Master Thesis

ZenVR: A biofeedback virtual reality experience for assisting meditation

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Abstract:

A virtual reality application utilising biofeedback to assist novice meditators in reaching a deep meditative state, is presented. Using a virtual reality headset, the meditator becomes fully immersed in a virtual forest, with peaceful music and a guided meditation. Biofeedback is based on the user's brainwaves and is mediated through fog in the virtual forest. Through the biofeedback, the user becomes aware of their own state of mind. The brainwaves are obtained through a brain computer interface device measuring EEG signals.
The system is evaluated on 21 subjects, divided in three groups, each with a different condition. Each subject meditated for five minutes while their heart-rate and brain-waves were monitored. Their meditative depth was measured through a questionnaire.
The test shows no significant difference between the three conditions, but indicates that the participants reached a state of relaxation. The proposed system did not assist the user in reaching a deep meditative state, but virtual reality with biofeedback does have potential to be an entertaining, intriguing and novel approach to meditation.

Contents

List of Tables

List of Figures

Acknowledgement

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1 Introduction

In modern times, mental health issues, such as stress, depression and anxiety, have become increasingly prominent elements in our busy everyday lives (Sundhedsstyrelsen, 2018). Accumulating notifications, emails, important deadlines - there is a wide array of factors that contribute to these hazardous psychological disorders. Stress is the most common disorder, and is defined as a reaction to high cognitive load, that the person can have difficulties handling by themselves (Sundhedsstyrelsen, 2018). Stress can be the consequence of a negative life quality and can i.e. increase the chance to get heart diseases.

Meditation has been used for millennia across various cultures to increase mental health, and has lately become an increasingly popular topic in the domain of psychotherapy. Several studies have found indications that meditation can reduce stress, anxiety, depression and various other psychological conditions (Sedlmeier et al., 2012). A questionnaire developed for preliminary research into meditation (see Appendix A), suggests that a lot of people have difficulties learning meditation as well as finding the time or motivation for practicing meditation.

As new technologies facilitate novel and interesting ways to learn - we believe that these technologies can be used to effectively assist meditation practice. Especially virtual reality (VR) is an interesting technology due to its facilitation of highly immersive experiences. VR makes it possible for the user to escape into a virtual world, that can be manipulated above and beyond the boundaries of everyday world (Difede et al., 2007). This technology can be supported by other methods for training and assisting meditation. Biofeedback is a method that has existed for several decades and that researchers and practitioners within the field of psychophysiology, have used to teach patients to modify physiological parameters. In short, biofeedback monitors a user's physiological information and feeds it back to them, thus training them to consciously modify specific physiologic functions, such as body-temperature, respiration or heart rate (Schwartz and Andrasik, 2016), (McKee, 2008). Providing biofeedback within a VR environment is assumed to be helpful in training and assisting novice meditators. Such a system could also make the experience of meditation practice more enjoyable.

This proposed biofeedback VR system will be evaluated through an experimental design. However, before the system and the experiment is developed and designed, related research areas are investigated throughout the analysis. Meditation as a concept is elaborated and biofeedback methods are examined. Furthermore, VR is researched in relation to therapeutic contexts.

2
Analysis

This chapter will describe and analyze the techniques and previous studies, about treatments of psychological disorders with technology. First the results of the preliminary research questionnaire is presented, as the foundation for further research. This is followed by a clarification of what meditation is, and what effect, meditation has on the brain and the cardiovascular system. Biofeedback is investigated as well as a framework for designing biofeedback. Several biofeedback systems uses VR, which is described and researched in the context of therapy. Furthermore, brain-computer interfaces (BCI) are be examined as these could be used as instruments of biofeedback. Finally, these research areas will lead up to the final problem statement, which can be considered the aim of this project.

2.1. The Preliminary Research Questionnaire

As initial research, a questionnaire was developed for preliminary research into meditation and VR. The main research questions, that the questionnaire shed light on was: How many people have meditated before? How often do people meditate? What tools do they use to meditate? What are holding people back from meditating? How many people have tried VR before and how did they feel during the VR experience? The questionnaire also helped suggest aspects of the design, such as the setting of the virtual environment and the duration of the experience. The complete list of responses from the questionnaire can be seen in Appendix A.

The questionnaire was shared on social media where 139 people participated. The age ranged from 21 to 74, with 32 being the average age. Stress seemed to be the most common psychological disorder, as 52 (37,4 %) responded that they had suffered from the condition. It should be noted that the question was formulated the following way: "Have you ever suffered from any of the following psychological disorders?" which means that it does not necessarily has to be clinically diagnosed.

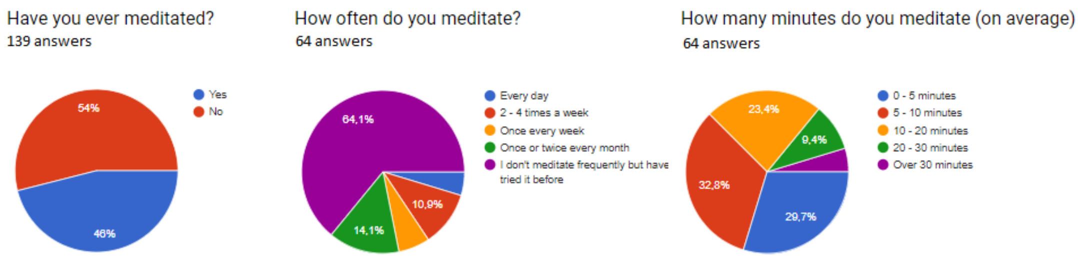

Figure 2.1: Diagrams, showing the answers from the questionnaire. From left: 139 answers on "Have you ever meditated?", 64 answers for "How often do you meditate?" and 64 answered "How many minutes do you meditate? (on average)"

As seen in Figure 2.1, over half of the participants has never tried meditation. Of all the participants who has tried meditation, the most popular answer was "I don't meditate frequently, but have tried it". On average 32,8% meditated somewhere between 5 and 10 minutes and 29,7% meditated somewhere between 0 and 5 minutes. This could suggest that 5 minutes is the most general duration of meditation within the participants. When asked why they started meditating, 15 participants reported it was to help relieve a psychological condition (e.g. stress or anxiety), 15 participants reported it was because of personal gain and 8 started meditating because it was part of a class (yoga or work related).

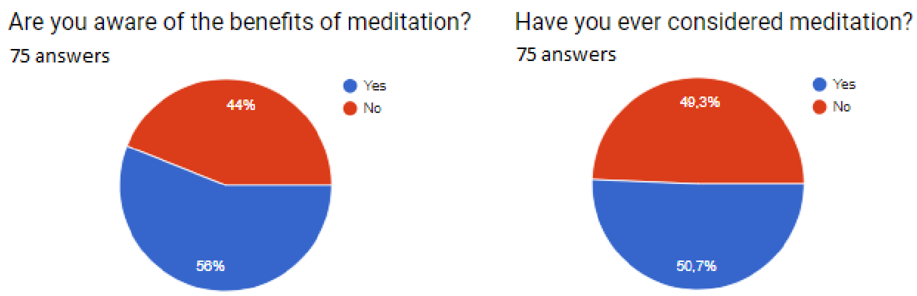

Figure 2.2: The answers from the questionnaire. These questions were asked to the participants, who reported, to not have tried meditation.

The answer distribution for the participants who has never tried meditation, is illustrated in Figure 2.2. The 54% of the participants who had not tried meditation got asked some different questions, including their attitude to meditation and what had held them back from trying it. Exactly half of the non-meditating participants had considered meditating and 56% were aware of the benefits of meditation.

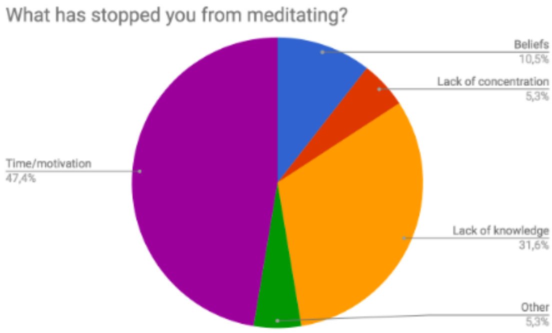

Figure 2.3: The distribution of responses, categorised qualitatively in themes.

The item: "What has stopped you from meditating?" was formulated as a open question, which means that this item provided qualitative data. As seen in Figure 2.3, the data for this item was categorised into three major groups: "time & motivation", "lack of knowledge" and "beliefs". Time & motivation refers to the fact that the participant do not feel that they have time for it or is not motivated to take the first step into meditation. Lack of knowledge reflects that they simply do not know how to get started. Lastly, beliefs refer to the participant not believing in the benefits of mediation, seeing it as a waste of time. Out of the 38 responses to this item, 18 did not have time or motivation, 12 lacked the knowledge to get started and 4 did not believe in meditation. It can be argued that not knowing how to meditate, and not having the motivation or time for it is associated, since it might not be the lack of knowledge that influences their motivation.
As with the above mentioned item, the question "What is your attitude towards meditation?" was also qualitatively analysed through a categorization method. The three main themes in the responses to this question was "Open", "Skeptical" and "Not for me". The item had 37 responses whereas; 7 were open for meditation, 7 were skeptical and did not believe in meditation and 18 were aware of the benefits but did not feel that it was for them. The rest of the responses are categorised as "Other", as they did not reflect any common theme.

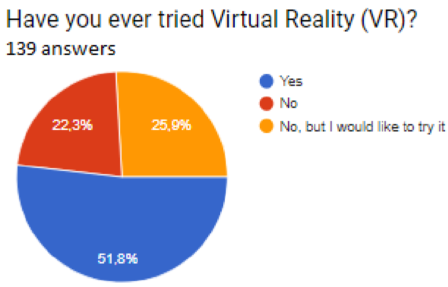

Figure 2.4: The answers to the questions, if the participants has ever tried VR.

Regarding the VR segment of the questionnaire Figure 2.4 shows that, 72 (51,8%) of the 139 participants had tried VR before and 36 (25,9%) had never tried it but would like to. When asked how they felt during their first experience with VR, most of the

responses were positive. This question provided qualitative data, that was categorised as either positive, neutral or negative. Positive responses encompassed answers such as "Curious", "Amazed" and "Excited", whereas negative refers to e.g. "Nauseous", "Dizzy" or "Overwhelmed". Neutral responses refers to e.g. "Fine" or "Nothing special". Out of the 72 participants that had tried VR, 39 had a positive reaction to it, 12 had a negative one, and 9 participants had a neutral reaction.
Their initial experience with VR is presumably shaped by the actual design of the VR experience they tried. Poorly designed experiences can make the user dizzy or nauseous.

The results of the questionnaire suggest, that approximately half of the population has tried some form of meditation, however quite few people (10%) meditate daily or weekly. Most people have tried it to help relieve a psychological condition or simply for improving mental well being. The questionnaire suggests that the main reason people have not embarked this practice, is mostly due to lack of knowledge, time or motivation. This only further supports the need for a novel and efficient way of assisting novice users in meditation.

2.2. The Science of Meditation

Meditation has been practiced for millennia and can be seen as the core ingredient to achieve enlightenment and a sense of pure consciousness in both Hinduism and Buddhism (Sedlmeier et al., 2012). While it is most often associated with India, meditation is a worldwide tradition that has been practiced in all of the major religions and cultures (Walsh and Shapiro, 2006). This chapter will investigate what mediation is, how it works and why people practice it. Furthermore, it will explore the underlying mechanisms that make meditation beneficial to improving mental health.

Walsh and Shapiro (2006) has in their research tried to combine eastern meditative disciplines with Western psychology, as they believe these two major intellectual and practical disciplines can challenge and enrich each other. They define mediation as follows:

"The term meditation refers to a family of self-regulation practices that focus on training attention and awareness in order to bring mental processes under greater voluntary control and thereby foster general mental well-being and development and/or specific capacities such as calm, clarity, and concentration." (Walsh and Shapiro, 2006)

In other words, meditation is a practice of awareness and attention, that promote mental development and specific traits such as clarity, calm and concentration. This definition is formulated by combining Western definitions, that sees meditation as a self-regulation technique, with Eastern definitions that sees meditation as a practice of mental well being, such as bhavana (mental cultivation) in Buddhism and lein-hsin (refining the mind) in Taoism (Walsh and Shapiro, 2006).

2.2.1. Meditation Techniques

An array of different varieties of meditation exists, which mainly differ in the type of attention, the relationship of cognitive processes and the goal of the practice. The most researched meditation techniques are Transcendental Meditation (TM) and mindfulness. Mindfulness meditation is an open focus and awareness technique where internal observation is key. This meditation technique emphasizes on staying present in the moment while maintaining an alert and aware state (Sedlmeier et al., 2012). One of the goals of mindfulness is to allow thoughts to arise and be examined dispassionately, and allowed to fade, without the meditators being emotionally influenced by their contents (Krygier et al., 2013a).
TM is a concentrative technique, where meditators train to rest their focus on a single object, which e.g. can be a mantra, their breath or an image. If the meditators as an example is resting their focus on their breath, the meditators can experience a heightened awareness of how the mind jumps around and they can thereby detach themselves from their thoughts, emotions or actions, simply by returning their focus to the breath.
A third major type of meditation is guided meditation. In this technique, the content of the meditation is regarded as very important, and is attended to in a mindful, rather than a judgemental or analytical way (Sedlmeier et al., 2012). While mindfulness, guided and TM are distinct, it is hard to classify meditation as exclusively belonging to a single class. Basically all meditation practices involve a combination of the techniques. An example is guided meditation, which where the content often has mindfulness themes. While these meditation techniques are the most researched, hundreds of other types of meditation await research (Walsh and Shapiro, 2006).

2.2.2. Mediation & Psychology

Even though a lot of studies have been performed, it has proven difficult to arrive at a psychological theory of meditation (Sedlmeier et al., 2012). This is mainly due to the vast amount of approaches in both Hinduism and Buddhism, and the fact that neither is a psychological theory but rather a religion and philosophy. The fact that meditation has strong spiritual and religious roots, means that adherents to that religion might not be willing to put their religious hypothesis to the test. Nevertheless, numerous studies have been conducted to search for the psychological effects of meditation in attempts to bring together meditation and psychotherapy.

Benson et al. (1974) has investigated the connection between body and mind, through studying meditation. He observed positive changes in metabolism, while subjects were meditating, which included decreased heart rate, respiratory rate and in some subjects, decreased blood pressure level. The meditators consumed 17% less oxygen while meditating compared to a resting state. Furthermore, he also observed the meditators brainwaves and reported that there were more low-frequency waves in the meditative period and fewer of the high-frequency waves associated with normal waking activity Benson et al. (1974). Refer to chapter 2.2.3 for an elaboration of brainwaves and their function. He suggested that this is due to a unique state of relaxation called the relaxation response - that is the opposite of the fight-or-flight response often associated with stress. While Benson's findings were striking for that time-period, they do still not support a comprehensive theory of meditation and they do not clarify the underlying mechanisms that elicit these changes to the metabolism.

As most other meditation researchers, Walsh and Shapiro (2006) report that the current literature suggests that meditation can have significant therapeutic and psychological benefits. However, they do also express that most meditation studies suffer from conceptual and methodological limitations. These limitations include small sample sizes, suboptimal control and few randomized controlled trials. Furthermore most studies do not explicitly state which type of meditation that was used or fail to mention other details about the meditation that was used. Sedlmeier et al. (2012) have in their meta-analysis found that meditation has a substantial impact on psychological variables (e.g. stress, self-realisation, state anxiety, negative emotions etc.), and that it especially has a stronger impact on negative emotional variables than the cognitive variables. However, they do acknowledge that, due to a lack of a comprehensive theoretical approach, the specific effects are not fully clear, and even less so, the mechanisms that yield the effects.

The studies mentioned above, all suggest that meditation can have significant therapeutic benefits. Stress has become a common psychological disorder in Western society (Eurofound, 2010), and meditation could be a strong contender to relieving stress and in general promote mental well-being. However, the studies also highlight the complexity of mediation, the vast amount of techniques which all have different psychological effects and benefits.

2.2.3. Neurological Effects of Mediation

Since the 1960's, multiple studies have been conducted that aims to measure the effect meditation has on the brain. One method of measurement is electroencephalography (EEG), which outputs quantitative data about brain waves. EEG is a powerful tool to reflect both the normal and abnormal electrical activity of the brain, within the field of neurology (Teplan, 2002).
EEG is a non-invasive procedure, where electrodes are placed on the head scalp, that records large populations of active neurons that generates electrical activity. Local current flows are produced when brain cells are activated. Only large populations of active neurons can generate electric potential, strong enough to be recorded (Teplan, 2002), (Schwartz and Andrasik, 2016). Because of the procedure being non-invasive and painless, the technology is widely popular and is used for studying the brain organization of cognitive processes, such as perception, memory, attention, language and emotion, in both adults and children (Teplan, 2002).

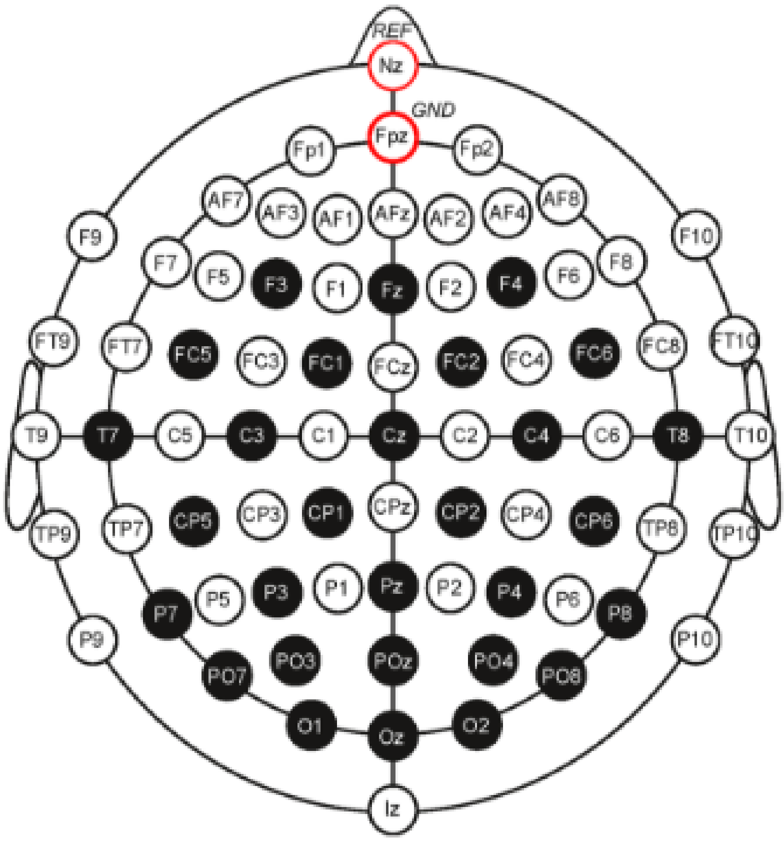

Figure 2.5: Electrode channels on a human head, seen from above. Each circle represents the placement of an electrode. Image obtained from ResearchGate (2018)

Figur 2.5 shows the placement of EEG electrodes, when measuring brainwaves. The system is called the international 10-20 recording system. Schwartz and Andrasik (2016) points out, that the number of electrodes and which ones to use, is highly depended on the research question.

The brainwaves are categorized into four basic groups: Alpha (8-13 Hz), Beta (>13 Hz), Delta (0.5-4 Hz) and Theta (4-8 Hz) (Teplan, 2002). The alpha wave is most dominant during relaxation or by the phenomenon of ”eye closing”. Alpha activity is often related to a wake resting state and is often seen in tests investigating the effect of meditation on the brain (Teplan, 2002), (Schwartz and Andrasik, 2016), (Cahn and Polich, 2006), (Aftanas and Golocheikine, 2001).
Beta waves are dominant during the normal state of wakefulness with open eyes. Delta and theta corresponds to deeper sleep, where higher proportions of slow delta waves are dominant. Theta has also been found to be most dominant in a deep meditative state (Aftanas and Golocheikine, 2001). While alpha activity is increased when relaxing, several studies have found that theta power is increasing, for experienced meditators (Cahn and Polich, 2006), (Kubotaa et al., 2001).

In a review of multiple neuroelectric and imaging studies of meditation, Cahn and Polich (2006) have found that there is a correlation between meditation and an increase in alpha and theta power. They investigated and compared 64 different studies, which uses different types of relaxation, meditation and yoga techniques. Their findings suggest that meditators compared to non-meditators have better control of their theta and alpha power, which may be related a specific meditative technique and a slower baseline. It is difficult to conclude anything from their review, other than theta and alpha activity is affected by meditation. More specifically, the review suggests that alpha and theta power is increased and frequency in the alpha band is decreased, during meditation. There seems to be high variations in their results which could be due to several factors, including the fact that meditation refers to an array of different techniques all having slightly different effects on the brain (Cahn and Polich, 2006).

2.2.4. Cardiovascular Effects of Meditation

The phenomenon of heart rate variability (HRV) has also been investigated during various meditation exercises. HRV is a sophisticated physiological measurement that reflects the modulation of the autonomic nervous system (ANS) on heart rate. It can, inter alia, underpin an individual's capacity to regulate their emotion (Krygier et al., 2013b). In short, HRV represents the beat-to-beat changes in heart rate (Wu and Lo, 2008). These changes are identified by looking at the interbeat intervals (IBI), which are the intervals between successive heart beats.

The variations of heartbeats can be analysed through a number of methods. In time domain methods, heart rate or the intervals between successive normal complexes, are determined. Some of the simplest time domain variables that can be calculated include the mean heart rate and the mean normal-to-normal (NN) interval. "Normal" refers to the fact that abnormal beats, such as ectopic beats, have been removed (Shaffer and Ginsberg, 2017). Some of the more complex calculations include the standard deviation of the NN intervals (SDNN), the standard deviation of the average NN intervals (SDANN) and the square root of the mean squared differences of successive NN intervals (RMSSD). The conventional short-term recording standard is minimum 5 minutes, however researchers have proposed ultra-short term recording periods ranging from 60s to 240s. The RMSSD can be calculated from ultra-short term recordings of 10s, 30s and 60s (Shaffer and Ginsberg, 2017).

Another way to analyse HRV data is through frequency domain methods. The periodic components of heart rate variability tends to aggregate at different frequency bands; mainly the high frequency (HF) band (0.15 - 0.4 Hz), the low frequency (LF) band (0.05 - 0.15 Hz) and the very low frequency band (0.003 - 0.04 Hz) (Berntson et al., 1997). These frequency domain measurements are usually measured in absolute or relative power, which is the signal energy found within a frequency band (Shaffer and Ginsberg, 2017).

Lehrer et al. (1999) found that respiration rates fell during a Zen breathing meditation for experienced meditators. Furthermore, total HR oscillation amplitude and power in the LF band increased, suggesting a shift in the respiratory sinus arrhythmia (RSA) towards lower-frequency waves. This research mainly focused on Zen meditation techniques involving slow breathing relative to a normal breathing condition during a resting baseline. During inward-directed attention meditation tasks, experienced meditators exhibited increases in normalised HF power and decreases in the ratio of LF to HF power (Wu and Lo, 2008). Similar patterns also emerged when novices performed a mindfulness breathing task and were compared to a control group who performed the same paced breathing (Murata et al., 2004).

The above mentioned studies highlights that there is a strong connection between meditation and the autonomic nervous system. The effects of meditation can be observed through HRV, although they differ from technique to technique. HRV can either be used to provide biofeedback, or it can be used to evaluate whether the user of the system has reached a certain meditative level, as an increase in normalised HF power would suggest this. The time-domain variabel: RMSSD has been proven to be highly correlated to the HF power (Shaffer and Ginsberg, 2017), which suggests that this value could show the cardiovascular effect of meditation. However, this data by itself is not sufficient as an indicator. It would need to be triangulated with other data as the autonomic nervous system is a complex entity that can be influenced by several factors.

2.3. Biofeedback

2.3.1. Biofeedback Methods

Biofeedback refers to a process of monitoring a user's physiologic information and feeding it back to them, thus training them to consciously modify specific physiologic functions (McKee, 2008). The term was coined in the late 1960s but describes laboratory techniques that was developed in the 1940s, where subjects learned to modify heart rate, blood flow and other physiological functions through feedback. A wide array of instrumentation can be used for biofeedback, where surface electromyography (EMG) is one of the most common (McKee, 2008), (Schwartz and Andrasik, 2016). Others include respiration rate, cardiovascular reactivity (blood pressure and heart rate), electrodermal response (EDR) and electroencephalographic response (EEG). EEG biofeedback, also known as neurofeedback, is a specialty field within biofeedback, which devotes itself to train people to gain control over electro-physiological processes of their brain (Yucha and Montgomery, 2008). This approach has especially been studied in the context of mental disorders such as attention deficit disorder, depression and anxiety.

According to McKee (2008), four conditions are important for effective learning through biofeedback, the user must; have the capacity to respond, be motivated to learn, be positively reinforced for learning and lastly, be given the accurate information about the results of the learning effort. While the design of the feedback is only limited by the designer's creativity and technical capabilities, there are certain learning models within biofeedback that can be used as frameworks. The direct feedback learning model tries to encompass the four above-mentioned learning conditions, thus resulting in the user gaining control of the targeted physiological variable. This means that the users must always see their physiological information and be able to change this through direct interaction. Their efforts must furthermore be positively reinforced, when improving their physiological responses.
Another model, which McKee (2008) refers to as the therapeutic/stress-management/ biofeedback model, treats each patient on a more individual level. This approach starts with a psychophysiological assessment, which can be done by measuring relevant physiological data. It is then followed by an imposition to stressors and lastly by a recovery period in which rate and extent of recovery are measured. A stressor is a method of measuring reactivity to stress (Schwartz and Andrasik, 2016). In addition, an interview is used to help determine the psychological vulnerabilities of the patient. While this method might work well in therapeutic contexts, it seems less generic, due to the necessity of a professional psychotherapist facilitating the process. The patient will not necessarily learn to manipulate their physiological variables, through direct feedback but rather through the interpretations of the facilitator/therapist.
It seems appropriate to design the biofeedback using direct learning feedback when using VR technologies, since this model only needs a facilitator to the extent of explaining the equipment and its use.

However, it is still worth considering whether the biofeedback should be mediated to the user through an explicit or implicit feedback loop. Kuikkaniemi et al. (2010) states that biosignals can be divided into explicit and implicit systems. In explicit biofeedback systems the purpose is to provide clear and easily perceivable information, thus making the subject more aware of their physiological processes.
In the system of implicit biofeedback the subject also becomes aware of their physiological processes, but on a more subconscious level. In this concept, the system modulates its behavior according to the biosignals of the subject, thus learning them to indirectly manipulate the system. Implicit biofeedback is quite similar to the notion of affective feedback, where an environment or a system adapts according to the user's affective reactions.
The choice of an explicit or implicit feedback system seems to rely partly on the instrumentation used. The more direct biosignal instruments (such as respiration and EMG) can be explicitly mediated in the virtual environment, since most users already have a conscious control of how they breath and activate their muscles. In the case of neurofeedback (using EEG), implicit feedback might be a better choice since most users do not have direct conscious control of their brainwaves. The goal of the system could also be to blur out the line between explicit and implicit feedback. By

providing implicit feedback to the user that they familiarize themselves with and learns to manipulate, the implicit will gradually become explicit.

2.3.2. Double Bind Theory

Before designing the biofeedback it is important to familiarize oneself with the double-bind concept, as it might have a crucial impact on the success of the system.

The double bind concept was first described by Bateson et al. (1956), as a situation in which no matter what a person does he can not win. In his behavioral study he hypothesizes how a person caught in the double bind situation may develop schizophrenic symptoms. He defined the necessary ingredients for the double bind as follows:

1. The situation involves two subjects, where one of them is designated as the "victim".
2. The double bind is a repeating experience and cannot be resolved as a single traumatic experience.
3. A primary injunction is imposed on the victim by either: (a) "Do not do X, or I will punish you" or (b) "If you do X, I will punish you".
4. A secondary injunction that conflicts with the first on a more abstract level, e.g. "Do not think of what you may do" or "Do not see this as punishment".
5. A tertiary injunction prohibiting the victim from escaping the situation (this injunction might already be reinforced by the two other injunctions).
6. Finally, the complete list of ingredients may be unnecessary if the victim already perceive reality in double bind patterns.

Any part of the sequence might be sufficient as the conflicting injunctions may be taken over by thoughts or hallucinatory voices. This sequence describes how the double bind occurs, which in other words is by two conflicting demands, each on a different logical communicative level that cannot be ignored or escaped.
Bateson et al. (1956) further states how metacommunicative messages may help one escape the double bind (by either questioning the injunction or commenting on the victim's position). He also mentions a Zen Buddhism analogy, where a Zen master is telling a student: "If you say this stick is real, I will hit you. If you say it is not real, I will hit you. If you do not say anything, I will hit you". The student then goes on to take the stick away from the master, which accepts this response, as the student has freed himself from the double bind situation by distancing himself from it. This can be seen as the overarching goal of mindfulness - to distance yourself from your thoughts, actions and emotions and observe them from a deeper level (Krygier et al., 2013a). The Zen Buddhism analogy can be seen as a way to escape the double bind, however as Bateson et al. (1956) states: *"[...]the schizophrenic has no such choice (unlike the Zen student) since with him there is no not caring about the relationship, and his mother's*

aims and awareness are not like the Master's."

When designing biofeedback it is of utmost importance to consider the double bind, in order to avoid the user being stuck within this vicious circle. The primary injunction, in our case, would be the biofeedback, informing the user what their meditative state is. The secondary injunction is the goal of the system - the "demand" that the user should achieve a deep meditative state. The biofeedback system must be carefully designed so it does not conflict with this demand, e.g. by contributing to accumulative thoughts - making the user unable to focus their attention and distance themselves from their thoughts.

2.3.3. Biofeedback & Meditation

Kosunen et al. (2016) has developed a system that uses neurofeedback and VR in a meditation context. The goal of this system was to invoke a feeling of presence and relaxation in the user. Utilized by the Oculus Rift DK2 head-mounted display, the user is seeing a tropical island paradise. The user is surrounded by an energy bubble that gets more opaque as the user relaxes. The application provides two modes of meditation practices: body scan and focused attention. Both of these practices use a graphical user interface (GUI) to guide the meditation. In the body scan practice, the user sees a transparent, androgynous human figure, that highlights the body parts the user is supposed to give attention. In the focused attention practice, the user can see five balls floating in the air, next to each other. The user is supposed to focus on one of the balls, being highlighted.
To create the neurofeedback, Kosunen et al. (2016) have created an algorithm that is based on the theta and alpha brainwave activity. By taking the mean of theta and alpha from six electrodes, they can generate a stream of real numbers for both theta and alpha activity.
In their evaluation of the system, they had a sample size of 43 participants, each of them lasting between 2 - 2.5 hours. There were three conditions in the experiment: A) head-mounted display. B) biofeedback. C) computer screen.
A baseline recording of 5 minutes was done to familiarize the participant with the recording apparatus. After recording their baseline the participant would perform 6 meditation exercises, each lasting 10 minutes. Between each exercise, there was a 3-minute memory task for evoking stress.
After the experiment, the participant would fill out a Meditation Depth Questionnaire (MEDEQ) (Piron, 2001) and a ITC-sense of Presence Inventory (ITC-SOPI) (Lessiter et al., 2001). The ITC-SOPI measures four facets of a media experience that are related to presence, where the MEDEQ measures meditative depth within the experience.
The results showed that the combination of neurofeedback and head-mounted display produced the highest level of presence, followed by the head-mounted display without biofeedback. The screen condition got the lowest level of presence. Kosunen et al. (2016) do not explicitly try to define presence, but measure it through the ITC-sense of Presence Inventory. The combination of neurofeedback and VR showed a deeper

meditation level, compared to the conditions without VR or neurofeedback.
By the work of Kosunen et al. (2016), it is shown that the combination of VR and neurofeedback has a positive effect, when meditating, towards the feeling of relaxation. The way they have designed RelaWorld by using VR provides interesting inspiration for the design of our system, as it seems that, their outdoor and calm design has a great impact on the experience.

Harris et al. (2016) aimed to decrease the frequency of anxiety disorders among children in the United States of America, through their VR and biofeedback application, DEEP. A well-validated technique, is diaphragmatic breathing (DB) to help people to relieve stress and tension. DB is deep breathing in the diaphragm muscle, placed under the rib cage (Troyer and Estenne, 1984). The virtual environment of DEEP is situated under water, where the user can move around and explore a highly aesthetic fantasy world. The user moves in the virtual environment through their breath. The breathing is measured by using a resistor/stretch sensor, that the user is wearing around their stomach. The breath is visualized as a ring in the VR world, that is expanding when the user is inhaling and decreasing when exhaling. DEEP was tested on 86 children, and the data that was collected was, observation of players behaviour, breatings and rating on a Likert-scale for describing the experience. The results of the Likert-scale indicated that the experience was relaxing. Furthermore, they found a significant decrease in state-anxiety when comparing scores from before and after the experience. They measured state-anxiety using the State-Trait Anxiety Inventory for Children (STAI) (Harris et al., 2016).
Another study involving DEEP was made in 2017, where the application was tested on 72 university students. The participants was exposed to a stressor, about preparation for public speaking, and would subsequently answer the Physiological Arousal Questionnaire, measuring their level of arousal. After the preparation, the student would play DEEP for 10 minutes and then answer questions about the feelings afterwards. Finally, the participants had to rate DEEP on a scale from 1 -10. The test showed an indication of the stress level being successfully reduced, as there was a significant decrease from before to after, playing DEEP. On the scale from 1 - 10 the mean score was 7, and most of the student did not feel any sickness.
Furthermore, the article provides recommendations for future implementations within the field of biofeedback as a game. They describe the importance of self-efficacy, and how this element has a great impact on the experience. The user must believe that they will be able to control and manipulate the biofeedback, and that they gradually progress in efficacy. However, they point out that self-efficacy and self-regulation in biofeedback technologies should be investigated further in future studies, as it can be designed in a way that has positive therapeutic outcome (Harris et al., 2017).

A lot of inspiration can be drawn from the design of DEEP, as it is a quite aesthetic and relaxing biofeedback experience. Although the fact that the user's breath dictates their movement within the environment might be a design issue, as their curiosity could lead the user to breath in a way that is counterproductive to their relaxation. However, the expanding and contracting circle provides the user with a clear and explicit biofeedback display, that can help them become more aware of their own breath.

2.4. Virtual Reality

Virtual Reality (VR) is defined as a computer-simulated, multi-sensory environment where the user experiences telepresence. Telepresence is the feeling of being present in an environment that is generated by a communication medium such as a computer or a mobile phone. In the context of VR, telepresence occurs when the user feels present or fully immersed in the VR environment and instead loses awareness of being present in the real world (Pierce and Aguinis, 1997). Parisi (2016) describes the goal of VR as follows: ”Virtual reality has one goal: to convince you, that you are somewhere else. It does this by tricking the human brain - in particular, the visual cortex and the parts of the brain that perceive motion.”

The idea of VR is not new. The first attempt on developing stereographic head mounted displays (HMDs) is from the 1960's by Sutherland (1968). Their objective was to surround the user with displayed three-dimensional information. They used a homogeneous coordinate representation, which made them able to display objects which appear close or infinitely far away from the user.

One of the goals of VR is to make the user feel present in the virtual environment, meaning the user acts and feels as if they actually is in that virtual world. To enhance the feeling of being present in the virtual world, the user's visual sense should be surrounded by three-dimensional visual information (Jiwon Lee and Kim, 2017). VR is a medium to facilitate high emotional engagement by enhancing the users imaginative and memorial capacities with a visual and auditory virtual experience. It can provide the possibility to manipulate the limitations of the everyday world (Difede et al., 2007). Within several domains, this immersive VR technology is currently being used. The U.S. military and aerospace programs are using simulated VR cockpits for training pilots and astronauts. The medical field is also using VR to simulate the situation of surgical operations, in order to train surgeons (Pierce and Aguinis, 1997).
In 1992, the most advanced and high resolution, full color HMDs cost nearly $1,000,000 (Pierce and Aguinis, 1997). Today, the devices are getting cheaper and more convenient. The gaming industry is progressively expanding with more VR games within different genres such as horror or games for rehabilitation. Parisi (2016) describes VR as a platform with endless possibilities; from gaming and cinema to architecture, education, training and medicine. He points out that:
”Even though it has a long way to go, virtual reality appears poised to become the next major entertainment medium, and perhaps even the computing platform of the future.”

Several large companies have developed popular VR equipment for the consumer mar-

ket. Some of the most popular HMDs for desktop VR, are Oculus Rift by Facebook and HTC Vive by Valve (Parisi, 2016). They both have motion tracking, handheld controllers and they both have a resolution of 1080 x 1200 per eye (vive.com, 2018), (Oculus.com, 2018). Through a partnership with Samsung, Oculus technology has developed Gear VR. Gear VR is a custom headset, where a mobile phone is attached. Currently the headset is compatible with Samsung smartphones from the S series, which has VR support. Using the Samsung S7 smartphone, Gear VR provides a resolution of 1280 x 1440 per eye (Parisi, 2016).
In 2014, Google introduced the Google Cardboard: a simple, low-cost way of experiencing VR, consisting of two lenses and thick paper. Users are claiming that the VR experience is not as immersive as the Rift or Vive, but according to Google, over one million Cardboards has been sold within the first year. Google has later developed Google Daydream as a high-end solution, which is a headset for mobile phones, made out of fabric, for a comfortable design. Daydream supports most smartphones, and not only their own Google Pixel.

While Google Cardboard and Samsung Gear VR, does not have the same computational power or high-end graphics as the Oculus Rift or HTC Vive, they do offer a cheaper, accessible and convenient alternative. As long as you have an Android phone you can basically use it whenever and wherever you want. As the desktop VR HMDs needs to be setup to a computer - and a rather powerful computer that is, it does make them less convenient.

2.4.1. Challenges with VR

A well-known problem when designing virtual reality applications, is the feeling of motion sickness (also known as simulator sickness) for the user. The symptoms varies from person to person, but are reported to be dizziness, nausea, loss of balance, sweating, and in some cases even vomiting. The symptoms can stick for days and can impact the performance of a person in the real world (Kortum, 2008). Reasons for motion sickness within VR, can be low update rate, high latency/lag, display flicker or even the weight of the headset (Kortum, 2008). Motion sickness can also be obtained if there is a mismatch in sensory information, e.g. if the eyes are telling the brain that movement is occurring, but the vestibular sense tells the brain, that there is no movement. Measurements of user comfort, can be made subjectively, using questionnaires or rating scales (Bowman et al., 2005).

Motion sickness should be kept in mind when designing the application. There should be a congruence between the sensory information displayed in the virtual environment and the sensory information perceived by the user. Too rapid movement should be avoided and the audio within the environment should be in congruence with the visual environment.

2.4.2. Virtual Reality Exposure Therapy

Experimentation with VR for treatment of psychological disorders and physical pain, has been a popular topic for several years. The method is called Virtual Reality Exposure Therapy (VRET) and has been used for treatment of stress and anxiety (Harris et al., 2017), but also the fear of height, flying, claustrophobia and even spiders (Difede et al., 2007). These treatments includes a confrontation with the specific situations, because a common reaction to these phobias, is the avoidance of the concerned stimulus (Difede et al., 2007).

VRET has been used for treatment of Posttraumatic Stress Disorder (PTSD) (Difede et al., 2007), where the patient often is exposed to the situation that caused the disorder, e.g. war or terror. The advantage of VR is that, there is no risk when the patient returns to the feared environment, compared to if they were going to return to a war (Difede et al., 2007). In a study of VRET's effect on people with PTSD caused by the World Trade Center attacks on 9/11, VR showed a significant decline in CAPS score (Clinician-Administered Posttraumatic Stress Disorder Scale). The experiment suggests that VR is an effective treatment tool. The range of symptom reduction within the participants ranged between 25% to 90%. It even showed that the effect of VRET was maintained after a six-month follow-up (Difede et al., 2007).

In an experiment on the effect of VRET for children with major burn injuries, an application called SnowWorld (Sharar, 2006) was tested. Sharar (2006) states that physical pain is perceived less intense, when the patient is distracted while in pain. The VR application SnowWorld was designed for patients who tends to think about the traumatic event, where the burn happened, during wound care. The virtual environment illustrates an icy and cool world with various animated objects and characters, which is the direct opposite of the unpleasant memories from the burn injury. During wound care, the patient will interact with the snowy world by visually targeting and shooting at snowmen, igloos and animals, with snowballs by pressing the spacebar on a computer keyboard. The test showed significant reductions, when using SnowWorld, in pain-related brain activity (Sharar, 2006).
VR is also utilised in the context of meditation. RelaxVR (Alsina-Jurnet, 2018) is an application with several environments the user can choose between. The environments are recorded with a 360 degree camera, so the user can choose to be at their relaxing place, e.g. a beach, a forest or over the skies. The video is supported with calm, soothing music and a guided meditation. The purpose with the application is to help people cope with stress and anxiety. The application has not yet been scientifically evaluated, so it has not been investigated whether it actually helps in this regard.

While other applications exist that are similar to RelaxVR in their aim (ProvataHealth, 2018), (FloatGuruVR, 2018), they have also not yet been scientifically evaluated by empirical data. This might be due to the complexity of meditation. It is not a straightforward variable to measure, and it might not even be possible to achieve the same meditative depths with VR as without. However, it is believed to be a more entertaining and intriguing method of learning and assisting meditation for novice meditators, due to its facilitation telepresence and immersive, multisensory environments.

2.5. Brain Computer Interfaces

Many techniques that measure brain signals exists, both invasive and non-invasive. While the invasive techniques are more accurate and produce less noise in the data, they are not suitable for mobile applications for healthy users (Hassib and Schneegass, 2015). Non-invasive techniques, which include functional near infra-red spectroscopy (fNIRS) and electroencephalography (EEG), have recently made the transition of being high complex lab-only devices to mass market products. The new brain computer interface (BCI) devices have increased ease-of-use and many are using bluetooth connectivity and batteries, which makes the devices able to be easily connected to a computer or a mobile. Although the devices have been made commercially available for the public, they are still primarily used in labs rather than everyday life (Hassib and Schneegass, 2015). Common for all of them is that they measure electrical impulses, generated by brainwave activity with sensors placed on the head. This data is then transmitted via bluetooth to a computer, allowing the user to see their brain activity in real-time.

	Emotiv EPOC+	Muse	Neurosky MindWave	Myndplay Brainband
Chip	Emotiv	InteraXon	TGAM Neurosky	TGAM Neurosky
Electrodes	14 (+2 ref) wet	4 (+1 ref) dry	1 dry	1 dry
Battery	6h	5h	8h	8h

Table 2.1: A comparison of the most common consumer BCI's, their EEG chip type, their number of electrodes and battery.

As seen in Table 2.1, the Emotiv EPOC+ is the most complex BCI headset, as it measures 14 channels (AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4), as well as two reference channels (P3, P4) (Emotiv, 2018). Refer to Figure 2.5 in section 2.2.3 for an overview of the location of EEG channels. The Muse is the second most complex BCI device, as it measures five EEG channels: TP9, AF7, AF8, TP10 and the reference: FPz, through dry sensors (Muse, 2018). The Myndplay Brainband is the most simple as it only measures a single EEG channel (FPz) using a dry sensor and two reference sensors on the ear (MyndPlay, 2018). This BCI device is very similar to the Neurosky MindWave device, as it essentially consists of the same hardware. Both of these devices measure EEG signals and calculates eSense$^{\text{TM}}$ meters (NeuroSky, 2018a), which are values representing meditation and attention, through proprietary algorithms (NeuroSky, 2018b). All of the BCI devices can be seen in Figure 2.6.

Figure 2.6: The most common used BCI devices.

When choosing a BCI device for the system one thing needs to be kept in mind. It needs to be compatible with a VR headset. Since the VR headset already takes up a lot of space on the head, the BCI device needs to be as small and discreet as possible. This makes the Myndplay Brainband the obvious choice, which also means that the eSense™ meters provided by Neurosky can be used. However, due to these values being proprietary, the developers are non-transparent, in the sense that they do not explain how their mediation and attention values are calculated. This means that we cannot know how valid these measurements are and if they in fact measure what they claim they measure. Another consideration is that meditation is defined by Walsh and Shapiro (2006) as, inter alia, a training of attention. This means that meditation and attention might be very close related although it does not seem like this is the case in the eSense™ meters. The calculated value for meditation might be more related to relaxation. Henceforth, the Myndplay Brainband device is simply refered to as Myndplay.

2.5.1. Validation of eSense Meters

To gain more insight into the calculation and the validity of the eSense™ meters (attention and meditation) a small experiment was conducted, with 15 participants. The experiment followed a within group design and had two conditions:

A) The participant takes 10 deep breaths with closed eyes.

B) The participant had five minutes to solve a mid-level Sudoku.

Condition I	Condition II	Condition I
10 deep breaths with eyes closed.	A mid-level sudoku in five minutes.	10 deep breaths with eyes closed.

Table 2.2: A schematic overview of the experiment.

As seen in Table 2.2, the participant first completed condition I, then condition II and then did condition I again. In order to elevate cognitive load during condition II, the test conductor would let the participant know when there were three minutes left and once more, when there was one minute left.

During the experiment, data was recorded from the Myndplay device and logged to a .csv file. The participants were not told about the Sudoku until after the first 10 deep breaths, in order to make the change from condition I to II more prominent in the data. The hypotheses developed for the experiment are as follows:

H_0: *There is no difference in the meditation means between condition I and II.*
H_1: *There is a difference in the meditation means between condition I and II.*

Results of the MyndPlay validation test

All 15 participants completed the whole test.

	Condition I	Condition II	Condition I	P-value
Meditation	64,06 ± 17,84	56,0 ± 10,06	68,73 ± 7,68	0,034
Attention	48,37 ± 15,48	51,35 ± 16,82	47,02 ± 10,96	0,727

Table 2.3: The mean and standard deviation of the meditation and attention level on the scale from 0 - 100, for each condition.

Besides calculating the mean and standard deviation, as seen in Table 2.3, an Anderson-Darling test is conducted (I = 0,47, II = 0,21, I = 0,24) showing a normal distribution. The Levene test (p = 0,026) shows a low variance and indicates a rejection of the H_0 hypothesis. An One-Way Independent ANOVA test is performed, showing a significant difference (p = 0.034).

For each test subject, the data has been plotted to illustrate the difference in attention and meditation in the conditions. Attention and meditation are measured on a scale from 0 - 100.

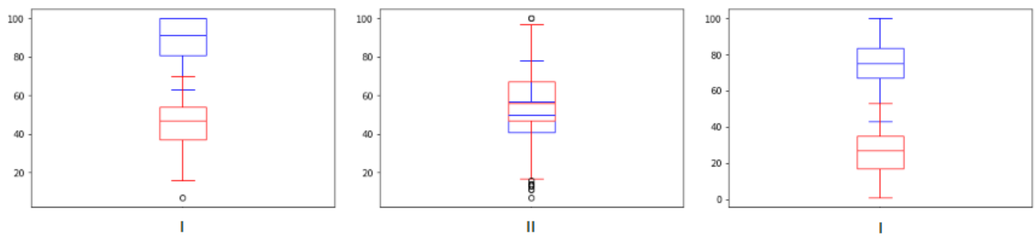

Figure 2.7: Data from one test subject, on the scale from 0 - 100. Red is attention, blue is meditation. The middle of each box shows the mean of the values obtained during each condition.

In Figure 2.7 the graphs shows that the mean during meditation is higher for condition I, and the mean for attention is higher during condition II.

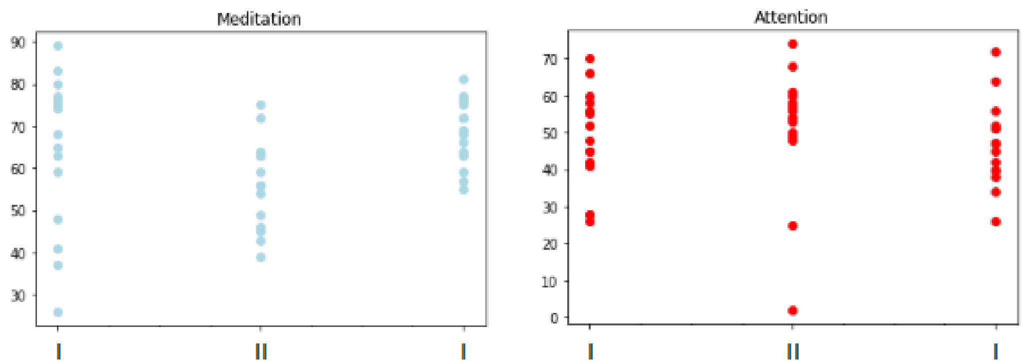

Figure 2.8: All test subjects, plotted in the two graphs. Each dot represents the mean of each condition from each subject.

Figure 2.8, shows that the meditation and attention values are closely related, but there is divergence between the two states for each condition. Meditation is higher than attention during condition I, while attention is higher during condition II.
As can be seen in Figure 2.8, the participants' meditation value during the first exposure to condition I has a very high variance. This can be caused by the uncertainty of what is about to happen. Some participants might have been quite relaxed while others might be excited to participate.
The results indicate that the values do measure what they claim to measure - at least to a certain degree. The significant difference found in meditation, between the two conditions, suggests that it measures relaxation, since the participants were not meditating but rather relaxing. It should be noted that relaxation is quite different than mediation, and that it is subjective how people relax. A more complex study could be conducted that measures the eSense™meters while experienced meditators meditate. This could give insight into whether the value actually represents meditative depth or whether it simply measures relaxation.

2.6. Final Problem Statement

Having attempted to answer some of the initial research question through this analysis, we have arrived at a final problem statement (FPS), that describes the main objective for this project:

"To which extent can biofeedback in an immersive virtual environment be used to assist novice meditators in reaching a deep meditative state?"

Empirical measurements need to be obtained in order to answer this problem statement. Chapter 2.2 has investigated what meditation is and how the effects of meditation can

be observed through various physiological variables. However, can we reliably measure meditative depth? While the physiological variables might indicate a certain mediative depth, they will not reliably tell us this. Chapter 5 will go more into depth with the specific methods that will be used to answer the FPS.
Another question that can be derived from the FPS is: How should the immersive biofeedback system be designed, in order to assist novice meditators? The next chapter will describe how the system is designed, based on the specific design requirements obtained throughout the analysis.

3
Design

A set of design requirements for the system can be derived from the analysis. The system should:

- Provide real-time biofeedback to the user, making them able to see their EEG and respiratory information, thus making them conscious of their meditative state and their respiration.
- Allow the user to immerse themselves in a relaxing VR environment, with no stressors or distractions.
- Use a TM or mindfulness technique, as these are the most researched and best documented techniques of meditation.
- Be non-invasive and comfortable to use, as an uncomfortable setup might make the user uneasy and be counterproductive to the goal of making them obtain a meditative state.
- Be available and convenient for the user, as it should serve as a pause in an otherwise busy day.

Furthermore the system must account for the double-bind, to make sure that the user does not get caught in a negative circle, where biofeedback only contributes to accumulative thoughts.

3.1. System Design

The user interacts with the system through their EEG signals and their respiration. This information is then used to manipulate variables within the virtual environment. The virtual environment also includes a guided meditation and calming background music. Finally, the virtual environment is mediated to the user through a VR headset. As seen in Figure 3.1, the loop is then repeated. This describes the overall feedback loop, but design considerations needs to be made for each step in the loop.

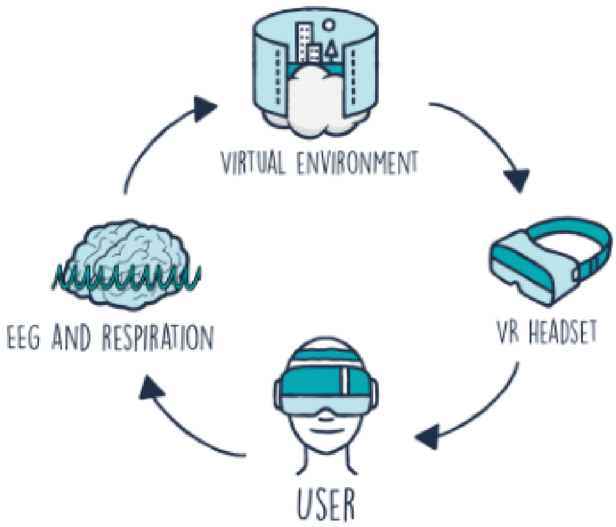

Figure 3.1: A concept image of the overall feedback loop of the system.

The preliminary research questionnaire (Appendix A helped inspire the setting of the virtual environment. In the questionnaire item: "What surroundings makes you calm and serene?", 79,1% (110 subjects) agreed that the forest made them calm and serene. It is unclear from this questionnaire, what specific elements of the forest that makes them calm and serene. It might be the fresh air, the ambient sounds or simply being engulfed with trees and nature. Nevertheless, the virtual environment was designed as a forest, with a lake and hills. The user should not move their head around too much, as it might add noise to the EEG signals. Therefore it is designed in a way where the most aesthetic and interesting elements are placed within a 180 degree angle of the user's field of view.

The user input; brainwave signals and respiratory information, is obtained by the BCI device Myndplay and a self-developed respiration belt. The meditation value calculated from the EEG signal and the respiration data from the respiratory belt, is sent forward into the virtual environment via bluetooth.
Finding the variables in the virtual environment that the user input needs to manipulate must be thoroughly considered in order to avoid the double bind. The meditation value obtained from Myndplay is mapped to fog within the virtual forest and the respiration value is mapped to an expanding and contracting circle. In this way both explicit and implicit biofeedback is provided. The contracting and expanding circle reacts explicitly on the user's breath, and is designed to be intuitive and easy-to-understand feedback. Furthermore it should make the user become aware of their breathing which is an essential element of mindfulness meditation. The fog within the virtual environment is more implicit, as the connection between meditation level and density of fog is not straight forward for the user.

3.2. Meditation Technique

As this experience is aimed at novice meditators, we decided to use a guided meditation within the virtual environment in order to assist the user through the experience. This guided meditation was recorded at the Sound Lab at Aalborg University in Copenhagen. The transcript for the guided meditation was obtained from The Mindful Awareness Research Center (MARC), which is a mental health research institution in Los Angeles, U.S.A.. MARC aims to foster and publicize scientific research of the benefits of mindfulness meditation (UCLA, 2018). The content of the meditation focuses primarily on bringing attention to the breath, and can be considered a mindfulness meditation, as it promotes internal observation. Below is a sample of the transcript.

"[...]And notice where you feel your breath in your body. It might be in your abdomen. It may be in your chest or throat. Or in your nostrils. See if you can feel the sensations of breath. One breath at a time..."

See Appendix B for the full transcript. The entire meditation takes approximately five minutes.

3.3. Music as a Therapeutic Means

To help facilitate relaxation within the experience, music is used as an addition to the guided meditation. The track: "Summer" composed by Niels Eje, MusiCure, was chosen primarily due to its background in therapeutic contexts. The music produced by Musicure is characterized through its universal and genreless soundscapes, that can be enjoyed by most people regardless of music taste or preferences. The compositions primarily consist of instrumental solos performed on acoustic instruments by professional classical musicians from Denmark and are integrated with nature ambience (MusiCure, 2018). MusiCure claims to have more than 16 years of scientific research and therapeutic use cases behind them.

A study conducted in danish hospitals (Sørensen, 2005), investigated whether MusiCure has an anxiety reducing effect on psychiatric patients. The study used quantitative and qualitative data, through the use of questionnaires given to patients by nurses before and after exposure to MusiCure, and through interviews with the nurses. While the results suggest that MusiCure can be beneficial and have a stress-reducing effect on both psychiatric or non-psychiatric patients, the experiment conducted by Sørensen (2005) lacks a systematic approach as it has not been documented whether the patients listened to MusiCure by themselves or how many patients refused to listen to it.
Furthermore, recording of the patient's physiological data would greatly benefit the validation and reliability of the experiment, as it right now only uses self-reported measures. While self-reported measures are good at indicating the individual's feelings and beliefs about a subject, their subjective nature will not give a clear and objective indication of whether they become more relaxed. While self-reported measures are

good at indicating the individual's feelings and beliefs about a subject, their subjective nature will not give a clear and objective indication of whether they become more relaxed (Field and Hole, 2002).

While it has proven difficult to find a cohesive and systematic study, proving MusiCure's positive effects on stress, anxiety or pain, it does through the qualitative studies appear to have a calming effect on the listener. Thus, it can be used as an additional element for facilitating calmness and relaxation. The music should be carefully mixed with the guided meditation as it should not become too dominant and drown out the content of the guided meditation.

4
Implementation

This chapter will describe how the system was implemented and elaborate on the implementation choices and challenges within the development of the system.

4.1. System overview

A Samsung S7 phone, running Android version Nougat 7.0, is used in conjunction with a Samsung Gear VR to immerse the user in the virtual environment. As stated in the design chapter 3.1, Myndplay is used to record the user's EEG data, while a self-developed respiration belt records the user's respiratory data. The respiration belt is made with flexible conductive fabric and an Arduino microcontroller. It measures the resistance in the fabric, as the abdomen is expanded and contracted.

Figure 4.1: The system in use, excluding the respiration belt.

As seen in Figure 4.1, the Myndplay device is attached to the VR headset. The dry sensor is placed on the upper part of the headset, and the amplifier is placed in the straps from the headset. A sensor is attached to the ear for ground. See Figure 4.2 for an overview of all the components of the BCI.

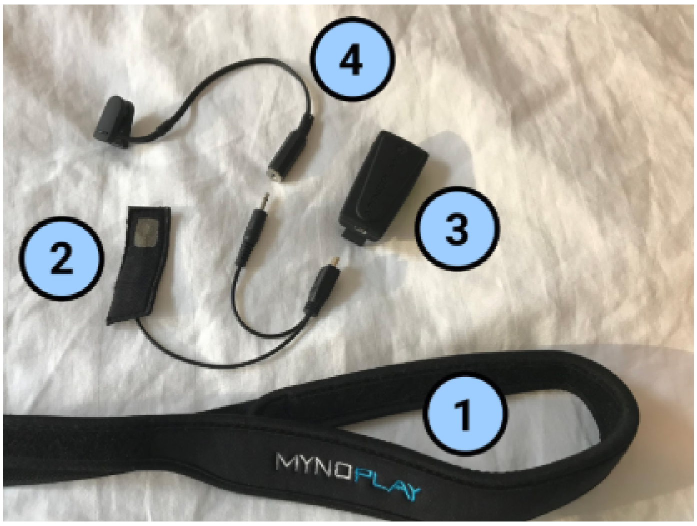

Figure 4.2: The components of the Myndplay, consisting of: 1) The headband. 2) The ThinkGear dry sensor, that is connected to 3) The amplifier and 4) The ground sensor (ear-clip).

When connected, the device sends EEG data into the virtual environment. As it would be out of scope for this project to develop an algorithm that takes specific brain waves into consideration (i.e. alpha and theta waves), the eSense™meters (meditation and attention) provided by Neurosky are used. Both the respiratory information and the EEG signals are sent via bluetooth to the Android phone, where they are used as input to the system. A virtual environment is developed within the game engine Unity3D, that handles the input data and mediates this information through biofeedback. Furthermore, in-ear headphones are used to mediate the guided meditation and the music for the participant. The entire Unity project can be seen through the Github link in Appendix C, Figure 4.3 provides an overview of the entire logic of the system. The following sections will go more in depth with each of these steps.

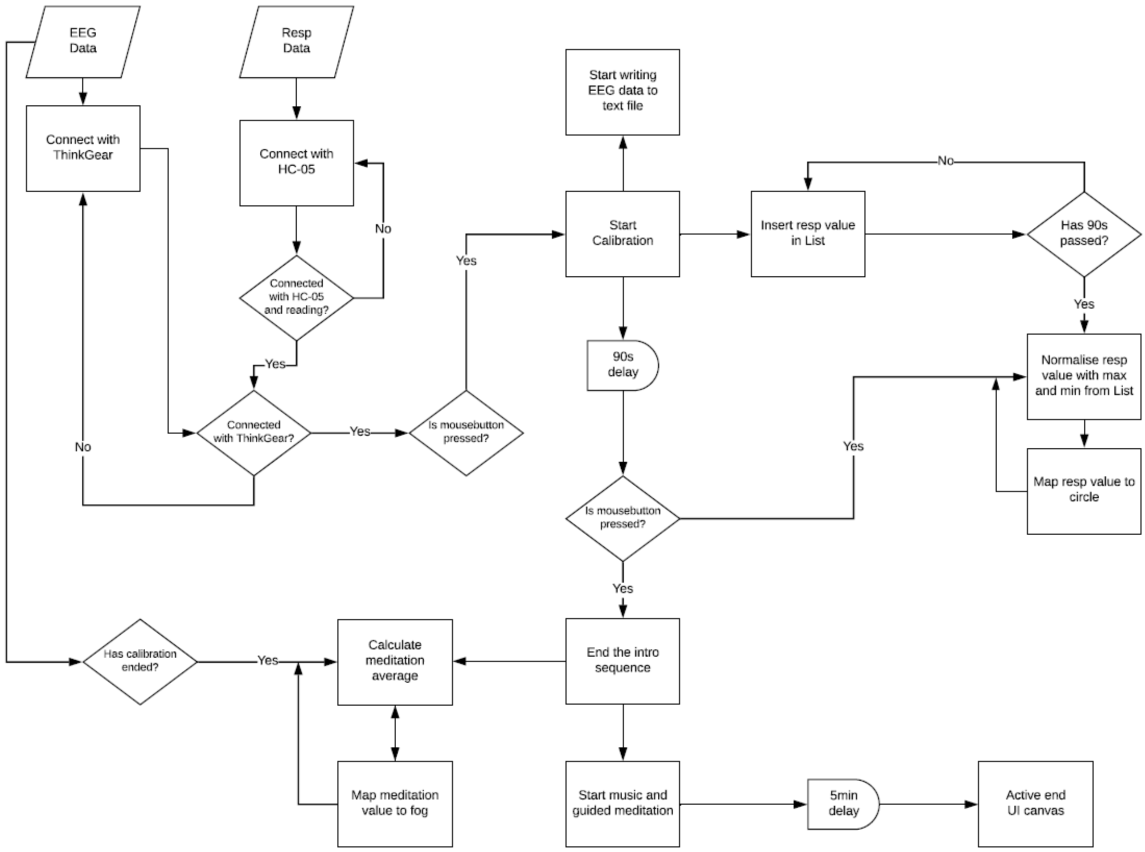

Figure 4.3: The logic of the entire system displayed in a flow diagram.

4.2. Virtual Environment

The virtual environment is developed in the game engine: Unity3D. The single scene in the Unity project consists of several low poly models, which includes trees, terrain, rocks, grass and logs, provided by a Unity asset (LMHPOLY, 2018). As seen in Figure 4.4, the level design is heavily inspired by nordic nature, with mainly pine trees, a few oak trees and an apple tree next to the main camera.

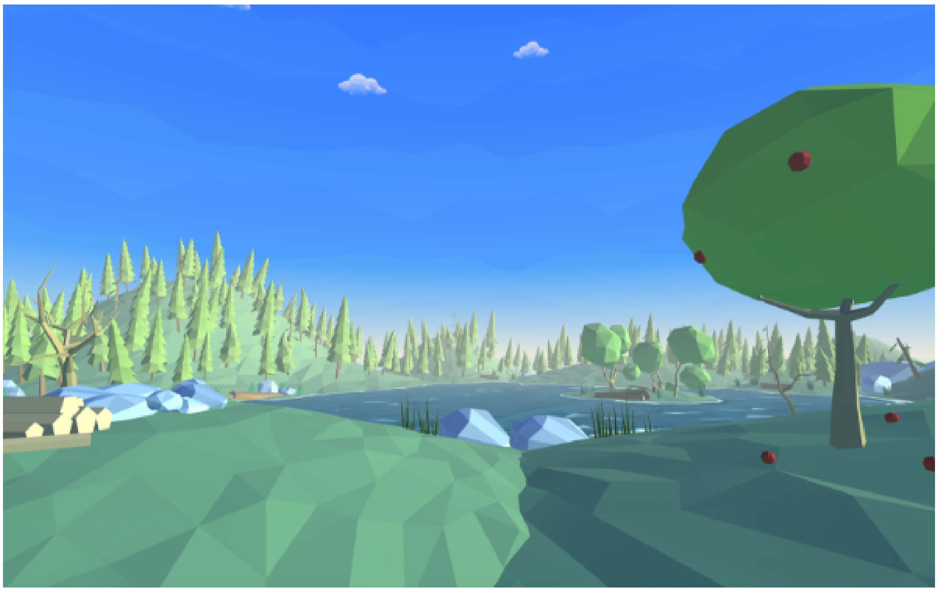

Figure 4.4: The virtual environment developed in Unity.

The level design is heavily inspired by nordic nature, with mainly pine trees, a few oak trees and an apple tree next to the main camera. The global position of the main camera can also be seen as the user's view point. The user is not able to move within the virtual environment but watches the entire forest from this one point. A wind shader (RenanBomtempo, 2018) is applied to the trees and the grass, in order to animate them. This shader has several properties such as wind size, sway displacement, sway speed and sway stutter. The wind should not be too extreme as this might be considered a stressor or a distraction and could in the worst case lead to nausea. Thus, through fine-tuning the shader properties, a gentle wind breese is simulated. This makes the virtual environment feel more alive compared to if the trees would just be stagnant.

A shader is used in order to make the water animate (danielzeller, 2018). This shader is assigned to a plane within the scene. This shader includes a script from where wave frequency, wave height and length can be manipulated. As with the wind, it is believed that a too volatile water can work as a stressor or a distractor in the experience, so a gentle animation is found through fine-tuning of the shader properties.

The skybox (Boxophobic, 2018) is chosen, primarily due to its aesthetic coherence with the low poly style. A skybox is a wrapper consisting of 6 textures, that encapsulates the entire scene in order to give the impression of a complex scenery at the horizon (Unity3D.com, 2018). Another benefit the chosen skybox, is that it comes with a shader that makes it possible to manipulate certain properties of the skybox. The most interesting properties of this shader, in regards to this project, are the fog properties: fog height, fog smoothness and fog fill. These are used for the EEG biofeedback.

4.3. The EEG Biofeedback

The EEG biofeedback is mapped to the fog in the virtual environment. This fog consists of three different elements: a skybox fog, a particle system and the global fog settings in Unity.

Once the greyish fog appears in the surroundings, the sky also needs to change to a uniform greyish color, in order to create the illusion that a cloud of fog has engulfed the user. Therefore, the meditation value obtained from the Myndplay headband is mapped to the ”fog fill” property of the skybox shader. If the ”fog fill” value is 1 the entire sky would be grey, and if the value is 0 the entire sky would be clear. As the meditation value ranges between 0 and 100, a value of 0 would mean the ”fog fill” is set to 1. If the meditation value is above 80 the ”fog fill” value is set to 0. This value of 80 is chosen in order to make the system a bit more forgiving. According to the Neurosky documentation, a meditation value above 80 means that the user is in an elevated state of meditation (NeuroSky, 2018a).

The fog in the experience consists of two other elements than the skybox: Unity’s integrated global fog settings and a particle system. The global fog is set to linear mode and ranges from 50 to 450. The global fog value starts at 50 because the user should always be able to see a few meters in front of them. If this value would be 0, the entire scene would be grey which does not realistically simulate fog. The meditation value is directly mapped to this value, where 50 means a meditation value at 0 and 450 means a meditation value above 80.

The particle system creates the illusion of the surrounding fog. It instantiates various particles, that differ in size, lifetime and rotation, all around the main camera. Each particle consists of a texture sheet animation that cycles through a sprite sheet containing a grid of ”fog” images (see Figure 4.5).

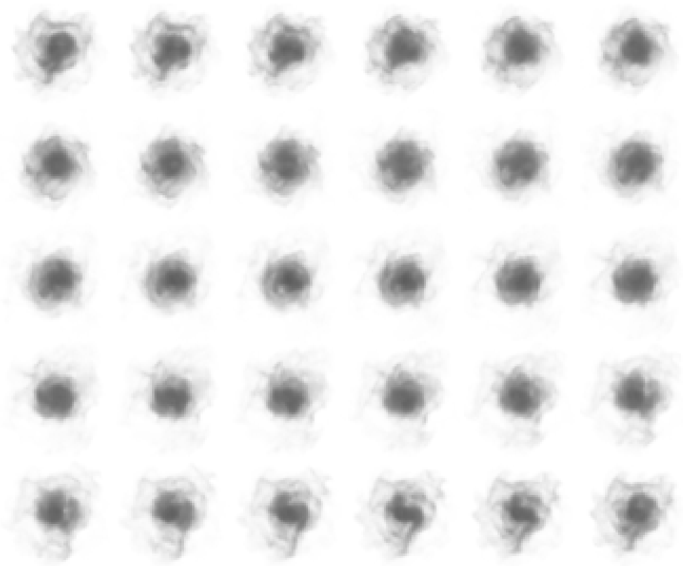

Figure 4.5: The sprite sheet for the animation of the fog particle system (MrBeast, 2018).

The alpha value of the particles' color component is reduced in order to make each particle more transparent. It is also this alpha value that the meditation value is mapped to. This mapping is performed directly on the material that each particle uses. The alpha value of the shader ranges from 0 to 1, where 0 is full transparency and 1 is no transparency. The max alpha value is set to 0.5, as any higher would make the fog look too dominant. Figure 4.6 displays the scene where the meditation value is above 80 (left) and 0 (right).

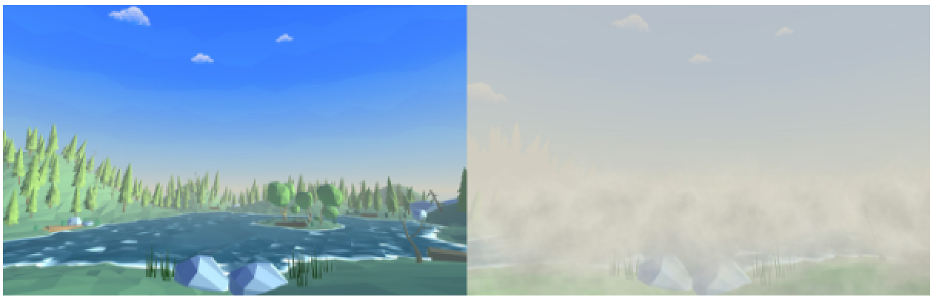

Figure 4.6: The environment without fog. (right) The maximum amount of fog.

The mapping of the meditation value is handled by a script in Unity. This script starts by setting the global fog, the skybox fog and the particle system fog material to their default values. The meditation value is smoothened out by a moving average technique. This technique adds all the mediation values, obtained within 2 seconds from the ThinkGear sensor, to a list. After the 2 seconds, the average is calculated and the list is cleared. It repeats this process throughout the entire experience. The mapping of this meditation value is handled by the function displayed in Codesnippet 1.0.

```
1  function MeditationMapping() {
2          // For the unity global fog
3          float fogAmountOld = fogAmount;
4          float fogAmountNew = 50f + meditationAvg * 4f;
5
6          // For the fog particle system
7          Color col = new Color();
8          col = startingCol;
9          float alphaOld = fogMat.GetColor ("_TintColor").a;
10         float alphaNew = Mathf.Clamp01(.5f - (meditationAvg/160f));
11
12         // For the skybox fog
13         float skyFogOld = skyBox.GetFloat("_FogFill");
14         float skyFogNew = Mathf.Clamp01(1f - (meditationAvg / 80f));
15
16         float t = 0;
17         while (t < calculationDuration) {
18             t += Time.deltaTime;
19             float blend = Mathf.Clamp01 (t / calculationDuration);
20
21             // Global fog
22             fogAmount = Mathf.Lerp (fogAmountOld, fogAmountNew, blend);
23             RenderSettings.fogEndDistance = fogAmount;
24
25             // The skybox fog
26             skyFog = Mathf.Lerp (skyFogOld, skyFogNew, blend);
27             skyBox.SetFloat("_FogFill", skyFog);
28
29             // The particle system fog
30             col.a = Mathf.Lerp (alphaOld, alphaNew, blend);
31             fogMat.SetColor ("_TintColor", col);
32
33             yield return null;
34         }
35     }
```

Codesnippet 1.0: The function that handles all of the fog mapping.

This function handles mapping of the meditation value to the particle system, the skybox and the global fog. It first declares a temporary variable that the previous value is assigned to. So for instance in line 3, fogAmountOld is set to fogAmount, which is the current value that the function has calculated. The newly declared variable, FogAmountNew (line 4) is then calculated. As the global fog ranges between 50 and 450, the meditation average is simply added to 50 and multiplied by 4. It then lerps from the old value to the newly calculated value in a 2 second duration, and sets the lerping value to the global fog settings. The method of mapping is similar for both the particle system and the skybox fog, however the calculations are slightly different. Since the particle's alpha value ranges from 0 to 0,5, the meditation average is divided by 160 and subtracted from 0,5. This means that a mediation value of 80 or above would equal an alpha value of 0 and a meditation average of 0 would make it 0,5. The skybox value ranges from 1 to 0, meaning that the meditation value divided by 80 needs to be subtracted from 1. The entire script that handles mapping of EEG, can be seen in Appendix D.

4.4. The Respiration Belt

In order to provide respiratory biofeedback, a respiration belt is developed, that measures the user's inhalation and exhalation. The belt is placed on the diaphragm muscle under the rib cage, matching the placement of the belt used by the DEEP project (Harris et al., 2017). The belt consists of a piece of conductive stretchable fabric, that works as a resistor. The conductive fabric is stretched, when the user is breathing which leads to the electric resistance increasing. The change in electric resistance, is then used as input to the system and mapped to a circle within the virtual environment, illustrating the users own breath.

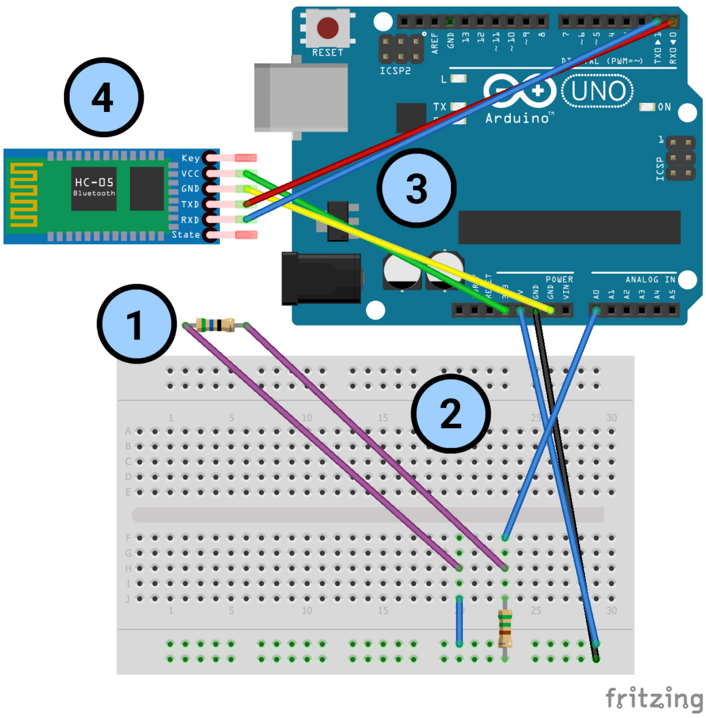

Figure 4.7: The hardware setup. 1.) The conductive flexible fabric (represented as a resistor) 2.) The breadboard 3.) The Arduino 4.) The HC-05 bluetooth module

Figure 4.7 gives an overview of the whole belt setup. The breadboard is connected with the Arduino by ground and 5 Volts. The resistor with purple connection to the breadboard, represents the conductive fabric. The Arduino receives the value from the conductive fabric at pin A0 and the resistance is calculated. The pull-down resistor which is connected to ground, is calculated by the equation 4.1:

$$pull - downresistor = \sqrt{R_{min} * R_{max}} \tag{4.1}$$

R_{min} is the resistance in the fabric, when it is not stretched. R_{max} is the resistance in the fabric, when it is stretched. To obtain R_{max}, the measurement was done five times and R_{max} is taken as the mean of the five measurements. The reason for this is that the particles in the fabric wants to reassemble again after being stretched. When the fabric is stretched at first, the resistance will be highest, but will decrease immediately after, even though the fabric is still stretched. The electric resistance is then noted, when the value has stabilised.

In Figure 4.7, it is illustrated, how the Bluetooth module HC-05 is connected to the Arduino. The module is connected to the Arduino Transmit Pin (TX) and Receive Pin (RX). This makes it able to send the electric resistance data from the Arduino to the Samsung phone. Section 4.5 will further describe how the data is sent and received.

4.4.1. The Respiratory Biofeedback

The respiratory data obtained through bluetooth, was mapped to a contracting and expanding circle in the virtual environment. The circle was a simple 2D texture, created in Photoshop, that was assigned to a plane in Unity, as seen in Figure 4.8. A plane is an flat surface that exists in 3D space (Unity3D, 2018).

Figure 4.8: The circle in VR, expanding and contracting according to the users breath.

In order to make the circle expand and contract according to the user's breath, the respiration data is mapped to its local scale. Before the respiration data can be mapped to the circle it is normalised, as seen in equation 4.2.

$$z_i = \frac{x_i - min(x)}{max(x) - min(x)} \tag{4.2}$$

Equation 4.2 normalises all of the data to range in between 0 and 1. Before normalising it this way, we need to know the resistance value at the peak of inhalation and the peak of exaltation. These can be treated as the minimum and maximum value of x, where x is the electric resistance from the respiratory belt. In order to obtain this information a calibration process is applied before the actual experience begins, where the user is encouraged to take five deep breaths. All of the respiration data is added to a list during this process. Once it has finished calibrating the highest and the lowest number of the list is used as $max(x)$ and $min(x)$ in the function. All of the respiration data is then used as input z_i to the normalization function, that outputs the number as a float variable ranging between 0 and 1.

The belt constantly outputs values each frame, so if the normalized values is mapped directly to the scale of the plane, it will not smoothly change size but rather jitter in size. Instead, the average mean of the respiration values are computed, for a set duration of time (every 150ms). An exponential smoothing technique (equation 4.3) is applied:

$$s_t = \alpha * x_t + (1 - \alpha) * s_{t-1} \tag{4.3}$$

Where s_t is the new smoothed respiration value, x_t is the actual respiration value, and s_{t-1} is the previous smoothed respiration value. α is the smoothing factor that ranges from 0 to 1, and can be treated as a weight. The closer α is to 1 the less smoothing effect is added to the data.

The exponential smoothing function helps smoothen out the respiration data so it appears more stable and less jittery. Finally, the data is applied to the plane containing the circle texture. It is applied every 150ms, and lerps from the previous smoothed respiration value to the new during the time period. Lerping means that it linearly interpolates between two points in a given set of time. The reason it lerps is so it changes size gradually instead of each 150ms. The entire code for mapping of respiration data, can be seen in Appendix E.

While the exponential smoothing function helps make the data more stable, it does not truly represent the user's respiration. When the conductive fabric of the belt is stretched the resistance increases, although it decreases again even though the fabric remains stretched. This is believed to be because of the particles within the conductive fabric trying to reassemble. This means that the data output from the Arduino not fully reflects the user's inhalation and exhalation which means that the biofeedback does not work as intended. Thus, the belt is not used during the experiment (chapter 5).

4.5. Bluetooth Connection

Since the system utilities Samsung Gear VR, devices cannot be directly connected to the mobile phone with cables. Therefore the devices are connected via bluetooth. The bluetooth manager within the main scene handles all of the bluetooth connections.

Both the respiratory belt and the Myndplay device needs to be connected to the application.

Arduino Connection

The asset: "Android & Microcontrollers / Bluetooth" (TechTweaking, 2018) is used to connect the Arduino from the respiration belt to the application running on the Android mobile phone. This asset provides a bluetooth library that includes two classes: *BluetoothAdapter*, which represents the local bluetooth adapter (the Android phone) and *BluetoothDevice*, which represents the remote bluetooth device (the Arduino). In order to create a connection between the two, a new *BluetoothDevice* instance is instantiated within the Awake() method (that is the first function run when starting the application).

```
1 private BluetoothDevice device;
2 void Awake () {
3     device = new BluetoothDevice ();
4 }
5 private void Connect() {
6     device.Name = "HC-05";
7     device.connect();
8 }
```

Codesnippet 1.1: The lines of code used to make a bluetooth connection to the Arduino.

In the Connect method (line 5 - 8 in Codesnippet 1.1), the name of the device is set, which in our case is the name of the Arduino bluetooth module: "HC-05". This does require the Android to be paired with the device before start the application. After setting the name, the method connect() is called, which is a method defined in the BluetoothDevice class. This method attempts to connect 10 times, once every second. Each connection attempt might differ than the other internally. When it has made a connection, the method ManageConnection is run once each frame.

```
float respValue;
void ManageConnection (BluetoothDevice device){
    if (device.IsReading) {
        byte [] msg = device.read();
        if (msg != null) {
            string content = System.Text.ASCIIEncoding.GetString (msg);
            respValue = float.Parse (content);
        }
    }
}
```

Codesnippet 1.2: The method used to read the respiratory data from the Arduino.

This method seen in Codesnippet 1.2, reads the message sent from the Arduino through BluetoothDevice's public method: read(). Since this method returns an array of bytes, we first need to create a new byte array and assign the method to this array. As long as it receives any byte packages, they are decoded into a string through the ASCIIEncoding.GetString method. This string is then parsed to the float variable: respValue, which is further used to provide the biofeedback for the respiration belt.

Myndplay connection

Asynchronously to the Arduino bluetooth connection, a connection is also established to the Myndplay device. For this, a Github project developed by Neurosky is used, that utilises a ThinkGear library (NeuroSkyWuxi, 2018). ThinkGear is the name of NeuroSky's sensor technology that allows the measurement, amplification, filtering, and analysis of EEG signals (NeuroSky, 2018c). The ThinkGear library is converted to C# and an event manager is utilised that runs an event for each variable obtained from the ThinkGear sensor (meditation, attention, alpha, beta etc.). By subscribing to this event manager, the values from Myndplay can be extracted and used within the system. Therefore, the Github project is integrated into the Unity project, which makes it possible for the application to connect with Myndplay, extract the data and use it for biofeedback.

4.6. User Interface

Since the application is developed to assist a user in meditation, there is not a high demand for a user interface (UI). However, since we need to connect both the Myndplay and the respiration belt and calibrate the respiration data, a short intro sequence was developed. As seen in Figure 4.9, the intro sequence consists of three parts: a welcome panel briefly explaining the application, the calibration part and lastly, a short notification when the calibration is done.

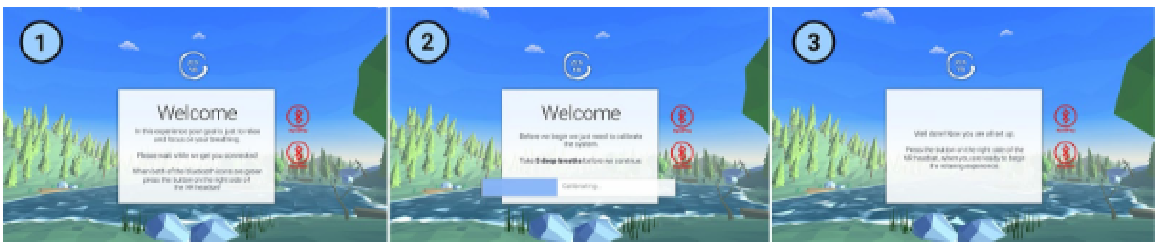

Figure 4.9: The three parts of the into sequence. 1) The welcome text. 2) The calibration 3) The last notification before the experience begins.

The UI elements within the intro sequence is a panel, an image for the logo and the two bluetooth icons, and four different UI texts; a header and one for each part of the intro sequence. These UI texts are faded in and out, through a function that gradually changes the texts opacity. Once the application has connected to both the Myndplay and the respiration belt, and the user has clicked the button on the right side of the headset, the welcome text is faded out and the calibration text is faded in. Two images are also faded in during calibration: one panel and one blue image on top of the panel. The blue image is gradually filled as the calibration process is running. Once it has finished calibrating, it fades out the calibration text and images, and fades in the last notification text. Once the user has clicked the button on the right side of the headset, all of the UI intro elements are faded out and becomes deactivated. The script that handles the entire intro sequence can be seen in Appendix F.

5
Data Acquisition

From the final problem statement in chapter 2.6, the dependent and independent variables can be derived. The dependent variable is meditative depth. The independent variable can be considered the parameters that can be used to manipulate meditative depth. In our case, the independent variable has three levels; biofeedback, immersion or no assisting technology. Empirical data gathered during these three levels can help determine the effect, that the biofeedback system has on meditative depth.

The instruments used for measuring our dependent variable is a heart rate (HR) monitor, the meditation value obtained from Myndplay and a questionnaire called the meditation depth questionnaire (MEDEQ).

5.1. Heart Rate Variability

A Polar H10 (Polar.com, 2018) is used for the heart rate monitor, as this sensor is able to capture accurate HRV data. The HR monitor consists of two parts; a strap, that the user wears under the chest, and a connector. The strap detects the heart rate through plastic electrodes that are in contact with the skin. The connector then computes the heart rate and sends it to a receiving device via bluetooth (Polar, 2018). The receiving device in our case is an iPhone running the app 'EliteHRV' (EliteHRV, 2018). Besides monitoring the HR (bpm) and HRV (ms) data real-time in the app, the IBIs can also be exported as a text file, that can be used for further data analysis. The IBIs are exported as R-R intervals in ms which can be used for time-domain analysis of both the HR and the HRV of the participant in a given time period.
The HRV data is evaluated by calculating the RMSSD and the HR mean, both during a 90 second baseline recording and the last 90 seconds of the experience. The participant's starting HRV can then be compared with their HRV during the end of the experience.

5.2. Meditation Depth Questionnaire

The Meditation Depth Questionnaire (MEDEQ) is a 30-item questionnaire, that measures the meditative depth of subjects who have been meditating. It was developed by Piron (2001) by interviewing 27 meditators of different levels and from different meditative schools, about their mediation experience within the past week. Piron (2001) found 50 aspects of meditation experiences that were reduced to 30, through careful selection, following certain criterias. They asked 45 authorized meditation teachers from different schools and traditions about the depth of the 30 items. The responses to the items are rated on a likert scale ranging from 0 to 4. By performing cluster analysis on the responses obtained from the 45 experienced meditators, Piron (2001) found five clusters interpreted as depth structures: hindrances, relaxation, personal self, transpersonal qualities and transpersonal self. These five categories refer to different meditative depths.
Piron (2001) describes these categories in simple terms as:

1. Hindrances: Restlessness, busy mind, laziness, feeling bored.
2. Relaxation: Feeling well, smooth breathing, patience and calmness.
3. Personal self: Mindfulness, attentive control over the mind, being detached to thoughts, emotions and sensations, strong energy and being centred.
4. Transpersonal qualities: Love, surrender, connection, joy, grace, humility, transcending time.
5. Transpersonal self: Complete rest of thoughts, no differentiations, comparisons and judgements anymore; unity of all; emptiness and infinity of consciousness; subject/object-transcendence.

Each of the 30 items belong to one of these categories. To evaluate the data from the MEDEQ, the score can be calculated for each category, by taking the summation of all items belonging in their respective category. This summed score is then divided by the number of items in the respective category which will give a score between 0 and 4 in each category for each participant.

5.3. Additional Questions About the Experience

In order to get a greater insight of the participant's experience, additional questions is added to the questionnaire. The purpose of these additional questions is to obtain knowledge about their subjective experience. One question (see last part of Appendix H) asks the user to rate the comfort the headset on a likert scale, to find out if the system is physically comfortable. This is crucial to the success of the system, as an uncomfortable setup will result in difficulties relaxing. Another question asks the participant to rate their feeling of nausea during the experience, as this is one of the biggest challenges when developing VR experiences. The participant is also asked about the interpretation of biofeedback and what part of the virtual environment, they primarily focused their attention to. These answers can be used for improving and refining the system. Furthermore, the last item is reserved for additional comments from the participant, that provides qualitative data. In this item they are free to express any thoughts or opinions about the experience.

5.4. Meditation eSense Value

The last type of data used for evaluation is the meditation value obtained from the Myndplay device. This is also the value that is used to provide the biofeedback within the virtual environment in condition C. As described in section 2.5.1, this value reflects the relaxation of the user, through calculations of the EEG signal. The data is acquired after the system has calibrated and is saved to a .txt file. This data is evaluated by taking the mean from the last 90 seconds of the experience and comparing it to the mean obtained during the baseline recording.

6
Evaluation

This chapter will describe the final experiment conducted in order to evaluate the proposed system. It should be noted that the respiration belt was excluded from the system, since it failed to provide stable and accurate respiratory data. A pilot test is described that helped shape the final experiment. Furthermore, this chapter will report and describe the results obtained from the experiment.

6.1. Experimental Method

In order to find out whether the proposed system can make the user obtain a certain meditative state, an experiment was conducted. A between groups design was used where each group got exposed to one of three conditions:

Condition:	**Description:**
A	A control condition, where the participant only listens to the guided meditation.
B	A non-biofeedback condition, where the participant listens to the guided meditation while wearing the HMD thus being immersed in the virtual environment.
C	The experimental condition, where the subject utilises the full system, meaning biofeedback, VR and guided meditation.

Table 6.1: An overview of the three conditions used in the evaluation.

The conditions derived from the three levels of the independent variable (as mentioned in chapter 5). The reason for including a VR-only condition is to isolate the biofeedback effect. If we did not have this condition, it would not be possible to say whether an effect is due to VR or biofeedback.

6.2. Pilot Test

A pilot test was conducted, at the Augmented Cognition laboratory at Aalborg University Copenhagen, with 7 participants, that utilised a different design than the final experiment. The pilot test used a between-within group design that is presented in Table 6.2. This experimental design was proposed in order to account for individual differences. A participant would get two conditions, where one of them was the control condition. This means we had two groups where one group would get condition A and then condition B, and the other would get condition A and then condition C. Since the order of which the participants are exposed to each condition can influence the results, a counterbalancing design is used (Field and Hole, 2002). This means that i.e. half of the participants in Group 1 is exposed to A and then B, whereas the other half is exposed to B and then A.

Group	1st Condition	2nd Condition
Group 1	A	B
Group 2	A	C

Table 6.2: The design of the pilot test. This design differs from the one used in the final experiment.

The participant would always get condition A, so the two other conditions always can be compared to condition A. This makes it possible to compare either VR or VR + biofeedback to the control condition for each individual, meaning we would see if the meditative depth of the participant would increase or decrease compared to the control condition. In between each of the conditions, a stressor was presented to the participant. The stressor was a set of arithmetic questions. The participant had three minutes to complete as many of the questions as possible. This approach was chosen, to increase the participant's cognitive load before the next meditation condition, in order to clear any effects of the previous condition.

Due to issues with Myndplay, this experiment was reworked. It was observed that it took a varying amount of time for the Myndplay to get clear signal, which could range from a few seconds to over 10 minutes. This was thought to bias the results, since some participants would wait a long time between the first and the second condition, whereas others would get the second condition instantaneously after the stressor. There were also a few times where the Myndplay never actually obtained a clear signal during one of the conditions, which meant that the biofeedback did not work and the EEG data could not be evaluated. This also affected the duration of the experiment, which resulted in difficulties managing the time schedule. Due to this uncontrollable factor a new experiment was designed.

6.3. Experimental Setup

The experiment was conducted the same location as the pilot test. Before the experiment, the participant was briefed about the procedure. The participant attached the HR monitor and was seated in comfortable chair. Before commencing the experiment, the participant would accept a written consent formulated in a questionnaire. The first part of the questionnaire consisted of demographics items and an item asking if the participant had been drinking coffee within the past two hours. The reason for this item, was due to caffeine having an effect on various physiological variables, such as heart rate, the central nervous system and respiration (Schwartz and Andrasik, 2016). The last item in this part asked if they had ever tried meditating.

In condition A, the Myndplay headband was attached to the participants head (see Table 6.1). The test conductor applied headphones for the participant and started the calibration period. When there was clear signal from Myndplay, the participant was told to close their eyes. After calibrating, the meditation session started. When the 5-minute meditation was finished, the Myndplay and HR monitor was removed from the participant. They were then presented with the Meditation Depth Questionnaire (MEDEQ).
The procedure was similar for condition B and C, however in these conditions a VR headset integrated with Myndplay was placed on their head. The participant was then introduced to its features: the wheel used for focussing the view, the volume buttons and the main input button situated on the right side of the headset. The participants in condition C, would answer additional questions about the virtual reality experience after the MEDEQ.

For each participant a 90 seconds baseline recording was made, where EEG and HR data was recorded. Furthermore, EEG and HR data from the last 90 seconds of the experience was used, in order to compare the meditative experience of the participant with their baseline.

6.4. Participants

The experiment had a sample size of 32 participants. Due to a low signal-to-noise ratio, 11 of these participants were discarded from the evaluation, reducing the sample size to 21 (7 in each condition). Most of the participants were students at Aalborg University. The demographic data, showed that 29% woman and 71% men, with the average age of 26 years. 57% had experienced either stress, anxiety, depression or distraction, where stress was the most prominent. 43% of the participants had tried meditating before, where most of them did not meditate frequently. 19% of the participants had been drinking coffee within two hours before the experiment.

6.5. Test Results

The following section will present the results of the data obtained during the test. The data for each participant, can be seen in Appendix I.

	Condition A		Condition B		Condition C	
	Baseline	Meditation	Baseline	Meditation	Baseline	Meditation
eSense Meditation (0-100)	54.39 ± 10.85	60.25 ± 5.67	55.77 ± 12.77	56.74 ± 11.35	51.24 ± 11.45	48.51 ± 10.50
Heart Rate (bpm)	78.85 ± 4.37	77.80 ± 7.10	76.19 ± 8.97	77.42 ± 8.63	71.71 ± 8.30	71.99 ± 9.62
RMSSD (ms)	37.59 ± 11.43	26.64 ± 13.16	51.43 ± 19.69	49.38 ± 18.63	58.08 ± 23.86	41.40 ± 21.19

Table 6.3: The mean and standard deviation for each measurement and each condition.

The mean for the eSense meditation value, as seen in Table 6.3, is increasing in condition A and B and decreasing in condition C. The standard deviation for Myndplay meditation value appears to be smaller in condition A during meditation, compared to the other two conditions. RMSSD, which represents the participants' HRV is decreasing during all of the conditions. The HR is quite similar, both in the baseline recording and during meditation in all of the conditions. The high standard deviations in all of the measurements, indicates the high individual differences in each participant and how they react differently to meditation.

6.5.1. eSense Meditation Data

The following test does not include the data recorded during baseline, but only the data recorded during the meditative experience.

H_0: *There is no significant difference of the means of meditation data in the three conditions.*
H_1: *There is a significant difference of the means of meditation data in the three conditions.*

As mentioned in chapter 2.5.1, the scale of the meditation value ranges from 0 - 100. Table 6.3 displays the mean and standard deviation values for the meditation data in each of the conditions. An Anderson-Darling test has been conducted (A = 0.226, B = 0.321, C = 0.369), indicating that the data has a normal distribution. To test for variance in the three groups, the Levene test has been performed ($p = 0.195$). This high p-value indicated that the variance test does not reject the null hypothesis, meaning that the variance is equal within all sample distributions. For this parametric data, a One-Way Independent ANOVA test has been conducted ($p = 0.118$). This shows that there is no significant difference. However, this result has potential for being improved, by testing a larger sample size for each group.

6.5.2. Heart Rate Data

For the recorded HR data (bpm), the hypothesis is the same as with the Myndplay data. Table 6.3 displays the mean and standard deviation values for the HR and HRV in each of the conditions. The following test is only HR data recorded from the meditative experience and not the baseline. The Anderson-Darling test showed a normal distribution (A = 0.291, B = 0.210, C = 0.338). The Levene test ($p = 0.079$) does not reject the null hypothesis, because of the p-value being $p > 0.05$. As this data is also parametric, the One-Way Independent ANOVA can also be performed, resulting in a p-value of 0.872, showing no significant difference.

6.5.3. Meditation Depth Questionnaire

As seen in Table 6.4. the MEDEQ mean and standard, was calculated for each category in each condition.

	Condition A	**Condition B**	**Condition C**
Hindrances	1,3 ± 0.9	1,6 ± 1,1	1,1 ± 1,1
Relaxation	2,6 ± 1,1	2,3 ± 1,1	3,2 ± 0,8
Personal Self	1,2 ± 1,1	1,3 ± 1,1	1,2 ± 1,1
Transpersonal Qualities	1,3 ± 1,0	1,6 ± 1,1	1,3 ± 1,2
Transpersonal Self	0,9 ± 0,8	1,2 ± 1,1	1,6 ± 1,2

Table 6.4: Mean and standard deviation of the scores from 0 - 4 in each category, for each condition.

The answers from each questionnaire, can be found in Appendix G. The category with highest scores, is relaxation. Relaxation in condition C, has the highest score of all categories and conditions, and the lowest standard deviation. Condition C also has the lowest score in the hindrances category. This could suggest that the test subjects did not find the experience boring or had a hard time of relaxing. Generally, the lowest scores is given to the items in the transpersonal self category, which reflects the deepest level of meditation.

6.5.4. Additional questions for condition C

After completion of the MEDEQ, the participants in condition C answered some additional questions regarding VR and the design of the system. The answers show that none of the subjects felt nausea in the virtual world. On a scale from 1 - 5, the subjects had to answer if they found the environment relaxing. 18,2% subjects rated 3, 54,5% rated 4, and 27,3% rated 5. On the same scale, the subjects had to rate the comfort of the Gear VR headset. Only one rated the headset to be completely comfortable, and four subjects rated it to be very uncomfortable. The subjects were also asked, what part of the virtual world, they looked at the most. The answers reports different parts such as the water, the trees, the fog and the skies. One participant notes, that the person had closed eyes most of the time, as it was more relaxing.
To obtain a greater insight of the biofeedback experience, the participants were asked if they had any other comments in the last item of the questionnaire. Here the fog was reported to be stressful and distracting, the waves was too fast and the resolution was too low. One participant commented "Very relaxing, and very surprised by what the experience was able to accomplish". Furthermore, some of the participants found the experience to be too short.

7 Discussion

Having designed and evaluated the proposed system, several topics have emerged that should be further discussed and addressed. When comparing the system to the control condition there is no significant difference. Furthermore, the users did not appear to reach a deep meditative state. There might be several reasons for this. It could both be due to the design of the system or the design of the experiment. The following chapter will discuss the results, challenges and insights of both the system and the experimental design.

7.1. Experimental bias

When testing whether an individual has become relaxed or achieved a certain meditative state, the experiment has shed light on several challenges. It can be assumed that some participants had difficulties relaxing, as the experimental environment could be perceived as discomforting. The room had no sunlight coming in and bad air flow. Furthermore, there were some environmental bias as you could sometimes hear voices of people in the hallway, as well as construction noise from the upper floor. Especially the latter was a disturbance factor as it was quite loud, though it only affected four of the participants.

The participants had to wear a HR monitor belt, along with either the Myndplay headband or the Samsung Gear VR. Having instruments measuring the participant's body might not be a problem for experienced meditators, although it could be a problem for novice meditators. The fact that they are being measured and observed doing something that they are not familiar with could stress them unconsciously. Field and Hole (2002) refers to this concept as, 'evaluation apprehension' - which refers to the participant being anxious, because they are being evaluated.

If the participant had not tried VR before it is also assumed to have been more difficult to relax, due to excitement or arousal of the immersive technology. It was reported by three of the participants that they felt discomfort because they were observed by both test conductors during the experience. Even though VR should immerse the user within the virtual reality, they were still conscious of the other people and the setting of the room. It would have been more optimal to have the participants sit quietly in a room by themselves during the experience. However, this would mean that the test conductors could not intervene in case of technical issues.

The Myndplay device could also have biased the results of the experiment. As was also observed during the pilot test, there was a lot of issues obtaining a clear signal. Having noisy signal refers to the Myndplay device picking up too much noise for it to produce valid EEG data. The meditation value could not be obtained unless the Myndplay had a clear signal. The application was designed so it could only be started once the signal value had reached 0 (which would mean clear signal). For some participants it reached 0 within the first minute, although other participants would have to wait over 5 minutes. There were even one participant waiting for 18 minutes, and another one where the experiment was terminated due to not reaching a clear signal within 20 minutes. Having the participants wait an unequal amount of time could mean the participants had a different mindset when the experience began. Some might be more restless - or even more calm - having waited, while others did not have time to "settle" and familiarise themselves with the environment.

The noisy signal also affected the data. The signal value only needed to have reached 0, in the second the experience began. It could then return to having noisy signal which meant that the meditation data was unusable. This was not only a problem for the evaluation but also for the biofeedback within condition C. If it had noisy signal during the meditation experience the biofeedback would stop working, thus breaking the biofeedback loop and leaving the participant perplexed. According to Myndplay, the device gets noisy signal when the sensors are not directly in contact with human skin. It was made sure throughout the experiment that no hair was caught in between the sensors and the skin. Furthermore, the equipment was fitted tight on the participant's head. It was also cleaned with dry alcohol after each session. However, it still provided a very unstable and noisy signal. This could be due to the dry sensor technology.

7.2. The biofeedback system

The fog was designed as a way to make the user aware of their own mental state. The more clear the environment was, the clearer and more calm their mind was. If fog would appear, it should assist the user in reflecting upon their mindset and help nudge them back into a calm and meditative state. The qualitative data (Appendix H obtained from the additional items on the questionnaire for condition C, indicated that the fog had a counterproductive effect. Three of the participants found the fog either stressful or distracting. This can be due to the double bind concept (see chapter 2.3.2). The biofeedback should bring awareness to their mental condition, but by making them aware of their condition it might conflict with the overarching goal to relax. The user needs to clear their head of unnecessary thoughts and focus their attention on their breath. The fog might promote accumulating thoughts and distract their attention away from the breath. It might also simply be claustrophobic, due to the user feeling enveloped in fog.

The biofeedback design was never tested, using a user centered design method. Having tested the biofeedback could have helped refine the design and avoid the double bind concept. An initial biofeedback design concept was implemented, where we mapped the meditation value to the wind in the trees and the waves of the water. In this design, the lower your meditation value was the more windy the environment would get. In this design the double bind was very apparent, as most people get stressed by windy and stormy environments. Thus, it would not nudge them to become calmer, but rather stress them further. The fog design was proposed as an alternative, as it was assumed that fog would not stress people but rather provide them with information about their mental state. However, this assumption proved to be false by the evaluation.

Several alternatives could be made for the design, although it has proven challenging to design biofeedback for meditation. The aim of mindfulness meditation is to distance oneself from thoughts and emotions, while focusing on an object of focus. The biofeedback needs to be designed in a way where it does not promote thought or emotion and it should not distract the focus of attention. An idea could be to have the biofeedback itself, be the object of focus. A design could be to have a spherical object within the virtual environment, that would increase in size or change color according to the user's meditative state. This means they would not be distracted by other factors. It would simply be the user and the object of focus. This would require the guided meditation to be tailored to the system, so instead of promoting internal focus through breathing it should promote attention to the spherical object. This does however, conflict with the goal of mindfulness, which is internal observation. Thus, another meditation technique, such as concentrative meditation might suit this design better. Another design idea could be to mediate the biofeedback through another modality. If mediated through audio, it could be perceived as less distracting for the user. A redesign of the system should investigate these possible design solutions and their effect on relaxation.

Another factor that could contribute to the biofeedback design not assisting the user in reaching a deep meditative state, is the meditation value obtained from Myndplay. While attempts were made to validate the value, it is still unknown, what exactly it measures and how it does so, due to the non-transparency of the developers. The meditation value did increase during the validation test, when the participant closed their eyes and took 10 deep breaths. However, it might just measure calmness or relaxation and not meditative depth. Meditation refers to an actual practice. A lot of meditation techniques will make you calm, but they will also foster mental well-being and development while training your attention and awareness. If the meditation value only measured calmness it would not fully represent the user's meditative depth. This would mean the aim of the system should not be to assist the user in meditation but rather in relaxation. A redesign could attempt to solve this issue by developing a novel algorithm that measures meditative depth. This was considered for this project but was thought to be out of scope, due to the complexity of such an algorithm.

7.2.1. Respiratory biofeedback

As mentioned in chapter 6, the respiration belt was discarded due to instability of the data. Seeing the challenges getting the EEG biofeedback to work this might have been for the better. The system was originally designed to both have the fog as biofeedback for the EEG and the respiratory circle, providing biofeedback for the user's inhalations and exhalations. The participants had difficulties focusing on just the fog, and some participants even perceived it as a distraction. If the user also had to focus on a contracting and expanding circle within the same modality it could in worst case result in cognitive overload. Cognitive overload (Mayer and Moreno, 2010) would mean that the user is being presented with too much information, which results in them being unable to process it. A way to solve this problem could be to present the information in a multimodal way. If the psychological information presented through visuals and audio, it could help the user relieve some of the cognitive load. This could e.g. be done by having the respiratory circle within the virtual environment, but instead of the fog, we would map the EEG value to the amplitude of the background music.

7.3. Results of the experiment

The findings from the experiment does not provide a clear pattern. This could be due to the small sample size. While 32 participants tested the system in total, eleven of these were discarded due to noisy signal. If the sample size was larger a more general pattern could emerge within the data.
The participants' HR was basically the same when meditating as during baseline measurements. It was expected to see a decrease as an indication for relaxation, however this was not the case. The HR data did have a very high variance, meaning that the people reacted differently to the experiment. This was also observed. Some participants were quite anxious to participate, while other seemed quite relaxed.
The HRV data was also perplexing, as we would expect to see an increase in the RMSSD value. Instead, it decreased by a quite large amount in all of the conditions. This could be due to the fact that meditation does not have as significant an effect on HRV in novice meditators, as it does for expert meditators (Steinhubl et al., 2015). Since this project targeted novice meditators, HRV cannot be considered a useful method for evaluating.
The eSense meditation value obtained from Myndplay was also evaluated. As described

in chapter 2.5.1 it is not known how well this value reflects meditative depth, however it does represent relaxation or calmness to a certain degree. This value increased the most during condition A, increased minimally during condition B and decreased during condition C. If we assume that the value does in fact reflect the depth of meditation, it means the system failed in its goal. The participants were in an even deeper meditative state during baseline compared to the meditative experience during condition C. This can be due to a number of reasons. Not all of the participants were aware of how the fog worked, and one even thought that the more fog in the virtual environment, the better. In hindsight, the participants should have been better briefed about the design of the biofeedback. Another reason could be that they simply found the fog distracting, as mentioned earlier. Finally, it could also be because they were excited by the experience. For a lot of the participants, it was their first time trying VR. This could suggest that they were aroused by the experience meaning they would have difficulties relaxing.
Lastly, the MEDEQ scores for each condition was highest in the relaxation category. This indicates that all of the conditions made the participants relax to a certain degree. It was also assumed that this category was the most prominent, as the participants could not reach a much deeper level of meditation, due to their lack of experience and the fact that they only meditated for five minutes. It is interesting to see that condition C had the highest score in this category. This finding does not correlate with the meditation value obtained from Myndplay, or the fact that some of the participants found the fog distracting. It could indicate, that even though the fog was distracting and the user did not fully understand the biofeedback, they did overall subjectively feel that the experience was relaxing.

7.4. Measuring the depth of meditation

Measuring meditative depth is no easy task, as meditation is a quite complex and sophisticated domain. The MEDEQ claimed to measure meditative depth, but was not developed for novice meditators. It was developed with the help of 45 authorized meditation teachers, meaning experienced meditators. As data was used from experienced meditators it might not reflect the experience of novice meditators. It was also observed, during the experiment, that eight of the participants asked the test conductors to elaborate certain questions, as they did not understand them. It was especially item 2, 7 and 28 that were perplexing. The questions were: *"I experienced equanimity and inner peace"*, *"There was no subject and no object anymore."* and *"There was no meaning of any meditation techniques anymore."*. While these questions might make sense for an experienced meditator, novice meditators have a hard time comprehending them.

Instead of assisting novice meditators in reaching a deep meditative state, the biofeedback system should simply assist them in relaxing. Deep meditative experiences are most often achieved by having closed eyes for at least half an hour and is only reachable by experienced meditators. Using a VR medium, for five minutes will not sufficiently assist the user in reaching a similar depth of meditation. Therefore, instead of measuring the meditative depth a future experiment should try to measure relaxation. However, this contradicted the motivation for the project. The goal was to develop a system that could help relieve stress, and other psychological disorders - through meditation. Relaxation will not necessarily contribute to this goal. It is also challenging to measure relaxation as it is a subjective concept. Individuals relax in very different ways: some find it relaxing to watch a movie, while others find it relaxing to go for a bike ride. This was also suggested by the preliminary questionnaire, as one item had the open-ended question: "What do you usually do to relax?". While a lot of people answered "watch a movie", there were also a large amount of the participants that relaxed while running, doing sports, playing video games or reading. It is therefore a great challenge to design a generic system that aims to make people relax.

8
Future Perspectives

This project still has a long way to go before the proposed system could be reality for novice meditators. As mentioned in chapter 7, alternatives to the biofeedback design should be investigated, as some of the participants found the fog distracting. A future test could help shape a redesign of the system. However before designing such a test, it is important to reconsider the aim of the system. It has proven hard to reliably measure meditative depth, and can even be argued whether a system utilising VR and biofeedback can be used in this context. Such a system could be used to make an individual calm and could serve as a 'break' from an otherwise busy everyday life. However, it will assumedly not be able to achieve the same meditative depths found among experienced meditators. Thus the aim of the system should be to make the user relax, instead of making them achieve a certain meditative depth.

This project has also served as an investigation into BCI devices in the context of meditation. As mentioned in chapter 2.5, these devices have increased in popularity and been made more cheap and convenient in recent years. To obtain the EEG signals from a person, one no longer has to have several wet-electrodes placed on their head, but can use as few as one single dry electrode (Hassib and Schneegass, 2015). The BCI devices also have bluetooth, making them able to pair with a smartphone. Using such a device shows great promise, as it makes it possible to quantify mental health. However, this project has found that they still have some way to go, before being fully adapted by society. The signal of the Myndplay device has proven to be very unstable, which affects the reliability of the EEG data. Furthermore, the validity of the EEG data is questionable, meaning that it might not accurately reflect an individual's mental state.

The users did not improve their meditative depth straight away, but the system could still be a good training tool. A future study should investigate how the aim of the biofeedback system transfers to learning of meditation. While this project aimed to assist the meditators obtain a deeper meditative state within five minutes, it did not investigate to which extent it assisted them in learning meditation. In the preliminary questionnaire (section 2.1), lack of knowledge about meditation was found to be one of the most prominent reasons why people do not meditate. Teaching them to meditate through an immersive biofeedback system could be a promising area to investigate. This could be evaluated through a long-term experiment, where an experimental group would get the system and a control group would meditate by themselves. Through comparison of the groups, it would show whether the experimental group learned to reach a deep level of meditation faster than the control group. Qualitative methods should not be neglected, as there might not be a significant difference in the learning rate, though it might be a more enjoyable and entertaining method for learning meditation.

9 Conclusion

This project sought to develop a system that could assist novice meditators in reaching a deep meditative state. The proposed system utilised biofeedback as a way to make the meditator aware of their mental state and their respiration. A virtual environment was developed in which the user's meditative level was mapped to fog and their respiratory information was mapped to an expanding and contracting circle. The respiratory feedback was later discarded due to issues obtaining accurate respiration data. In order to enhance the feeling of immersion and presence, the system utilised a virtual reality environment.

The proposed biofeedback system was furthermore evaluated through an experiment using a between group design with three groups, each getting exposed different conditions. In short, the conditions were as follows: A) A control condition where the participant meditated with closed eyes and listened to a guided meditation. B) A condition where the participant listened to a guided meditation while being immersed in the virtual reality environment. C) An experimental condition where the participant got exposed to the full biofeedback system in virtual reality while listening to a guided meditation. In all of these three conditions, heart rate variability, electroencephalography data and meditative depth were measured. No significant difference in the data between the groups was observed. This could be due to several factors. First, the participants were only exposed to the conditions for five minutes, meaning it would be hard for them to reach a deep meditative level within this period of time. Second, due to challenges obtaining a clear signal, much of the electroencephalography data was discarded meaning. Thus, only seven participants in each group were used. A larger sample size could have provided more generalisable data. Third, some participants did not fully understand the biofeedback system. They did not know that the fog reflected their mental condition and found it more confusing and distracting than helpful.

It is safe to say that the proposed biofeedback system did not help the users reach a deep meditative state. However, the results suggested that it did make the users relax. Whether the biofeedback system is more relaxing than a traditional guided meditation approach is still uncertain. A future experiment could reveal this, where the dependent variable should be relaxation instead of meditative depth. Reactions of the participants did suggest that VR utilising biofeedback methods could be an entertaining, intriguing and novel approach to meditation.

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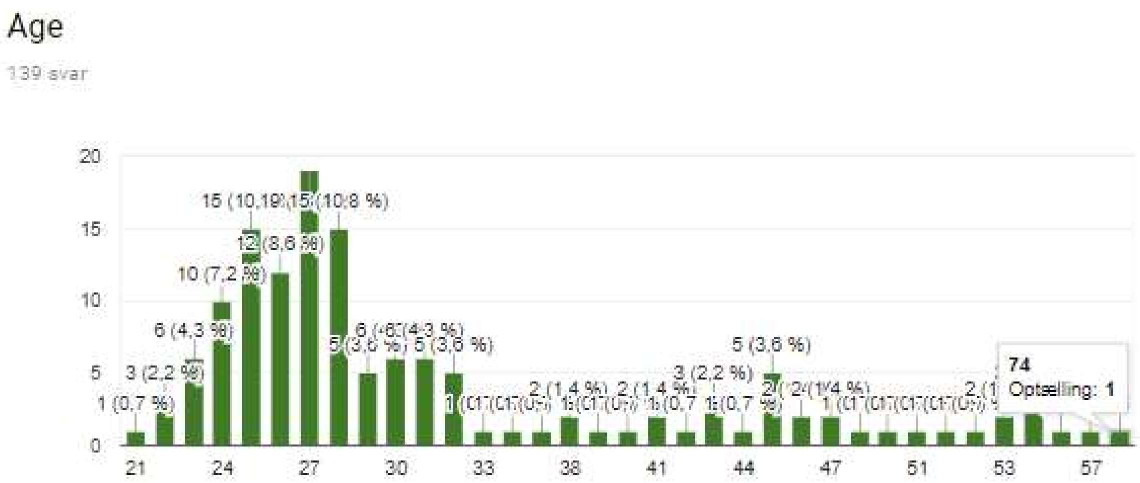
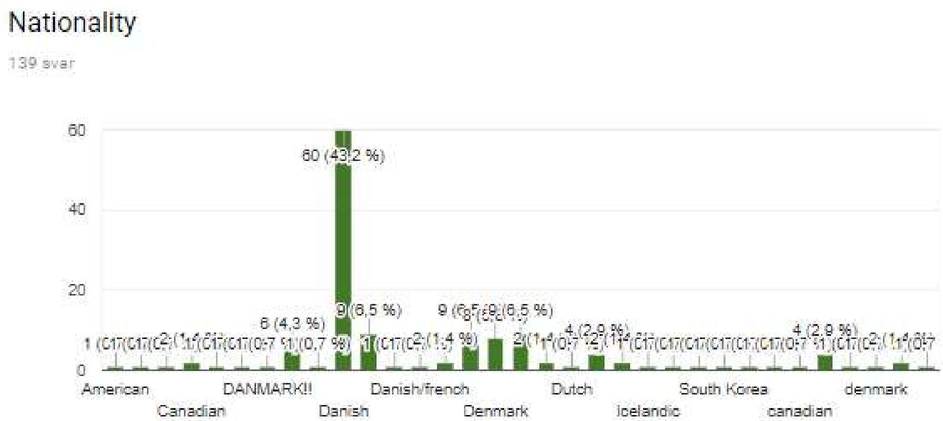
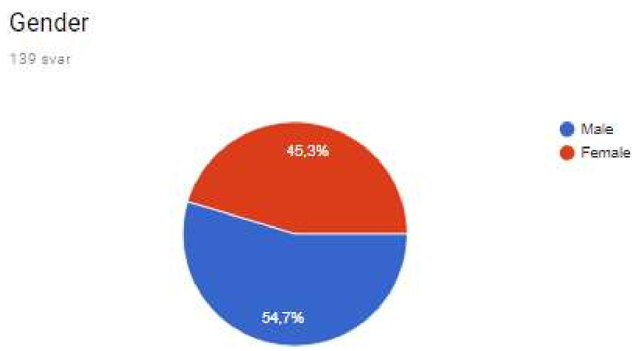
A
Appendix

All responses from the preliminary questionnaire.

139 answers:


Age
139 svar
20
15
10
5
0
21
24
27
30
33
38
41
44
47
51
53
57
15 (10,1%)
15 (10,8 %)
12 (8,6 %)
10 (7,2 %)
6 (4,3 %)
3 (2,2 %)
1 (0,7 %)
5 (3,6 %)
5 (3,6 %)
74
Optælling: 1


Nationality
139 svar
60
40
20
0
60 (43,2 %)
9 (6,5 %)
6 (4,3 %)
4 (2,9 %)
American
Canadian
DANMARK!!
Danish
Danish/french
Denmark
Dutch
Icelandic
South Korea
canadian
denmark


Gender
139 svar
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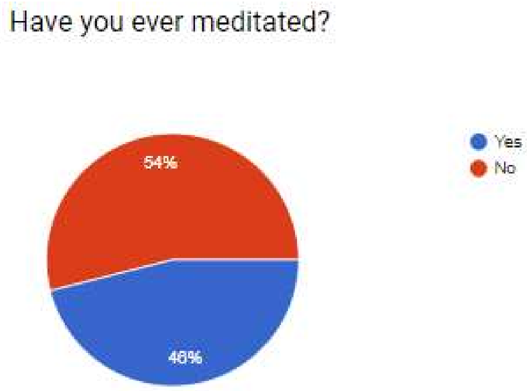
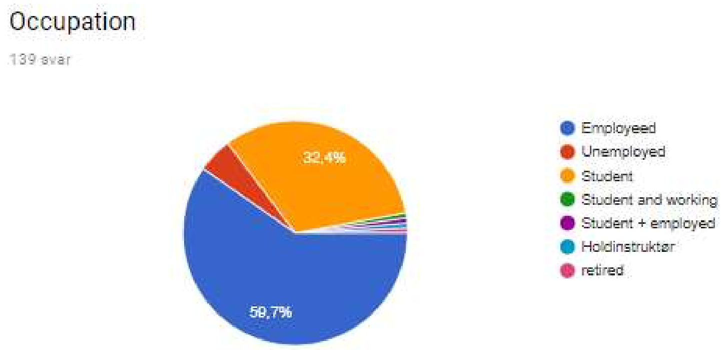
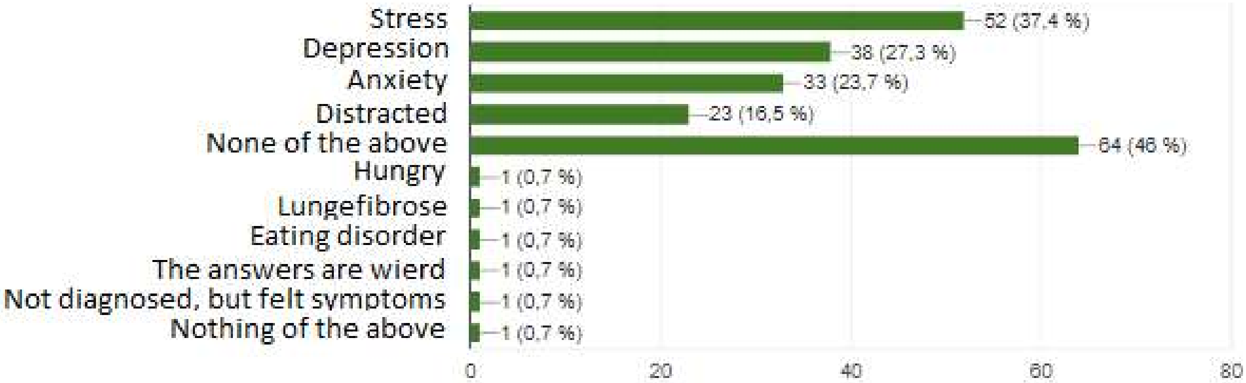
54,7%
Male
Female


Have you ever meditated?
54%
46%
Yes
No

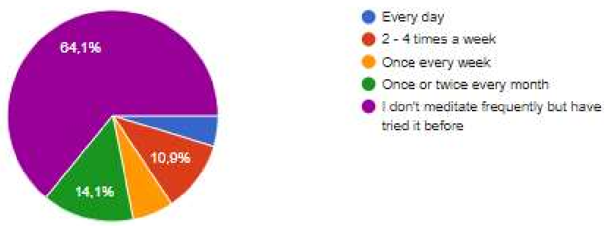

Occupation
139 svar
32,4%
59,7%
Employeed
Unemployed
Student
Student and working
Student + employed
Holdinstruktør
retired

Have you ever suffered from any of the following psychological disorders?



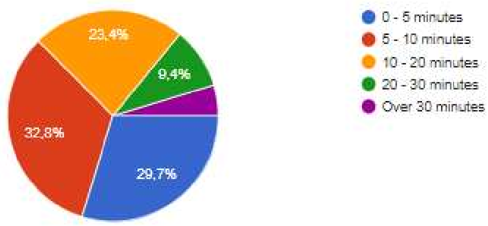
How often do you meditate?

64 svar



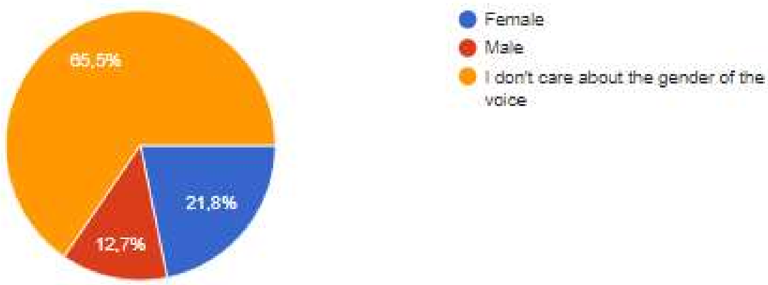
How many minutes do you meditate (on average)

64 svar



If you use guided meditation - which voice do you prefer?

55 svar

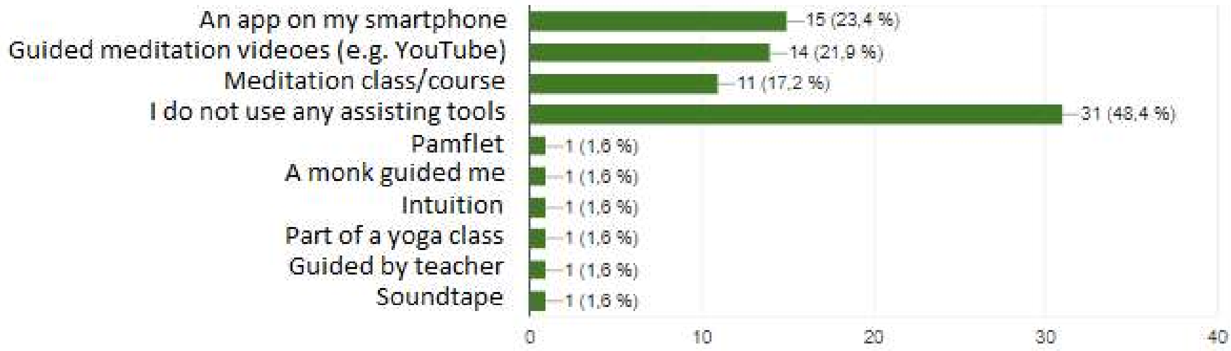


Why did you start meditating?

Stress (2)
1998
It is good for your brain
a workshop about meditatu
I do it as part of my daily yoga practice
Ved et tilfælde
I use meditation when I’m stressed and Everything is to much
Doing guided meditation when i get the chance
Tried it via a lecture
To relax
6 months ago
To lower stress
I took a course in meditation, to find out what it was and if it was something for me
Trying to relieve stress
Because I have issues.
Mental health reasons
Sitting comfortably with closed eyes concentrating on my breathing
Just to try it
For pleasure
To counter anxiety
To find peace in the body
stress
Recommendation from my mother and boyfriend
It's a natural state of mind !
Part of a work off-site
To calm myself down and start the day on a positive note.
Flying, dentist, before an important meeting
Well being boosts
Tried it during a school trip to a budist monastery
2013
To calm my anxiety
Trying something regarding stress
Depression and a break up. To control my emotions
It was a part of jiu jitsu training
Stress
i had problems with sleep
To sleep when using drugs
As a part of yoga class
It was a part of a yoga class.
Better sleep
To gain inner peace
Because i was told to do so before getting a "henvisnig" from my doctor to a therapist.
Wanted to get out of some bad habbits, with anxety. So i first started practicing lucid dreaming meditaton
I tried to creat an alternative place for my mind and thoughts
To focus
mobilapps
to become calm
As a part of my religion
Trying to keep the mind in top shape
Part of a kite-surfing course

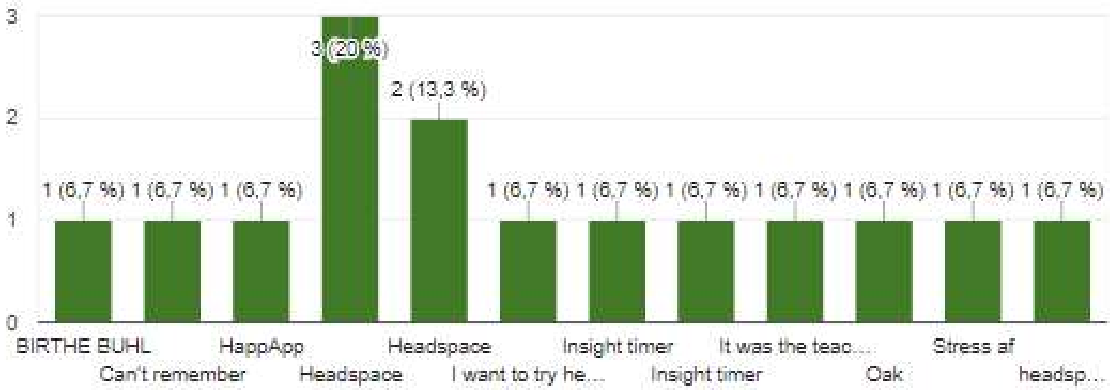
Do you use any tools for meditation?

64 svar



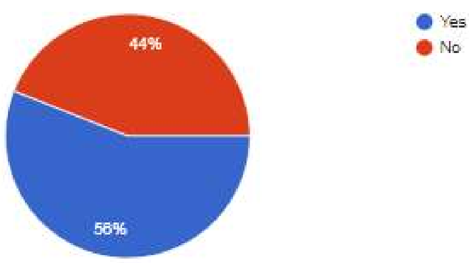
If you use a mobile app, please name it:

15 svar



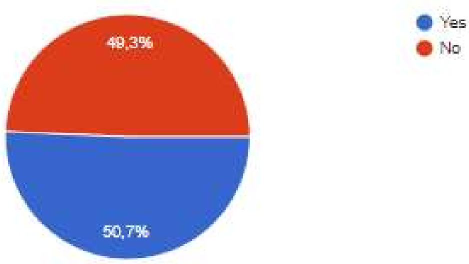
Are you aware of the benefits of meditation?

75 svar



Have you ever considered meditation?

75 svar



What has stopped you from meditating?

I'm too easy distracted
lack of time and motivation
Never took the step.
Tjaa
Manglende tid
Lack of knowledge on subject
I am not sure whether I think it seems silly or as a waste of time..
At noget af det virker som hokus pokus
I was thinking about it, but never found further motivation to actually do it
Don't have the concentration ability required.
I wouldn’t know how to start
If we are talking about meditation in the literal buddhist way, I do not know where to start, and I am not sure if it would actually benefit anything.
Not knowing how to start
Priorities
Lack of knowhow
Har aldrig fundet tiden til det - mest på grund af manglende viden
Lack of knowledge
Not knowing how to do it right, I guess
Don’t have the time, affinity, or interest
Time
Don’t know how to, need guidance and decide a time for it
I don't have anyone close to me doing it
Getting started, and taking the time to do it.
I simply don't know where to start. As in, how should I learn it "the right way". I do know that there's probably a ton of YouTube videos - But I don't know if the quality is good, and I don't want to waste a ton of time looking around for it.
finder andre øvelser
Time to get into it
Time, how to to
Not quite sure how to start
Time
In the moment it is, almost per definition, a waste of time.
No time for it
No rime
time, at sætte tid af til at sætte sig ind i det, eller skulle på "kursus"..
Taking the initiative
time
time, tedious, results
Tid
Not had the drive to approach a coaching session

What is your attitude towards meditation?

Indifferent (3)
bwaah
Probably works for some people- however I never saw the need
Sceptical
I don't have an attitude towards it - if it works for the people who use it, then its fine for them. I choose to use fitness/workouts instead.
Complicated - difficult to do ‘right’.
Skeptical
Its boring
I don’t really believe in it

I'm open to any suggestions
Don't really know anything about it
I feel a great barrier towards meditating - I am very much “in my head” and have an extremely hard time letting go of my thoughts. To the extent that I do not trust that I will ever be able to meditate
It’s not for me
Might help some people. Don't feel I need it as I am a very calm person.
?
I think it has many benefits, but I think I'm not patient enough
funky
I respect people who use it as a way to mentally stay positive and calm themselves, however, I don't see myself using it very regularly
My brain require too much constant entertainment to do it
Boring
Det hjælper nogen. mit temperement er bare ikke til det
I'm not suitable for it. You need a certain kind of relaxing attitude which I don't have
it can be helpful to collect yourself and relax
Neutral to positive
Only know the concept through word of mouth or through movies. Haven't considered the purpose and benefits of it, nor considered it as a means to improve any conditions of mine whether they might be physical or phsycological. On that note, i consider my attitude towards meditation as neutral.
As long as it helps people it’s fine
I believe I achieve the same by sleeping
Open to it
Seems to work out fine for many people.
unknown
Positive
It can help some people hwo have problems with stress ect. Relaxing
OK - just not for me
If it works for people go for it but its not for me.
May work for some, not for me

What do you usually do to relax?

Tv (3)
Watch tv (3)
walk (2)
Go for a walk
Watch tv, read, stay in bed with my boyfriend
Watch TV
watch youtube videos
Watch a movie, read a book, go for a walk, exercise
Læser
Watch tv, hang out and chill with friends
Gaming
Gaming/Workout
Sleep, watch series, walk.
Listing to Music
Watch a movie
watch videos, hang out with friends, listen to music
Sport
Yoga / Slow deep breathing / read a book / listen to music
Exercise or walking
Breathe
Read
Friends, sports, video games, smoking

Read or take long walks
Sleep, watch tv, play with children
Take a walk in the nearby forest
Meditation or bookreading
Alt muligt forskelligt - nogle gange er det sammen med en ven andre gange er det social medier
Play video games
Sofa, food, drink
Sports
Take a nap
Take a walk, read.
Play games and listen to music
Watch a movie or something on the tv
Watch tv or read a book
Watch tv-series
Play games, read about stuff that interrest me, watch sports/movies and series
Walk, watch a movie
Cycling (mind only), video games
I watch discovery , animal planet
Listen to music, watch sports.
It might sound strange but I do practical things like carpentry, clean my bike, cross stitch, cook and similar activities where I'm using my hands - when I do that there is not a single work related thought in my mind or other duties that will haunt me while in that "zone" of concentration
Sit or lie in bed, use TV or mobile phone, walk in nature, have a long talk with my partner
Chill alone reading or searching the web.
Read, walk or drink. Very rare a cigar.
Watch tv, listen to music, play conputer
Gaming or reading
Drink coffee in my armchair
Music, tv
I read
Ser sport i tv
Reading
Sleep or read, watch tv
Listen to (classical) music, read
Simply laying on the coach, watch a good movie, play some computer, not thinking of anything school/work related
Take a walk with my dogs
Read + TV perhaps cross words
Sleep
Play video games and watch movies / series
breathe, music, sport
run
Sport
Flute musiv, running water and other nature sounds
Sew, watch tv
Bicycling, breathing, thinking and sometimes cannabis
Take a walk, read, tv series
Watch series, youtube. listening to podcast
Sports
Read a book
Watch TV; go for a walk in the woods
Lay down in couch, usually looking at phone or tv.
play games, watch series
Read, train or just simply relax
It depends largely on what i did before i decided to relax. If it relates to work or schoolwork i simply enjoy being home, watchin TV or play computer.

I read or cook.

feel my littlefinges at the dentist, walk through the path, breath control

Drink beers

Play guitar, take a bath or hot tub, sleep

går i seng

Warch TV

Cup of tea, couch & Netflix

Watch tv, read a book

Sleep or Clean the house or exercise

Play video games, watch TV or listen to music

Yoga, watch a movie or cuddle with my dogs

Eating, sleeping

Breath, look at trees, smile

Music

Spend time outside or watch a movie

Music, tv, ridning A bike, walking

Walk with a audiobook

Fitness

Crochet, reading, yoga

lay down

Lay down + youtube streaming

Lie down, go a walk, sports, yoga, stretching, drink tea, or go for a coffe, eat a healthy snack

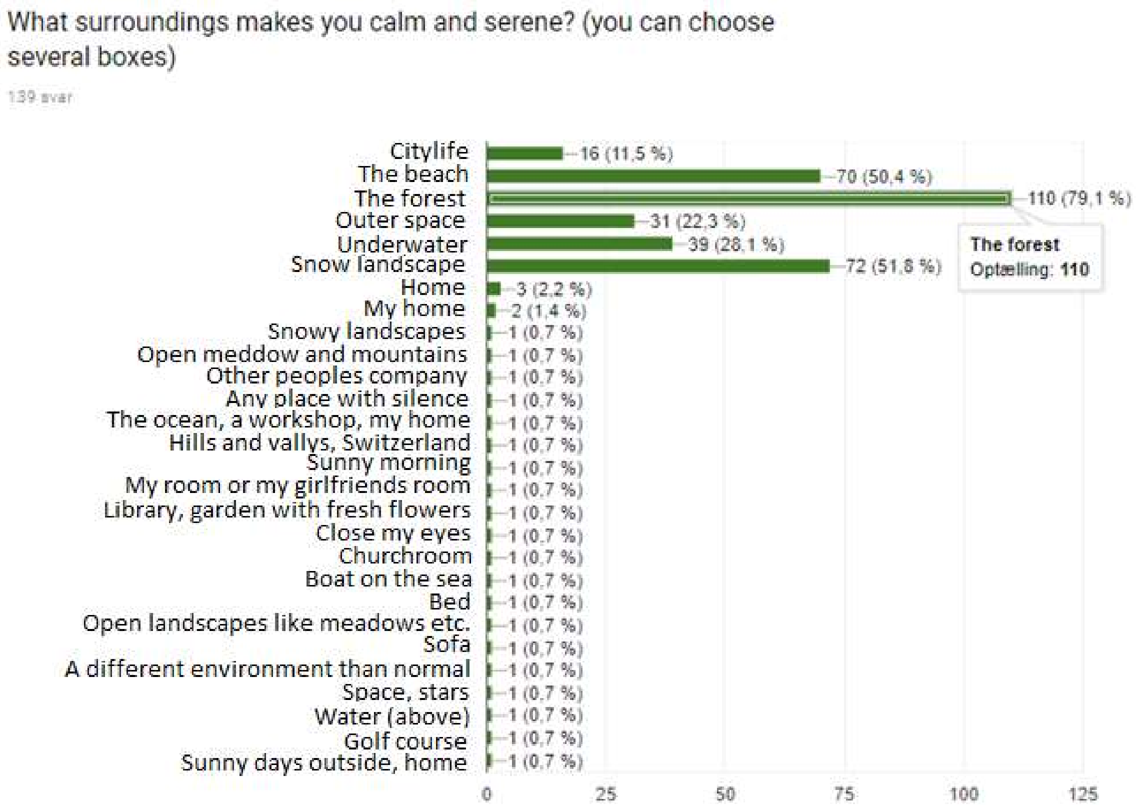
Be creative: Draw, knit, paint, etc.

Read, play video games, spend time with friends and family

Do ipad

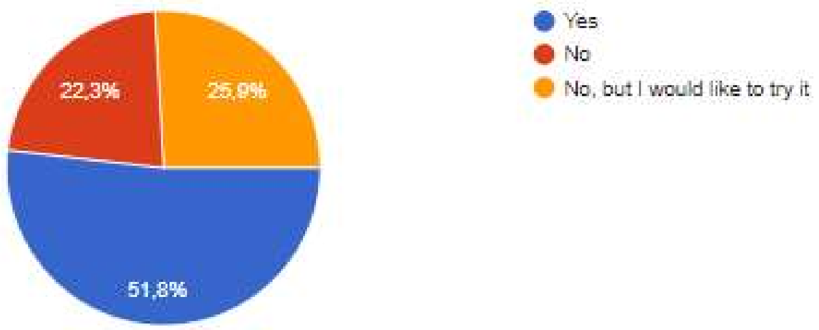
Sex, youtube, netflix

Andet (19)



Have you ever tried Virtual Reality (VR)?

139 svar



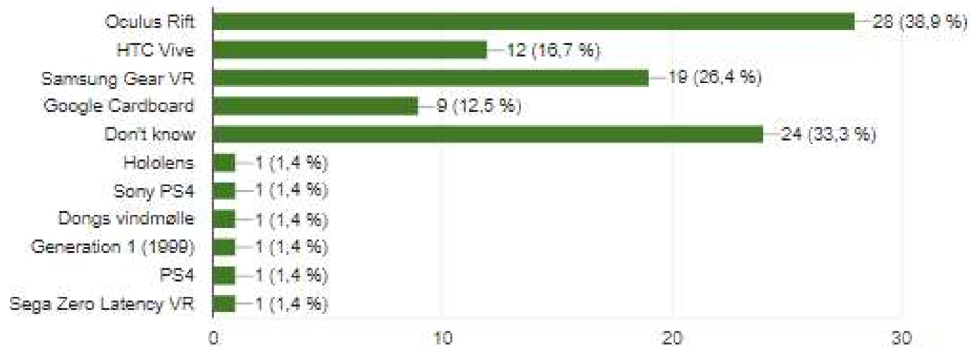
Can you describe how you felt during your first VR experience?

Amazed (4)
Curious (2)
PS4 game
It was fun, but I was a bit disappointed with the limit of the platform
Entertained, challenged
thought it was cool
Nauseous
excited
Curious
Dizzy but excited
Confused, a lot of unknowns happening at once
Odd :)
Dizzy
Ok. It was an VR of a windmill.
Cant rally remember, excited probably thought it was cool
Pleasantly surprised, dizzy
dizzy, like in a Montagne russe
Somewhat impressed by the possibilities
Wow this really feel 3 dimensionally!
Fine, tried to "walk the plank" from a skyscraper.
Overwhelmed
Weird
Weird, but also awestuck
Entertained
crazy
Excited and high anticipation to what I was about to experience
Waw
Wierded out
It was too dark and had very low resolution, so it was rather disorienting
Impressed
Confused

Excited, curious, in awe
A very weird, but fun experience. 10/10, would try again.
i felt great, it was a fun and new experience, which i would love to do more of
Curious and engaged as iv'e never tried it before.
Fine. Cool experience. More fun than expected.
Fine
Floating, couldn’t see my feet so O felt like not being on the ground even though the scene was in a building
Awe
Old, yet i really felt excited, like i was on The vanguard of innovation, then i just felt like Playing a game while being surronded by screene
i watched a gorillaz music video, it was pretty great.
Excited to try it, and thrilled
It is cool, but it has a tendency of making me dissy (if there's movement)
Cool, but not too impressed with the technology. It didn't convince me with the "reality" part.
Nothing special
Exciting
I felt excited, and curious
Dont know
curious
A bit confused as to what I was supposed to do. Other than that, I was only intrigued.
Funny
overwhelmed
somewhat weird, but entertained
Immersive
strange - had to find my feet
confused

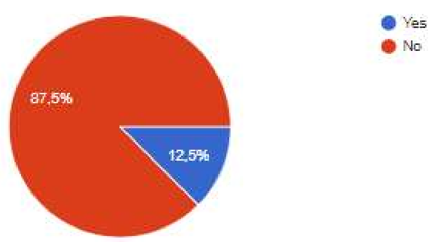
Which platform did you try?

72 svar



Do you own a VR headset?

72 svar



B
Appendix

The manuscript for the guided meditation, used in the application.

Guided Meditation Speak

Close your eyes when you are ready
Keep your back upright
Hands resting wherever they're comfortable
Tongue on the roof of your mouth, or wherever it's comfortable.
Notice your body
From the inside
Noticing the shape of your body, the weight, touch
Let yourself relax
Become curious about your body
Seated here
The sensations of your body
The touch
The connection with the floor
The chair

Relax any areas of tightness or tension
Just breathe
Soften
Now, begin to tune into your breath
In your body
Feeling the natural flow of breath
Not long not short just natural
Notice where you feel your breath in your body
It might be in your abdomen
It may be in your chest or throat
Or in your nostrils
See if you can feel the sensations of breath
One breath at a time
When one breath ends, the next breath begins
Now as you do this you might notice that your mind start to wander
You might start thinking about other things
If this happens it is not a problem
It's very natural
Just notice that your mind has wandered
You can say "thinking" or "wandering" in your head softly
Gently redirect your attention right back to the breathing
So we'll stay with this for some time in silence
Just a short time
Noticing our breath
From time to time getting lost in thought and returning to our breath
See if you can be really kind to yourself in the process
Once again you can notice your body, your whole body, seated here
Let yourself relax even more deeply
Offer yourself some appreciation
For doing this practice today
Whatever that means to you
Finding a sense of ease and wellbeing for yourself and this day

C
Appendix

Link to Github, with the entire Unity project.
The scripts are located within Assets/Scripts.

Link:
https://github.com/Malthdk/MasterVRET

D
Appendix

The code that handles the mapping of EEG signals to the fog.

EEG to fog mapping

```
using System.Collections;
using System.IO;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using System.Linq;

public class EEGMapper : MonoBehaviour {

    public Calibration calibrationScript;           // A reference to the calibration script
    public Intro introScript;                       // A reference to the intro script
    public EEGListener eegScript;                   // A reference to the EEG listener script
    public Material fogMat, skyBox;                 // The material of particles and skybox
    public float calculationDuration;               // Duration for calculation average

    private List<float> meditationDataList;         // List for meditation value - used to calculate average
    private float meditationAvg, fogAmount, skyFog; // Float variables for mapping
    private Color startingCol;                      // Starting color of particle system
    private bool mapping;                           // Bool used as trigger

    void Start () {
        // Instatiates new list
        meditationDataList = new List<float>();

        // Sets default values
        startingCol = fogMat.GetColor ("_TintColor");
        startingCol.a = 0.2f;
        fogMat.SetColor ("TintColor", startingCol);
        skyBox.SetFloat ("_FogFill", 0f);
        RenderSettings.fogEndDistance = 450f;
    }

    void Update () {
        // Has the intro sequence ended? Then start calculating average and the mapping process
        if (introScript.introEnded && !mapping) {
            mapping = true;
            StartCoroutine ("CalculateAverage");
        }
    }

    // Handles all meditation mapping
    IEnumerator MeditationMapping()
    {
        // For the unity global fog
        float fogAmountOld = fogAmount;
        float fogAmountNew = 50f + meditationAvg * 4f;

        // For the fog particle system
        Color col = new Color();
        col = startingCol;
        float alphaOld = fogMat.GetColor ("_TintColor").a;
        float alphaNew = Mathf.Clamp01(.5f - (meditationAvg/160f));     // We start with 0.5 alpha (as this is default for the texture) and we divide with 160 since a meditation value of 80 should clear the fog!

       // For the skybox fog
       float skyFogOld = skyBox.GetFloat("_FogFill");
       float skyFogNew = Mathf.Clamp01(1f - (meditationAvg / 80f));   // We divide the meditation value with 80 and subtract this value to 1 (as 1 makes it completely foggy)

       // If meditation value is 0 (meaning singal is lost - set all variables to "default" values)
       if (meditationAvg == 0) {
           skyBox.SetFloat("_FogFill", .5f);
           fogMat.SetColor ("_TintColor", startingCol);
           RenderSettings.fogEndDistance = 250f;
           yield break;
       }

       float t = 0;
       // While t (time) is lower than the calculation duration, map the values
       while (t < calculationDuration) {
           t += Time.deltaTime;
           float blend = Mathf.Clamp01 (t / calculationDuration);          // Creates a value reflecting time, interpolating between 0 and 1

           fogAmount = Mathf.Lerp (fogAmountOld, fogAmountNew, blend);     // Lerp from old fog value to new fog value
           RenderSettings.fogEndDistance = fogAmount;                      // Assign fog value

           skyFog = Mathf.Lerp (skyFogOld, skyFogNew, blend);              // Lerp from old skybox fog value to new skybox fog value
           skyBox.SetFloat("_FogFill", skyFog);                            // Set value on the skybox material

           col.a = Mathf.Lerp (alphaOld, alphaNew, blend);                 // Lerp from old alpha value to new alpha value
           fogMat.SetColor ("_TintColor", col);                            // Set color alpha calue on particle material

           yield return null;
       }
    }

    // Calculates average of meditation value
    IEnumerator CalculateAverage()
    {
       float t = 0;
       // While t (time) is lower than the calculation duration, add meditation values to list
       while (t < calculationDuration) {
           t += Time.deltaTime;
           meditationDataList.Add (eegScript.Meditation);
           yield return null;
       }
       meditationAvg = meditationDataList.Average ();      // Take average of meditation data list
       meditationDataList.Clear ();                        // Clears the list so it is ready to be filled again

       StartCoroutine ("MeditationMapping");               // Starts this function again
       StartCoroutine ("CalculateAverage");                // Starts the mapping function
    }
}
```

E
Appendix

The code that handles mapping from the respiratory belt to the circle.

Respiration to circle mapping

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.Linq;

public class CircleBreath : MonoBehaviour {

    public Calibration calibrationScript;                          // A reference to the calibration script
    public float duration = .2f;                                   // The duration of the average calcuations
    private float respValue, smoothRespValue, prevSmoothRespValue; // Values used for the exponential smoothing function
    private bool initialisedSmoothing;                             // Has smoothing been initialised

    private Vector3 startScale;                                    // The circle's starting size

    void Awake () {
        // Sets average and starts calculating the average
        startScale = transform.localScale;
        StartCoroutine ("MovingAverage");
    }

    // Handles the mapping
    IEnumerator SetScale() {
        float scaleOld = transform.localScale.x;                   // Sets the scales old value to the current value
        float scale;                                               // Temporary variable

        // Makes values proper scale values for our circle
        smoothRespValue += .5f;
        smoothRespValue *= 12f;

        float t = 0;
        // While time (t) is less than the set duration (0.2)
        while (t < duration) {
            t += Time.deltaTime;                           // Time counter
            float blend = Mathf.Clamp01 (t / duration); // Turn the time into an interpolation factor between 0 and 1.

            scale = Mathf.Lerp (scaleOld, smoothRespValue, blend);  // Lerp from old value to newly obtained value
            transform.localScale = new Vector3(scale,scale,scale);  // Set the lerp value to the circle image's local scale
            yield return null;                                      // Repeat
        }
    }

    // Calculates the average and starts the setscale function
    IEnumerator MovingAverage() {
        List<float> respValues = new List<float>();
        float t = 0;
        while (t < duration) {
            t += Time.deltaTime;
            respValues.Add (1f-calibrationScript.normRespData); // We add the normalised electrical resistance value to a list. We subtract the normalised electrical resistance from the belt from 1, since it reverses the values
            yield return null;
        }
        respValue = respValues.Average ();                     // Calculates the average of the list
        respValues.Clear();                                    // Clears the list making it ready to run again
        // This is used to initialise smoothing. As the function depends on a previous value, we dont have this initially. Therefore the average is used instead
        if (!initialisedSmoothing) {
            prevSmoothRespValue = respValue;
            initialisedSmoothing = true;
        }
        smoothRespValue = ExponentialSmoothing (respValue, prevSmoothRespValue, 0.2f);  // Runs the exponential smoothing function and sets it to smooth rest value
        prevSmoothRespValue = smoothRespValue;                 // Sets the previous smoothing value to be equal to the newly calculated (so it has this information next time it is run)
        StartCoroutine ("SetScale");                           // Starts mapping function
        StartCoroutine ("MovingAverage");                      // Reruns this function
    }

    // Function used to find exponential smoothing value
    float ExponentialSmoothing(float value, float prevValue, float a) {
        float s = a * value + ((1f - a) * prevValue);
        return s;
    }
}
```

F
Appendix

The code that handles the intro sequence.

Intro sequence script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

// Intro class - the current one not incorporating the respiration belt. For the respiration belt we had one additional blueooth image and used btScript.respConnected to find out whether it was connected
public class Intro : MonoBehaviour
{
    public GameObject breathingCanvas, fogParticleSystem, circle;                       // The gameobjects
    public Calibration calibrationScript;                                               // A reference to the calibration script
    public BluetoothConnection btScript;                                                // A reference to the bluetooth script
    public Text calibrationText, title;                                                 // UI text object for calibrationtext and title
    public Text[] textObjects;                                                          // UI text array (consisting of the three text objects)
    public Image calibrationPanelImage, calibrationImage, logo, mainBackground, btImageResp, btImageEEG;   // All of the UI images in the intro sequence
    public bool startCalibration, introEnded;                                           // Bools primarily used by other scipts

    private bool btConnected, textChanging;                                             // private bools for whether bluetooth is connecting or text is changing
    private int index;                                                                  // Index number used for keeping track of the current active text object

    void Start() {
        // Sets starting alpha of all text (except the first) to 0
        Color col = textObjects[0].color;
        col.a = 0f;
        for (int i = 1; i < textObjects.Length; i++) {
            textObjects [i].color = col;
        }
    }

    void Update() {
        // If mouse button (or gear VR button) is down and myndplay is connected and we are not calibrating
        if (Input.GetMouseButtonDown (0) && !startCalibration && !textChanging && btScript.tgConnected) {
            textChanging = true;                // Text is changing
            index++;                            // Increment index by 1
            // If index is less than the length of the textobject array (3) change text
            if (index < textObjects.Length) {
                StartCoroutine ("ChangeText");
                if (index == 1) {
                    StartCoroutine ("StartCalibration");        // Special case for calibration as we need to display certain images
                }
            }
        }

        // If mouse button is down and the current text is the last in array: end the intro sequence
        if (Input.GetMouseButtonDown (0) && index == 2){
            StartCoroutine ("EndIntro");
        }

        // Used to display bluetooth icon
        DisplayBluetooth ();
    }

    void DisplayBluetooth() {
        if (btScript.tgConnected) {
            btImageEEG.color = Color.green;     // Makes it green if it is connected
        } else if (btScript.tgConnecting) {
            btImageEEG.color = Color.yellow;    // Makes it yellow if connected but with noisy signal
        } else {
            btImageEEG.color = Color.red;       // Makes it red if not connected
        }
    }

    // Courutine that makes us able to fade in and out graphical objects (by changing their alpha value)
    IEnumerator FadeTo(Graphic gfx, float targetOpacity, float duration)
    {
        Color color;

        // Cache the current color of the material, and its initial opacity.
        color = gfx.color;
        float startOpacity = color.a;

        // Track how many seconds we've been fading.
        float t = 0;

        while (t < duration) {
            // Step the fade forward one frame.
            t += Time.deltaTime;
            // Turn the time into an interpolation factor between 0 and 1.
            float blend = Mathf.Clamp01(t / duration);

            // Blend to the corresponding opacity between start & target.
            color.a = Mathf.Lerp(startOpacity, targetOpacity, blend);

            // Apply the resulting color to the material.
            gfx.color = color;

            // Wait one frame, and repeat.
            yield return null;
        }
    }

    // Courutine that changes text based on index. Uses FadeTo courutine
    IEnumerator ChangeText() {
        StartCoroutine(FadeTo(textObjects [index - 1], 0f, 1f));
        yield return new WaitForSeconds (delay);
        StartCoroutine(FadeTo(textObjects [index], 1f, 1f));
    }

    // This courutine controls the calibration UI in the intro secuence. Fades in all of the calibration images and fills image
    IEnumerator StartCalibration() {
        yield return new WaitForSeconds (delay+3.5f);
        textChanging = false;
        startCalibration = true;
        StartCoroutine(FadeTo(calibrationPanelImage, 1f, 1f));
        StartCoroutine(FadeTo(calibrationText, 1f, 1f));
        float t = 0;
        while (t < calibrationScript.calibrationDuration) {
            // Step the fade forward one frame.
            t += Time.deltaTime;
            // Turn the time into an interpolation factor between 0 and 1.
            float timeLeft = t / calibrationScript.calibrationDuration;
            calibrationImage.fillAmount = timeLeft;
            // Wait one frame, and repeat.
            yield return null;
        }
        StartCoroutine(FadeTo(calibrationPanelImage, 0f, 1f));
        StartCoroutine(FadeTo(calibrationText, 0f, 1.5f));
        StartCoroutine(FadeTo(calibrationImage, 0f, 1f));
        StartCoroutine(FadeTo(title, 0f, 1f));
        index++;
        if (index < textObjects.Length) {
            StartCoroutine ("ChangeText");
        }
    }

    // This courutine ends the into secuence by fading out UI elements and activating game elements
    IEnumerator EndIntro() {
        introEnded = true;
        StartCoroutine(FadeTo(logo, 0f, 3f));
        StartCoroutine(FadeTo(textObjects[2], 0f, 1.5f));
        StartCoroutine(FadeTo(mainBackground, 0f, 2f));
        StartCoroutine(FadeTo(btImageEEG, 0f, 1.2f));
        StartCoroutine(FadeTo(btImageResp, 0f, 1.4f));
        yield return new WaitForSeconds (3f);
        fogParticleSystem.SetActive (true);
        Destroy(this.gameObject);
    }
}
```

G
Appendix

The answers for every participant in the test. The numbers are the mean of the total score for each category.

Meditation Depth Questionnaire Answers

Subject nr.	Condition	Hindrances	Relaxation	Personal self	Transpersonal qualities	Transpersonal self
14	A	1,5	2,3	1,4	0,8	1,1
18	A	1	2	0,5	0,7	0,3
26	A	1	3,3	1,5	2,1	1,6
27	A	1,8	0,6	0,1	0,2	0,1
28	A	1,6	4	1,2	1,1	0,8
29	A	0,8	3,3	2,4	1,8	1,5
32	A	1,1	3	1,4	2	1,1
4	B	2,1	3,6	1,8	2,6	1,3
5	B	1,3	1,6	0,5	1,3	1
8	B	2	1,3	0,1	0,3	0
12	B	1,5	2	1,8	1,5	1
13	B	1	3,3	2,7	2,2	2,5
24	B	1,5	2,6	1	1,8	1,6
25	B	2	2	1,4	1,5	1
6	C	1,3	2,3	0,2	0,6	0,6
7	C	0,5	3	1,5	1,5	1,3
10	C	1,6	3,6	2,2	2,3	3,6
15	C	1	3,6	1,4	8	2
22	C	1,1	3,6	1	1,1	1,6
30	C	1,8	2,3	0,2	1	0,5
31	C	0,3	4	1,7	1,7	1,6

H
Appendix

The questionnaire used for the test. First the written consent, then questions about demographics, followed by questions about the participant's meditation habits. After completing the meditation, the participant answered the Meditation Depth Questionnaire.
This Appendix is the questionnaire for Condition C. Condition A and B are similar but does not have the additional questions after the MEDEQ.

Meditation

This experiment is investigating biofeedback for novice meditators. By participating and filling out this questionnaire, you agree to letting us use your data for our Master Thesis. Your answers will be processed anonymously. If you feel any discomfort, please let us know and we will stop the session.

Thank you very much for helping us!

*Skal udfyldes

Demographics

1. **Age** *

   ____

2. **Nationality** *

   ____

3. **Gender** *

   Markér kun ét felt.

   - ( ) Female
   - ( ) Male
   - ( ) Other
   - ( ) Prefer not to say

4. **Occupation** *

   Markér kun ét felt.

   - ( ) Employeed
   - ( ) Unemployeed
   - ( ) Student
   - ( ) Andet: ______________________

5. **Have you had any coffee within the last two hours?**

   Markér kun ét felt.

   - ( ) Yes
   - ( ) No

6. **Have you ever felt any of the following psychological disorders?** *

   Markér alle, du er enig i.

   - [ ] Stress
   - [ ] Depression
   - [ ] Anxiety
   - [ ] Distracted
   - [ ] None of the above

7. **Have you ever meditated?** *
Markér kun ét felt.

- Yes *Gå til spørgsmål 8.*
- No *Gå til "Please contact a test conductor".*

Unavngivet sektion

8. **How often do you meditate?** *
Markér kun ét felt.

- Every day
- 2 - 4 times a week
- Once or twice every week
- Once every week
- I don't meditate frequently but have tried it before

9. **How many minutes do you meditate? (on average)** *
Markér kun ét felt.

- 0 - 5 minutes
- 5 - 10 minutes
- 10 - 20 minutes
- 20 - 30 minutes
- Over 30 minutes

Please contact a test conductor

Please describe your meditation experience

The scale is 0 - 4 (0 = not at all, 1 = a little bit, 2 = mediocre, 3 = much, 4 = very much)

10. **I found it difficult to relax** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

11. **I experienced equanimity and inner peace** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

12. **I got intuitive insights or understandings about my life** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

13. **There was a constantly change of thoughts in my mind** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

14. **I became aware of a center inside myself** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

15. **I felt myself at one with everything** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

16. **There was no subject and no object anymore** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

17. **I became more and more calm and patient** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

18. **I was very busy in order to use the recommended method properly** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

19. **I experienced some control over my mind; I could observe my thoughts from a distance** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	◯	◯	◯	◯	◯	Very much

20. **My mind was alert and clear** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

21. **Mainly I was more in a state of dozing or sleeping** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

22. **I felt bored** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

23. **I sensed a field of energy around me** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

24. **I felt love, surrender, connection** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

25. **Thoughts had come completely to rest** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

26. **I felt well** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all						Very much

27. **I was glad that the meditation had finished** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

28. **The feeling of time disappeared** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

29. **I sensed my breathing comfortably calm and fluent** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

30. **Sometimes I sensed my body as very light** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

31. **I experienced boundless joy** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

32. **My mind/consciousness expanded to an infinite space** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

33. **I felt being accepted unconditionally** *
Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

34. **There was no differentiation, comparison or judgement anymore. Everything could be as it was** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

35. **My mind, the field of consciousness and awareness was empty from thoughts, emotions and sensations** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

36. **I experienced humility, grace, gratitude** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

37. **There was no meaning of any meditation techniques anymore** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

38. **I felt a strong energy or power within myself** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

39. **I sensed myself as formless energy** *

Markér kun ét felt.

	0	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	⬭	Very much

Virtual Reality

40. **I felt nausea during the experience** *

Markér kun ét felt.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

41. **I found the environement relaxing** *
Markér kun ét felt.

	1	2	3	4	5	
Strongly disagree						Strongly agree

42. **I found the head mounted display comfortable** *
Markér kun ét felt.

	1	2	3	4	5	
Strongly disagree						Strongly agree

43. **What part of the virtual world did you look at the most? E.g a special tree, a rock or the fog.** *

44. **Any other comments?**

I
Appendix

The mean values of eSense meditation value, heart rate (HR) and heart rate variability (HRV), for each participant. Additionally, whether they had been drinking coffee.
The grey numbers, are from the participants where the EEG data was not usable, and therefore was not included in the statistical test.

Subjects	Condition	Myndplay Baseline	MyndPlay Mediation	MyndPlay Difference	HR Baseline	HR Meditation	HR Difference	RMSSD Baseline	RMSSD Meditation	RMSSD Difference	Coffee
1	A	-	-		64,67	68,00	3,33	42,48	28,21	-14,28	Yes
3	A	-	-		70,67	76,67	6,00	63,02	51,30	-11,72	Yes
9	A	-	-		88,00	88,67	0,67	79,62	97,95	18,33	Yes
14	A	51,62	60,03	8,41	72,67	69,33	-3,33	42,26	36,35	-5,92	No
16	A	-			92,67	99,33	6,67	29,94	15,45	-14,49	Yes
17	A	-			65,33	70,67	5,33	64,68	26,42	-38,26	No
18	A	73,42	68,15	-5,27	83,33	81,33	-2,00	46,38	16,81	-29,57	No
26	A	41,41	56,32	14,91	75,33	78,00	2,67	55,47	28,11	-27,36	No
27	A	67,32	63,96	-3,36	86,00	88,00	2,00	19,13	10,64	-8,49	No
28	A	52,67	66,38	13,71	76,00	69,33	-6,67	34,09	52,76	18,68	No
29	A	44,78	52,23	7,45	78,00	72,67	-5,33	25,86	23,76	-2,10	Yes
32	A	49,53	54,68	5,15	80,67	86,00	5,33	39,96	18,08	-21,88	No
4	B	63,47	62,70	-0,77	64,00	62,00	-2,00	74,92	53,75	-21,17	No
5	B	34,93	41,26	6,33	80,67	82,67	2,00	24,50	33,39	8,90	No
8	B	50,2	55,84	5,64	90,67	91,33	0,67	83,46	82,20	-1,26	No
11	B	-	-		73,33	74,00	0,67	35,71	34,46	-1,25	No
12	B	71,71	71,56	-0,15	74,00	75,33	1,33	35,19	28,75	-6,44	Yes
13	B	71,71	71,59	-0,12	70,67	76,00	5,33	39,21	56,02	16,81	No
20	B	-	-		86,67	89,33	2,67	35,18	33,95	-1,22	No
24	B	52,44	47,38	-5,06	85,33	82,67	-2,67	51,05	62,88	11,83	Yes
25	B	45,92	46,84	0,92	68,00	72,00	4,00	51,71	28,73	-22,98	No
2	C	-	-		84,00	82,67	-1,33	29,51	22,39	-7,12	No
6	C	36,5	36,45	-0,05	69,33	71,33	2,00	25,98	22,05	-3,94	No
7	C	54,61	47,47	-7,14	83,33	80,00	-3,33	91,57	57,06	-34,52	No
10	C	46,18	50,00	3,82	70,67	78,00	7,33	49,32	48,18	-1,14	No
15	C	36,1	37,64	1,54	55,33	53,33	-2,00	73,88	79,35	5,47	No
19	C	-	-		70,67	66,67	-4,00	57,20	47,85	-9,34	No
21	C	-	-		94,00	90,00	-4,00	14,33	25,07	10,74	No
22	C	68,1	63,97	-4,13	77,33	75,33	-2,00	86,42	12,86	-73,56	Yes
23	C	-	-		76,67	75,33	-1,33	40,31	41,85	1,54	No
30	C	63,16	63,00	-0,16	77,33	82,67	5,33	35,90	26,58	-9,32	No
31	C	54,03	41,05	-12,98	68,67	63,33	-5,33	43,51	43,74	0,23	No