MIND YOURSELF

Using an artistic psychological brain-computer interface to increase self-consciousness

Miriam Riefel

University of Twente

m.h.riefel@student.utwente.nl

Master Interaction Technology

Supervisor: dr. M. Poel

University of Twente

m.poel@utwente.nl

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Preface

This thesis is not only an academic research about artistic brain-computer interfaces and self-consciousness, but also a source for novel methodology encompassing this field of technology. It includes the development of MIND YOURSELF, an artistic psychological brain-computer interface that allows users to 'crawl inside their own mind', of which photos are included on the title page. Because all components of MIND YOURSELF were tailor-made, its development inadvertently resulted in designing additional novel interactive technology methods, especially in interactive music production. My hope is that this project does not only supply new exploratory knowledge of artistic psychological BCIs and self-consciousness, but also inspires artists and designers that work with other interactive multi-model technology. Examples are intimate meditation spaces with sensory stimuli or music pieces that are interactively controlled but keep their artistic integrity.

This project has originated from a passion for the human mind and psychology, interactive technology, coding, music production and design. I am grateful for the space and creativity allowed by the master program Interaction Technology, enabling me to incorporate so many academic and personal passions into one project. I have worked on my graduation project for a year approximately. Besides the gained experience in academic research, the year has included learning a vast amount of skills, such as working on wood construction and soldering and producing music and audio for weeks and months. I have been able to do every aspect of the project myself and gain these skills because I was given all the time and freedom, for which I want to thank my supervisor Mannes Poel. I have plunged into this project with many ideas, all the motivation and a lot of optimism, but with more than a little scarcity in practical know-how. The people at DesignLab at University of Twente, as well as my sister, should be thanked for being patient enough to help me with the practical execution of the construction. I also want to thank Geert Jan for teaching me about electronic hardware and saving my construction. Furthermore, all my study companions helped me stay on path through the challenges imposed by the Covid crisis and restrictions. My close friends should finally be thanked for encouraging me throughout the whole project.

CONTENTS

1 INTRODUCTION

Brain computer interface (BCI) technology uses brain signals for interacting with external parameters. The extent to which the user of the BCI purposefully controls parameters, differs per application [1]. In passive BCIs, the user is not aware of how they are directly affecting the output. In active BCIs, users control a certain output or action by deliberately changing their brain state. Reactive BCIs use sensory stimuli to provoke determined or undetermined responses [2]. Brain-computer interfaces are, amongst other applications, used by artists as novel mode of artistic expression. The common conceptual procedure of a reactive artistic brain-computer interface is visualised in figure 1.1. Examples of artistic BCIs include sonification of brain waves [3] and virtual visual art that is affected by mental states [4]. More recently, artistic BCIs are becoming more common as tools to understand or improve mental states and mental health [5, 6]. Especially passive and reactive brain-computer interfaces are implemented to gain understanding of the mind. Such BCIs mediate artistic projections of mental states of users.

The present study aims to advance understanding and design methodology of artistic and psychological BCIs as means for individuals to gain self-consciousness in non-clinical setting. Self-consciousness is used as an overarching term for self-reflection and insight. [7]. Self-Reflection is defined as ”the inspection and evaluation of one’s thoughts, feelings and behavior” [7, 8]. Insight is defined as ”the clarity of understanding of one’s thoughts, feelings and behavior” [7, 8]. Brain-Computer Interface technology may be suitable for increasing self-consciousness because it enables a unique projection of the mind in the form of art. As the consciously and unconsciously experienced mental states of the user are extracted via biological signals and presented back to them, the user sees their own mind from a different perspective, which may lead to enhanced self-consciousness. Whilst many artistic psychological brain-computer interfaces have been developed, little strive to holistically represent continuous mental states, combining both features of mental activeness and affective state. Moreover, the effect of such a brain-computer interface on self-consciousness specifically, has not yet been measured.

The present study has therefore employed a newly designed artistic psychological BCI installation that relies on a holistic representation of continuous mental states, called MIND YOURSELF. A brief video which can be found on **YouTube**, provides a conventionalised summary of the project. The installation is a small, intimate space that individuals can enter. Inside the space, there are auditory and visual stimuli, whose parameters are affected in real-time by the mental state of the user. As such, the intention of the experience is to offer an intuitive and artistic representation of the user’s mind at the present time. During this experience, the user may also develop an implicit understanding of how they can alter their mental states by interacting with the stimuli inside the space. Using MIND YOURSELF should feel to the user like crawling inside one’s brain, where the perceived changes in the installation result from changes in the user’s mental state. The goal of the experience is to increase self-consciousness through sparking an interest in the user’s own brain and mind, advancing understanding of the connection between their biological brain and their self-experienced mind, and/or developing an increased sense of control over their own mind. The installation is designed and evaluated through an in-

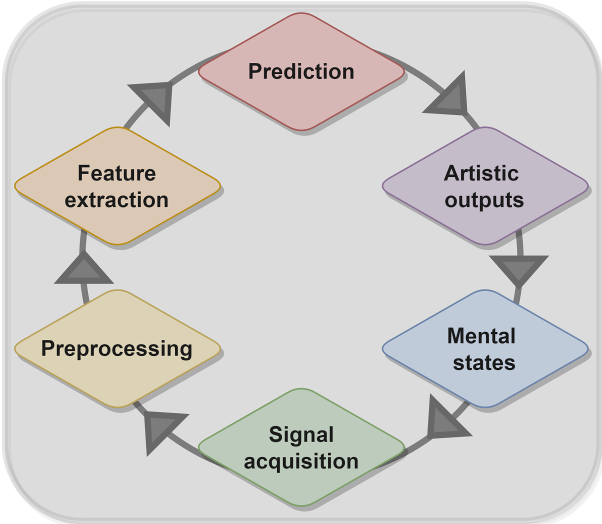


Figure 1.1: The general circular pipeline of a reactive artistic brain-computer interface

terdisciplinary perspective, based on artistic value, technological advances, and psychological understanding. Through the process of the design, prototyping and testing of MIND YOURSELF, the present study explores a novel methodology for artistic BCIs aimed at advancing self-consciousness, which is based on existing state-of-the-art BCIs and neuro-psychological and technical knowledge. Moreover, through the evaluation of MIND YOURSELF, understanding is advanced of how an artistic BCI can mediate an increase of self-consciousness by using a holistic representation of mental states. The development and evaluation thereby examine the question: How can an artistic psychological brain-computer interface be designed and developed that increases self-consciousness using real-time continuous multi-modal representations of changing mental states?

Chapter 2 is an overview of the state-of-the-art knowledge of psychological and artistic BCIs. The design of MIND YOURSELF and experimental methodology of the evaluation are summarised in chapter 3. Chapter 4 contains the results of the experiment. The meaning of the results in relation to the research field, shortcomings of the present study, recommendations and open questions are found in the discussion in chapter 5. The conclusion is presented in chapter 6, followed by references. The final section contains appendices, including a review of the basics of brain-computer interface technology, a list of examples of relevant BCI technologies, the audio script used during the MIND YOURSELF experience, the invitation the experiment, the information brochure of the experiment, the employed questionnaires and the textual feedback of participants.

2 A REVIEW OF STATE-OF-THE-ART KNOWLEDGE AND APPLICATIONS OF BRAIN-COMPUTER INTERFACES

Passive and reactive BCIs are often used to gain understanding of and/or manipulate mental states. The term psychological BCI is used in the present report to refer to passive or reactive BCI technology whose main goal is to gain understanding of and/or manipulate mental states. This can be in a clinical setting or with healthy individuals [5]. These applications are driven by bridging knowledge of psychology with neuroscience, where the BCI acts as mediator. At the same time, the field of BCI technology has also evolved through the arts, where it serves as an innovative means of expression [9]. Whilst 'brain artists' make use of knowledge of neuropsychology and technology to different extents, their main goal is artistic, such as provocation, aesthetics, exploration and/or expression [10, 1, 11]. In practice, however, the division between psychological and artistic BCIs is artificial, because applications can very well root in both arts and neuropsychology [12]. Artistic psychological BCIs (APBCIs) performances and installations rely on arts as representation of the mind. The aims of these BCIs are not only gaining understanding of the mind, but also exploiting the mind as artistic tool and/or exploring the interaction between psychology and arts. The development of APBCIs thus relies on different fields of knowledge, including psychology, neuroscience, arts and technology. Using an interdisciplinary perspective, APBCI developers eventually aim to translate brain waves to artistic output. Appendix B contains a list of psychological and/or artistic BCIs that relate to the present study.

2.1 Physiological signals as encoders of mental states

Designing the translation from EEG signals to artistic output in most cases is a two-step process. The first step is mapping retrieved EEG signals and their features to psychological concepts. The key questions to be answered here are: what types of mental states are considered in the BCI installation, what EEG features are relevant to these mental states and how are the mental states encoded from the EEG data. This section lists some of the most common features, mappings and decoding methods of passive and reactive BCIs.

2.1.1 Frequency band power encoding mental activeness

A very common set of features amongst passive and reactive BCIs is the set of power values of frequency band widths, which are also discussed in appendix section A.5. To obtain these features, the EEG data in the time domain - showing the activation per electrode per time unit - is translated into the frequency domain [13]. This is valuable information because electrical activation often appears in wave-like patterns. The frequencies of these patterns in different areas of the brain reveal key information about the mind. EEG data in the frequency domain displays the average power of frequencies in a specified time range and brain area. This is referred to as power spectral density (PSD) or band power, meaning the relative presence of a range of frequencies. A Fourier transform is used to translate data from the time domain to the frequency domain [14]. An example of a Fourier data transform can be seen in figure 2.3.

Name	Frequency range (Hz)	Associated features
Delta	0.5–4	Fatigue, sleep, severe slowing of mental processes, possible to occur in meditation by very experienced practitioners able to maintain consciousness in delta state
Theta	4–7	Deep meditation, reduced consciousness, hypnosis, attention lapses, slowed processing, stage 1 of sleep, memory consolidation
Alpha	8–14	Relaxed wakefulness, readiness, inactive cognitive processing, most prominent during meditation
Slow Beta	15–20	Intense focus, cognitive enhancement
Medium Beta	20–30	Anxiety, distractibility
Fast Beta (Gamma)	30–70	Hyper-alertness, processing of various attended stimuli (tactile, visual, auditory), stress

Figure 2.1: “EEG waves, their frequencies and features” [10]

Band	Frequency (Hz)	Amplitude (μV)	Location	Activity
Delta	0.5–4 Hz	100–200	Frontal	Deep sleep
Theta	4–8 Hz	5–10	Various	Drowsiness, light sleep
Alpha	8–13 Hz	20–80	Posterior region of head	Relaxed
Beta	13–30 Hz	1–5	Left and right side, symmetrical distribution, most evident frontally	Active thinking, alert
Gamma	>30 Hz	0.5–2	Somatosensory cortex	Hyperactivity

Figure 2.2: An overview of the different defined frequency bands, along with predominant amplitudes, associated brain areas and associated cognitive state. From Rashid et al. [14].

The ranges of frequencies are commonly divided according to the bands defined as delta, theta, alpha, beta, and gamma, optionally including subdivisions within these bands. These frequency bands are defined as such due to associated cognitive functions and states, see figure 2.1. This means that after pre-processing and extraction of the PSDs of these bands, a straightforward mapping can immediately be made to different mental states, namely those of different levels of mental activeness, see figure 2.2. A time frame may be chosen in which the average PSD is calculated for each electrode. This can range from a few hundred milliseconds to the duration of the whole experience, depending on the BCI set-up and aims.

As final features to be used in the BCI loop, a designer of a BCI installation may choose to use the most dominant frequency band as a single qualitative feature, or the PSDs per frequency band as array quantitative features (The Sensorium 3 [15]). These features may be based on the whole brain averagely (You Are the Ocean [16]) or differentiated per defined brain area (Moodmixer [17]) or per electrode (Insight2OSC [18]), adding another dimension to the feature space. Other options include creating metrics of presences of mental states based on subsets of PSDs (Moodmixer [17]) or using pre-programmed metrics from the EEG software (Eunoia II [19]). The discussed APBCI applications make use of features updated in real-time every few hundred milliseconds or few seconds, because they consider continuously changing mental states, adding a time dimension to the data. Emotiv PRO, acquisition software from Emotiv, outputs performance metrics, consisting of individual scores for stress, engagement, interest,

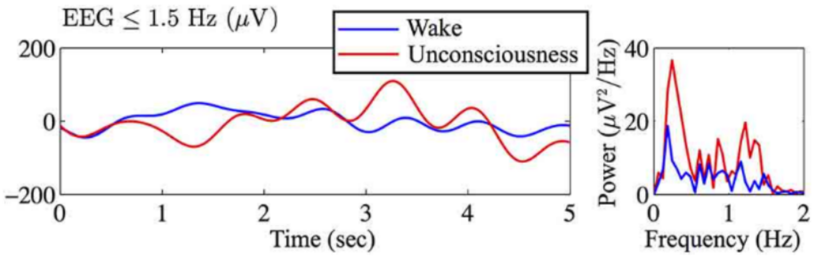


Figure 2.3: EEG data of awake and unconscious participants in time domain and frequency domain, translated using a fast Fourier transform revealing high relative presence of the sub-delta band (□0.3 Hz) in the unconsciousness state. From Wang et al. [22].

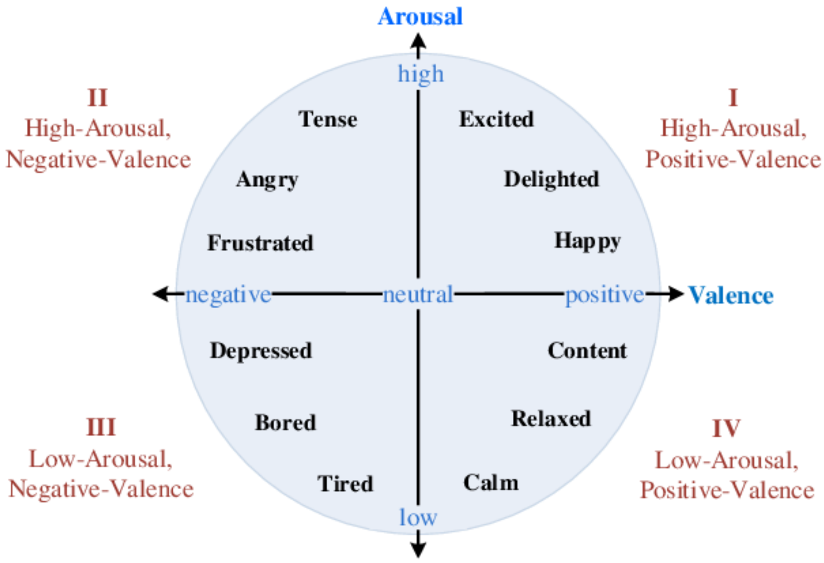


Figure 2.4: A diagram of the dimensional model of affective states. From Yu et al. [24].

excitement, focus and relaxation. [20]. The website discusses the psychological meaning of these features, but the exact mathematical definitions and acquiring methods are not open-source. Strmiska and Koudelkova [21] analysed Emotiv's performance metrics and found that the extracted features accurately correspond with expected values of mental activeness. For example, the values for stress, engagement and interest in the performance metrics all peaked at marked times during a math exam condition.

2.1.2 Frequency band power encoding affective state

Frequency band powers have also been employed as features to analyse affective state. Often, the relative powers of specific frequency bands in specific brain areas are factored in a function that computes affective values. A very common framework to describe affective state is that of valence and arousal, also referred to as the dimensional model [23]. This model is depicted in figure 2.4. Many studies about psychological BCI have suggested methods to decode values of valence and arousal from EEG data using the frequency band powers.
Lin et al. [25] summarise some of these in their review paper from 2010. Frequency band power patterns were used as input features in a support vector machine algorithm decoding affective states defined by joy, anger, sadness and pleasure. Lin et al. report power changes in both alpha frequency and theta frequency in the parietal lobe to be associated with change in affective

$$\text{Arousal} = \frac{bF3+bF4}{aF3+aF4} \quad \text{Valence} = \left(\frac{aF4}{bF4}\right) - \left(\frac{aF3}{bF3}\right)$$

Figure 2.5: Formulas for 2D affective states. (a: alpha power in defined electrode); (b: beta power in defined electrode). From Ramirez et al. [28].

state. Moreover, theta power in the midline and beta-power asymmetry and gamma spectral changes in the parietal lobe are relevant features for decoding affective states [25]. Chakladar et al. [26] reports that valence is positively correlated with power of the alpha frequency in the frontal region. Furthermore, arousal is assumed to be positively correlated to beta power in the parietal lobe, which is partially in line with the earlier findings of Lin et al. [25]. The Space Between Us [27], one of the examples discussed in the APBCI application section, uses a set of decoding functions for affect that is based on a methodology suggested by Ramirez and Vamvakousis [28]. Valence and arousal are calculated using alpha and beta power values in two electrodes in the frontal cortex, F3 and F4 as defined by the Emotiv Epoc, see figure 2.5.

It becomes clear that some overlap exists in different studies and applications of affective BCIs as to how valence and arousal are defined based on EEG signals. However, each decoding function is defined and evaluated under the horizon of a specific BCI installation, a specific type of EEG cap and/or a specific set of participants or users. It is therefore difficult to conclude which function is most accurately defining valence and arousal for general purposes. A broader approach is proposed by Sticik et al. [29]. They used discriminant function analysis (DFA) to develop classifiers that are both participant-specific and generalisable. Not only the power spectral densities were used, but also the time-domain wavelet shapes, both measured per electrode. Significant features were selected based on F-tests and these were used for the classification functions. They were created based on the identification of elicited emotions, using sad and happy movie clips (valence) of different emotional intensities (arousal). It is not clear whether the developed models would also work for non-elicited affective states.

In recent affective BCI applications, machine learning is often employed to decode affective states from EEG signals. The advantage of this method is that it does not need to rely on any study-specific, inconsistent knowledge of neural encoding of affective states, as the learning algorithms consider all potential models. Moreover, there are general pipelines that can be employed in many different applications. At the same time, the resulting mapping functions are specific to users and applications because they are learned to those circumstances. Daly et al. [30] have developed an machine-learning algorithm for affective state classification for their affectively-driven algorithmic composition (AAC). They used the features that were deemed as significant by Sticik et al. [29]. These, along with heartbeat, galvanic skin response (GSR), blood pulse oximeter signals (BPS), and the respiration rate served as input features in a support vector machine (SVM) classifier. Iacoviello et al. [31] proposed a similar methodology; a real-time SVM classifier of emotions. They, however, trained their model using self-induced emotions. Features were based on time-domain wavelet shapes and selected via Principal Component Analysis (PCA). Each participant first did a training session in which they continuously received feedback about which emotions were detected. In the process, both the participant and the classification model are trained co-dependently to encode and decode neural representations of emotions. Therefore, the method may not be equally appropriate to classify less artificial affective states, ones that are not self-induced nor trained. This problem was partially evaded by Daly et al. [30], as they used participant-independent validated elicitors of affective states. Nevertheless, it cannot be said whether their model would be able to classify naturally occurring affective states, as the negative and positive states were elicited through external stimuli

The studies of Daly et al. [30] and Iavoviello et al. [31] shine a light on another challenge posed by machine-learning based emotion detectors. Machine learning methods are specific to each user and each scenario, which is a two-sided coin. In order for most of these mapping functions to work, they need to be trained off-line in advance with each user, before the BCI application can be used. The training time makes the BCI application much less accessible [23]. To tackle this challenge, some studies have also tried to train models that are general for different users and participants. In addition to their participant-specific SVM algortihm, Daly et al. [30] created a model for participant-independent affective state detection. The resulting classification accuracy was, however, a lot lower than their participant-dependent alternative. Moreover, their methodology is already much less accessible than that of others, as many different non-EEG physiological features are included.

In conclusion, affective state decoding is a much less established pursuit than mental activeness state decoding. There is no clear consensus on the most appropriate model that is appropriate for different circumstances and different users. Machine learning may be used to circumvent this problem and find an optimal model, but this requires off-line training, rendering the BCI application much less accessible. Therefore, the most suitable methodology for affective state detection without subject-dependent off-line training, is a recently validated model that was developed under circumstances most alike the BCI application that is being developed.

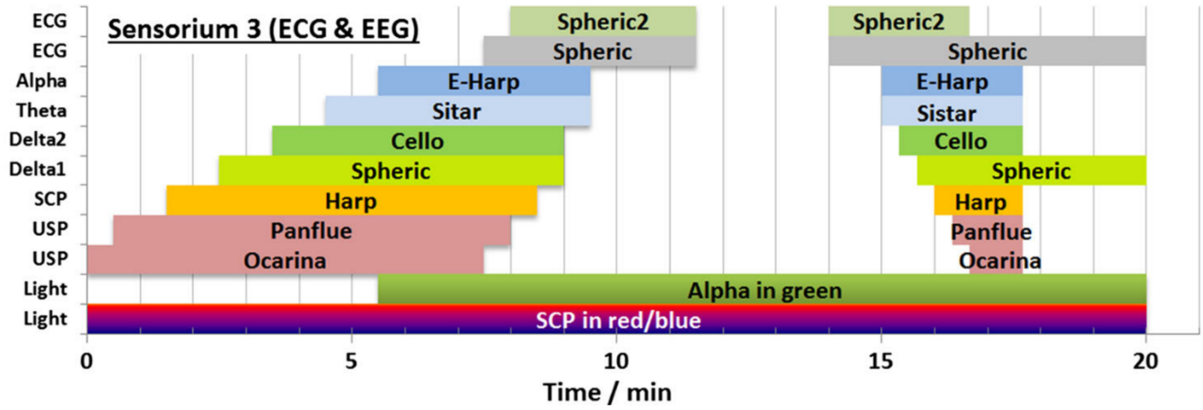


Figure 2.6: The mapping between EEG and output in The Sensorium. Adapted from Hinterberger. [35]

2.2 Sensory representation of mental states

The following section takes a more in-depth look into the second step in designing an APBCI: artistic representations of the measured mental states. In the pursuit of enhancing self-consciousness, the aim is to supply an intuitively accurate representation of the mind in an installation. Important questions to be asked in this stage of development are: what existing models exist for mapping mental states to artistic outputs and how does a designer make design choices to find the best representation of mental states?

2.2.1 Sonification and soundscapes

All discussed APBCIs in the example application section employ music or sound. This is no coincidence, as audio has a great impact on the human mind and is also a key method of conveying mental states [32, 33, 34]. Just like a musician communicates their emotion through song, an APBCI may use music or soundscapes to project the mental state of the user. One of the most straightforward ways of representing EEG-acquired mental states is sonification: music or sound that corresponds to direct changes in the EEG data. This makes immediate intuitive sense, as sound and EEG data share important parameters: frequency (pitch) and amplitude (volume). The Sensorium [15] is a nice example of this. Each frequency band corresponds to an instrument that has their own natural pitch range and variance. A higher PSD of a specific frequency leads to more prominence of the corresponding instrument. A complete overview of the mappings for light projections and sonification of Sensorium 3 is given in figure 2.6.
In the sonification method of Wu et al. [36], power of different frequencies led to different notes, rather than instruments, as well as rhythmic variance. Both methods have in common, however, that a more relaxed state of mind corresponds to slower pace and calmer atmosphere (less melodic or rhythmic variance), whilst higher mental activeness or arousal is represented by a higher pace and more variance. In Eunoia II [19], relaxation in mental states also corresponds to a lower tempo of the amplified sounds. Insight2OSC [18] and The Space Between Us [27] put emphasis on representing affective state rather than mental activeness. In the former, more positive affective states (prompted by smiles) led to higher pitch of the generated music, amongst other mappings. The Space Between Us made use of live singing and piano play, where positive mental states were translated into a higher tempo and major keys, whilst negative mental states prompted minor keys and a lower tempo. Moreover, arousal positively corresponded to tempo and variance in dynamics. An overview of the system is given in figure 2.7.

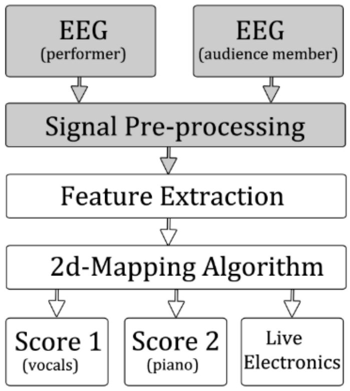


Figure 2.7: A simplified diagram of the mapping system of The Space Between Us. From Eation et al. [27]

Besides music, mental states can also be mapped to parameters in soundscapes, which are auditory tracks that convey a certain atmosphere or environment and include appropriate ambient sounds and optionally ambient music (abstract and subtle melody and/or rhythm). Melomind provides excellent examples of soundscapes, such as a campfire environment [37]. Likewise, You Are the Ocean [16] has a soundscape that makes the user feel as though they are at sea. In both APBCIs, a more relaxed state leads to less ambient sounds, less variation amongst the sounds and a lower volume, whereas a more active mind has the opposite effect, such as thunder in case of You Are are the Ocean. STATE.SCAPE [38] similarly has a bird-themed soundscape, but also incorporates abstract music, like base sounds and percussion.

Looking at existing APBCIs that use sound, we find a lot of common parameter mappings. These are also largely in line with psychological research on how certain mental states are associated with certain musical parameters. This can be organised according to the common valence-arousal model of affective states. First, positive valence is most clearly associated with major keys, and negative valence with minor keys [39, 40, 41]. Second, a higher tempo is linked to both more positive valence as well as higher arousal [39, 42], which comes down to mental states such as excited, delighted and happy. Third, a high note density is likewise associated with both positive valence and high arousal [43]. Fourth, variation in terms of rhythmic, melodic and volume dynamics in musical pieces is positively correlated with positive valence and high arousal [42] [40]. Fifth, articulations with shorter notes and more abrupt play (staccato) are found more often in happier music, whilst articulations with longer notes and more fluent play (legato) are more common in sad music [43, 40]. Sixth, musical pieces with higher average pitch are often regarded as happier, where musical pieces with lower pitch are perceived as sadder [43, 44]. Finally, loudness is commonly associated with high arousal of affective states [32].

All sonification and soundscapes methods have in common that they consist of a default auditory track with a set of parameters that may be adjusted by changing mental states. This discloses the challenge that comes with designing auditory outputs APBCIs: balancing pleasantness and effectiveness of representing mental states. Whilst the changing mind should have a clear impact on the soundscape or sonification through a set of parameters, the continuous output should retain its own artistic integrity [45]. For example, a forest-themed soundscape may always want to make the user believe that they find themselves in a forest. And a musical piece needs to always keep sounding like coherent music. This potentially entails having a consistent set of instruments, a consistent key or a theme around which the musical piece

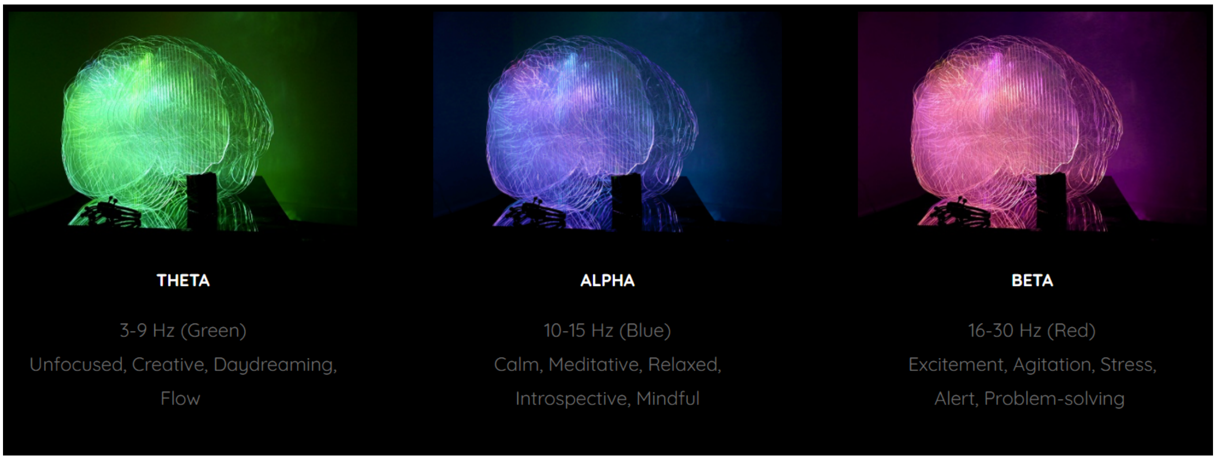


Figure 2.8: The colour mappings of Brainlight. From Jade et al. [49]

keeps revolving. Changes in the soundtrack prompted by changes in the mind should not be too abrupt and disrupting the listening experience.

2.2.2 Visualisation, lightscapes and visual art

Visual output is the next most popular mode of projecting mental states in APBCIs. There are a lot of different types of visual modes as well as mapping strategies to represent the mind through visual parameters. This section discusses some common options amongst APBCIs. A straightforward method is simply showing the EEG waves in the time-domain, such as implemented in EEG KISS [46]. This could be an effective method of gaining explicit awareness with users of the impact their actions have on their brain. Some multi-BCIs that are discussed in the example section use a different mapping strategy, where visuals display the extent to which different users feel connected or in sync. In both Ringing Minds [47] and The Mutual Wave Machine [48], synchronisation is represented by enlarging visuals that excite and impress users and the audience.

Furthermore, many installations use visual art to project levels of mental activeness. In You are The Ocean [16], users listen to and look at a continuously moving sea. When the mind is more relaxed, the sea looks calm, whilst a stressed mind results in a stormy sea. Similarly, in STATE.SCAPE [38], users listen to and look at flying birds in a coloured sky, which are more abundant and fly faster when the mind is less relaxed and more exited. Also in Eunoia II, a more engaged and/or excited mind results in more active and vibrant visuals: the pools of water have increasing ripple speed. Finally, colour has been used frequently, not only as aesthetic means, but also to represent mental activeness. In Brainlight [49], green signals daydreaming as defined by high relative theta power. Blue, defined by relatively high alpha power, means calmness, whilst excitement and stress, high beta power, is visualised through red. The software applications by Emotiv [50] use a similar colour scheme. Green stands for focus, blue for relaxation, yellow for excitement and purple for stress. The colour scheme may be found in figure 2.8. The Sensorium [35] also uses a colour scheme, but here alpha power is represented in green, whilst red and blue are controlled by slow and ultra slow cortical potentials.

The relations between visual art and mental state are unfortunately less established than with sound and music. However, some associations to visual parameters have been found in research. One of such topics is about colour mapping. Green, especially foliage colours, and blue are associated with calmness, while red and yellow are associated with anxiety [51, 52].

Figure 2.9: A photo of a performer lifting up in Ascent.From Duenyas [54]

Red is, moreover, found to be agitating and exiting, whilst blue is soothing and relaxing [53] and green to help focus and concentration [52]. These findings are in line with the colour schemes used by Brainlight [49] and Emotiv EPOC [50].

2.2.3 The conceptual design of BCI installations

All sensory outputs take place in and are partially determined by the shape - conceptual and physical - of the installation itself. They are features within the realm of the art piece on its whole, ruling the scope of possibilities. In the search of self-consciousness through BCI, two themes can be often found in examples of installations: symbolism and immersion.

Firstly, a large amount of installations are based on symbolic representations of the mind, the brain and its features. This helps the user to comprehend the idea that what they are observing really is based on their own mind and brain. The Ascent [54] is a unique example, as can be seen in figure 2.9. In this installation, a performer is physically lifted up as they reach a more meditative state, in line with the ancient Buddhist concept of enlightenment [55]. Melomind [37], You Are the Ocean [16] and STATE.SCAPE [38] all use a nature environment to symbolise the mind, as if you could crawl inside your brain and take a walk, flight or boat trip there. The simulated nature environment of STATE.SCAPE can be seen in figure 2.10. Eunoia II [19] takes a more concrete set-up to symbolise the brain. Here, different water dishes and amplifiers are placed almost alike an EEG set, or neurons and their connections, creating a sense of physically stepping inside your own brain. This may be seen in the photo in figure 2.11 Brainlight implements an even more concrete interpretation: an sculpted brain representing your mind. Threats shaped from Plexiglas that spark up consecutively symbolise the neurons and their firing. The discussed Emotiv EPOC software [50] takes a similar approach: users can look at a digital brain representing theirs. Again, neuron firing-inspired bulbs and links are seen in the brain. Here, the brain area that lights up in different colours is determined by the differences in measured brain areas, see figure 2.12. All these different types of symbolism are means to communicate the idea that the user is experiencing projections of their own brain and mind, potentially enhancing self-consciousness.

The second feature in BCI installations that can be important to reach the aim of enhanced self-consciousness is immersion. Users should feel immersed in the installation, so that they easily focus on the sensory output and forget about the exterior world and irrelevant stimuli. This is similar to the idea that meditation is more successful when a person immerses themselves

Figure 2.10: An example of the digital visual art in STATE.SCAPE. From Prpa et al. [38].

Figure 2.11: A photo Lisa Park performing in Eunoia II [19].

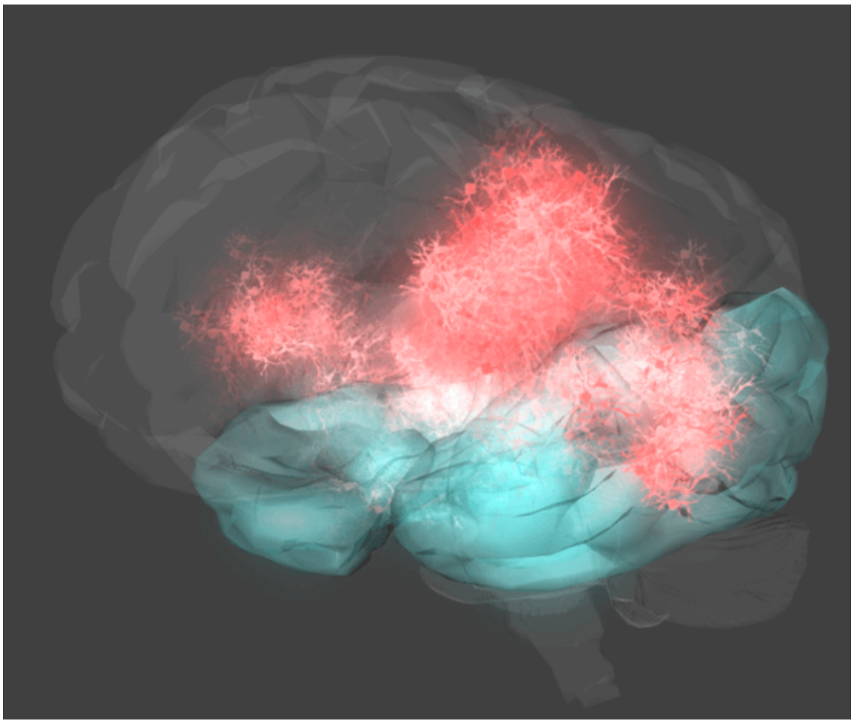


Figure 2.12: A photo of digital projections from Emotiv EPOC software.[50]

Figure 2.13: A photo of EEG KISS with performances and audience. [46]

in the practice, forgetting about external stimuli and the exterior world [56]. Likewise, if a user would be overly aware of the world outside the BCI installation, or of the idea that they are inside a technological machine, they might be less likely to be affected by the projected sensory output or the symbolism of the installation. Installations with an audience may attempt to immerse users, performance and/or audience by using grotesque and impressive projections, sounds and other modes of art. For example, in Ringing Minds [47], the visual art was projected onto a large screen and in performances of EEG KISS [46] the art projections reach all the way around the performers close to the audience, as can be seen in figure 2.13.
In BCI installations with only a single user and no audience, immersion may be increased by leaving the user alone in a space that only holds objects and stimuli that are part of the artistic outputs, which was done in You Are the Ocean [16], see figure 2.14. This is different from, for example, The Sensorium [15], which looks more like an experimental lab and where a supervisor stays in the room. However, in The Sensorium, developers still aimed to create a more intimate space by using a cloth to shield the participant and hide the technology. The Mutual Wave Machine [48] is an example of a unique method to supply intimacy for the sake of immersion. Here, two users take place together inside a cocoon-like installation, creating an intimate space,

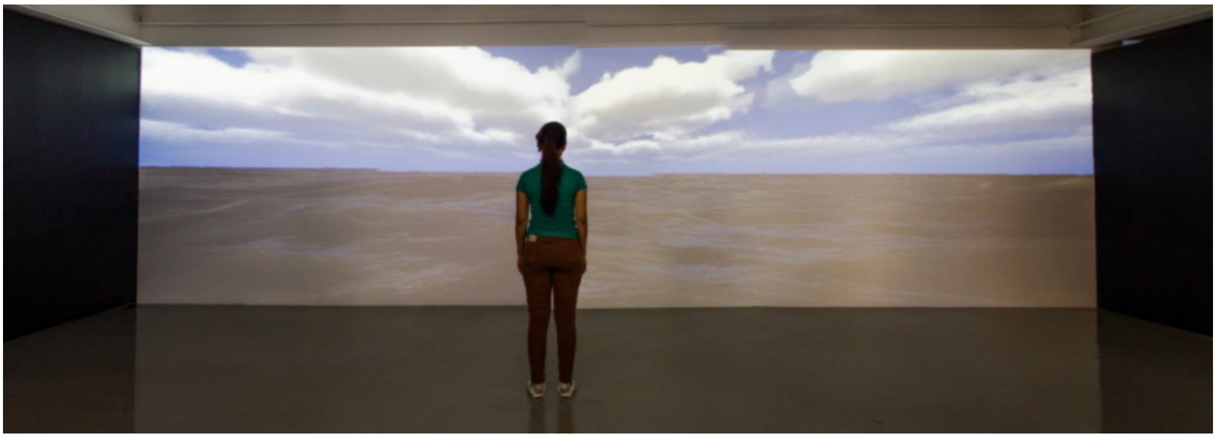


Figure 2.14: A photo of a set-up of You Are the Ocean with a single user. From Lancel et al. [16]

Figure 2.15: A photo of the installation architecture of The Mutual Wave Machine. From Dikker et al. [48]

which can be seen in figure 2.15. Dikker et al. [57] found that this installation enabled a very engaging atmosphere for their users.

2.3 Conclusions

All these findings lay a basis for the design of MIND YOURSELF. Keeping in mind the aim of enhancing, self-consciousness, a few sub-aims are defined along with potential ways of achieving them. Firstly, the installation should accurately project the mental state of the user in real-time, which means that the sounds, visuals and atmosphere represent the users' mind well. To begin with, this calls for an accurate decoding of mental states from the measured EEG data. Well-established mapping of frequency bands and mental states of activeness are therefore used, as well as the state-of-the-art mapping technique between EEG data and arousal and valence of affective states. Moreover, the decoded mental states should be effectively projected through sound and lights inside MIND YOURSELF. Affective states are therefore mapped to a soundscape, whilst states of mental activeness are mapped to a lightscape. This is because most knowledge is available of associations between sound and emotion, and colour and states of relaxation and focus. The established theories are implemented as much as possible in the design and production of the soundscape and lightscape, with plenty of space left for the designer's artistic interpretations of aesthetics and pleasantness. The auditory and visual mappings are evaluated and adapted by comparing user-associated mental states in response to sensory parameters to aimed mental states.

Secondly, in order for the installation to be effective, the design aims for a symbolic representation of the mind and an immersive space. Immersion refers to an engagement to the stimuli of the installation and a disengagement from the exterior world and irrelevant stimuli. Symbolism means that certain aspects of the design are inspired by or are analogous to the brain or mind, such as a storm at sea as analogy for the dis-stressed mind (You are The Ocean [16]) or water dishes and amplifiers placed like neurons and their connections (Eunoia II [19]). As found in some of the examples of using symbolic representations of the mind and brain and its features, symbolism can really help to increase the intuition of users that they are in fact experiencing features of their own brain and mind. In the same sentiment, MIND YOURSELF is inspired by the appearance of a brain and neural networks. Getting inside the installation should thereby really feel as if crawling inside one's own mind. To achieve immersion, the installation is inspired by some of the features of discussed APBCIs. The user is shielded from the exterior world as well as from the technology as much as possible. Moreover, the auditory and visual stimuli are completely surrounding the environment inside the installation. The initial design concept including the sound and light mappings that result from the conclusions of the state-of-the-art review can be found in chapter 4.

The range of existing artistic psychological BCIs both helps to understand what knowledge can be deployed in the design of a new one, as well as draw a picture of what knowledge still may be missing in the research field. The design of and research around MIND YOURSELF situates itself inside a few research gaps. Many APBCIs take into account either affective state, often measured in valence or arousal, or states of mental activeness. The Sensorium [35] is one of the few examples that attempts to project a more holistic picture of their user's mental state in real-time. This might be the case, because defining affective state is an ill-established pursuit and furthermore computationally expensive. Combining the classification of affective state with mental activeness variables might make the combined outputs too complicated for effective mapping. At the same time, this is the exact reason why it may be very useful to continue attempts in representing holistic states of minds in APBCIs. MIND YOURSELF therefore both implements mental activeness variables as well as affective state variables to represent the mind as comprehensively as possible, as discussed in the previous paragraph. Moreover, the present study relates the design of this APBCI directly to self-consciousness, which has not yet been explicitly tested in the scope of similar projects.

The design of and research around MIND YOURSELF investigates the following question: How can an artistic psychological brain-computer interface be designed and developed that increases self-consciousness using real-time continuous multi-modal representations of changing mental states?

3 METHODOLOGY

In order to answer the research question, three main steps were undertaken. First, the physical installation and the stimuli mapping were designed, based on the lessons learnt from the review of the state-of-the-art. Second, the physical installation, hardware and software were built. Third, the research question was evaluated using the built installation, following protocols similar to evaluation protocols of related works. Figure 3.1 shows an overview of the methodology. The left side denotes the building blocks and the right side of the figure the corresponding tasks that are included in each building block. The initial designs per building block were based on knowledge and inspiration from the related work discussed in the previous chapter. Some were translated into low-fidelity prototypes and tested separately, where the results lead to changes in the prototype. All components were then combined into a full design of MIND YOURSELF. This full design was constructed on its whole and evaluated using an experimental protocol.

3.1 Design

MIND YOURSELF is a one-person brain-computer interface installation in which users can have a short BCI-based multi-sensory experience with the aim of increasing self-consciousness. An overview of the conceptual BCI loop can be seen in figure 3.2. The installation is a small tent that fits a single person, in which they can take place and lie down wearing an EEG headset. The installation is designed for one person only, because it is a personal experience in which the user symbolically crawls in their own mind. A lying down position helps the user to relax and focus on their surroundings and prevents physical movement that could create noise in the brain signals. The interior is lit up by coloured lights and audio is playing. EEG data of the user is measured in real-time and processed online to extract features of mental states. The measured affective state is translated to a changing soundscape, while the state of mental activeness is translated to a changing lightscape and affects parameters of the soundscape.

3.1.1 The physical installation

The concept of MIND YOURSELF is to crawl inside your own mind. In line with the idea of using symbolism to make an APBCI more effective, the initial physical design is based on conceptual and physical properties of the brain. These include the neural network and its connections amongst neurons which communicate via electrical charges. The fabric surrounding the installation has patterns alike neural connections, which can be seen in figure 3.3a. The installation is also shaped like a dome similar to the shape of a head. The interior is made up out of LED lights placed around the dome that are connected to each other, mimicking the looks of brains and their continuously firing neural networks, as can be seen in figure 3.3b. The space is small and cosy, fitting just one person, whilst hiding all technical items. This may help users to experience the space as intimate, potentially increasing immersion, which has also been suggested by the literature review. For the same reason, sound is playing from different angles, creating a surround-sound experience.

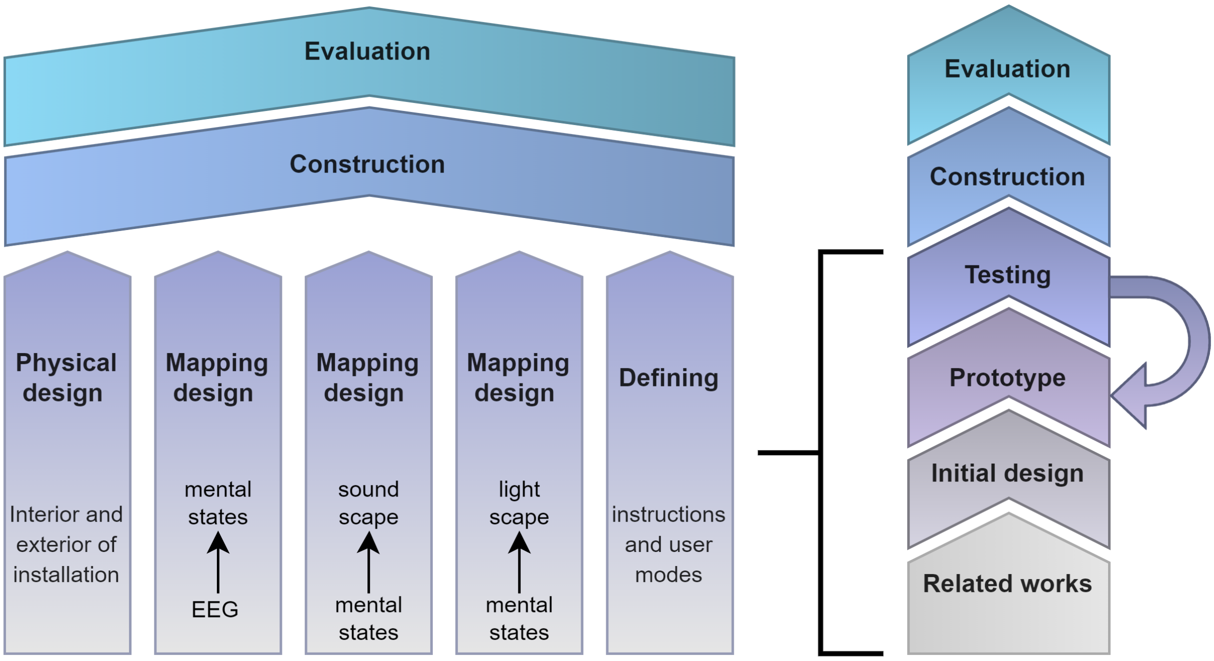


Figure 3.1: An overview of the development methodology per component.

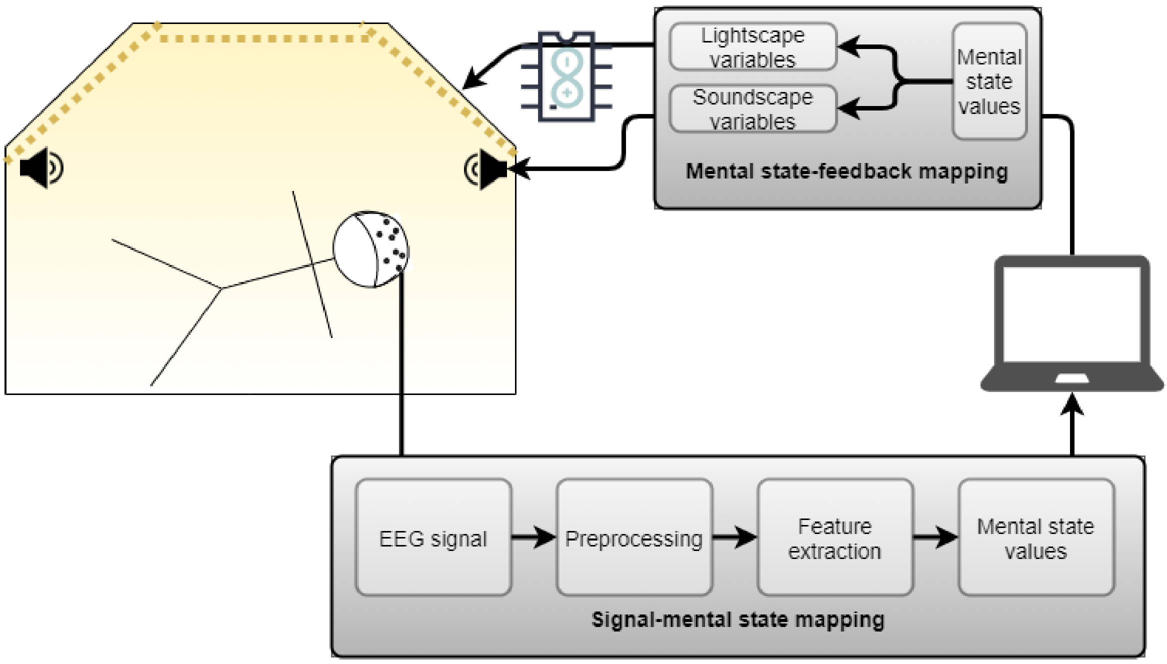
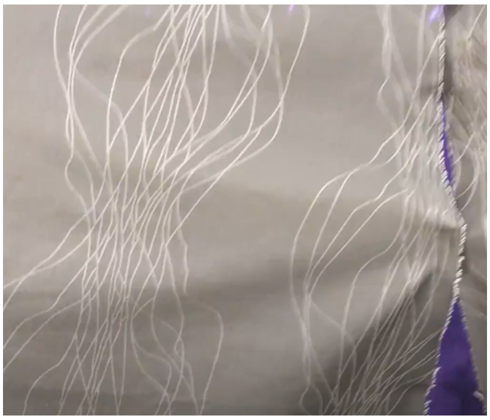
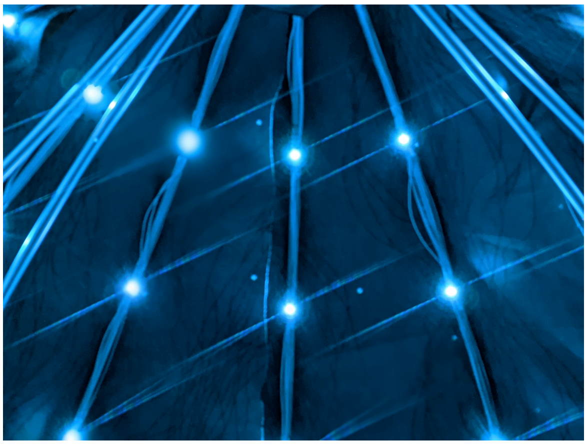


Figure 3.2: A flowchart of the basic structure of MIND YOURSELF.



(a) The fabric used in the MIND YOURSELF tent



(b) LEDs lighting up consecutively

Figure 3.3: Symbolism in the design of MIND YOURSELF

$$\text{Arousal} = \frac{bF3+bF4}{aF3+aF4} \qquad \text{Valence} = \left(\frac{aF4}{bF4}\right) - \left(\frac{aF3}{bF3}\right)$$

Figure 3.4: Formulas for 2D affective states. (a: alpha power in defined electrode); (b: beta power in defined electrode). From Ramirez et al. [28].

3.1.2 Decoding mental states from EEG

Accurately representing the user's mental state in artistic output starts with accurately decoding mental states from continuously acquired brain signals. The protocol for decoding mental states from measured EEG data is based on the literature review in section 2.1 as well as the technical basics of EEG processing discussed in section A. EEG data is measured and pre-processed according to established methodology. During acquisition, the data is re-referenced to the reference electrode and normalised. The data is then transformed to the frequency domain and time-epoching splits the data in chunks of five seconds. After transformation, two types of features are extracted. Firstly, the chunks of data that are used to determine mental activeness values are represented in performance metrics as defined by Emotiv [20]. These performance metrics consist of six features: stress, engagement, interest, excitement, focus and relaxation, which all take on values between 0 and 1. The exact mapping from data chunks to performance metrics values is property of Emotiv and unknown to the public.
Secondly, the chunks of data are used to calculate affective state. This is done according to the methodology of by Ramirez and Vamvakousis [28]. Valence and arousal are calculated using alpha and beta power values in two electrodes in the frontal cortex, F3 and F4, see figure 3.4. They undergo time-epoching to create chunks of 30 seconds, updated every 10 seconds. The average of these chunks output the valence and arousal levels, which may take on values between -10 and 10.

3.1.3 Representing mental states in a lightscape

The output mappings are based on findings from the literature research in section 2.2. Mental activeness is represented by colours and saturation in LED lights. The measured values for relaxation, focus and stress directly determine the saturation of the corresponding lights, using to the RGB (red-green-blue) protocol. Moreover, the level of stress determines the flickering frequency of all LED lights. Flickering is established through a slow alternation between the

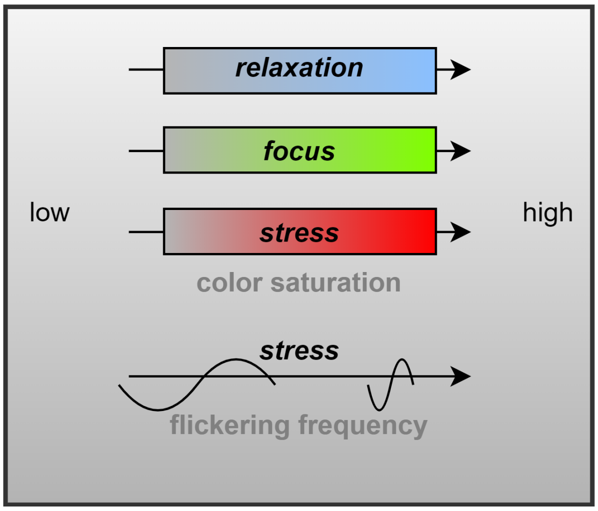


Figure 3.5: Overview of the mapping state of mental activeness to lightscape parameters

default saturation and a decreased saturation. The colour mapping is based on the best established mapping option found in literature and similar applications. Blue saturation is determined by relaxation, green saturation by focus and red saturation by stress. An overview of these is given in figure 3.5. The mapping is in line with that of Brainlight [49] and Emotiv [50] and colour associations found by Roohi et al. [51], Kexiu et al. [52], Wolfson et al. [53].

3.1.4 Representing mental states in a soundscape

Writing the original samples

The soundscape on its whole is an accumulation of 15 tracks, which each can be either muted or playing one of three potential samples. Parameters of the soundscape are determined by values of affective state as well as by relaxation, stress and excitement. The three samples within one track each correspond to low valence, middle valence or high valence respectively. The samples are created with theory of affective music in mind [32, 33, 34]. Samples with low valence are predominantly made up off minor chords, whilst high-valence samples contain mostly major chords. Low-valence samples are mostly slower-paced, have less variation and contain lower notes. High-valence samples have a higher pace, more variation and higher pitched notes. The musical parameters of middle-valence samples lie in between.

Testing and labelling samples

The valence-scores of the samples have been tested and readjusted accordingly. In a separate user-test with 34 participants, each participant rated the affective state score of each sample. The participant selected a coordinate of valence by clicking on a FEELTRACE image [58] in a questionnaire. These coordinates were normalised and transformed to valence scores between -10 and 10. The average amongst participants yielded a new valence-score for each sample. The results of this user-test can also be found in the results chapter. The valence-scores have been used to reorganise the samples according to low, middle, and high valence. Measured valence in a participant is matched with a set of melody samples with the same valence-score averagely. The total number of active (between two and fifteen) is determined by arousal of affective state, where higher arousal levels lead to more tracks playing simultaneously. Here, the arousal level of the soundscape at a moment is defined as the -12 + the weighted sum of all activated samples. Three tracks contain only percussion samples, where more complex

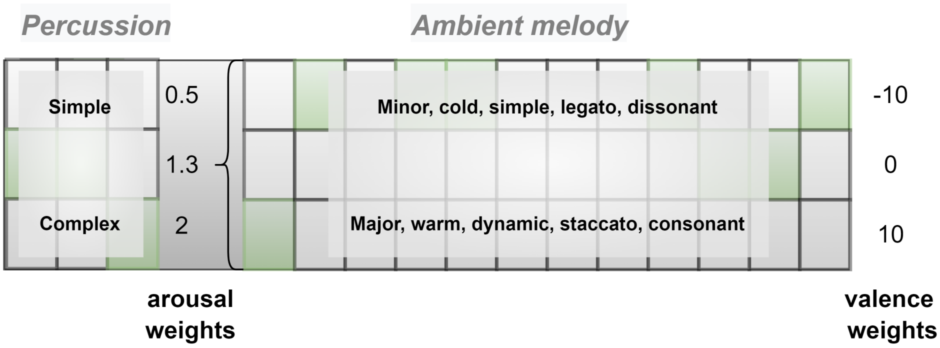


Figure 3.6: Overview of the affective state - sample-selection scheme

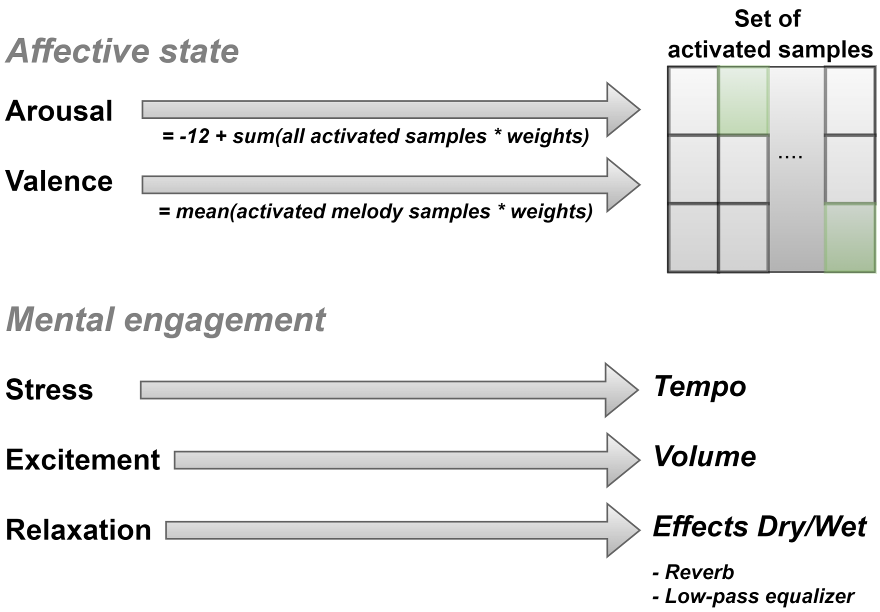


Figure 3.7: Overview of the mapping of mental state to soundscape parameters

percussion patterns correspond to a higher weight. For example, an arousal value of -10 measured with a user, could lead to 1 simple percussion track and one melody track playing. The sample-selection scheme is visualised in figure 3.6.

Soundscape hyper-parameters

Moreover, the tempo of the whole soundscape is determined by measured stress. The volume is determined by levels of excitement. The amount of reverb and the intensity of a high-frequency equaliser are determined by measured relaxation. The mapping of mental states to soundscape parameters is visualised in figure 3.7. Even though the selection of samples, tempo, volume and effects are constantly changing, any change is performed as gradual as possible. The sample-selection changes via a minimal amount of steps from the currently playing selection. Newly selected samples are activated starting from the next measure and are limited to a total amount of 8 per update (approximately every 10 seconds). Tempo, volume and effects changes are limited to 20 percent per update.
Furthermore, all samples are written in the same key, tempo and time signature and fit well together in terms of instruments, timing and dynamics. These choices were all made to find the

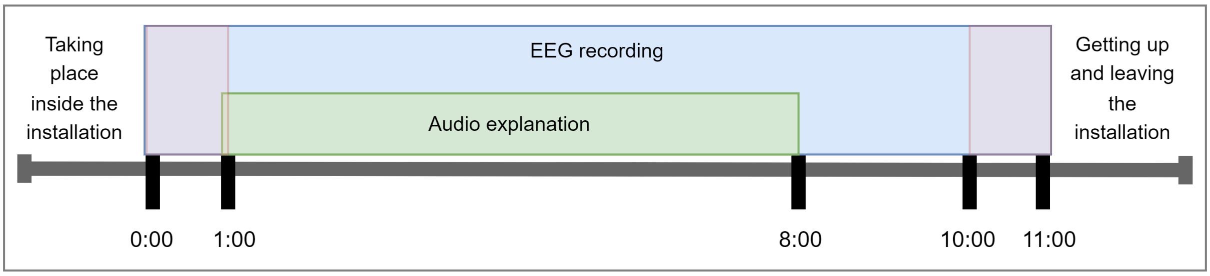


Figure 3.8: The timeline of the MIND YOURSELF experience

right balance in pay-off between how accurately the soundscape represents mental states and the musical integrity, quality and pleasantness of the soundscape.

3.1.5 Audio explanation

Besides the soundscape, the user is also listening to explanations about their own mind and the installation. The explanation is started 60 seconds after the EEG recording is activated and takes approximately 12 minutes. The time schedule of the experience is displayed in figure 3.8. The pink sections at the start and end of recording denote the first and last minute, which are relevant for the experimental protocol.
The audio script was written with the aim of helping the user understand how the brain-computer interface works. It explains the very basic concept of the relation between psychology and neuroscience, as well as the basic concept of EEG and how EEG features are used to control the stimuli around the user. The idea is that, in order for the user to feel like they are crawling inside their own mind, the user should understand how the space around them can be a representation of their own mind. Moreover, the explanation may also spark extra interest for the user in the workings of their minds. The full script of the audio explanation can be found in appendix C and the used file can be found on **Soundcloud**.

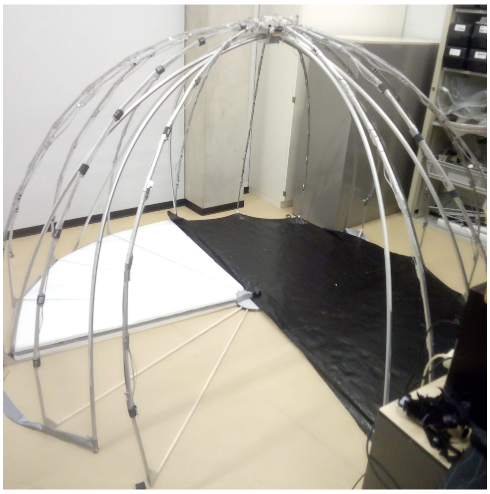
3.2 Construction

The actual construction of MIND YOURSELF also consisted of separate building blocks which were all developed and adapted independently. This includes construction of the physical installation, the hardware and the software. This section explains how the design concepts were carried out for the sake of transparency and rebuild-ability. Moreover, links to technical manuals, software scripts and other source material are included.

3.2.1 The physical installation and hardware

The physical installation is essentially a tent, whose frame is made up out off 135 short wooden slats forming 15 arching beams together. Each connection point between two slats holds a single LED, which are all connected via cables that run along the beams. The beams and cables come together in the centre, forming a dome. This can be seen in picture 3.9a The weight of the frame is also supported by arching PVC-pipes. The dome-shaped framework is surrounded by fabric that has a characteristic neural network-like pattern in dark and light grey. The fabric can be opened and closed at the entrance with Velcro, see picture 3.9c The floor of the installation is polystyrene shaped around the wooden support system, covered by insulation material and a bedspread to assure a fully comfortable floor. The floor build-up can be viewed in picture 3.9b. On top of this lies a yoga mat, a soft blanket and a pillow, so that the user can lie comfortably in a determined position, see picture 3.9d. The whole interior also gets a cosy look from these soft materials, all in dark grey.

(a) The frame

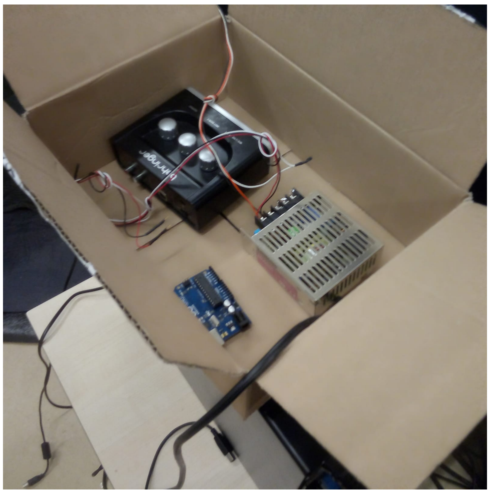


(b) The floor

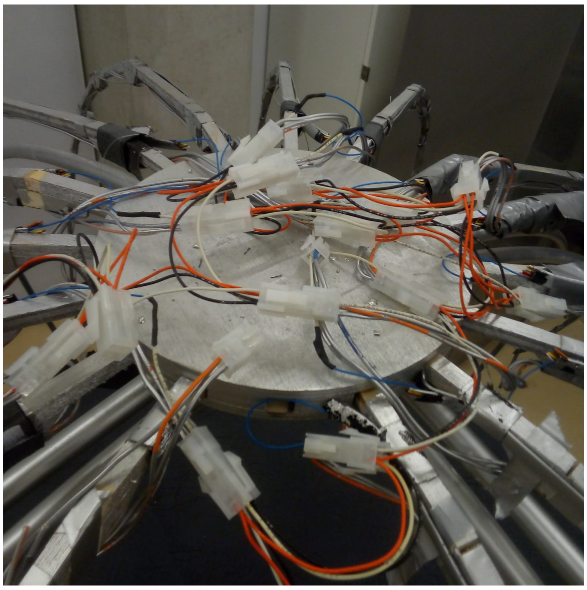
(c) The tent canvas

(d) The entrance

Figure 3.9: Construction of the physical installation



(a) An Arduino Uno, an external power supply and an Audio interface



(b) LED-strip wire connections

Figure 3.10: Hardware of MIND YOURSELF

The 120 separate digital RGB-LEDs form one long LEDstrip together which is controlled by an Arduino Uno. Each sub-string of LEDs on a beam is separately connected to a single external power supply, see picture 3.10. The audio is regulated via an audio interface, to reduce audio processing latency and prevent potential audio port streaming problems. The audio is outputted via two stereo amplifiers, which are positioned at right and left ear-angles to increase the feeling of immersion in the soundscape.

EEG acquisition

The EEG signals are acquired with an Emotiv EPOC X, positioned in top-position. This device is wireless, has 14 channels, and makes use of saline-based electrodes. The 14 channels are: [AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4]. The resolution is 0.1275μV and the internal sampling rate is 2048, which is down-sampled to 256 SPS. The bandwidth of the Emotiv EPOC X is 0.16 - 43 Hz, with notch filters at 50Hz and 60Hz. The device also includes a built-in 5th order Sinc filter [59]. The EEG signals are sent via Bluetooth to a USB-port plugged in the PC.

3.2.2 Software

The construction of the software also consisted of separate building blocks that were all developed and adapted individually. In case of re-building, if the developer wants to carry out a partially different concept or design, any of these building blocks can be changed without affecting the other elements. All building blocks are summarised in figure 3.11. The daily set-up of the MIND YOURSELF software and communication protocols between software is also explained in a **video**. The complete documentation of the software execution of MIND YOURSELF can be found on **GitHub**.

EEG processing

Emotiv PRO is used to acquire the measured EEG data. In this app, the headset is first connected and fitted well on the user. To obtain levels of stress, focus, excitement and relaxation,

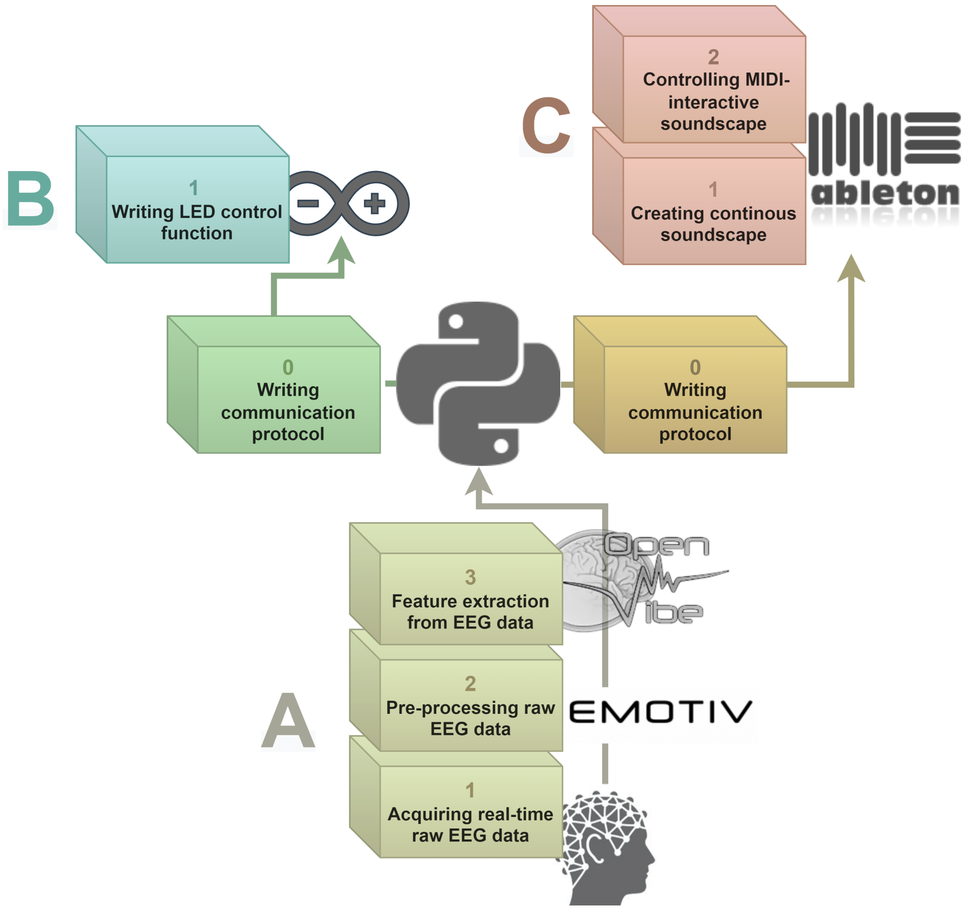


Figure 3.11: Overview of the building blocks of the MIND YOURSELF software

the automatically generated performance metrics of Emotiv PRO is used. The lab streaming layer is then activated to output raw EEG, as well as the performance metrics in seperate data stream. The raw EEG data stream is picked up by the OpenVibe acquisition server, which is connected to Emotiv PRO and activated. The pre-processing steps and valence-arousal feature extraction are implemented via an OpenVibe scenario following the steps as defined in section 3.1.2. The OpenVibe scenario is available via **GitHub**. Finally, OpenVibe outputs another lab streaming layer with valence and arousal levels. Both the performance metrics and the valence and arousal levels are retrieved inside a continuous loop in Python. The main Python script can be found on **GitHub**.

Interactive lightscape control

A standard open-source Arduino script was used to digitally control LEDstrips, with three important adaptations. Firstly, all LEDs keep automatically changing with decreased and increased saturation levels in a loop (blinking) with a specified waiting time in between. Secondly, the colours and the indices of the LEDs that are to be changed, as well as the waiting time inside the blinking loop are defined as variables. Thirdly, the whole script is inside a loop that checks for updates from the communication port. When there is a new message, the indices of LEDs and to colours to which they change are re-defined. The indices are a generated random half of all LEDs, such that colour changes are more varied and gradual. The Arduino control script is available via **GitHub**. Meanwhile, the Python script keeps fetching messages from OpenVibe and Emotiv PRO. Whenever a lab streaming layer message form Emotiv PRO is received, the values for stress, focus and relaxation are used as weights for RGB-values respectively, as explained in section 3.1.2. Stress is also mapped to flickering frequency, by reversing the value to define the variable waiting time for the blinking loop. These four values between 0 and 255 are sent to the same communication port as the Arduino is connected to.

Interactive soundscape control

Ableton Live 11 is used to create and continuously change the soundscape. The audio is regulated via the Behringer audio interface. Asio4All is used as audio driver in combination with the Behringer audio software. In Ableton, each sample sits in its own slot under a track, in groups of three. If a sample is activated, it will automatically wait for the next measure to play as well as deactivate another potential playing sample inside the same track. The MIDI mapping protocol of Ableton was used to connect all play buttons to MIDI-notes. Tempo, volume and dry/wet percentages of audio effects are mapped to continuous MIDI continuous controllers (MIDI CC). Dry/wet is the measure for to what extent the affected versus the original sound is heard.
Loop MIDI station was used to simulate a MIDI port. This was selected as MIDI control device in Ableton. MIDI notes and controls received in this software are automatically forwarded to Ableton, which makes corresponding changes.
Whenever Python receives a lab streaming layer message from Emotiv RPO, stress, excitement and relaxation are used as weights for the midi CCs, corresponding to the design explained in section 3.1.4. The tempo ranges between 40 and 140 Hz and the volume between -12 and 2 dB. The percentages dry/wet for the effects range between 0 and 80. Whenever Python receives a lab streaming layer message from OpenVibe, the selection of activated samples is renewed. The selection is defined as an array of length 15 (the number of tracks) with values of either 0, 1, 2 or 3 (muted or track 1/2/3 activated). First, it is determined how many samples should be playing. If it should be less, one of the non-zero values is changed to zero. If it should be more, either one of the zeros corresponding to the melodic tracks is changed to another value, or one of the values for the percussion tracks is increased. Next, the values of the melodic tracks are changed step-wise, by either increasing a 1 or 2, or decreasing a 2 or 3. When the array of sample selection is fitting to the desired valence and arousal scores, as calculated in figure 3.6,

it is translated to corresponding MIDI notes. These MIDI notes are either activating the first, second or third sample in a track, or deactivating the track. The array of MIDI notes is finally sent to the MIDI port. The Ableton Project, which includes references to the sound samples, MIDI note and CC mappings and production settings, can be found on **GitHub**.

3.3 Evaluation

3.3.1 Experimental protocol

After all components were independently prototyped and tested and the installation on its whole was operative, the MIND YOURSELF experience was tested in an user experiment. The experience itself takes approximately 10 minutes, excluding the time used to set up the EEG headset and for participants to get ready and lie inside the installation. The timeline of the experience is presented in figure 3.8. The aim of the experiment was evaluating the research question: How can an artistic psychological brain-computer interface increase self-consciousness using real-time continuous multi-modal representations of changing mental states? Participants for the experiment were invited via a note on the door of the experiment space, emails in the research group and the master's program Interaction Technology at the Univeristy of Twente and via personal networks. The invitation can be found in appendix D. The information brochure of the experiments is presented in appendix E. The experiment received ethical approval from the ethical committee computer and information science at the University of Twente with reference number RP 2021-206.
During the experiment, participants were presented with a questionnaire before and after their MIND YOURSELF experience. In both questionnaires, self-consciousness was measured, as well as self-reported current sensations. Self-consciousness is evaluated with the Self-Reflection and Insight scale, created by Grant et al. in 2002 [7]. Self-consciousness is subdivided in two factors: self-reflection (SRIS-SR) and insight (SRIS-IN). The questions regarding self-reported current sensations are based on the questionnaire used by Hinterberger et al. [35] to test their Sensorium experience. The answers to these questions before and after the experience illustrate how the MIND YOURSELF experience affect how the participants feel. Moreover, the EEG data during the experience is also recorded, resulting in measured affective state and mental activeness over the duration of the experience. The before and after questionnaire may be found in appendices F and G
In total, 35 people participated in the experiment. They were subdivided in two conditions: experimental and control. The experimental condition was the genuine MIND YOURSELF experience, such as described in the methodology. In the control condition, everything was the same, except for that the lightscape and soundscape were not interactive with the participants, nor based on or related to their EEG data. The parameters of the lightscape and soundscape changed according to measured mental states of another participant's randomised EEG data. This EEG data was randomised by dividing the original data in 10 chunks and randomizing their order, in order to prevent a predictable pattern. The participants in the control condition were still led to believe that they were experiencing an interactive experience. Comparing the results of the control condition to the experimental condition illustrates whether any changes in self-consciousness, self-reported sensations, and recorded mental states are caused by the interactivity of the brain-computer interface. If no significant difference appears between the control and experimental condition, it may be the case that the artistic outputs and the experience itself, or the placebo effect of believing one is in an interactive installation, are the main cause for any potential effects.

3.3.2 Analysis

Obtained factors

Through the questionnaire before the experience, the following pre-experience self-consciousness factors are measured for the control condition (CC) and the experimental condition (EC): SRIS, SRIS-SR and SRIS-IN. These are, in combination with the matching post-experience factors, the main results necessary to answer the research question. In addition, self-reported sensations are measured, using a seven-point Likert scale in accordance to the methodology of Hinterberger et al. [35]. These are detailed in table 3.12. The post-experience questionnaire similarly yields self-consciousness scores and self-reported sensations for both conditions. Moreover, the opinion of the experience is measured in the post-experience questionnaire using a four-point Likert scale alike Hinterberger et al. [35]. The participants were asked whether the found the experience ordinary or extraordinary, tiring or vitalizing, demotivating or motivating, and too short or too long. Finally, the participants reported to what extent they perceived a connection between their mind and the artistic outputs (perceived connection).
The recorded mental states that are extracted via EEG throughout the experience, result in eight temporal factors: affective arousal, affective valence, stress (FRU), engagement (ENG), valence (VAL), excitement (EXC), focus (FOC) and relaxation (MED). Each factor has an average value per time chunk of ten seconds and per condition. Moreover, the overall value for each factor is found by averaging over all time chunks. In addition, the average value for each factor is computed over the first 60 seconds and over the last 60 seconds of the experience. These time chunks are denoted in figure 3.8 as the pink blocks. These time chunks are chosen as indicators for the mental state at the start of the experience and at the end of the experience, because the audio explanation starts after the first 60 seconds. The extracted mental state values for the start and the end of the experience, and the difference between them, are useful values to understand whether the experience affected mental states. Whilst self-consciousness is the main measure for answering the research question, the other factors supply additional exploratory information about the project. They may be used especially to get a more well-rounded insight of the strengths and weaknesses of the project and supply grounds for recommendations. All factors are lined up in table 3.12, along with the type of value in which they were recorded and their time of recording with respect to the experience.

Statistical tests

All mentioned factors are subjected to statistical tests to analyse whether any significant differences are found amongst time and/or condition. A summary of all factors and statistical tests that are used to analyse them can be found in table 3.12. An alpha value of 0.05 is used for all statistical tests in the present study. Factors may be tested for normal distribution. Two statistical tests of normality are implemented: Kolmogorov-Smirnov and Shapiro-Wilk. Normal distribution of a factor is assumed if the significance value of each test is greater than alpha. In case of normal distribution, the mean and standard deviation are computed.
Moreover, the increase over time of factors can be computed by subtracting the post-experience value from the pre-experience value. Paired samples T-tests are used to analyse whether there was a significant change in any self-consciousness factor. This statistical test is implemented because the analysis concerns a before and after measure for each participant.
Furthermore, in order to understand whether true brain-computer interaction is a necessary condition for any change in a factor, the interaction effect between condition and time is computed. The condition is either control (placebo) or experimental and the time is either before and after. If the factors are normally distributed, a two-way ANOVA test can be used, where the factors are dependent variables. A significance of the two-way ANOVA test that is lower than alpha, suggests that being in the experimental condition or being in the control (placebo) condition

Factors and subfactors	Type of value per participant	Time of measurement	Implemented statistical tests
Self-consciousness • SRIS • SRIS-SR • SRIS-IN	Continuous number (weighted average of multiple 6-point Likert scale questions)	• Pre-experience questionnaire • Post-experience questionnaire • Change between pre- and post-experience	• Test for normal distribution • Paired sample T-test (before and after) • Two-way ANOVA test (before and after X condition) • Permutation tests
Self-reported sensations • Narrow-wide • Weak-intensive • Tense-relaxed • Uncomfortable-comfortable • Powerless-empowered • Activated-calm • Unbalanced-balanced • Sad-happy • Unsatisfied-satisfied • Anchorless-secure • Dissociated-connected • Confused-clear • Introverted-extraverted • Empty-satisfied	7-point Likert scale	• Pre-experience questionnaire • Post-experience questionnaire • Change between pre- and post-experience	• Test for normal distribution • Permutation tests
Recorded mental states • Arousal • Valence • FRU • ENG • VAL • EXC • FOC • MED	Continuous number between -10 and 10 Continuous number between 0 and 1	• Average EEG recording first minute of experience • EEG recording throughout the experience • Average EEG recording last minute of experience • Change between first and last minute	• Test for normal distribution • Two-way ANOVA test (before and after X condition) • Permutation tests
Opinion of experience • Ordinary-extraordinary • Tiring-vitalizing • Demotivating-motivating • Too short-too long • Perceived connection	4-point Likert scale	• Post-experience questionnaire	• Test for normal distribution • Two-way ANOVA test (before and after X condition) • Permutation tests

Figure 3.12: Factors and sub-factors measured as part of the experimental protocol of the MIND YOURSELF experience, including the value type and the time of measurement of each factor

does have an interaction effect on change in the factor.
Finally, permutation tests are used to analyse whether the experimental condition had a different effect on participants compared to the control condition. Permutation tests are useful in case there is little data and/or the data is not normally distributed. Because there is little data in the present study, using permutation tests makes the results more well-rounded. In all permutation tests in the present study, the data is split 50.000 times in two groups, whose mean values are subtracted. The chance of finding the subtraction value of the real two groups (experimental and control condition) is then computed. A significance value that is smaller than alpha suggests a significant difference between the two groups.

4 RESULTS

4.1 Associated valence of music samples

The first section contains the results of the intermediate user-test as part of designing affective sound samples. The samples were created in one of either three categories: low valence, middle or high valence, based on affective theory of music. The valence scores of the created samples were tested by 34 participants. The measured average valence score is normally distributed with a mean of -1.18 and a standard deviation of 0.59. The average valence score for each sample is presented in figure 4.1 on the y-axis. The hue of each sample shows the newly computed and assigned label for the soundscape based on these scores. The x-axis shows the original valence-category in which the sample was created. Low valence is equivalent to approximately -6.66, middle to 0 and high approximately 6.66. Data points close to the diagonal line represent music samples whose measured valence are similar to its hypothesized valence and whose label thus remains unchanged.
The sample labels were re-assigned based on the measured valence scores. The labels of 17 samples remained unchanged. 14 samples received a label that had changed by a single step, such as a low-valence sample being redefined as a middle-valence sample. The labels of 5 samples changed drastically with two steps: from high valence to low or vice versa. Figure 4.2 visualises these changes. The new labels were used in the final soundscape as described in the methodology. The samples with their corresponding category can be found here and the complete interactive soundscape Ableton project can be found here.

4.2 Self-consciousness

The following sections contain the main results from the experiments conducted around the MIND YOURSELF experiment. The questionnaire the 35 participants took before and after the MIND YOURSELF experience, measured self-reported self-consciousness using the Self-Reflection and Insight Scale [7]. Self-Reflection and Insight Scale (SRIS), as well as its two factors: self-reflection (SRIS-SR) and insight (SRIS-IN) were normally distributed. Their means and standard deviations can be found in table 4.1

Factor	Mean	St.Dev.
SRIS-SR	56.00	0.98
SRIS-IN	31.40	0.65
SRIS	87.40	1.16

Table 4.1: Means and standard deviations (St.Dev.) of SRIS-factors amongst control and experimental conditions

Average self-reflection decreased amongst the experimental condition as well the control condition between the before and after questionnaire. Average insight increased amongst both conditions. The overall SRIS self-consciousness score decreased amongst the control condition and increased in the experimental condition. The changes per factor and condition are

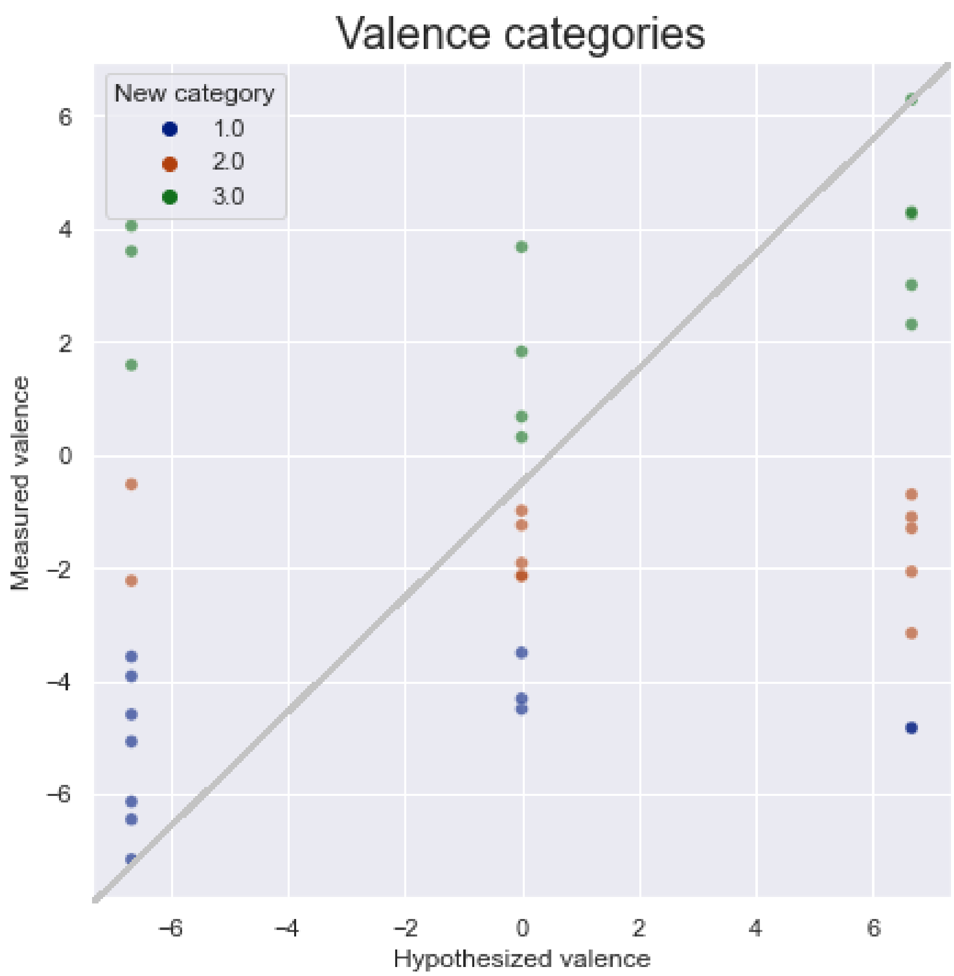


Figure 4.1: Hypothesised and measured average valence scores of each created sound sample. The grey diagonal line denotes (measured valence = hypothesized valence)

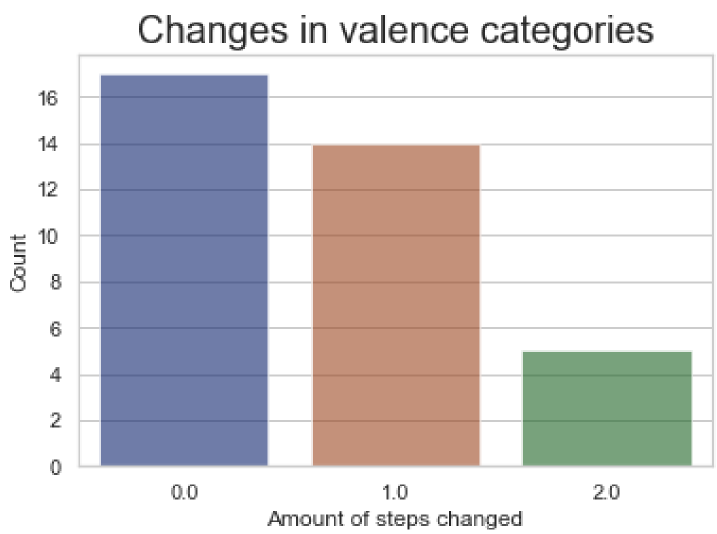


Figure 4.2: The amount of samples whose valence label remained unchanged, changed by one step and that changed by two steps

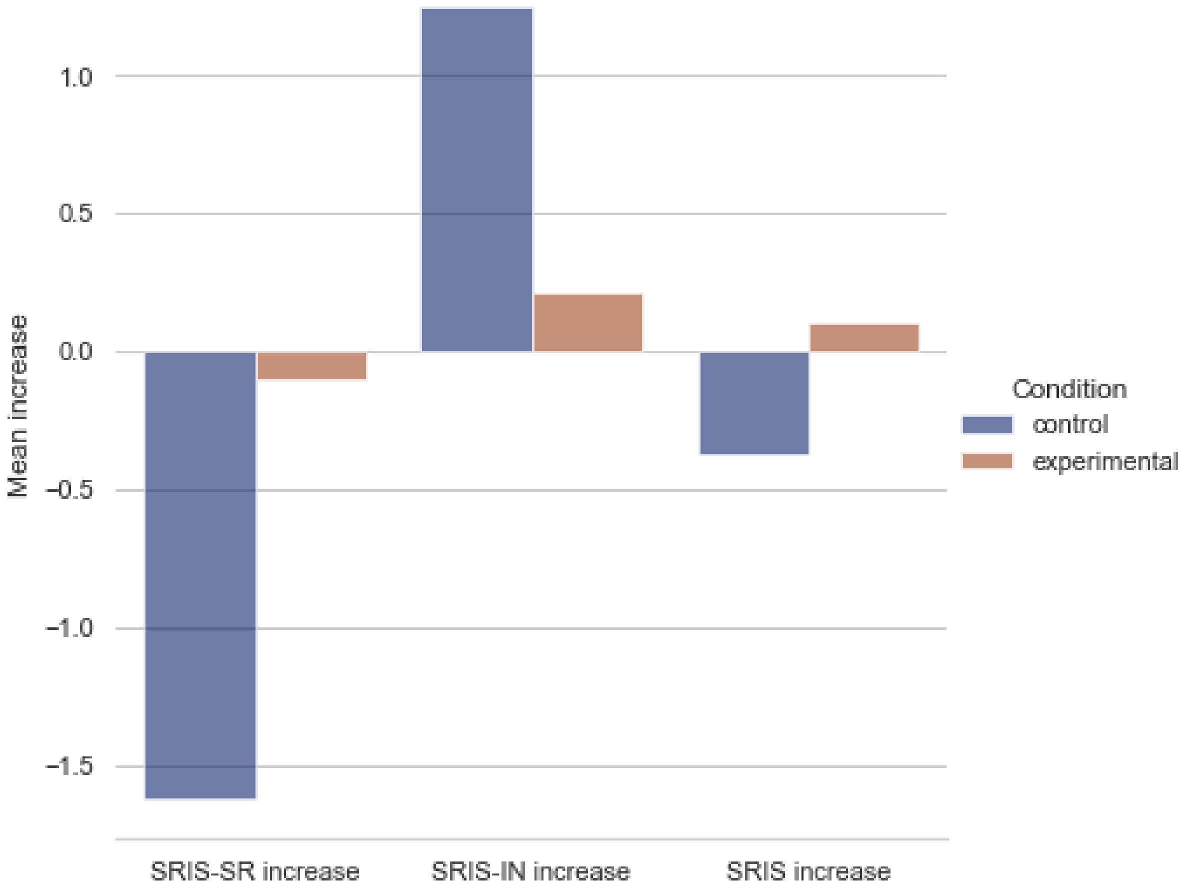


Figure 4.3: Increase of SRIS factors amongst experimental and control condition

visualised in figure 4.3. The changes between before and after values were analysed by means of a paired samples T-test for the control condition, the experimental condition and overall. Only the average decrease in SRIS-SR amongst control participants appeared significant: a change of -3.153 with significance of 0.007.

The differences between the changes found in control and experimental condition were analysed using an two-way ANOVA test and a permutations test. In the two-way ANOVA test, SRIS-SR, SRIS-IN and SRIS were taken as dependent variables, and condition and time of recording (before or after) as independent variables. The aim here was to test an interaction effect between condition and time: whether the condition affected the increase or decrease for each SRIS factor. No significant interaction effect was found. In the permutations test, the value for increase between after and before were used to compare the control and experimental condition. All data was split randomly 50.000 times in two groups. The chance was calculated of finding the difference in means between the real two groups (control and experimental) amongst all differences in means for each split. No significant difference was found in any of the factors between the conditions. The difference (experimental average factor increase - control average factor increase) and significance scores are given in table 4.2.

4.3 Self-reported sensations

The questionnaire the 35 participants took before and after the MIND YOURSELF experience also measured self-reported sensations. The factors were duplicated from the evaluation of the Sensorium [35] and likewise scaled from 0 to 4. The average scores for each factor before and

Factor	Average difference	Permutations sig.	Two-way ANOVA sig.
SRIS-SR increase	-1.52	0.19	0.16
SRIS-IN increase	1.04	0.33	0.31
SRIS	-0.48	0.70	0.69

Table 4.2: Mean increase comparison between control and experimental condition of SRIS factors

after the MIND YOURSELF experience for both conditions are plotted in figure 4.4. The factors of the self-reported sensations were not normally distributed. Permutation tests with again 50.000 repetitions of random splits were used to determine whether the changes between before and after the experience were significant in either condition. The factors narrow-wide, tense-relaxed, activated-calm, unbalanced-balanced, sad-happy, unsatisfied-satisfied, anchorless-secure and dissociated-connected significantly increased for participants in the experimental condition. In the control condition, the factors weak-intensive, tense-relaxed and uncomfortable-comfortable significantly increased, while introverted-extraverted significantly decreased.
Permutation tests were also implemented to compare the increases and decreases between the two conditions. No significant difference was found in change in the above mentioned factors between the control and experimental condition.

4.4 Recorded mental states

Affective state, consisting of values for valence and arousal, as well as mental activeness, consisting of values for stress (FRU), engagement (ENG), interest (VAL), excitement (EXC), focus (FOC), and relaxation (MED), were recorded for each time step during the MIND YOURSELF experience. Each time step is approximately 10 seconds. These were the mental state factors that were used to control the sound- and lightscape. During the experience, each mental state factor in each time step was printed into a CSV file. The recordings are started at the time the audio explanation states ”The MIND YOURSELF experience will now start” and are ended at ”This is the end of the MIND YOURSELF experience, see the script C. All values for mental states over time were averaged and are presented in figure 4.5 and figure 4.6.
All values for mental states were normally distributed. Their overall mean and standard deviation are shown in table 4.3.

Factor	Average control condition	Average experimental condition
Arousal	0.34	0.21
Valence	-0.13	0.04
FRU	-0.58	-0.62
ENG	-0.22	-0.20
VAL	-0.34	-0.36
EXC	-0.57	-0.57
FOC	-0.34	-0.27
MED	-0.39	-0.40

Table 4.3: Average differences of extracted features of mental states throughout the MIND YOURSELF experience (average last 60 seconds - average first 60 seconds)

In order to observe if and how mental states changed between the start and the end of the experiment, the average value for each factor during the first and the last minute were computed for each participant, as well as the differences between the last and first minute. Valence and

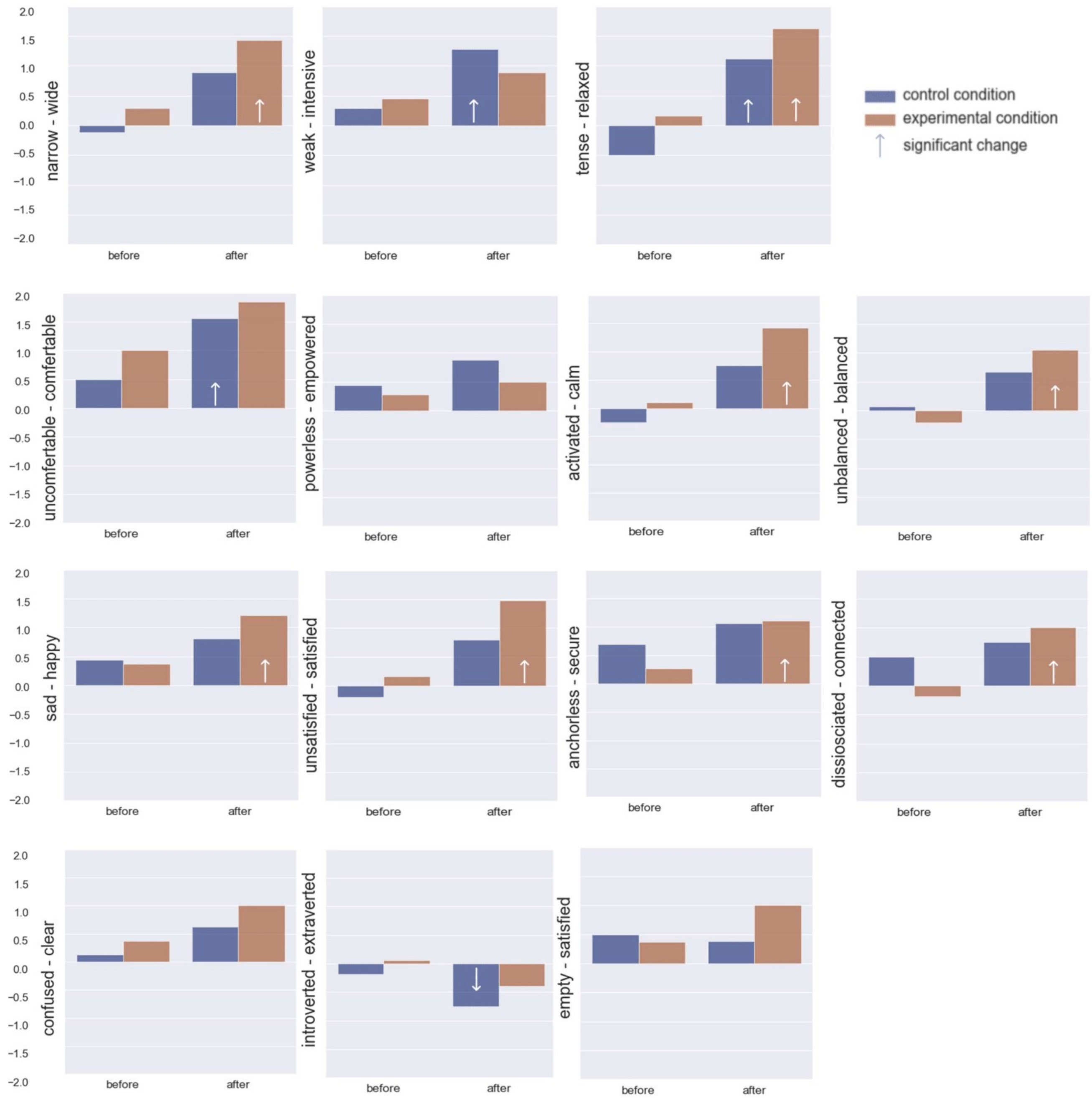
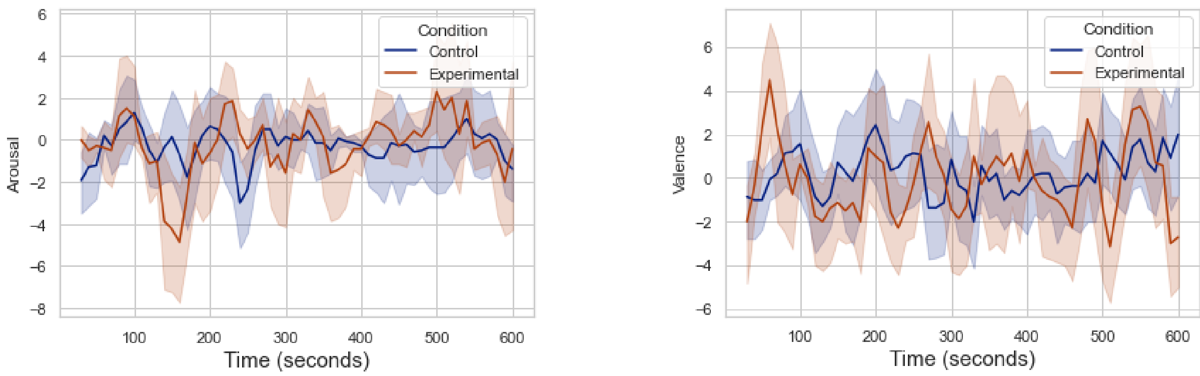


Figure 4.4: Average values for each factor of self-reported sensations amongst participants before and after the MIND YOURSELF experience



(a) Arousal (b) Valence

Figure 4.5: Affective state during the MIND YOURSELF experience averaged over control and experimental condition

arousal of affective states increased averagely amongst the control condition. In the experimental condition, arousal decreased slightly, whilst valence increased. The difference between the mental states before and after in both conditions were analysed using permutation tests again with 50.000 repetitions of regrouping. Out of these changes, only the increase in valence amongst the experimental condition is significant. The changes in affective state for both conditions are visualised in figure 4.7.

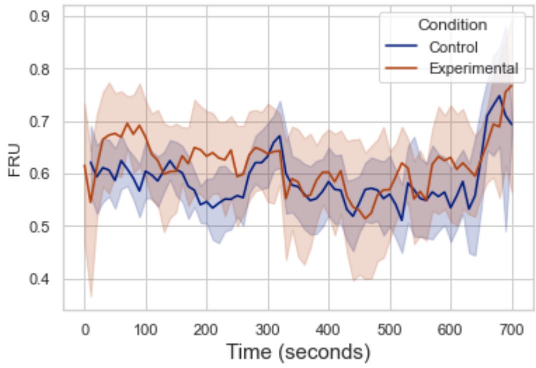
All values for the factors of mental activeness decreased averagely amongst both conditions throughout the MIND YOURSELF experience. From the permutation tests, it appeared that the decreases were significant in the experimental condition for stress, engagement and valence. In the control condition, only stress and focus decreased significantly. All changes in mental activeness factors are visualised in figure 4.8.

Two-way ANOVA tests were implemented to test whether an interaction effect exists between the condition and changes in factors of mental states. From these, it was concluded that none of the factors was affected significantly by the condition the participants were in.

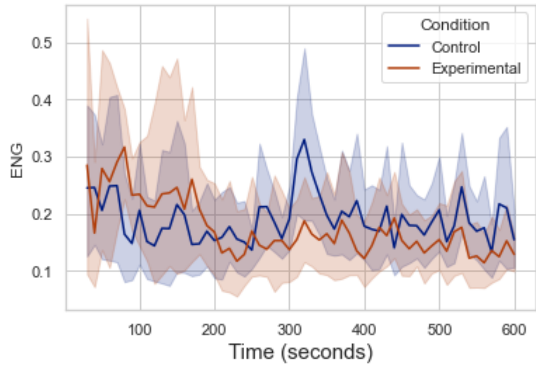
Permutation tests were also conducted, again with 50.000 repetitions of random-group assignment, using the values of increase between the last minute of recording and the first minute of recording. The aim of these tests was also to determine whether there was a significant difference amongst control and experimental condition in terms of change throughout the experience for any of the mental state factors. It appeared that there is no significant difference between control and experimental condition for any of the mental state factors. The average differences between conditions and significance scores can be viewed in table 4.4

Factor	Average difference	Permutations sig.	Two-way ANOVA sig.
Arousal	-1.2	0.51	0.23
Valence	2.18	0.55	0.28
FRU	-0.06	0.56	0.64
ENG	-0.10	0.60	0.61
VAL	-0.15	0.18	0.27
EXC	-0.02	0.84	0.59
FOC	-0.05	0.58	0.93
MED	-0.08	0.49	0.50

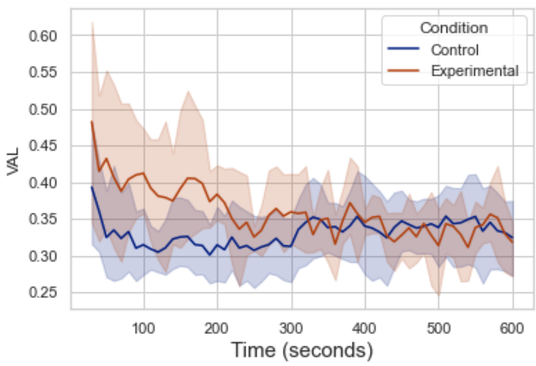
Table 4.4: Mean increase comparison between control and experimental condition of mental state factors. Average difference: experimental - control



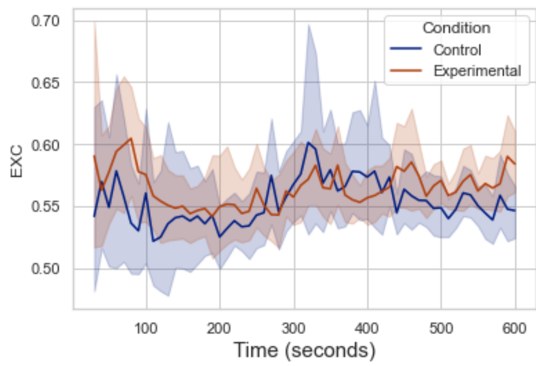
(a) Stress



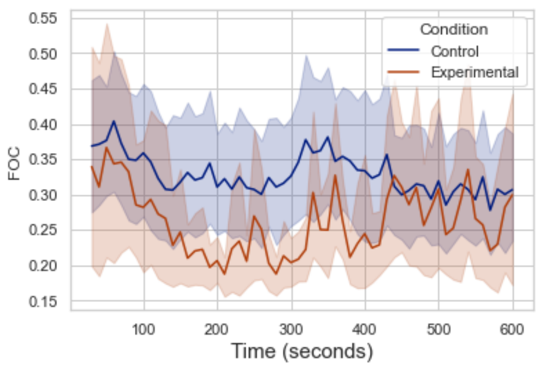
(b) Engagement



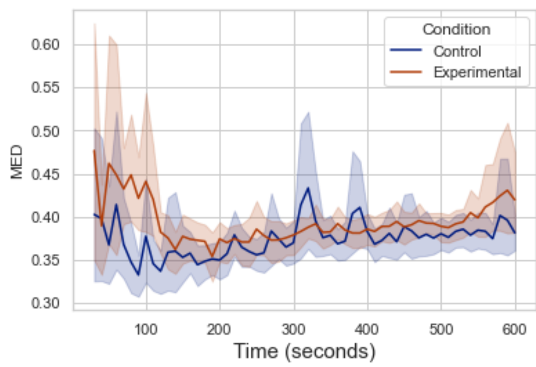
(c) Valence



(d) Excitement



(e) Focus



(f) Relaxation

Figure 4.6: Mental activeness during the MIND YOURSELF experience averaged over control and experimental condition

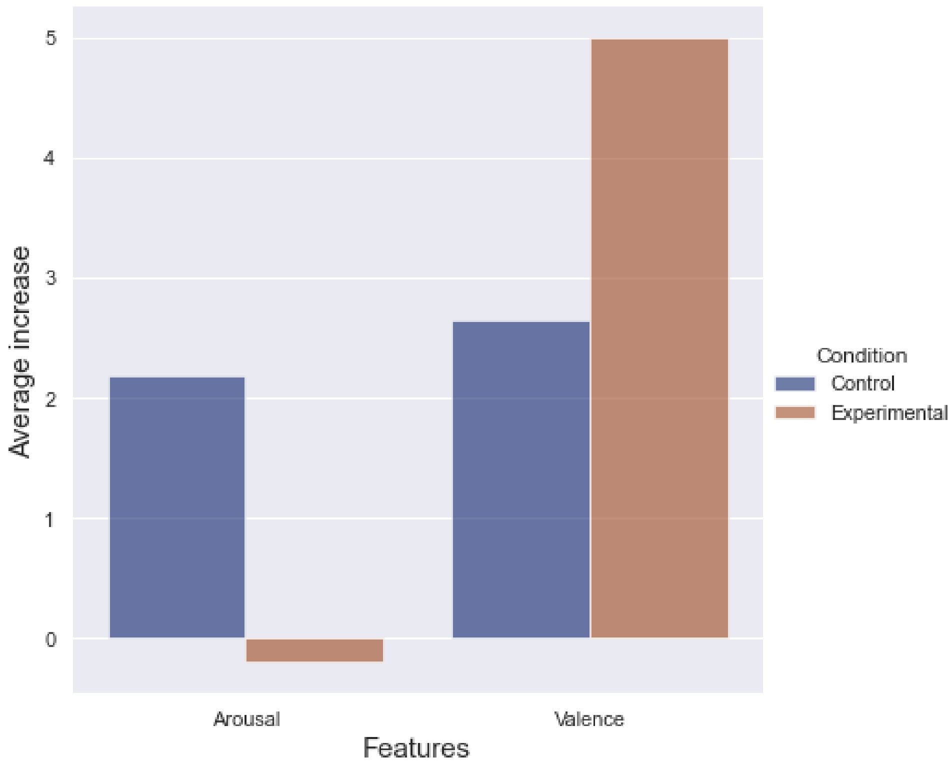


Figure 4.7: Average increase of affective state factors between the last and first minute of the MIND YOURSELF experience for the control and experimental condition

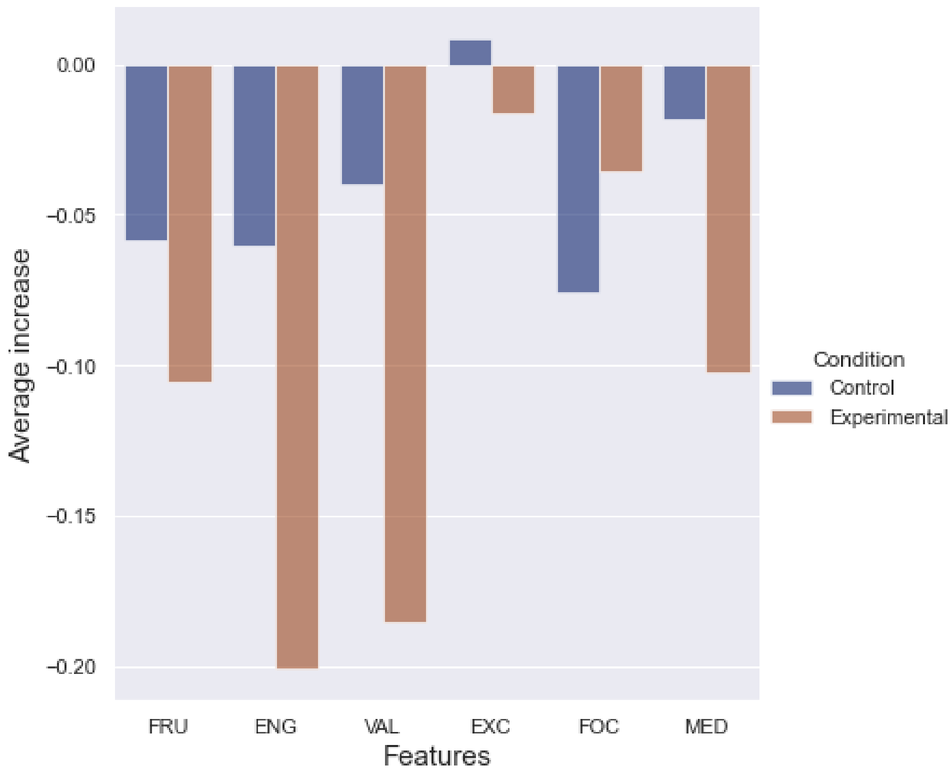


Figure 4.8: Average increase of mental activeness factors between the last and first minute of the MIND YOURSELF experience for the control and experimental condition

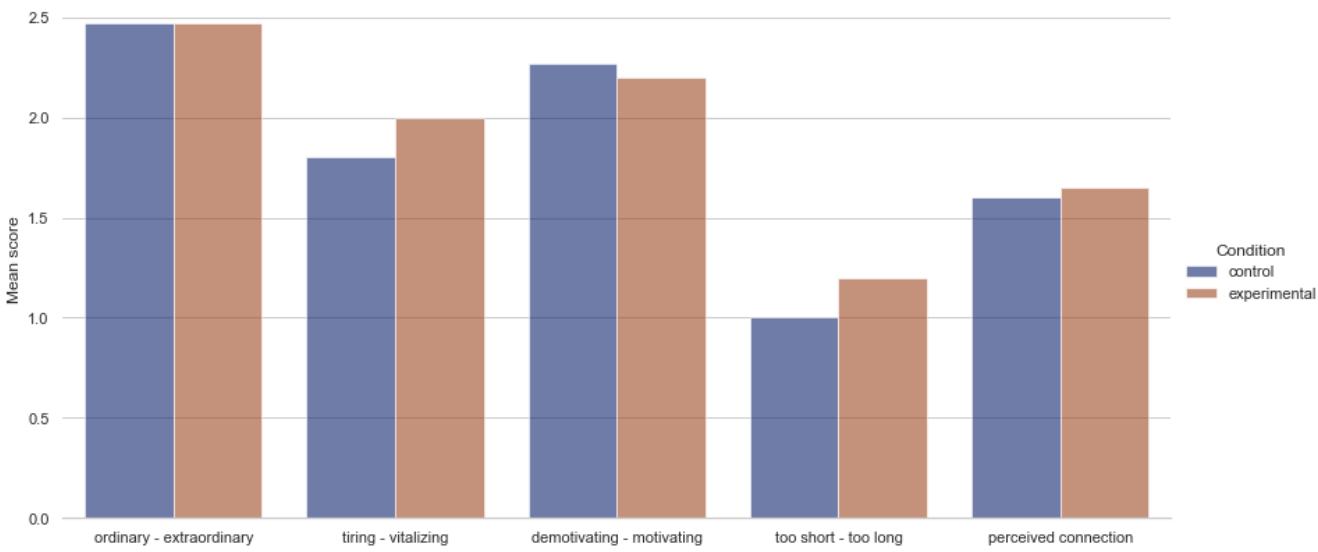


Figure 4.9: Opinion of the MIND YOURSELF experience amongst experimental and control condition

4.5 Opinion of experience

Finally, the questionnaire conducted after the MIND YOURSELF experience also contained questions that measured how the participants subjectively perceived the experience. These questions were also duplicated from the evaluation method of The Sensorium [35] and were scaled between 0 and 3. Participants were asked whether they found the experience ordinary or extraordinary, tiring or vitalizing, demotivating or motivating and too short or too long. Finally, the participants were asked whether they could notice a connection between themselves and the auditory and visual stimuli. The average answers amongst control and experimental condition are visualised in figure 4.9. A permutations test with 50.000 repetitions of random regrouping was used to determine whether there are any significant differences in perception of the experience amongst the two conditions. None of the factors was rated significantly different between control and experimental condition.
Moreover, participants conveyed their opinion of the experience in free text fields at the end of the questionnaire. All free-text answers are collected in appendix H.

5 DISCUSSION

5.1 Interpreting the results

5.1.1 Associated valence of music samples

In order to for users of the MIND YOURSELF experience to feel like their affective state was represented accurately by the changing soundscape, the samples used in the soundscape were all tested. Nearly half of the samples (17 out of 36) was rated in this user-test with the same valence-label as originally intended. This suggests that the total set of assumptions on affective associations with musical parameters, is to some extent useful for creating affective music samples. However, the larger part of samples was relabeled. There are multiple potential explanations for why the initially created affective samples did not correspond more accurately to the average associated valence in the user-test. Firstly, the assumptions on how certain parameters affect the emotional association of a music piece do not directly lead to a clear cut method for making an affective music sample. Creating music remains a form of art. No matter how extensive the guidelines for making a low-, middle- or high-valence music sample are, a practically infinite amount of possibilities remain within each category. Secondly, findings in literature on how musical parameters correspond to emotions, are never completely accurate nor universal [60] [27]. This is because music perception is extremely subjective and depends on the individual's personal preferences, associations and current mood amongst many other potential variables [39] [27].

5.1.2 Self-consciousness

The change in self-consciousness amongst participants of the MIND YOURSELF experience was tested using the Self-Reflection and Insight Scale (SRIS) [7] before and after the experience. The results for the control and experimental condition are compared. In the control condition, participants are led to believe that they are interactively controlling the changing sound and lights around them. They are, however, deceived, as the lights and sounds are in reality controlled by another person's unrelated brain waves. Participants in the experimental condition are surrounded by sounds and lights controlled by their own brainwaves, thereby undergoing the genuine MIND YOURSELF experience. The aim of the experience was to increase self-consciousness. However, overall SRIS-scores did not significantly change. The only significant change was the SRIS-factor self-reflection in the control condition, which decreased. A potential explanation may be that participants in the control condition may have been confused by perceiving sounds and colours unrelated to their mental state, whilst being told that they should be related. As such, they may have lost some confidence in their ability to self-reflect.

5.1.3 Self-reported sensations

Multiple self-reported sensations changed significantly between before and after the MIND YOURSELF experience. The most significant change was an increase in how relaxed both the control and experimental participants felt. Eight factors changed significantly amongst the experimental condition, while four factors changed significantly amongst the experimental condition. This suggests that the MIND YOURSELF experience has an impact on its users, that could be summarised as consolatory, relaxing or invigorating. However, the permutation tests yielded no significant difference in any of these effects between the control and the experimental group. This may indicate that the brain-computer interaction is not the essential factor in the effects the MIND YOURSELF experience has. Potentially, taking place in this unique immersive environment and/or the mere belief in the promise that the user is in control of their environment, suffice to explain the described effects of the experience.

5.1.4 Recorded mental states

The plots per extracted feature display potential temporal effects of the experience on users in the control and the experimental condition. Through visual inspection, a difference can be found between the experimental and control condition in arousal between 120 and 190 seconds. Participants in the experimental condition averagely show less arousal during this time chunk. This might be caused by an initial relaxing effect of lying down inside the tent. However, this does not explain the absence of such a decrease in arousal amongst participants in the control condition. Speculatively, it could be that amongst this group, the relaxing effect is mitigated by confusion about artistic outputs mismatching their self-perceived mental states. Another clear marker can be found in the stress plot at approximately 630 seconds. At 625 seconds the audio explanation announces the end of the experience. A potential explanation for the increase in stress level after this marker may be participants disengaging from potential states of relaxation. Another explanation could be a poor connection quality of the electrodes caused by participants moving after being in a steady lying position. Most of the features of mental activeness also peak at the start of the recording. Similarly,it could be that this is caused by poor connection quality to electrode, as participants are still moving to find a comfortable steady position. However, it is not possible to draw such conclusions, since the connection values have not been recorded. For each feature, the values throughout the first and last minute of the experience were averaged. All mental activeness features decreased. This could be explained by the notion of the peaks in the first minute, rather than describe the effect of the experience on these features. A visual inspection of the time plot for relaxation, for example, indicates a steady increase of relaxation throughout most of the experience in the experimental condition. This would be more in line with the self-reported sensations by participants than concluding that relaxation decreased between the last and first minute.

5.1.5 Opinion of experience

The experience was evaluated by participants in the questionnaire they took after the experience, using values between 0 and 3. The results indicate that participants found the experience especially extraordinary, as well as bit vitalizing and quite motivating. The average participant found the experiment a bit too short. It was not apparent that participants perceived a connection between themselves and the visual and auditory output. Surprisingly, there was hardly a difference between the control condition, where the output was based on completely random brainwaves, and the experimental condition, where the output was based on the participant's brainwaves. In fact, none of the factors of the personal opinion of the MIND YOURSELF experience are significantly different between control and experimental condition. This finding may be key to understand the lack of difference between control and experimental in the results in general. If the amount of perceived connection was similar for both conditions, it can be expected that there is no significant effect from being inside a genuinely brain-computer interface. Either the audiovisual outputs were not accurate representations of the mental states of the participants in the experimental condition, or they were so subjectively interpretable that participants in the control condition found equally meaningful patterns as a placebo effect. These possible explanations are further explored in the following section.

5.2 Limitations of the present study

Before discussing how limitations in the present study relate to the aforementioned interpretations of the results, a note should be made about the result section. In the present study, results are based on the existence or absence of significant changes in many different factors amongst time and participants. However, the results in significance scores did not account for the false discovery rate (FDR). FDR relates to the concept that if many hypotheses are tested with a certain error rate, it is expected that a number of hypotheses will be evaluated falsely under this error rate. A correction of the significance thresholds should be introduced to control for the false discovery rate (FDR) in multiple hypothesis testing [61]. Genovese, Lazar and Nichols [62] proposed an FDR-controlling procedure in which the average FDR is no higher than alpha, which is 0.05 in this case. However, to be able to compute the correction in this procedure, the false-positive rate of a certain variable should be known, which is only possible if these variables are analysed in replicated studies. This method is therefore not suited for the present study, but could be implemented in case the hypothesis testing is replicated in future work. In a simpler method for FDR correction, the significance scores of each variable are multiplied by the amount of variables tested [62]. However, whilst this method is known to decrease the rate of false-positive evaluations of variables, it also increases the rate of false-negative evaluations. Similarly, when this procedure was applied to the results of the present study, none of the significant differences in factors between experimental groups or time, remained significant. As such, it is difficult to conclude which FDR-correction is suitable for the hypothesis tests in the present study. However, it is important to keep the false discovery rate in mind when reading the results. It should be taken into account that many variables are tested for significance, and it can be the case that the some significant changes are false-positive.

In spite of uncorrected false discovery rates, results suggest that self-consciousness did not increase through the MIND YOURSELF experience. This section explores some possible explanations for these results. It may be the case that an artistic psychological brain-computer interface using real-time continuous multi-modal representations of changing mental states is not an appropriate method to increase self-consciousness. However, the results may also be affected by limitations in the methodology specific to the MIND YOURSELF experience and the present study. The finding that SRIS scores did not significantly increase amongst the experimental condition might be attributed to several potential reasons. Limitations may be found in any of the design components: the physical installation, decoding mental states from EEG, representing mental states in a lightscape and soundscape and the audio explanation, as well as in the experimental methodology. Firstly, it could be the case that participants did not find the installation or experience immersive or pleasant, or disliked the sounds and or music. However, the findings that the experience was relaxing, extraordinary and motivating suggest that participants did have a pleasant and immersive experience. The free-text answers, which are featured in appendix H also indicate that they generally found the installation impressive, and the sounds and light enjoyable, relaxing and/or ethereal.

Secondly, it could be the case that the mental states decoded from EEG were not accurate. If the extracted features of mental states were not accurate, the sounds and lights they affected would also not be accurate representations of their mental state. If so, the participants would find the audiovisual outputs to some extend arbitrary, similar to the control condition in which the audiovisual outputs are truly arbitrary. That would explain the lack of distinction between the control and experimental condition. Participants in either condition would then not recognise their self-identified mental states in the audiovisual output and might lose confidence in either the accuracy of the installation, or in the accuracy of their own judgement of their mental states. In the former case, it can be expected that the experience does not affect self-consciousness, while in the latter case, self-reported self-consciousness could even decrease. The mental activeness values were taken directly from Emotiv's performance metrics. These are designed to measure its features during mental tasks without personal pre-processing stage. However, measuring emotion in real-time has been disputed in literature. The more recent methods are based on machine learning and use a training stage to learn a mapping model specific to one participant's mind. It may be the case that current EEG technology is not yet ready to accurately extract features of affective state in real-time. It is not possible to report the accuracy of the feature extraction from the raw EEG, because no benchmark values were recorded during the experience. Furthermore, the quality of EEG contact was not recorded. As such, any results from potential experiences relying on low EEG-quality have not been filtered out. Moreover, the present study did not test the decoding of mental states from EEG in isolation.

Thirdly, the mapping from mental states to audiovisual output may be inaccurate, too vague or too subjectively interpretable. Even if decoded mental states were very accurate, participants may have not recognised their mental states in the soundscape and/or lightscape parameters. Participants in the experimental condition would then also find the audio and/or lights arbitrary, which would have the same implication as inaccurate mental-state decoding that is described in the previous paragraph. The finding that participants in the control condition did sometimes feel a strong connection to the audiovisual output, suggests that the lights and sounds may indeed be too subjectively interpretable. The experience does not explain the meaning of the colours, flickering speed or sounds. Answers in the free-text section also display some participants' vast belief in mappings between mental states and audiovisual parameters that were not designed as such, even amongst the control condition. This implies that the soundscape and lightscape and changes in their parameters are in such a degree vague and/or subjective that they allow false pattern-finding. The valence test of music samples also displays a discrepancy between the judgement of the researcher and that of the average participant in affective association to music. Moreover, the samples were only tested in isolation. The system of a selection of samples with specific valence scores together accumulating to an average valence score, has not yet been used in affective BCI music, nor was it explicitly tested. Similarly, basing the arousal level of a soundscape on the weighted summation of tracks played is also a novel method that has not been used before, nor tested. The mappings between mental activeness value to soundscape parameters (tempo, speed and effects), LED colours and flickering speed are based on findings in literature, but have also not been tested in isolation in the set-up used in the MIND YOURSELF experience. Therefore, it is not possible to validate the representation method of the present study of mental states in soundscape and lightscape.

Fourthly, the experience also included an audio explanation of the mind and the installation. Its aim was to help the participant understand themselves better and to understand the workings of BCI and the MIND YOURSELF installation. It was assumed that, with increased understanding, the participants would also be more likely to belief that the audiovisual output was a representation of their mind. However, it was not tested whether the audio explanation helped the participants to understand the mind or the installation.

Finally, self-consciousness was measured using the SRIS-questionnaire. Most of the questions, however, are targeted towards habits regarding self-consciousness, using phrases such as 'often I...", "I never...", "Sometimes I...". It is unlikely that a participant changed their habit within 15 minutes. It may be possible that they changed their view on their habit, by, for example, having had time to contemplate their habits regarding self-consciousness. Grant et al. [7] originally designed two sub-factors in the self-reflection scale: need for self-reflection and engagement in self-reflection. It may be the case that if participants would be primed by the experience to change their habits regarding self-consciousness, their self-reported need for self-reflection would change. However, the final SRIS questionnaire resulting from factor-analysis did not contain any sub-factor measuring need for self-reflection anymore. It may be the case that self-consciousness cannot change within the scope of an hour. An alternative explanation is that a potential immediate effect of the MIND YOURSELF experience on self-consciousness should be measured with a different questionnaire. Furthermore, it is possible that within the scope of an hour, interest in or view of importance of self-consciousness is changed. Such a change could be the seed for a long-term change of self-consciousness.

5.3 Recommendations for future research

The present study was an exploration of how an artistic psychological brain-computer interface can increase self-consciousness using real-time continuous multi-modal representations of changing mental states. It supplies ideas for methods of designing components of such artistic psychological BCIs along with novel viewpoints on these methods based on the results. It is the task of future research to isolate all methodological and design components and develop and test them in isolation. These components includes the design of an immersive installation or space for the experience, extracting mental state features, mapping mental states to audiovisual output and measuring self-consciousness. Especially the methodology for decoding affective states from raw EEG in real-time should be further developed. Advanced technology may also enable faster and more easily incorporated techniques to train affective state detection specific to each user. If mental state decoding and mapping systems from mental states to audiovisual parameters are advanced, it can be further researched how artistic psychological BCIs can be implemented to increase self-consciousness.

Some components of the MIND YOURSELF design methodology may also be used outside the field of brain-computer interfaces. Even though the MIND YOURSELF experience did not significantly increase measured self-consciousness in participants, it did have significant effects on how the participants felt. The experience was especially extraordinary and relaxing, even without true brain-computer interaction. The construction techniques of the installation, soundscape and lightscape could therefore be used to create spaces for meditation, relaxation or contemplation. Furthermore, the interactive soundscape control is a novel method that may be used in combination with any active or passive control. A sound designer could collect sound or music samples that are rated, for example, from cold to warm, or from gentle pop-rock to heavy-metal. They could then use any input feature that can be retrieved digitally, for example detected movement, digital sliders or facial expressions to continuously and automatically control the soundscape, with smooth transactions.

6 CONCLUSION

The aim of the present study was to advance understanding and design methodology of artistic and psychological BCIs as means for individuals to gain self-consciousness in non-clinical setting. To achieve this, an APBCI installation called MIND YOURSELF was developed, using real-time continuous multi-modal representations of changing mental states. MIND YOURSELF facilitated experiments to answer the research question: How can an artistic BCI installation facilitate enhancement of self-consciousness? Results from participants in the experimental condition were compared with the placebo condition: the MIND YOURSELF experience without true interaction with the participant's mind. The MIND YOURSELF experience significantly affected the mental state of participants overall, mainly in the self-reported sensations, such as increased relaxation, comfort, and calmness. The average participant also found the experience quite extraordinary. These results illustrate the effect of the MIND YOURSELF experience but do not provide a direct answer to the stated research question. For that purpose, self-consciousness was measured before and after the experience in the experimental and control group. Amongst these results, only the self-reflection factor (SRIS-SR) decreased significantly amongst the experimental condition. The other factor, insight (SRIS-IN), and the general self-consciousness score (SRIS) did not change significantly. There was also no signifcant interaction effect found between the two conditions and the change in self-consciousness. This indicates that true brain-computer interaction does not necessarily lead to a different experience in an APBCI such as MIND YOURSELF, in comparison to a deceptive experience in terms of interaction. This is subscribed by the finding that the experimental condition did not differ significantly from the control condition either in other measures, such as self-reported change in sensations or evaluation of the experience, These results thus suggest that an APBCI installation may not be the right tool for direct enhancement of self-consciousness. However, though based on state-of-the-art technology and knowledge of APBCI, MIND YOURSELF remains a subjective and specific execution of an APBCI to advance self-consciousness. The discussion section has examined the many ways in which the development of MIND YOURSELF and the experimental protocol may be imperfect. It could therefore be the case that, by applying some of the changes suggested in the discussion section, a different version of an artistic-psychological BCI may succeed in advancing self-consciousness. The present study is not able to provide a decisive answer to whether or how an artistic BCI installation can facilitate enhancement of self-consciousness. However, the unique method of development of MIND YOURSELF, especially in terms of projecting mental states in artistic outputs can inspire future APBCI projects. It is clear that using the design methodology as implemented in the development of MIND YOURSELF, an APBCI can be an extraordinary and relaxing experience. However, in order to understand how an APBCI can affect self-consciousness, all components of design, especially decoding mental states and mapping mental states to audiovisual outputs, have to be picked apart further and developed and tested in isolation. The suggestions mentioned in the discussion section may be used as guidebook for future development of artistic-psychological brain-computer interfaces. The MIND YOURSELF experience marks only the start of a long list of possible applications of artistic psychological brain-computer interfaces for the sake of increasing self-consciousness. And the present study is only a single viewpoint on a long academic journey of using brain-computer interfaces to understand the mind and artistic representations of the mind.

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A THE BASICS OF BRAIN-COMPUTER INTERFACES

This additional chapter organises existing knowledge of the basic technical principles of brain-computer interfaces (BCIs). It may be used to enhance background understanding of the technique behind discussed technologies. A Brain-Computer Interface (BCI) is a system of communication that uses brain signals as controllers for the outside world [63]. The great advantage of using BCI technology is thereby employing an alternative pathway to analyse the mind and/or exercise control. This may mean that brain signals allow for insights of the mind that are not consciously experienced and can therefore not be expressed otherwise by healthy individuals, or that they allow for an alternative pathway to control functions for individuals that are physically impaired.

A.1 BCI paradigms

Bypassing motor control pathways has always been an important mainspring for advances in the field of research. The main premise of these medical BCIs is to improve quality of life for people who suffer from motor disabilities, such as locked-in syndrome [64]. Independence can be gained as BCIs allow for control of the environment, communication devices or mobility devices, amongst others [65, 66, 67]. Such BCI technologies that serve as alternative pathway to physical control give users active agency. They may also be applied in non-clinical setting, for example as controller in a virtual game [68]. Using brain signals in BCIs as representation of mental processes, is often done using passive or active BCIs [69, 70]. Through different modes of output, implicit mental states or processes are extracted and externally represented, for example through visualisations [71, 72]. Potential aims are gaining understanding of the mind, making adaptations to the mind, and using the brain as inspiration [73, 74, 75]. Implicit mental states and processes that are often of interest in these psychological BCIs include mental activeness and affective states. [48, 27]. Besides passive and active, Prpa and Pasquier [10] describe a third type of BCI control: reactive. In reactive interfaces, a user is presented with some stimulus and their response to it is measured.

A.2 Brain signal acquisition devices

Many devices may be used to extract brain signals as basis for BCIs. Each type of device differs in invasiveness, temporal resolution, spatial resolution, costs, and accessibility, and are therefore suited for different applications [76]. The most common devices for acquiring neural signals are electroencephalography (EEG), functional magnetic resonance imaging (fMRI), electrocorticogram (ECoG), positron emission tomography (PET), and functional Near-Infrared Spectroscopy (fNIRS) [13]. ECoG is an invasive technique, as it requires surgical placement of receptors directly on the brain [64]. The other mentioned types of devices are non-invasive. Figure A.1 provides an overview of the different brain imagining techniques and their invasiveness, temporal resolution, and spatial resolution.
The advantage of systems with a high resolution, such as fMRI, is that they can comprehend more complex and delicate brain signal patterns [64]. However, most BCI applications require

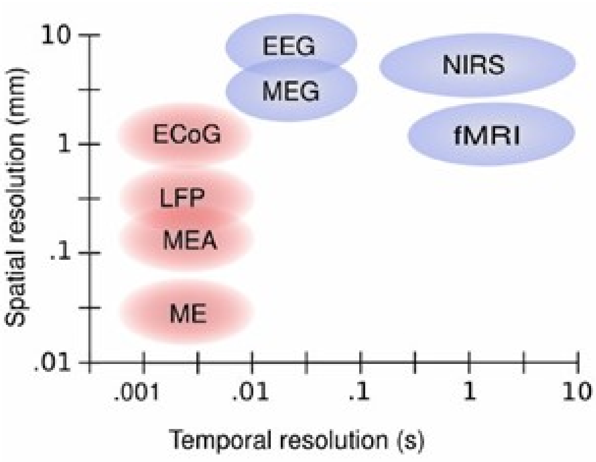


Figure A.1: An overview of brain imaging techniques and their spatial and temporal resolution, with non-invasive methods in blue and invasive methods in red. From Gerven et al. [77].

a brain imaging technique with a higher temporal resolution because they rely on short neural responses or aim for quick control. With its high temporal resolution, as well as its relatively low costs, EEG is the most common brain imaging technique used for Brain-Computer Interfaces [78, 12, 34]. EEG technology is discussed in more detail in the following paragraphs and is most apparent amongst the example applications that follow.

A.3 The neurological basis of EEG

To understand the workings of BCIs, it is important to know what brain signals are and how they are picked up by an acquisition device. EEG technology relies on the changes in electrical fields caused by neural communication. This is also believed to be the basis of information processing in the brain [79]. Neurons communicate with one another through action potentials. Simply put, a neuron receives synaptic potentials from connected neurons. If the accumulated potential exceeds a certain threshold, it fires an action potential, prompting synaptic potentials in connected neurons in its turn [79]. Local electrical activity caused by these action potentials affects the average field potential. If synchronous, the accumulation of the changes in local fields may result in signals that are detectable on the scalp [78]. Each of the electrodes on an EEG head set measures electrical activity at subsequent time points. The closer the origin of an electrical field is to an electrode, the stronger the signal. This also means that there is overlap between the signals that are picked up by different electrodes. There are different techniques in the BCI pipeline that may be used to take this into account [63].

A.4 The BCI pipeline

Nam et al. [13] provide an overview of the different phases of using neural signals in a BCI setting, which is shown in figure A.2. To ensure that signals can be picked up by the electrodes of an EEG-headset, they must be well-connected to the scalp. This may be achieved by using firmly placed dry electrodes or applying liquid for wet electrodes. As both techniques have significant drawbacks - the former is uncomfortable and the latter messy - most modern BCIs implement a new type of electrode: semi-dry, which make use of a saline solution [10]. The signal is amplified either in the electrodes or through an external device to reduce the relative amount of environmental noise [80].
After acquiring the neural signals, the data is processed in multiple steps. The difference between online and offline processing mentioned in figure 2, refers to whether the BCI is being

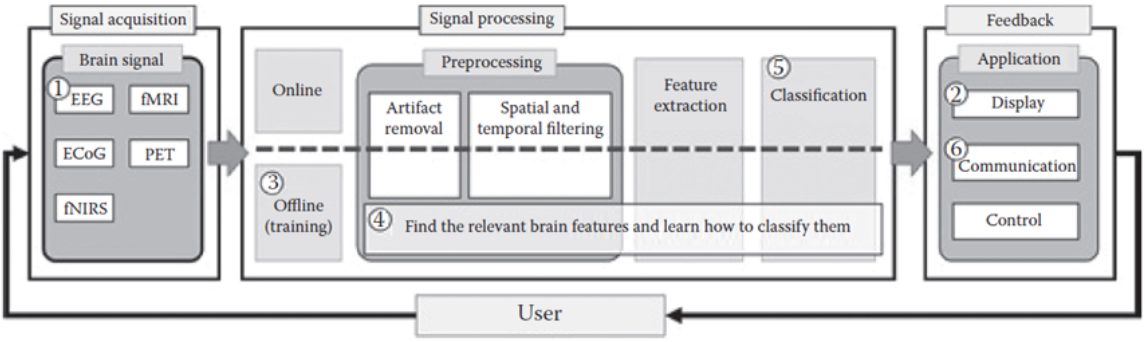


Figure A.2: From Brain-Computer Interfaces [13]: "Overview of a general BCI system framework"

trained or in use for its purpose. For some applications, training of either the participant or the classification algorithm is required. An example of the first instance is a patient with locked-in syndrome that needs to practice imagining motor movement, such that they are able to produce EEG signals that are correctly classified by the BCI [67]. The second type of training refers to machine learning, where the algorithm needs to train classification based on EEG signals, by using exemplary data combined with the aspired output [81, 29].
EEG signals that are acquired contain a lot of artifacts and noise, patterns in the data that are arbitrary or caused by factors irrelevant to the experimental conditions. Common artifacts are eye blinks, facial muscle contraction, heart rate, power line signal and movement of the EEG electrodes [13]. They can be removed to some extent by filtering out the specific frequencies that correspond to the artifacts and noise. Furthermore, the data needs to be spatially filtered, in order to gain specificity to the brain and EEG placement of a user at a particular time [63]. A reference electrode is placed on a spot that is inactive in the experimental condition and used to filter out noise.
However, a lot of task-unrelated noise remains after this step [75]. Additional spatial filtering is therefore required, such as surface Laplacian reference methods or common average referencing [13]. To find the most suitable spatial filtering method, with optimal parameters, statistical analysis may be used, like principal component analysis or even machine learning, such as support vector machines [31]. The next step is to extract features from the denoised data.

A.5 Types of EEG features and classifications

The types of features that are used for classification are mainly dictated by the corresponding BCI paradigms. BCIs based on controllable variables enable active agency. In contrast, BCIs that are meant to gain information about the mental state of an individual often have passive or reactive agency [5]. In the former case, the mental state is analysed as it naturally is at that point in time. In the latter case, mental states resulting from some stimulus are observed. Rather than classifying particular shapes or patterns of potentials, general wavelet coefficients and/or the amplitude of signal frequencies throughout brain areas are analysed [78]. The power is measured for ranges (or bands) of frequencies, predefined according to their function. These are often described as power spectral densities (PSDs). An overview of the commonly defined frequency bands and their functions can be found in figure A.3. Different frequency bands are generally predominant in different areas of the brain. Rashid et al. provides an overview of this, which can be found in figure A.4.
More global neural variables can also be used as features. Such variables include functional asymmetry between the two lobes [82, 83] or connectivity between different brain areas [84].

Name	Frequency range (Hz)	Associated features
Delta	0.5–4	Fatigue, sleep, severe slowing of mental processes, possible to occur in meditation by very experienced practitioners able to maintain consciousness in delta state
Theta	4–7	Deep meditation, reduced consciousness, hypnosis, attention lapses, slowed processing, stage 1 of sleep, memory consolidation
Alpha	8–14	Relaxed wakefulness, readiness, inactive cognitive processing, most prominent during meditation
Slow Beta	15–20	Intense focus, cognitive enhancement
Medium Beta	20–30	Anxiety, distractibility
Fast Beta (Gamma)	30–70	Hyper-alertness, processing of various attended stimuli (tactile, visual, auditory), stress

Figure A.3: “EEG waves, their frequencies and features” [10]

Band	Frequency (Hz)	Amplitude (μV)	Location	Activity
Delta	0.5–4 Hz	100–200	Frontal	Deep sleep
Theta	4–8 Hz	5–10	Various	Drowsiness, light sleep
Alpha	8–13 Hz	20–80	Posterior region of head	Relaxed
Beta	13–30 Hz	1–5	Left and right side, symmetrical distribution, most evident frontally	Active thinking, alert
Gamma	>30 Hz	0.5–2	Somatosensory cortex	Hyperactivity

Figure A.4: An overview of the different defined frequency bands, along with predominant amplitudes, associated brain areas and associated cognitive state. From Rashid et al. [14].

Furthermore, in recent studies, hybrid methods are sometimes used combining multiple types of features, often implemented through machine learning [14, 26, 85].

B EXAMPLE APPLICATIONS OF PSYCHOLOGICAL AND ARTISTIC BRAIN-COMPUTER INTERFACES

This section lists BCI applications in different corners of the paradigm of artistic and psychological BCI technology. Its goal is to sketch out the rich and diverse field of possibilities for BCIs, to get a more concrete image serving as inspiration. Example applications that are selected show a unique method or understanding that is at least partially relevant to the present study.

B.1 Psychological BCIs

Affective state classification

An important implementation of passive and reactive BCIs is classifying mental states from EEG features. Stikic et al. [29] studied classifying affective states that were induced by different video samples. Elicitors of positive states included humorous video clips and happy-ending narratives. Video clips of unjust narratives, war scenes and cemetery visitations are examples of materials that were used to elicit negative affective states. Both PSDs as wavelet coefficients were exploited as features to classify valence corresponding to the video stimuli. Where Stikic et al. [29] identified affective states based on valence only, Taran et al. [75] designed a machine learning algorithm that predicts both valence and arousal of affective states. These were also evoked by video clips. The prediction model was trained with single-channel activation values as input.

Melomind

Already on the border of artistic psychological BCIs is the commercial BCI tool Melomind [37]. It is a headphone with four attached and integrated EEG electrodes that aims to increase calmness of users. The state of mental activeness of the user is decoded from calculated power of the alpha frequency band in the parietal lobe. A relatively high alpha activity is associated with high relaxation. It is then presented back to the user by changes in a soundscape that is playing from the headphones. The soundscape is a themed nature-inspired setting with ambient sounds. Samples of the soundscape can be found on their website. In digital PDF format, **this link** forwards to the website. When using Melomind, the volume of the soundscape changes according to the real-time acquired EEG data and its associated mental states. A presumed high level of relaxation is represented by a lower volume of the ambient sounds. The tool is meant for regular usage and connected through Bluetooth to an app, which also generates graphs of the user's decoded mental states over time. Melomind promises long-term changes in the brain that help users relax and concentrate.

EmotivBCI

The prominent EEG brand Emotiv also develops software for everyday use [50] under the name EmotivBCI. A headset may be bought which comes with software that can be installed on a

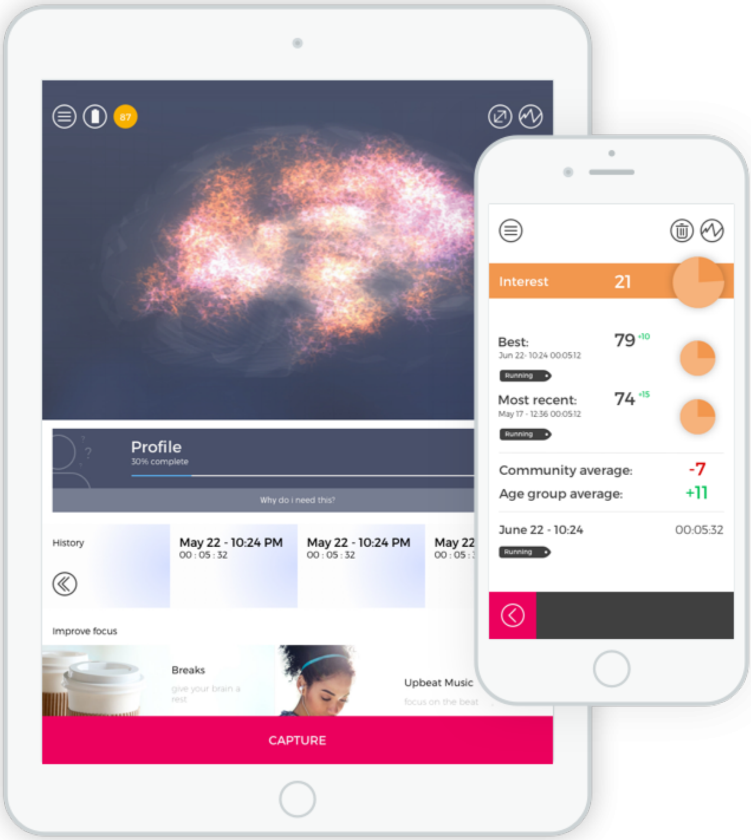


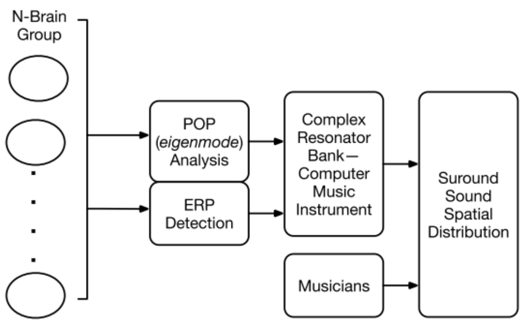
Figure B.1: An image of an application from EmotivBCI [50]

smart device or PC. Their applications make use of measuring the power spectral densities of different frequency bands. These are visualised through graphs and brain projections in the BCI software. Using an application for a smart device, users can use EmotivBCI to train meditation, relaxation and focus. An example application may be found in figure B.1.

B.2 Artistic BCIs

Insight2OSC

The Insight2OSC [18] is a Brain-Computer Musical Interface (BCMI) developed in 2017 that combines neural features with bodily features as input to generate music. These include the average band powers per electrode (5 in total), head movements parameters and facial expression parameters. The head movements are measured by a gyroscope, accelerometer and magnetometer. The facial expressions - blinking, winking, surprise, furrow, smile and clench - are derived from artifacts in the EEG data using a 5-channel Emotiv headset and Emotiv Insight software. As part of Insight2OSC, four musical applications were developed using MaxMSP [86], a software that regulates audio and video output from different modes of input. In one example, head movement encoded by 3-dimensional gyroscope input is used as control for pitch, timbre and dynamics. In another application, alpha band power controls the dynamics of a sound piece. Observed smiles are used in yet another application to increase tempo.



(a) A simplified diagram of the mapping system.

(b) A performance in 2015 at the Whitney Museum of American Art, New York. Photo by Paula Court.

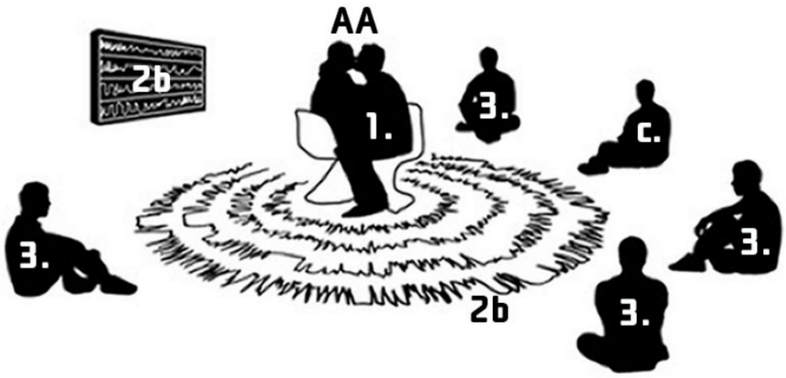
Figure B.2: Ringing Minds. From Rosenboom and Mullen [47].

Ringing Minds

In their account of artistic multi-agent BCIs (MABCIs) [47], Rosenboom and Mullen describe several artistic performances and installations based on BCI technology that have more than one simultaneous participant. Such MABCIs measure EEG data from several people at the same time, rendering an extra dimension of features, which may display concepts such as synchronisations amongst different participants. One of these MABCIs described in the chapter is Ringing minds a BCI art piece in which four participants actively co-create a multi-modal performance. The participants each wear one active electrode placed near Cz, as well as a reference electrode at the left mastoid. The signals are in accumulation viewed as a 'hyper-brain'. Besides detection of ERPs, the EEG data is processed to multivariate principal oscillation patterns (POPs or eigenmodes), which, simply put, reflect communal synchronicity. A flowchart of this system is displayed in figure B.2a
The EEG data of four performers triggers both changes in music and visuals. The artistic concept is that of the resonating of brainwaves amongst performers causing nature-inspired ripples. Features of the enquired POPs determine spatial positions of different colour splashes. Moreover, resonance found amongst the performers is mapped to a large amount of digital sound resonators. A photo of a performance is found in figure B.2b. Here the four 'brain performers' are seated on the right. Video excerpts of this particular performance can be found on Youtube using **this link** in a digital PDF [87]

EEG KISS

In 2018, Lancel et al. designed EEG KISS [46], another example of a multi-agent brain computer interface. During the performance of EEG KISS, two people kiss while their EEG data is projected on a screen and downward onto them and their surroundings from a projector above. The idea is to explore a novel way of expressing the shared experience of this intimacy. Besides the two people that kiss, a host and an audience of observers are also part of the experience. The set-up of EEG KISS and a picture of a performance can be seen in figure B.3. The EEG waves were also represented in sounds. This sonification was carried out by representing the EEG frequencies in pitch. Performers of the kiss reported that the created soundscape made experience of kissing more intense. Performers, hosts and audience experienced EEG KISS as 'an imaginative, secret portrait of their kisses' [46].



(a) A systematic sketch of a performance set-up. A: E.e.g. headsets, B: Screen/projection, C: Host, 1: Actors kissing, 2: Realtime kissing data, 3: Observers.

(b) A performance at House for Electronic, Basel, 2018

Figure B.3: EEG KISS. From Lancel et al. [46].

The Ascent

The Ascent is a performance driven by the concept of meditation as enlightening, uplifting and elevated. These associations are presented in a literal manner by physically elevating a person in a harness based on their meditative state. This performer is wearing an Emotiv EEG headset and aims to control their state of relaxation such that they will ascend. This BCI application therefore falls under active control, unlike the other discussed applications. The performance also includes lights and sounds based on the measured EEG data of the performer. Unfortunately, the artist has not reported on the workings of the BCI loop or the mappings used for light or sound.

Eunoia II

In 2014, artist Lisa Park created Eunoia II: an artistic BCI installation made-up out of 48 sound amplifiers that are dishes of water. The idea is that the water reflects the mental state of the performer, as the music amplified into the water creates ripples. The installation makes use of the Emotiv EPOC which comes with build-in classifications of mental activeness states: frustration, meditation, boredom, engagement, and excitement. Whilst the amplifiers are continuously playing a sound, its tempo, panning and speed are determined in real-time by the classified mental state.

B.3 Artistic psychological BCIs

Affectively-driven algorithmic composition

In 2010, Wu et al. created a mapping between mind and music [36]. This concept may be referred to as affectively-driven algorithmic composition (AAC). Wu et al. used EEG to measure levels of mental arousal during sleep, defined by wave amplitude and frequencies. These features are mapped to musical parameters, generating a music scores. Morlet wavelet coefficients were calculated to obtain the main frequency, rate of alpha and variance of the EEG signal. The wave amplitude and average energy are also included as features. The average

Figure B.4: A photo a performance of The Ascent. From Duenyas [54].

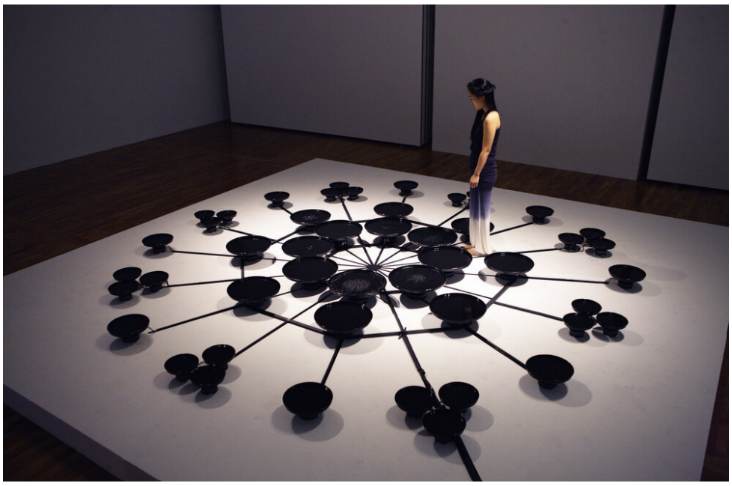


Figure B.5: A photo of Eunoia. From Park [19].

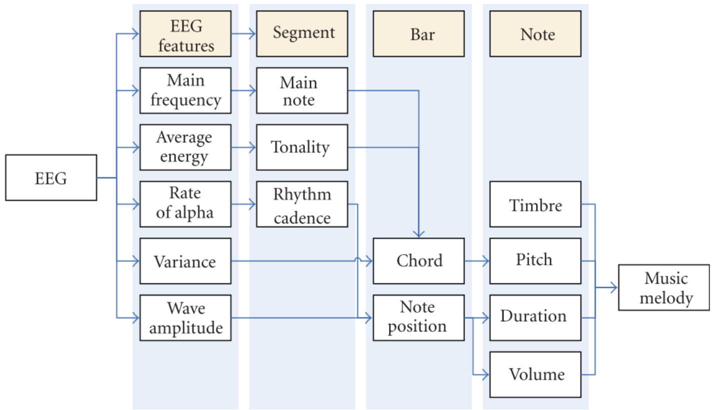


Figure B.6: The mapping system of sonification used by Wu et al.. [36]

EEG frequency determines the main note, whilst the rate of alpha determines the rhythm cadence. These parameters stay the same throughout the generated score, creating a base for melody generation. From the main note, chords for each bar are created based on the variance in the EEG signal. Within each bar, notes are generated with unique timbre, pitch, duration and volume. A short overview of this scheme may be found in figure B.6. A comparable method of AAC has been proposed and evaluated by Daly et al. in 2015 and 2016 [88, 30]. In their evaluation, a correlation was found for each participant between the affective states targeted by the generated music and the affective states reported by the participant. To measure the latter, participants continuously traced their valence and arousal levels by using FEELTRACE, a recording instrument proposed by Cowie and Savvidou [58].

The Space Between Us

The Space Between Us [27] is a live BCMI, created in 2014, and another example of affectively-driven algorithmic composition. However, where the previously described AAC systems were passive BCIs, The Space Between Us is reactive. The generated music is directly used as elicitor of emotional states, creating a looping interaction between music and emotion. The performance includes the music of a pianist, a singer and electronic sounds. The piano and vocal scores, as well as the electronic sounds, are determined in real-time by emotional states decoded from EEG data of the singer and an audience member. The concept relies on successful elicitation of emotional states of the two individuals. Here, valence of emotion is defined as relative asymmetry between the left and right frontal lobes. Before the performance, the correlation between this neurological feature and different pre-composed musical phrases was analysed for individualised calibration. During the performance, measured asymmetry values of the singer and audience member are translated to musical score, corresponding to emotional states. Controllable musical parameters include tempo, dynamics and key. These scores are continuously played by the pianist and singer, and listened to by the audience member.

The Sensorium

Hinterberger [15] designed a BCI installation that aims to display a holistic implicit interpretation of mental states, called the Sensorium 3 (the most recently revised and documented version). The premise of the installation is to provide feedback on neurological and biological signals to enhance awareness of the body and the mind. Participants are placed in an atmospheric space in which multi-coloured lights are projected and ambient music is playing, both affected in real-time by the measured physiological signals. The ambient space and experimental set-up can be seen in figure B.7. The experiment is overseen by a supervisor to set-up the EEG headset

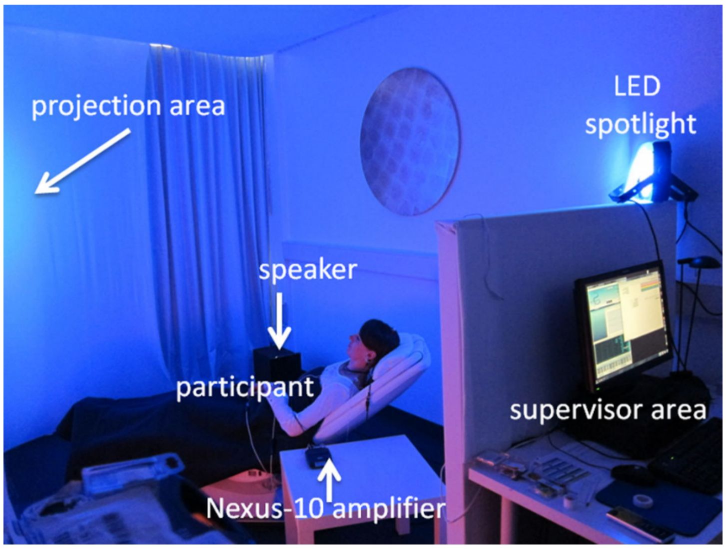


Figure B.7: A photo with descriptions of experimental the set-up of The Sensorium. From Hinterberger. [35]

and experimental setting. The measurement methods include EEG, ECG, skin conductance and respiration. Participants lie down in the Sensorium for twenty minutes and are instructed to simply observe their surroundings and sensations without consciously judging or aiming to manipulate them. The projected colours are determined by different frequency bands. More specifically, the polarity of slow cortical potentials is mapped to a red-blue range and alpha oscillations are reflected in green. Both ECG and EEG signals are subject to sonification. Each of the EEG frequency bands, as well as slow and ultra slow cortical potentials affect the melody of a specific instrument, all within pantatonic harmony. Moreover, heartbeats, which are identified through variance in ECG, are also included in the final part of relaxing sonification.

Moodmixer

In 2011, Leslie and Mullen designed Moodmixer [17], an MABCI that carries out collaborative sonification, making again use of affectively-driven algorithmic composition. Its idea is to adapt the outputted music in real-time to match the mental states of the two users. A schematic of the set-up is visualised in figure B.8. Spectral powers of the commonly defined frequency bands are measured for the users. Relatively high alpha power in the frontal lobe is interpreted as a relaxed mental state and relatively high beta power in the frontal lobe is interpreted as focus. Subsequently, potential mental states are divided into four categories depending on high/low focus and high/low relaxation (referred to as 4-way panel curve). These four states are represented both in soundscape and visuals. Firstly, each state corresponds to one of spatial corner of four-channel surround sound system (audio tracks). Secondly, in a similar manner, each state is matched to a colour that can be amplified in an otherwise static projection (visual gradients). The four weights are determined by the predominance of a corresponding mental state and translated into volume (audio tracks) and colour intensity (visual gradients). Moreover, the users have control of a held cursor that they can move over the projected colour screen to illuminate the area surrounding their cursor. The use of this manual cursor is to communicate their self-observed mental state through the same mapping scheme. Users can trigger short events such as drum beats and light flashes by eye blinking. The technical execution of mapping pre-processed signals to these visual and auditory outputs is carried out using MaxMSP [86].

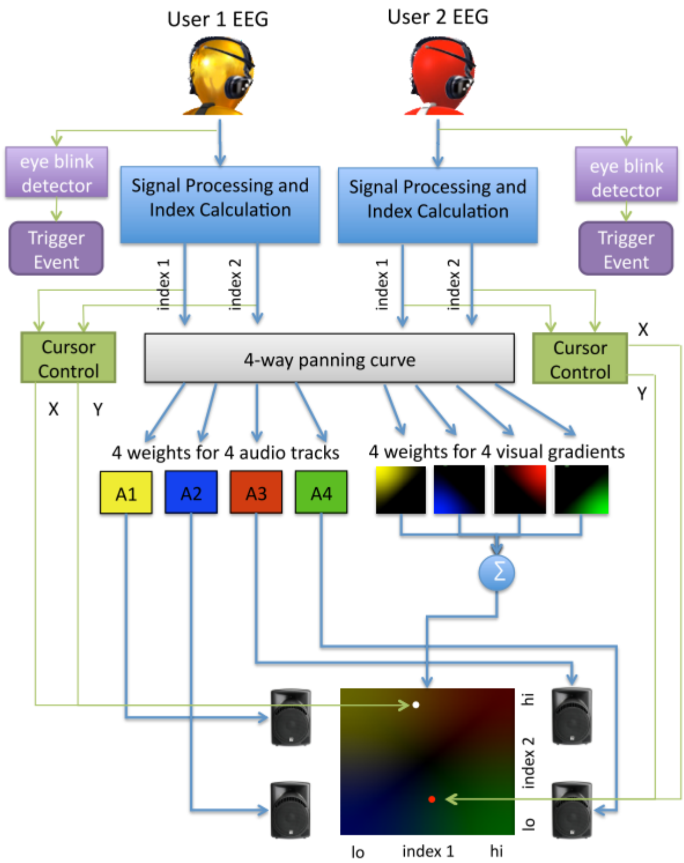


Figure B.8: A diagram of the technical set-up of Moodmixer. From Leslie and Mullen [17].

Brainlight

Brainlight [49] is simple APBCI consisting of a brain sculpted of Plexiglas, with neuron-like shapes and connections, as can be seen in figure B.9. A person wears an EEG headset and from there, the data is translated into power spectral densities for the alpha, beta and theta bands. The brain sculpture lights up in colours according to the measured PSDs, where higher relative powers result in higher saturation and intensity of the corresponding colour.

The Mutual Wave Machine

Dikker et al. [48] are exploring a different psychological concept through BCI technology: connectedness. Their aim is to find out how connection between two people can be analysed, quantified and amplified using a reactive BCI. The Mutual Wave Machine is a BCI installation that looks like an intimate capsule in which two people sit across from each other, see figure B.10. Audiovisual projections inside the capsule represent the amount of connection between two people found from their brainwaves. Patterns in sound and lights become more coherent and vivid when more synchronisation is found. The projected patterns opposite of a user advance into an image of them as the noisy patterns increasingly clear up. Conversely, the visuals become darker, less coherent and less pleasant with less synchronisation. Audio is a translation of activation in the brain of both individuals, varying volume and pitch. Synchronization between two people is defined as real-time correlation of power in frequency bands. What the experience in The Mutual Wave Machine looks like can best be understood from a video from Suzanne Dikker, which may be found by clicking **this link** in digital PDF format.

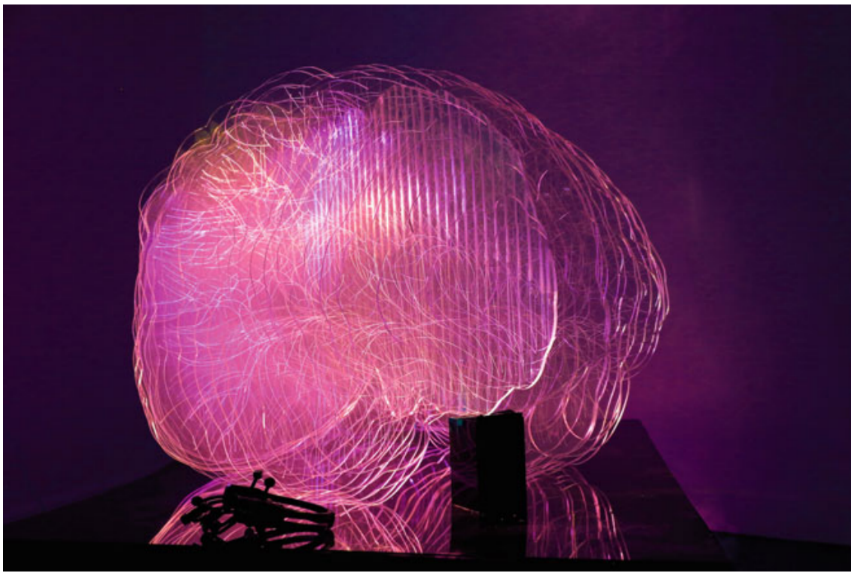


Figure B.9: A picture of Brainlight. From Jade et al. [49]

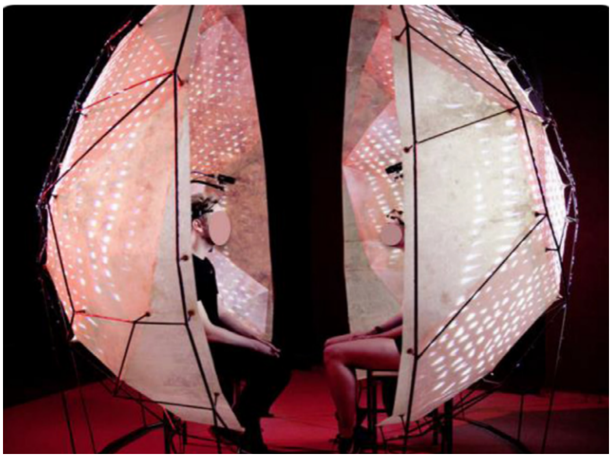


Figure B.10: A photo of the Mutual Wave Machine. From Dikker et al. [57]

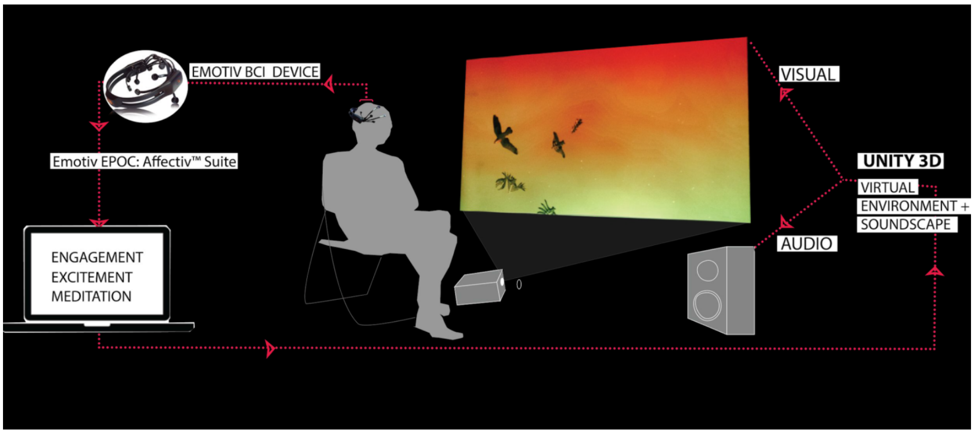


Figure B.11: A photo of STATE.SCAPE. From Prpa [38].

STATE.SCAPE

STATE.SCAPE [38] is a BCI installation designed in 2015 where users sit in front of a screen on which changing visuals are projected, based on their real-time acquired EEG data. The screen shows a flock of birds, whose behaviour is determined by the brain activity of the user. The conceptual idea of the design is that the birds represent thoughts that can now be observed and escape freely, to help people let go of any unpleasant thoughts of sensations such as anxiety or stress. During the experience, the user is left alone in an intimate dark space, without prior instructions. Prpa made use of the software of the Emotiv EPOC that directly outputs mental states, specifically the levels of meditation, engagement and excitement. The level of excitement is represented by the number of birds, the level of meditation by slowness of flying and the level of activeness by the flying height. Furthermore, the predominance of the three states was also mapped to volume levels of three audio tracks in a soundscape. Here, a deep droning bass track is controlled by meditation, a mid-high frequency instrumental track by engagement and ambient percussive track by excitement. Figure B.11 shows the set-up of all components of STATE.SCAPE.

You Are the Ocean

You Are the Ocean [16] is a BCI installation from 2019 that similarly involves a set-up with a user in front of a large screen with a projected simulation. In this case, the installation can also be used by multiple people at the same time. A video of a simulated ocean is playing of which the roughness is constantly changed by the mental activeness measured in the EEG data of the user. A more meditative state is renders a still ocean with a clear sky and only gentle sounds of waves, whereas high levels of activeness and attentions result in a stormy scene with high waves, clouds, louder storm sounds and in the extreme case thunder. A photo of a participant using the installation can be found in figure B.12.

Figure B.12: A photo of You Are the Ocean. From Samanci and Caniglia [16].

C AUDIO EXPLANATION

//// silence in explanation track

Welcome in the MIND YOURSELF experience
Please take some time now to lie comfortably. You can place your pillow wherever you like and even lie under the blanket if you prefer. You will lie down for the duration of the experience, which is approximately 10 minutes. If the volume of the sound is too high or too low, please say so out loud. During the experience you can at any time let the researcher know if the volume is too high or low or if you are feeling uncomfortable in any other way. If you are ready, let the researcher know that you are okay and comfortable by saying 'yes' or 'ja' out loud.
The MIND YOURSELF experience will now start. While you are lying down, I will explain something about your brain and this installation.
//
The sounds and music you hear and the lights and colours you are seeing, are controlled by your brain. So, no one else is going to see and hear what you are perceiving right now, because no two minds are the same. But how can a brain control things?
Your thoughts, memories, perceptions, body control and emotions are all processed in your brain. Maybe you knew, or maybe you didn't know, but a brain is basically a collection of billions of cells. In order to think, feel, remember, move, these cells constantly communicate with one another, so that you can function. Whenever two brain cells communicate, they create a very small electrical signal.
//
This means that everything that happens in your brain, corresponds to a pattern of electrical signals, brain waves. Your brain waves look very different when you're sleeping or when you are going for a run. Likewise, sadness and happiness, relaxation, and stress, eye blinks, body movements, all correspond to different patterns of brain waves.
//
The device that you are wearing on your head right now is measuring these electrical signals. The computer is analysing the incoming brain waves constantly. From these, we can make an estimation of how you are feeling. This is constantly affecting the music and sound and the colours of the lights you see around you. So, in a way, you are now inside your own mind.
///
Take a minute to observe what is happening around you. And think about if it is anything like how you are feeling right now.
///
There is no right or wrong music or colour.
///
The MIND YOURSELF experience is designed, not so that you can become instantly happier or more relaxed, or so that you can compose music with your mind. The goal is for you to get a different perspective on your own mind and brain, by crawling inside it. So that you might become more interested in your own brain and mind, or even understand yourself a little bit better.
///

So, observe your surroundings, and observe how you feel, but don’t judge anything.
/////
You will lie here for a few more minutes.
///////////
This is the end of the MIND YOURSELF experience. Please get up slowly and the researcher will open the curtains

D INVITATION FOR EXPERIMENT

MIND YOURSELF – Graduation Project Experiment

18 – 31 November

You can sign up here for participation in a unique experience.

mind yourself

UNIVERSITY OF TWENTE.

Miriam Riefel

As part of my graduation project, I have created an installation called MIND YOURSELF. You can crawl inside your own brain by lying comfortably inside a small dome. The lights and sounds you hear and see around you, reflect how you are feeling at the moment. They are controlled by electrical currents from your own brain, using EEG technology.

The experiment takes approximately 45 minutes. This also includes set-up, questionnaires, and debriefing. There will be a drink and snack.

You can sign up via Google Forms by scanning the QR code. →

E INFORMATION BROCHURE OF EXPERIMENT

Information brochure

Interactive Brain-Computer Interface experience: MIND YOURSELF

As graduation project for the master Interaction Technology at the University of Twente, I am designing MIND YOURSELF: a brain-computer-interface experience that can be used for anyone to get a new perspective on what is going on in their own mind. To use MIND YOURSELF, you wear an EEG headset that is set-up with assistance and then lie down inside the tent-like construction for approximately 10 minutes. EEG is a method to measure brain activity through electric activity. The headset is a headband with buds with electrodes inside that lightly press against your skin but should not be uncomfortable. Whilst lying inside MIND YOURSELF, you will see colourful lights and hear sounds and music which should reflect how you are feeling at the moment based on the measured EEG data.

You should not participate if you are prone to epileptic seizures.

The goals of the current test are to evaluate to what extent

- the installation accurately reflects the mental state of the user
- the user enjoys the experience
- the user feels like they have gained understanding of their mind.

If you are taking place in the user test, you will be experiencing MIND YOURSELF as described above. Whilst lying inside the construction, you will continuously hear music/sounds and see many lights that continuously change in colour and brightness. You may hear instructions to help you relax or to think about something. Your EEG signal is measured and processed continuously and will affect the sounds and lights in real-time. In addition, you will fill in questionnaires before and after the experience. This will consist of questions where you can self-report how you are feeling, as well how you experienced certain aspects of the installation. The answers to the questionnaires as well as the EEG data are collected and used as results for my thesis. Your data is anonymous and will be erased after completion of the research.

Participation is completely voluntary, and you can terminate your participation at any moment without explaining the reason. You can easily take off your EEG headset at any time without warning and go out of the installation. You may also say that you would like to stop and then I can immediately help you to get out and take off the headset. You can also contact me within 24 hours after participation if you would like to erase your data immediately. It will then not be used in the research.

Feel free to contact me or my supervisor for any additional questions.

Miriam Riefel
Raadhuisstraat 12-200
+316 37302045
m.h.riefel@student.utwente.nl

Supervisor
Dr. Mannes Poel
+31534893920
m.poel@utwente.nl

You can email the ethics committee for complaints or independent advice.
ethicscommittee-cis@utwente.nl

F QUESTIONNAIRE CONDUCTED BEFORE THE MIND YOURSELF EXPERIENCE

Screening

Please answer the screening question before continuing with the experiment

Do you think you may be prone to epileptic seizures?

- No
- Yes

Message before Self-Reflection

In the questions below, please move the slider to indicate how much you agree with each statement

Self-Reflection

I don't often think about my thoughts

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I rarely spend time in self-reflection

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I frequently examine my feelings

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

I don't really think about why I behave in the way that I do

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

I frequently take time to reflect on my thoughts

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

I often think about the way I feel about things

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

I am not really interested in analyzing my behavior

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

It is important for me to evaluate the things that I do

	Strongly disagree			Strongly agree	
1	2	3	4	5	6

I am very interested in examining what I think about

Strongly disagree				Strongly agree	
1	2	3	4	5	6

It is important to me to try to understand what my feelings mean

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I have a definite need to understand the way that my mind works

Strongly disagree				Strongly agree	
1	2	3	4	5	6

It is important to me to be able to understand how my thoughts arise

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I am usually aware of my thoughts

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I'm often confused about the way that I really feel about things

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I usually have a very clear idea about why I've behaved in a certain way

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I'm often aware that I'm having a feeling, but I often don't quite know what it is

Strongly disagree				Strongly agree	
1	2	3	4	5	6

My behavior often puzzles me

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Thinking about my thoughts makes me more confused

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Often I find it difficult to make sense of the way I feel about things

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I usually know why I feel the way I do

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Current sensations

Please indicate your agreement with the following statements about yourself by moving the scale

Please indicate your agreement with the following statements about yourself by moving the scale

Please describe your current physical sensation by moving the slider

Narrow						Wide	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Weak						intensive	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Tense						Relaxed	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Uncomfertable						Comfertable	I don't know
-3	-2	-1	0	1	2	3	

Uncomfertable					Comfertable		I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Powerless					Empowered		I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your emotional condition by moving the slider

Activated						Calm	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Unbalanced					Balanced		I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Sad						Happy	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Unsatisfied						Satisfied	I don't know
-3	-2	-1	0	1	2	3	☐

Unsatisfied Satisfied I don't know -3 -2 -1 0 1 2 3

Please describe your current emotional condition by moving the slider

Anchorless						Secure	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Dissociated						Connected	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current mental state by moving the slider

Confused						Clear	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current mental state by moving the slider

Introverted						Extraverted	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current mental state by moving the slider

Empty					Satisfied		I don't know
-3	-2	-1	0	1	2	3	☐

G QUESTIONNAIRE CONDUCTED AFTER THE MIND YOURSELF EXPERIENCE

Current sensations

Please describe your current physical sensation by moving the slider

Narrow						Wide	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Weak						intensive	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Tense						Relaxed	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Uncomfertable						Comfertable	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current physical sensation by moving the slider

Powerless					Empowered		I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your emotional condition by moving the slider

Activated						Calm	I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Unbalanced					Balanced		I don't know
-3	-2	-1	0	1	2	3	☐

Please describe your current emotional condition by moving the slider

Sad						Happy	I don't know
-3	-2	-1	0	1	2	3	☐

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Unsatisfied					Satisfied		I don't know
-3	-2	-1	0	1	2	3	☐

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Please describe your current mental state by moving the slider

Empty						Satisfied	I don't know
-3	-2	-1	0	1	2	3	☐

Message before Self-Reflection

In the questions below, please move the slider to indicate how much you agree with each statement

Self-Reflection

I don't often think about my thoughts

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I rarely spend time in self-reflection

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I frequently examine my feelings

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I don't really think about why I behave in the way that I do

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I frequently take time to reflect on my thoughts

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I often think about the way I feel about things

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I am not really interested in analyzing my behavior

Strongly disagree				Strongly agree	
1	2	3	4	5	6

It is important for me to evaluate the things that I do

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I am very interested in examining what I think about

Strongly disagree				Strongly agree	
1	2	3	4	5	6

It is important to me to try to understand what my feelings mean

Strongly disagree				Strongly agree	
1	2	3	4	5	6

I have a definite need to understand the way that my mind works

Strongly disagree Strongly agree

Strongly disagree Strongly agree

1 2 3 4 5 6

1 2 3 4 5 6

It is important to me to be able to understand how my thoughts arise

Strongly disagree Strongly agree

1 2 3 4 5 6

I am usually aware of my thoughts

Strongly disagree Strongly agree

1 2 3 4 5 6

I'm often confused about the way that I really feel about things

Strongly disagree Strongly agree

1 2 3 4 5 6

I usually have a very clear idea about why I've behaved in a certain way

Strongly disagree Strongly agree

1 2 3 4 5 6

I'm often aware that I'm having a feeling, but I often don't quite know what it is

Strongly disagree Strongly agree

1 2 3 4 5 6

My behavior often puzzles me

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Thinking about my thoughts makes me more confused

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Often I find it difficult to make sense of the way I feel about things

Strongly disagree				Strongly agree	
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I usually know why I feel the way I do

Strongly disagree				Strongly agree	
1	2	3	4	5	6

Opinion of experience

Please give your feedback about the MIND YOURSELF experience inside the installation by answering the following questions.

Please describe the experience by moving the sliders

Ordinary			Extraordinary
0	1	2	3

Tiring			Vitalizing
0	1	2	3

Demotivating			Motivating
0	1	2	3

Too short			Too long
0	1	2	3

Could you notice a connection between yourself and the audiovisual perceptions?

Not at all			Clearly
0	1	2	3

In your own words, please describe what you thought of the music/soundscape you heard during the experience.

In your own words, please describe what you thought of the visuals you saw during the experience.

In your own words, please describe what you thought of the experience in general.

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H FREE-TEXT ANSWERS TO THE POST-EXPERIENCE QUESTIONNAIRE

Experimental condition **Control condition**

In your own words, please describe what you thought of the music/soundscape you heard during the experience.

- ethereal, although I'm not sure I had any impact on it.
- It was calming, but I didn't notice it changing while the lights changed a lot more. Which made it feel like it was not corresponding to my mind
- The music was generally relaxing, sometimes i felt like it struck a chord inside of me but those moments were quite short
- i noticed the music less than the lights, but in general it was just kind of relaxing to hear the sound all the time, also to hear someone talking was nice background sound
- it sounded like some low screeching but was very satisfying at the same time
- I didn't feel the music respond to me until at the end of the experiment when the lights didn't change. The visuals were overpowering.
- It reminded me of the music from Simcity 4; especially when designing landscapes. Very serene, calm with also a hint of the wideness and intensity of nature
- It was very relaxing but I am not sure to what extent it was connected to my thoughts and emotions. I felt mostly relaxed during the experience, but I was also reflecting on some things in my life that make me uncomfortable and the music didn't change much then.
- I did noticed some difference and was amused by the sounds that peaked sometimes. And the changes in between the different moods were also depicted.
- Initially it was calm. I tried to think about things that make me agitated to see if it will change, while the music did change I could not really map it to the emotion i was feeling. But the music would change depending on my thought process
- i really had the feeling that i could really feel it going a bit faster when i thought about something stressful or something which made me less comfortable and the other way around which increased the way i was feeling that was very interesting. At one point I however did not focus on it anymore and it became a nice background sound
- The music was very calming and relaxing. However, sometimes it changed without my mental state changing
- The music was nice and relaxing
- -

- I was amazed by it. It also made me really curious what activity in my brain triggered certain sounds. The soundscape really made me feel connected and emerged me into the experience.

- I wonder what the colors mean

- It was surprisingly pleasing, in that the transitions were not so abrupt and it was gentle. The music looping was also seamless when it seemed to move from 1 state to another. Overall great!

- I was aware it was there, sometimes I noticed it, but most of the time I don't think I was consciously aware of it. It felt like a river I was floating on, very soothing, but I'm not sure I have a conscious thought about it.

- Calming music, relatively consistent and the same, didnt really experience a change

- Werkte goed om te kunnen ontspannen

- It was very relaxing and calmed down my mind. At certain moments, I felt strongly inspired and sometimes my mind wondered off. Also, I really tried to understand the connection between my mood/thoughts and the music I heard.

- Overall, it was quite relaxing, but I didn't really see a connection with my own thoughts or feelings.

- The sound is sometimes calming and sometimes thrilling.

- Very calming, it helped me with focussing on my thoughts, and on the music itself

- reminded me of spa or sauna music, but i didnt notice any influence of my thoughts on the music

- There was a nice variety in the sounds. Not all were mediative waves etc, and were interesting enough to engage me and allow me to feel like there was some connection between what I was thinking and what I was hearing. They were very pleasantly sounding, and could harmonize with one another to almost create something melodic. This often made me feel good. The meditative soundscape in the background (apart from all the sound effects) was nice as well as it allowed me to stay somewhat focused on what I was thinking and take control of my responses. However, it continuously led me back to a "calmer" state of mind than what I sometimes tried to achieve, hence, resulting in the same sounds again and again

- I cound't really place the sound, but I did perceive a connection between what the light colors meant; Red - relaxed, blue - movement (eyes, breathing), green - imagination/thought

- Deep and mysterious, at some points I feel flow in the space.

- Very relaxing. The music helped me wander of in my thoughts.

- The music and lights were very nice, I liked how everything flowed together. It was quite interesting to realize this combination came from my own brainwaves.

- Relaxing, ambient, could have been a little more present, sometimes when i got distracted by the lights I didnt notice it was there

- it was quite chill, and i liked the upbeat parts. I didnt really notice how my thoughts influenced the sounds all the time and was confused how the music came to be from a methodological point.

- it was meditative and relaxing. Appropriate for contemplating upon something.

- abstract, unclear what it means, but correlated to my thoughts somehow

- Generally quite relaxing

In your own words, please describe what you thought of the visuals you saw during the experience.

- It was funny to see that when I thought about the alphabet, the colour changed when i said D and F to yellow and blue respectively.

- In the beginning the lights changed a lot, but later on the color pattern stayed in the same kind of colors which I believe matched my thoughts and emotions quite well. The lights were placed in a non symmetrical pattern which I found confusing.

- Mostly blue&green tones which I usually associate with calm, sometimes there were sparks of yellow but I didn't feel such change as something I enacted consciously

- the lights were very nice, i was trying to figure out what they meant as the experiment went on, but i could not really decipher it instantly. I also tried to keep them the same/change them by f.e. blinking which was nice to play around with.

- it was often blue, orange and green, it was satisfying to look at but didn’t exactly make sense to me

- I could feel as if I was able to control the colours. At one point I noticed that if I liked a colour it came up more often and I tried playing around with that, seeing if I could make other colours appear or blink.

- I mostly saw pink ,with sometimes hints of white. For me, it symbolized the intensity of my feelings, with pink being more relaxed and white experiencing more intense emotions like happiness/love, worry/sadness

- I don't think the visuals changed that much during the experience, e.g. the lightning of the LEDs stayed mostly the same also the frequency in the change of the light intensity stayed mostly the same, however, perhaps my own emotional stayed mostly the same as well?

- Sometimes they were instantly switching, which did not really aligned with my constant feelings at that time, however for neutral relaxed thoughts they were relatively accurate.

- Depending on my thoughts the color changed, but the color change was not consistent. The color for when I tried to feel different things sometimes was the same.

- The visuals were nice to look at sometimes the changing of it felt a bit random but on other times it really changed when I changed thought so that was cool. Furthermore just really nice to look at and follow the lights.

- The visuals are nice. Although I didn't really like the orange colour and the green was very bright.

- The visuals were simple but satisfactory. Sometimes the lights were annoying because of their brightness when they became white

- The lights were nice, a bit like a night sky with more colors. I was very intrested in trying to change them by trying to conder a specific feeling or though.
- I thought the visuals were beautiful and it worked well with the soundscape. It made me feel a bit nostalgic and I wanted to connect the colours with certain memories.
- Colorful
- I could see the changes in that when I was more relaxed (without external thoughts arising), lights changed to green and also the music became slower and less diverse. Maybe reflecting a calmer state.
- Calming visuals, slowly changing, could tell the difference when i relaxed my thoughts vs when i would focus to see if the visuals would change. Also found it interesting that my eyes started blurring the lights pretty quickly
- Was fijn icm de muziek. Maar ik weet niet zeker of ik in de veranderingen verband zag met mijn gedachten. Al helpte het samen wel om beter te ontspannen
- Amazing. At some point I almost felt like the lights were part of me. Most often there were purplely pink or icy blue colours, and it at least felt to me like the blue ones were related to my more analytic thoughts, the purple ones to my more emotional phases. When I was calm the lights were very steady. I had a few moments of anxiety/nervousness, and when those happened the lights flashed a lot, once or twice even turning yellow.
- Again, very relaxing and inspiring at the same time. I noticed that my lights were often pink and blue and I really wondered why this was the case. One time it was orange and I am still not sure why this was the case. This all made me curious and wanted to try to understand my own mind better.
- Again, quite relaxing but no clear connection with my thoughts and feelings.
- They made me confused. I had a difficult time to locate this confusion. Sometimes, they made me calm but thrilled at the same time.
- A little more distracting, each time the color changed I started thinking about what happened that caused them to change
- was a little too bright for my eyes. was a little random, but when letting the focus a little loose, it was enjoyable
- The visuals were intense but not overwhelming. Certain colors of the lights instigated certain emotions in me that (I don't think) are associated with that color, especially when flashing occurred. This was nice because it sort of took me on a tour of the possibilities at first and "showed me" which colors and effects are tied with each emotion/thought. Generally, like with the soundscape, it seemed the visuals tried to imply a sense of calm, hence, reaching the same visuals. But this was only towards the end and was not an issue at all.

- the visuals where smoothing and relaxing, but did provide feedback to where my mind was wondering to

- the visuals where smoothing and relaxing, but did provide feedback to where my mind was wondering to

- Relaxing as well. It was nice to look at

- I tried to think of some thoughts and breathe differently to test what the installation would do. I thought that the pink/white lights represented relaxation, and blue and green meant more activation within the brain. But I did find it hard to say for sure. I tried to put my finger on the sound combinations too but I found that harder to reason about than the lights because different sounds overlapped each other. But the lights and sounds did look/sound really nice.

- Cool, flashy, stimulating

- Very cool, i feel like i got the gist of which feelings/thoughts called to specific colours.

- mesmerising patterns of lights which could be used to meditate or contemplate upon something.

- abstract, unclear what it means, but correlated to my thoughts somehow

- The flickering and red/magenta lights were a little annoying to look at. The green and blue lights were more soothing

In your own words, please describe what you thought of the experience in general.

- It was nice, although im not sure if responsive behaviour is beneficial for meditation. It felt more like a playground for your mind. (which is also fun!)
- It was a calming experience and I found it very interesting to see how the lights changed, however I found it difficult to control my mind into a state such that the lights changed.
- It was a positive experience, more relaxing than exciting. I would like to try in a different context, such as right after physical activity to see how the stress influences both the sounds and the lights.
- i thought in general the experiment was just very relaxing, i dont feel that i have a better understanding of my brain that much, because i didnt really know how to interpret the sounds and lights, but it felt very nice and comfortable to lay down and take in the surroundings of the experiment.
- it was fun, was mostly zoning out and listening to the music, kinda relaxing how i was in my mind without having any distractions.
- The experience was really great. It was something unique and didn't feel like an experiment. It felt more like introspection.
- It was very relaxing to lie down and very intense to almost stand still and examine the work process that is your brain and how busy it is every second of every day. I don't usually realize that all these processes are happening and it's even touching to think that all those cells are working together to keep you alive and going.
- I liked it a lot, it was very relaxing and I would like to have stayed longer. I feel more focused and more awake now.
- It was a really cool experience and I could imagine to do again. It helps to relax and to step into your own mind.
- It was overall a good experience. It was fun to see the colors change when I try to think about random things, More than the sound, I actively concentrated on the lights.
- Cool experience which I would defenitely do again.
- Very relaxing
- I thought the experience was relaxing, because I got to comfortably lay down and listen to relaxed music. Looking at the lights, listening to the music and thinking about how I am feeling also helped me distract from stressing topics. It also makes me curious about how the experience would be like if I was in a different state of mind, because the music & visuals stayed the same a lot

- Weird but nice. It made me reflect on a lot that has happend and stimulated me to figure myself out even more. I did expect more visual change but I kept getting red and white lights.

- It thought the experience was extraordinary and amazing. It was really mindful, a step back from your busy life of everyday and it helped you relax in a sort of cocoon. I also really saw the analogy for the brain when the voice over said, you can see it as being inside your brain, I thought "wauw". It was beautiful.

- nice way to take some time to feel and think about my own brain more deeply

- I really liked it, I think I could see the entire spectrum of my feelings but maybe some others might be stuck in 1 state and unable to switch. It seemed like a responsive system.

- Enjoyable and calming experience, kind of like a (slightly guided) meditation, but i did not experience any extra insights into my mind

- Een fijne manier om te mediteren, bewust te worden van je gedachten en gevoelens

- Transcendental? I felt very disconnected from the universe, like me and the lights were all that was. At the time that was a very good feeling. I found the experience amazing at the time, and very interesting to look back on.

- Again, very relaxing and inspiring. I really liked the design of the tent which was making me feel comfortable, like in my own little bubble. And I liked the soundscape and lights very much. Very calming. I did not really feel the connection between my thoughts/mind and the experience so this leaves me with a curious feeling and need for exploring more. I could be in the tent for hours I think. So all in all, great experience!

- Pretty nice and relaxing. Almost meditation like.

- It was an exciting but confusing experience. I couldn't locate my thoughts and couldn't name my feelings most of the time.

- I really enjoyed it, I enjoyed trying to figure out what caused the music and lights to change.

- The intention is interesting, but I did not learn anything about myself. I think the user needs more information about what the infuence of thoughts is on the visual and sound effects. Plus a point to take into account is that the positive effects on i.e. calmnes might be due to lying down relaxing rather than of the visuals or sounds

- "The experience was very nice. I thoroughly enjoyed this feedback loop between what I saw, what I thought, and what was displayed.

- The visuals definitely had some tie into what I thought and I could ""choose"" which colors I wanted to see by feeling different emotions. Furthermore, the sound effects were very pleasant as they tied into one another and, like I said, could harmonize and make some sort of melody. Though I did not figure out how to control those, but they generally seemed to go with the emotion that I was feeling and color that was being displayed.

- Overall, this was a very mind-opening experience. I feel calmer and more in touch with my thoughts. Having this feedback feels incredibly empowering, like you don't just have to think of your thoughts alone in your head, you can have ""something"" that helps guide you through it. It is different than a person, as this is a direct response to what you think, rather than a different view on it. "

- I really enjoyed the relaxation of the experience, and the suttle feedback it gave towards where my mind was wondering off to. I would prefer a bit softer matras but it would defenitly enjoy it as a meditation aid

- I would like to do it at my own space as a meditation, leads me to do sefl-reflection. calm myself down and clear the messy thoughts, think about the direction and the way I will go

- Nice to take part in and very relaxing.

- Very special! It made me less relaxed than I was before I went into the tent, but that was because I got very curious as to how it worked exactly. I'm curious to read about it in your thesis!

- Relaxing, it felt really good to just take 10 minutes out of my day to meditate in there

- It was very nice, gave me some time to experiment with how thoughts were visualized and i got to make a schedule for the rest of the week which made me less stressed so that was nice. I was just starting to really relax at the end of it, so it was sad it ended because i totally could have napped.

- Unique and fun

- relaxing, interesting, but I didn't feel like I understand what was the point. I feel that if the light and sound would be similar but random and not correlated to thoughts, the experience would b similar

- Interesting idea, though I couldn't really see the connection. It felt rather the other way around; that the lights and music were influencing how I was feeling.