback devices highly influence the process of imagining and creating new art practice paradigms. Additionally, the physical, emotional and cognitive capabilities of humans interacting with these artworks have to evolve in conjunction with the technology. The frameworks (i.e., cognitive, physiological, technological, ecological and sociological) by which such artworks are created and perceived have a determining influence on the quality of the experience.

Hunch-based Conclusion

It is challenging for an artistic mind to express itself mathematically. Equally, it is tough for a mathematical mind to translate artistic expressions into Virtual Reality. Good communication is key. Playfulness is a vital part of innovation. Even though something looks simple, it doesn't mean it will be easy. Endurance is more important than mere enthusiasm. It's ok to be different. Just because you are a woman doesn't mean you can't do VR. Ideas come when you least expect them. Originality can't be copy-pasted. VR can be used addictively or consciously. Biofeedback is very complex to understand and even harder to illustrate. It is impossible to understand the human heart in its entirety. There is an ethical contradiction in some VR applications. VR can train people to go to war or treat people coming back from war (PTSD). What counts is the intention behind the experience. A good headset and a good *heart-set* are equally crucial in virtual and mundane reality. What happens after a VR experience is equally important to what happens within a VR experience. The passage is the message. Coherence is what happens when you enjoy more and worry less. Practise-led research is not a linear process. Scientific research is a difficult but necessary process to understand your own un-knowingness. It is unpleasant to be unknowing, but it is important to overcome the fear of not trying. Simplicity is the supreme discipline.

7. Future Directions

Biofeedback VR could become highly relevant in the hospital of the future and healthcare practitioners' general practice. Psychologist and Clinical VR pioneer, Albert “Skip” Rizzo, PhD states, “we strongly believe that clinical VR applications will become indispensable tools in the toolbox of psychological researchers and practitioner and will only grow in relevance and popularity in the future” (Rizzo and Koenig, 2017, 877). Since this exegesis has been written from a screen practitioner/filmmaker's perspective and not from a healthcare practitioner's standpoint, this project can only act as a starting point for aesthetic discussion rather than as a definitive contribution on any healthcare field.

Each aspect of *HeartSpace VR* would need to be re-evaluated and assessed in terms of Clinical accuracy. This work should be understood as a proof of concept for what could be a clinical trial in a healthcare faculty. The physiological and psychological impact on the user would need to be scientifically examined before this experience can become available to the general public or any healthcare sector.

In conclusion, the aesthetic exploration of VR in conjunction with biofeedback can provide a far-reaching and complex learning ground for contemporary screen practitioners and visual artists. It can demonstrate the close links between physical condition, mental activity, emotion, and heart rate variations using immersive media tools.

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Appendices

Appendix A

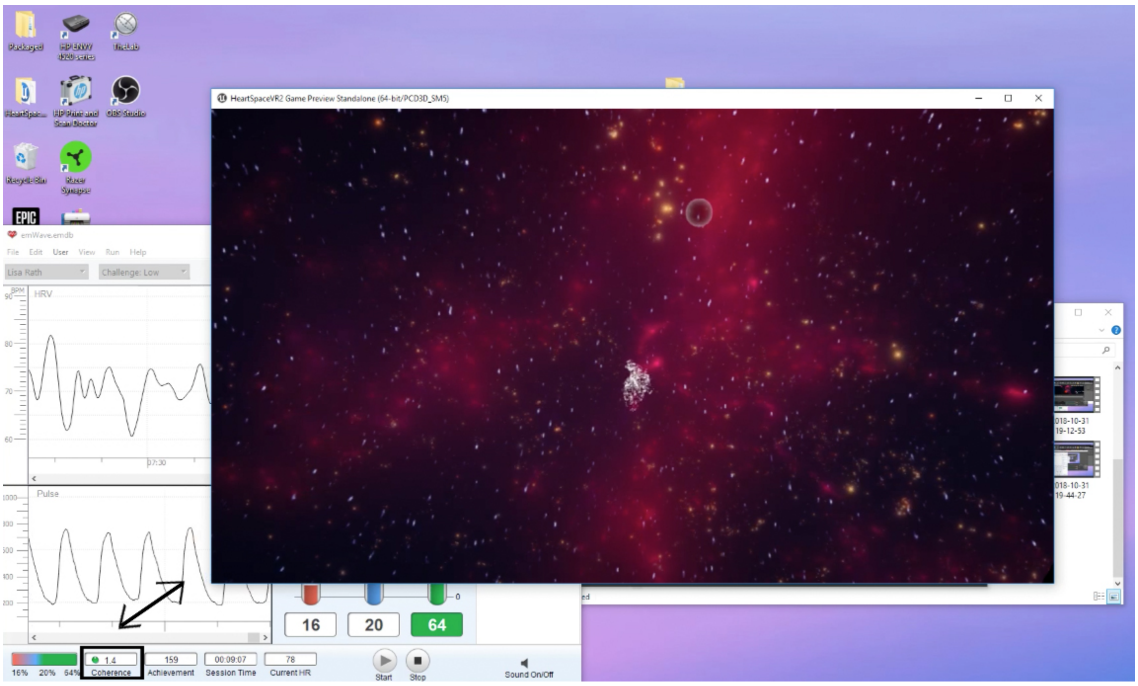
HeartSpaceVR

Please note: Since the *HeartSpace VR* can only be experienced using the emWave® Pro hardware and software, an additional version has been created to review the content on any given HTC- Vive VR-station using an artificial coherence score. To activate that score, please press A on the keyboard to start. When you press A again, the artificial coherence score will stop again.

Appendix B

HeartSpaceVR [Screen Recording]

Please note: To see the correlation between the coherence score and the sounds and visuals, please see the numbers highlighted below.



Appendix C

Interpretation of the data coming from emWave® Pro

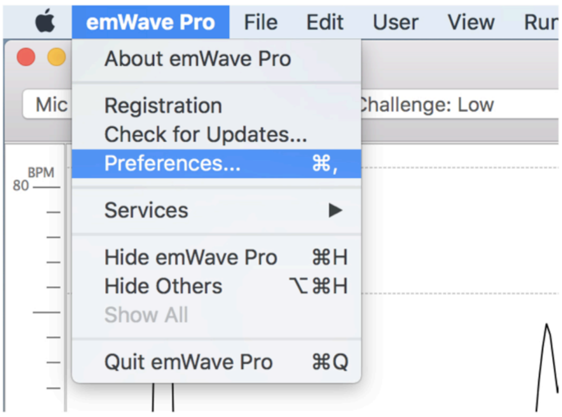
Written by Mike Atkinson from the Heart Math Institute on the 29th August 2018

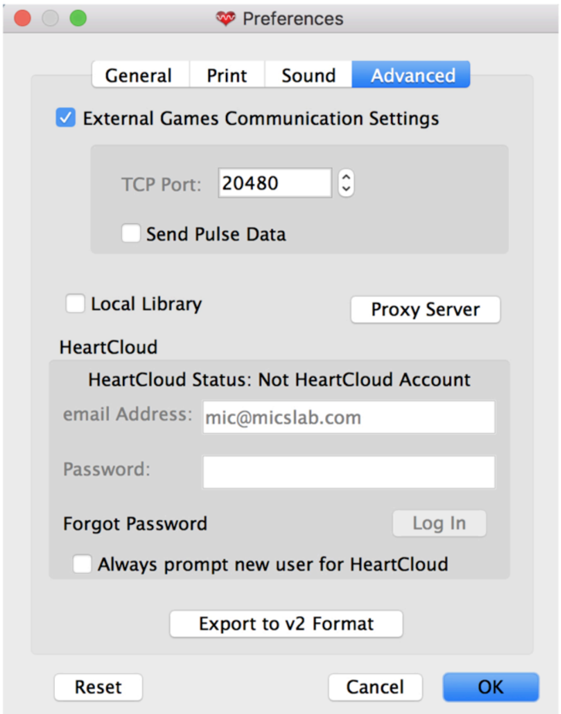
S = is the current "score" a 0, 1 or 2 for low medium or high coherence for the current scoring interval (scoring intervals are every 5 seconds).
S = is based on the users' challenge level setting; each challenge level has two thresholds levels for EP the low/medium and medium/high threshold values.
EP = can be transformed to what we call coherence score (CS) with the following formula. CS is more linear than EP and has a range of approximately 0-15 (but you don't typically see scores passed 7-8 for most people).
CS = log(1.0 + EP/10).
Here is an explanation of other TCP outputs.
IBI = is an interpolation or resampling of the currently measured IBI, resampling rate is 2 per second.
EP = Entrainment Parameter is a computed physiological measure reflecting the coherence level. (Also known as Coherence Parameter). Generally, it is a ratio between power at the coherence frequency in the power spectrum relative to the rest of the power spectrum.
S = Score - a value set to 0, 1, or 2 based on EP passing a certain threshold set by your challenge level (LVL), reflects low=0, medium=1, or high=2 coherence.
AS = Accumulated Score, reflected on the zone graph data. AS is the accumulated sum of S, during low coherence 1 point is subtracted from AS, but **AS** is not allowed to go below 0, it is never negative.
ART = is the artifact flag indicating if the current sample IBI was considered an artifact, either from excursive movement or ectopic heartbeat. Live IBIs are the actual real measure IBI and occur after each detected pulse on their own line of the output.

Appendix D

emWave Set Up

Download and Install emWave Pro software

<table>
<tr>
<td>


</td>
<td>Go to Preferences from the top menu</td>
</tr>
<tr>
<td>


</td>
<td>Enable “External Games Communication Settings” and keep default port of 20480</td>
</tr>
<tr>
<td></td>
<td>Set up a TCP connection to this port from your game engine</td>
</tr>
<tr>
<td></td>
<td>Read the byte array and convert to a string</td>
</tr>
<tr>
<td></td>
<td>Parse the string as XML to get key values</td>
</tr>
<tr>
<td><D01 NAME="Mic Black" LVL="1" SSTAT="2" STIME="572500" S="2" AS="126" EP="29" IBI="777" ART="FALSE" HR="69" /></td>
<td></td>
</tr>
</table>

Example NodeJS code

```
const net = require('net')
const client = new net.Socket()
const opts = {
	ip: '127.0.0.1',
	port: 20480,
	runtime: 60 * 1000 // 0 to run forever
}

client.connect(opts.port, opts.ip, () => {
	console.log('Connected to emWave Pro')
	// client.write('')
})

client.on('data', (data) => {
	console.log(data.toString())
})

client.on('error', (message) => {
	if (message.toString().indexOf('ECONNREFUSED') > -1) {
		console.log('Error: could not find emWave Pro on ' + opts.ip + ':' + opts.port)
		client.destroy()
	} else {
		console.log('Unknown Error:')
		console.log(message)
	}
})

client.on('close', function() {
	console.log('Connection closed')
})

opts.runtime && setTimeout(() => { client.destroy() }, opts.runtime)
```

Appendix E

The Screen Recording of Jonno Ament explaining the background of *HeartSpace VR* in Unreal Engine from a developer's perspective.

Appendix F

Skype Recording of Patrick Hoffman explaining the key areas of his work and the challenges of this project.

Appendix G

Video recording of the emWave® Pro pro test session with Mic Black.

Appendix H

Feedback from Violeta Rodriguez after experiencing *HeartSpace VR* at the Master Show Case at Griffith Film School on 28th October 2018.