René Weber, BSc

A Neuroadaptive Virtual Environment for Arachnophobia Treatment

Master's Thesis

to achieve the university degree of

Master of Science

Master's degree programme: Biomedical Engineering

submitted to

Graz University of Technology

Supervisor

Assoc.Prof. Mag.rer.nat. Dr.phil. Selina Christin Wriessnegger

Institute of Neural Engineering
Head: Prof. Dr. Gernot R. Müller-Putz

Graz, February 2024

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master's thesis.

21.02.2024

Date

Signature

Acknowledgments

I wish to show my gratitude to my professor and supervisor, Selina Wriessnegger, who supported me throughout my whole master thesis. I also want to thank all the participants and friends who took part in the experiment, although some of them have to overcome their spider fear for the VR confrontation with a spider. Additionally, I am also very grateful for the mental and financial support of my whole family over the last few years as a student. Specially, my brother Michael gave me a lot of support and motivational speeches during the whole thesis.

Abstract

An alternative therapy form for treating phobic patients to overcome their specific phobia is the usage of virtual reality exposure therapy (VRET), where the patients are only confronted virtually to their specific fear. In this study, a neuroadaptive virtual environment was generated for the treatment of people with arachnophobia, the fear of spiders. Since it is known from the literature that especially emotions of fear are generally processed in the right frontal hemisphere of the brain, the frontal alpha asymmetry (FAA) index of the frontal EEG channels and the heart rate (HR) were used to automatically detect the fear level of the participant during the VR spider confrontation and decide if the fear stimulus should be increased, decreased, or stay the same for the next upcoming exposure to the fearful stimulus. Therefore, EEG and HR measurements from a pretest, consisting of a relaxed and spider fear VR scenario, was taken to train a support vector machine (SVM) classifier for the neuroadaptive VR spider exposure experiment. Participants without a fear of spider were also invited to act as a control group. The results of the pretest revealed that the spider fear group experienced a shift of the alpha asymmetry index values to more positive values during the spider confrontation for the channel pairs $F3/F4$ and $F7/F8$, and therefore, a higher activity in the left frontal cortex. For the control group there was a decrease of $F3/F4$ and $F7/F8$ FAA index values from the relaxed to the spider VR scenario. Based on these findings a main experiment was performed where participants additionally report subjectively their fear level to estimate the accuracy of the classifier. The classifier had an accuracy rate of 65.71% for the control group and an rate of 50% for the spider fear group. Overall, the study showed that the classifier was not perfectly able the determine the current fear rate of the participant, but it was at least over the chance level. The study showed that by considering the FAA index value, the VRET can be improved in such a way that the VR environment is automatically adapted according to the individual fear level.

Keywords— Virtual Reality Exposure Therapy, Arachnophobia, passive BCI, Frontal Alpha Asymmetry, emotional lateralization

Zusammenfassung

Eine alternative Therapieform zur Behandlung phobischer Patienten zur Überwindung ihrer spezifischen Phobie ist der Einsatz der Virtual-Reality-Expositionstherapie (VRET), bei der die Patienten nur virtuell mit seiner spezifischen Angst konfrontiert wird. In dieser Studie wurde eine neuroadaptive virtuelle Umgebung für die Behandlung von Menschen mit Arachnophobie, der Angst vor Spinnen, erstellt. Da aus der Literatur bekannt ist, dass insbesondere Angstemotionen im Allgemeinen in der rechten vorderen Gehirnhälfte verarbeitet werden, wurde der frontale Alpha Asymmetrie Index der frontalen EEG Kanäle und die Herzrate verwendet, um das Angstniveau während der VR Spinnen Konfrontation automatisch zu erkennen und um zu entscheiden, ob der Angstreiz für die nächste bevorstehende Stimulus Exposition erhöht, verringert, oder gleich bleiben soll. Daher wurden EEG und HR Messungen aus einem Vortest, der aus einem entspannten VR-Szenario und einem Spinnenangst-VR-Szenario bestand, herangezogen, um einen Support-Vector-Machine (SVM) Klassifizier für das neuroadaptive VR-Spinnenexpositions-Experiment zu trainieren. Um auch eine Vergleichsgruppe zu haben, wurden auch Teilnehmer ohne Angst vor Spinnen als Kontrollgruppe eingeladen. Die Ergebnisse des Vortests zeigten, dass die Spinnenangstgruppe während der Spinnenkonfrontation für die Kanalpaare $F3/F4$ und $F7/F8$ eine Verschiebung der Alpha-Asymmetrie-Indexwerte zu positiveren Werten und damit eine höhere Aktivität im linken Frontalkortex erfuhren. Für die Kontrollgruppe gab es einen Rückgang der F3/F4- und F7/F8-FAA-Indexwerte zu negativeren Werten vom entspannten zum Spider-VR-Szenario. Basierend auf diesen Erkenntnissen wurde ein Hauptexperiment durchgeführt, bei dem die Teilnehmer zusätzlich subjektiv ihr Angstniveau angaben, um die Genauigkeit des Klassifikators abzuschätzen. Der Klassifikator hatte eine Genauigkeitsrate von 65,71% für die Kontrollgruppe und eine Genauigkeit von 50% für die Spinnenangstgruppe. Insgesamt zeigte die Studie, dass der Klassifizierer nicht perfekt in der Lage war, die aktuelle Angstrate der Teilnehmer zu bestimmen, sie lag aber zumindest über dem Zufallsniveau. Die Studie zeigte, dass durch die Berücksichtigung des FAA-Indexwerts die VRET so verbessert werden kann, dass sich die VR-Umgebung automatisch an das individuelle Angstniveau anpasst.

Schlüsselwörter— Virtual Reality Exposure Therapy, Arachnophobia, passive BCI, Frontal Alpha Asymmetry, emotional lateralization

Contents

1 Introduction

1.1 Prevalence, Symptoms and Treatment of Arachnophobia

One of the most specific phobias across the general world population is the fear of spiders, or also called arachnophobia. According to Schmitt and Müri (2009), the prevalence is about $3.5 - 6.1\%$, and there is a higher proportion of women having this phobia. People with arachnophobia are getting the typical panic attack symptoms during the confrontation with a spider or a spider related environment, like a room with spider webs or cellar rooms. These typical symptoms are increased heart rate (HR), sweating, faster breathing, feel disgusted or experience a flight instinct. It is thought that most of the affected people develop their arachnophobia during the period of childhood and adolescence. Arachnophobia can have a severe impact on the daily live, such as the avoidance to do outdoor activities or entering a cellar room. The main treatment for arachnophobia is the standard exposure therapy (Albakri et al., 2022). In this therapy, people with arachnophobia are first confronted with their fear by pictorial representation of spiders in form of images and videos of spiders. At the point where the patient feels comfortable enough, a real interference with a living spider is arranged, where the patient tries to minimize the distance to the spider as much as possible and may also try touching the spider. An alternative, fast developing therapy is virtual reality exposure therapy (VRET), where the phobic person gets in contact with their phobia in a virtual reality (VR) environment. The VR environment is a computer-generated, three-dimensional reality which gives users the feeling of being present in a realistic, virtual environment by presenting it on so-called VR glasses, like a head-mounted display (HMD). A feeling of presence is simulated due to real-time adaption of the environment according to the position of the user's head, regulation of sound sources, and sometimes the interaction of VR objects with hand trackers. Beside the main VR usage market, the entertainment industry, it is also becoming more and more popular in the medicine market (Safikhani, Pirker, and Wriessnegger, 2021). VR is already used as a learning and skill improvement tool for medicine students and doctors, and as a therapy form for rehabilitation therapy and mental therapy, like the VRET. In contrast to the standard exposure therapy, VRET has the advantage of avoiding a more dangerous and stressful real phobic situation, which is often more pleasant for the patients. It has the additional advantage to evoke a more realistic and immersive feeling compared to pictorial 2D stimulus material used in the first stage of standard exposure therapy, and therefore, patients perceive a phobic feeling more related to their real fear. Besides from that, therapists have a higher control level of the stimulus level, and therefore, can provide a more individualized therapy. It also reduces the therapy costs by eliminating the need to get a real spider, and giving the possibility for practicing a telemedicine approach, where the patient is doing the therapy from home and the therapist just analyze the results. One of the smaller disadvantages which comes up with VRET, is that some people develop a motion sickness during a VR session, where they feel eye fatigue, disorientation, and nausea (Chang, Kim, and Yoo, 2020). This motion sickness, also called VR-sickness, is caused through a conflict in the sensory system of the VR user, where the perceived orientation and self-motion is in disagreement with the user's expectation. Nevertheless, several studies (Carl et al., 2019) arguing that VRET is at least as effective as the standard exposure therapy.

1.2 EEG

Electroencephalogram (EEG) is a non-invasive, harmless measurement method to measure the electrical activity coming from the neurons of the brain. Therefore, electrodes are placed on the scalp to detect the sum potentials evoked by a synchronized synaptic activity of a nearby neuron population. Generally, the EEG signal reflects the postsynaptic potentials which arises from excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs). During an EPSP, neurotransmitters binding on the receptors of the postsynaptic neuron, causing an inflow of positively charged ions, and this depolarization triggers an action potential. The extracellular space becomes more negative, which will be measured by the EEG electrode. On the other side, IPSPs causing a hyperpolarization of the postsynaptic neuron due the influx of negatively charged ions into the postsynaptic neuron, and therefore, the extracellular space becomes more positive. Since the EEG signal represents the cyclic activity of these neurons, it is built up of different frequency components. Different cognitive states are reflected by specific frequencies, and the magnitude of these frequency components tell us which brain areas are active at the current time point.

1.2.1 Frontal Alpha Asymmetry

It is known from several studies (J. Wang and M. Wang, 2021) that EEG signals are strongly influenced by emotions, and therefore, can also be used for emotional recognition. In comparison with other physiological measurements for emotional classification, EEG has in general a high classification accuracy and a fast reaction time to emotional changes. In general, emotions, like happiness and sadness, are mainly processed in the frontal cortex of the brain (Houssein, Hammad, and Ali, 2022). Further studies (Mouri, Valderrama, and Camorlinga, 2023) have also shown a lateralization effect in processing of positive, for example happiness, or negative emotions, such as sadness. One of the first researchers, which introduced the hemispheric lateralization during emotional processing and the frontal alpha asymmetry (FAA) index, was Richard J. Davidson. In one of his studies (Davidson and Tomarken, 1989), they were able to distinguish two contrary emotions like happiness and disgust in participants, who were confronted with visual stimuli in form of short film clips. Their findings were that positive emotions evoke a left hemisphere frontal (LHF) activation and negative emotions a right hemisphere frontal (RHF) activation. Two widely used theory models are used as explanation: the valence model and the approach-withdrawal model. The former model says that generally, all positive related emotions activate the left frontal hemisphere and all negative related emotions the right frontal hemisphere of the brain. In contrast, the approach-withdrawal model concentrates more on the motivational direction than on the emotional valence score. More specifically, emotions which cause an approach motivation will evoke a LHF activation and emotions causing a withdrawal attempt will evoke a opposite RHF activation. The main difference between these two models can be observed by looking to emotions like anger (Harmon-Jones, 2003). According to the valence model the emotion of anger is clearly a negative related valence, and therefore, assumed to induce RHF activation. However, as Harmon-Jones and Allen (1998) have shown, anger induces a LHF activation. This is more in agreement with the approach-withdrawal model since an angry emotion can be accomplished by the feeling of needing to approach. Nevertheless, for the emotion of fear both models assume the same outcome, a RHF activation. For assessing the frontal lateralization during emotional stimulation, neuroscientists use the FAA index, which compares the frontal lateral activation in the alpha band ($8 - 13$Hz). This index factor helps to distinguish between different emotions and is a good indicator of how strong a certain emotion is present in the brain of the participant. It is obtained by extracting the alpha spectral power of two counter electrodes, like $F3$ and $F4$, and subtracting the natural logarithm of the left alpha power from the natural logarithm of the right alpha power. A positive resulting index will indicate a higher LHF activation, caused by the higher right alpha power and the consideration that the higher RHF alpha spectral band power is negatively correlated with brain activity. Consequently, a negative index is related with a higher left alpha power, and therefore, a higher RHF activation. Taking this in mind, the emotion of fear is expected to raise a negative FAA index due to the assumption of a higher RHF activation. Looking into the literature, the first FAA studies were done by confronting the experiment participants with emotional loaded pictures (Wiedemann et al., 1999), especially by usage of the International Affective Picture System (IAPS) image dataset, or with short movie clips (G. Zhao et al., 2018), which should elicit specific emotions. Afterward, some studies also focused on the question, if the FAA index could reflect the feeling of fear, and if it was different between anxious and non-anxious participants.

Davidson, Marshall, et al. (2000) reported the FAA index of participants with social phobia during preparation of a public speech in front of a group of 24 students and compared the values with a non-phobic control group. Much higher, negative FAA index values were found at the social phobic group, which confirmed the expectation of an increase in the RHF activation, and therefore, that the anxious group can be distinguished through the FAA index from the non-anxious group during the anxious situation.

Rabe et al. (2008) wanted to investigate if the effect of a cognitive behavioral therapy (CBT) is also visible on the change of the FAA index value. Therefore, 35 traumatized persons which had experience a severe motor vehicle accident, were invited to this study. 17 out of them received a cognitive behavior therapy and the rest was the wait-list control group. EEG was measured before and after the 3 month therapy. At the pretreatment measurement, both groups had the same increased RHF activation during the confrontation of trauma-related pictures, but at the post-treatment measurement, only the CBT group showed a reduction of this RHF activation during the confrontation. They interpreted their results as evidence that the FAA index can be used to evaluate the success level of therapy.

1.3 Virtual Reality Exposure Therapy Studies with usage of EEG

Some few studies have already expanded the VRET by integrating EEG measurements. This is supposed to give a more accurate image of the participant's fear level, since it is a physiological measurement and has a unique pattern for the emotion of fear, which can be used for fear detection. By using a physiological measurement, the therapist receives a better picture of the participant's fear level, since no dependency on the subjective assessment of the patient exists, which can be incorrect due to a wrong self-assessment from the patient. Other physiological measurements which are used for study fear are the heart rate (HR) and heart rate variability (HRV), the galvanic skin resistance (GSR), the diameter of the pupils, the electrocardiogram (ECG), the electromyogram (EMG), the fear-potentiated startle reflex, the blood volume pressure, or the skin temperature.

Basbasse et al. (2022), for example, used a mobile EEG setup to measure the FAA index values during a virtual walk across a plank on a skyscraper, which was around 80 stories up the ground. Therefore, they had placed a real wooden plank in the experiment room. Their 80 participants had different levels of acrophobia. As a neutral compare condition, the participants had to do a plank walk at ground level. Beside the EEG asymmetry measurement, they also took subjective fear measurements, ranging from 1 (no fearful) to 10 (extreme fearful), to see any correlation between the subjective rating and the FAA index. Furthermore, the traditional IAPS task was also performed for comparing it against the VR plank task. In the IAPS task, participants had to watch selected fearful and neutral pictures. The expectation of this study was that there would be a higher activation in the right frontal cortex in both tasks during the negative, fear condition. And additionally, that there would be a higher activation for the VR task, since a more realistic fear situation should also cause a higher level of frontal lateral asymmetry in the alpha frequency band. Their findings showed that only in the VR task the $F3/F4$ FAA index was significant more negative for the fear condition, whereas the ISAP task evoked a more positive FAA index for the negative condition compared with the neural condition. They also observed that the subjective fear rating was positively correlated with a more negative FAA index during the negative VR condition.

Kisker et al. (2021) created a physical replica of a cave and used the VR experience to evoke a feeling of fear by displaying a gloomy environment with a corpse laying around in one edge, or a werewolf approaching the participants. Additionally, at one point they also played the sound of crying, like in a horror movie. For having a comparison to this so-called "negative VR cave", they also used a control group to experience a "neutral VR cave", where the VR environment was more friendly and the negative fear stimuli were replaced with neutral stimuli, like a tree trunk or an approaching sheep. The participants had to walk through the VR cave to reach the exit. During the experiment, the EEG and HRV were recorded as physiological measurement. Their assumption was that both groups would differ in the evaluation of the FAA index values, and would have a different HRV result, since a decrease in HRV indicates an increase in the stress level. Despite their assumption, they observed no significant difference in the HRV between both groups during pre- and post-exploration phase. Both groups had an equally increase in the HRV, which might come from the fact that both groups were left in uncertainty about what they would find in the cave. This fact can be considered as a stressful situation. Whereas, at the cave exit, the participants might feel a relief followed by a stress decrease. Furthermore, the FAA score of the two groups could only be distinguished from each other in 2 out of 7 cave exploration sections. Namely, after passing the corpse or the tree trunk, and after the werewolf or sheep were approaching them. In both situations the group in the negative VR cave showed a greater left frontal activity, which can be linked to an approach behavior according to the approach-withdrawal model. Whereas, the neutral VR cave group had a higher right frontal activity, indicating withdrawal behavior. The argumentation for this disagreement was that the negative VR cave group might want to find the exit more quickly, and counter-wise the neutral VR cave group had no urge to get to the exit so fast and probably wanted to explore the cave in more detail.

Apicella et al. (2023) also wanted to determine which brain regions and which frequency bands can be used in an EEG recording, to classify different levels of fear of heights. Therefore, they used a VR-App where participants are on a platform in a canyon and experiencing three different height levels by elevation of the lift. From 8 subjects, which participated in this study, the EEG was recorded, and the frequency spectrum was separated into different bands. For classifying the three different height level stimuli from each other, the absolute power of the 5 bands were used as features for different classification algorithms. Their results showed that the best results with the maximum accuracy were reached by using the absolute powers of the frontal brain channels as features. And by looking at the most significant frequency bands for the frontal region, the high-beta and gamma band reached the highest accuracy.

Balan et al. (2019) wanted to estimate the fear level of participants with acrophobia during a VR height exposing game with the use of a deep neural network (DNN) architecture to determine automatically the next height exposing game level in real-time. Therefore, they used the EEG, GSR and HR data from an *in vivo* and VR height exposure pre-session of four participants to train two DNNs.

The first DNN should determine the current fear level in a 2-choice fear scale ("relaxation", "fear") and alternatively also in a 4-choice fear scale ("relaxation", "low fear", "moderate fear", and "high fear"). And the second DNN should then give the next VR height exposure level as an output by feeding it with the first DNN's fear level prediction and the biophysical data of the participant. After training of the DNNs, the participants played the VR game, where the DNNs should automatically adjust the game level according to the recorded, biophysical data. Additionally, to get the accuracy of the first DNN, the participants had to give a self-assessed fear level feedback after each completed level. All in all, they achieved an accuracy rate of 73% for the 2-choice fear level scale and a rate of 42% for the 4-choice fear level scale.

1.4 Passive Brain Computer Interface for Adapting VR

In this study, a passive brain computer interface (BCI) system will be implemented to detect certain fear features out of EEG and HR measurements during a VRET session for arachnophobia, to further automatically adapting the VR environment according to the participant's fear level. In contrast to an active or reactive BCI, where the user tries to actively change their EEG signals or just react to a short introduced stimulus, a passive BCI system uses real-time measurements during the participants executing a task or is just sitting still and experiencing the situation. Therefore, the signals are divided in different frequency bands to observe the band power changes. These band power changes are then used as features for a classifier who can then give feedback or even alternate the interface of the user. Subjects, who participate in this study, are put into a VR basement environment, and confronted with a different amount of VR spiders of various size according to the detected fear level. A support vector machine (SVM) classifier uses the FFA index values of the frontal channels and the HR value as features, to distinguish between relaxed and fear state. Furthermore, to group the participants into a spider fear group and a control group, the Fear of Spider Questionnaire (FSQ) was used as an evaluation tool. The hypothesis is that the spider fear group should show more activity in the right frontal hemisphere, and therefore, a more negative FAA index value, during the VR spider confrontation in comparison to the relaxed scenario, whereas the control group's FAA index value should not differ between the two scenarios. Furthermore, the classifier should be able to detect the correct fear level of the participant by using the FAA index values and the HR value as feature. Since it is assumed that the FAA index values are proportional to the amount of participant's fear during the VR spider confrontation, another hypothesis is that the FAA index values of the spider fear group will be more negative with the increase of the spider confrontation level.

2 Methods

2.1 Unity Environment

The VR environment was created in the Unity game engine (Version 2020.3.25f1). For learning how to use Unity (Unity Software Inc., San Francisco, United States) and which features it has to offer, the book from Linowes (2020) was used as learning tool, which offers a general understanding of how the Unity engine works and gives many code strips for self-tryouts. As VR environment, a virtual basement was constructed as a square room with suitable wall textures, taken from the Unity Asset store packet "18 High Resolution Wall Textures" (A dog's life software, 2016). Since the VR environment should provide two different scenes, a neutral and a fearful spider scene, different wall textures were used. For the neutral scene a bright, facade-like wall texture is used. On the other side, to provide a dirty, cold impression of the room for the fearful scene, the wall texture was a crumbling wall texture, and the floor and ceiling had a concrete texture. Since the VR environment should represent a basement in the underground, a self-created concrete stair leading to the door was also implemented into the scene. Different room objects were downloaded from the Unity Asset Store online, provided by different publisher, and added to the scene, like a shelf (Pixel Games, 2015), a cardboard (PolyWorkshop, 2015), a barrel (Simple Forge, 2017), a pallet (MyNameIsVoo, 2016), a rusty pipe (James Lowart, 2021), a door (Tim H., 2018), chairs (ANRUVAL_3D_MODELS, 2018 and NEKCOM Entertainment, 2014), and some smaller tool objects, which were a shovel (Sergi Nicolás, 2018), a sledge hammer (RRFreelance, 2018), and a fire extinguisher (KrazyFX, 2015). Some room object offered different optional prefab appearance. Like the shelf had a normal and broken prefab, or the barrel had also a rusty prefab. Therefore, two different prefabs from the same object could be used for each scene, but with the corresponding normal or fearful appearance. Figure 2.1 shows the two scenes in comparison. The spider scene also included several spider webs (Figure 2.2), created in the graphics software Blender (Blender Foundation, Amsterdam, Netherlands), and positioned in the edges of the room to increase the participant's feeling of a spider presence. Furthermore, to give the participants a more immersive VR feeling, a first-person character was added to the scene. Denisova and Cairns (2015) have proven that if the VR user experiences the scene from a first-person view, it will be easier to accepting the VR reality. As a VR first-person character the prefab model of the Unity Asset Store package "First Person Lover" (ISBIT GAMES, 2015b and ISBIT GAMES, 2015a) was used, which provides a male and female character with different clothes options (Figure 2.3). The first-person character was positioned sitting on a chair, having the hands on the thighs to imitating the real participant's posture. According to the gender of the participant, the matching, male or female, character was used, whereas the other character was unselected in the Unity editor inspector window to not be visible in the scene. The main camera was positioned where the character's head was, and the head scale was set to a very small value to make it invisible for the user. Additionally, two different types of lights were included to the scene. A point light source for the normal scene and a spot light source for the spider scene. For the spot light a script was attached to the object for a light flickering effect. This script changed the light intensity randomly to different time points. Furthermore, to implement a realistic light bulb, a sphere object was added to the scene with a special material, where the emission was set to active, which made the bulb appearing to emit light.

2.1.1 VR Spider Model

The Unity Asset Store also offered a spider model of a black widow spider ([prism bucket], 2015), which had already attached some animations, like a walking animation or a relax state animation (Figure 2.4). There were some more animations but only these two were used in this project. Additionally, a crawling sound effect for the walking animation, and a clipping sound, played during the relax state animation, were attached to the spider prefab model. These sound effects were taken from Pixabay (2022a) and Pixabay (2022b). For letting the spider really walk along the floor, a walking script was written and attached to the spider prefab model. In this script, a random target position in room was obtained and a vector pointing from the current spider position to the target position was calculated. With the Unity quaternion's functions, the spider was rotated towards the target position, and the new spider position was determined by the function "MoveTowards" by giving the appropriate speed parameter. This script also handled the time points when the walking or relaxing animation was started and for how long it was played. Additional to the walking spiders on the floor, there was also a walking-along-the-wall-spider prefab, which used a different script. The difference to the previous

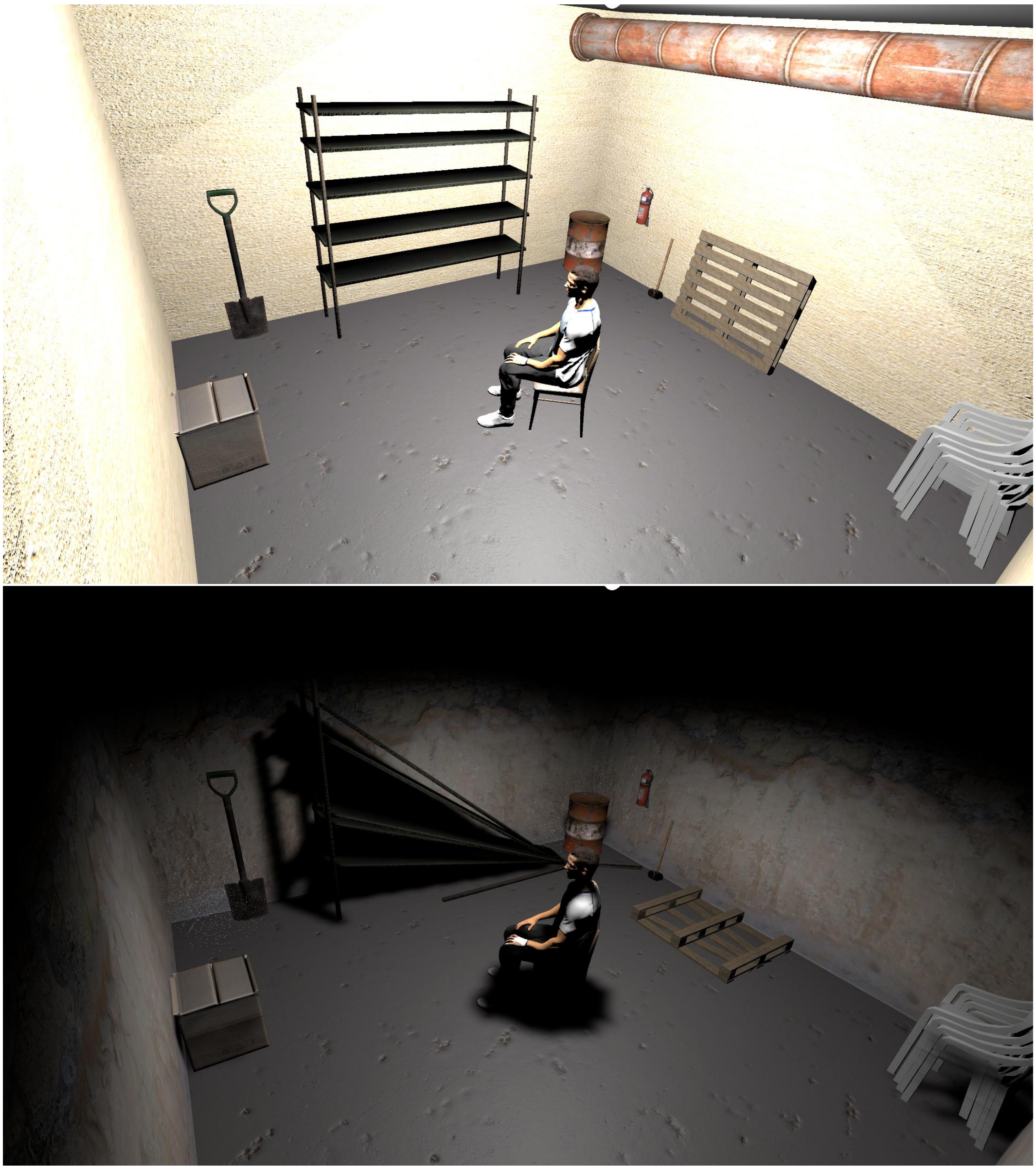


Figure 2.1: The upper picture shows the normal VR environment scene, whereas the bottom picture displays the VR spider scene.

script was that instead of changing the x-coordinate, it was kept constant, but therefore, the y-coordinate was changed according to the target position. Furthermore,

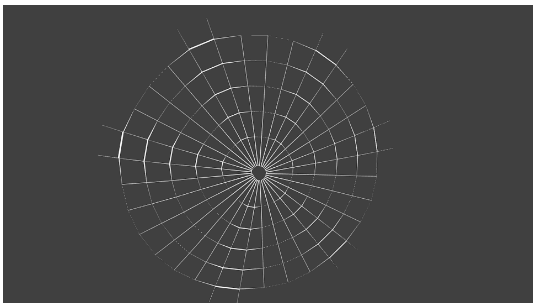


Figure 2.2: The spider web model created in Blender (http://www.blender.org).

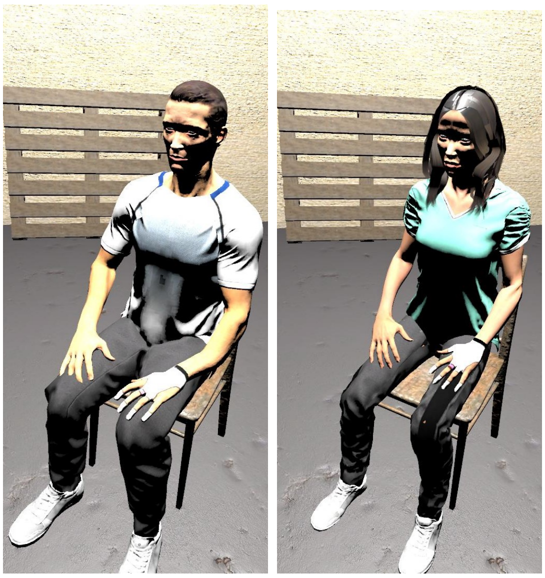


Figure 2.3: Male and female character from ISBIT GAMES (2015a) and ISBIT GAMES (2015b)

the gravity option was disabled in the Unity inspector window to keep the spider on the wall. And as third spider prefab model, the web-net-spider prefab model was generated, where a spider was coming from above the ceiling, hanging on a spider web fade. For this model a kind of rope physics was added by combining two anchor spheres with joint spheres. Each joint had a configurable joint property and a spring property, so that the joints will oscillate back to the principal position after being distracted. One anchor was positioned statically to the ceiling, and on the other anchor the spider was attached in a way that it looked like it was hanging on a spider web fade. The different spider stimuli can be seen in figure 2.5.

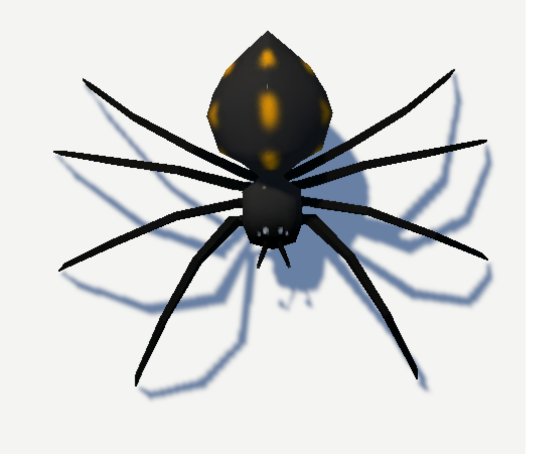


Figure 2.4: VR Spider prefab model of a black widow from [prism bucket] (2015).

2.1.2 Spider Stimulus Regulation

For regulating how much spiders were in the scene and how large their size should be, a script called "GetSpiderEnv" was created which handled this. Therefore, this script was listening to the global variables "TriggerSpiderStimulus", generated in the "GlobalVariablesSpiderScene" script, which themselves were changed whenever the Marker Stream sent a "Increase_Spider_Stimulus" marker or a "Decrease_Spider_Stimulus" marker. Where a "Increase_Spider_Stimulus" marker caused an increase in the number of spiders in the scene and their size by calling the Unity Instantiate function and changing the local scale. And a "Decrease_Spider_Stimulus" marker initiated the opposite effect by calling the Unity Destroy function. The LSL streams were handled by the script "StreamHandlerFunction" attached to an empty object. This script was adapted from the git repository "https://github.com/labstreaminglayer/LSL4Unity" in such a way that it listened to the Marker Stream and changed the global variable "TriggerSpiderStimulus" accordingly.

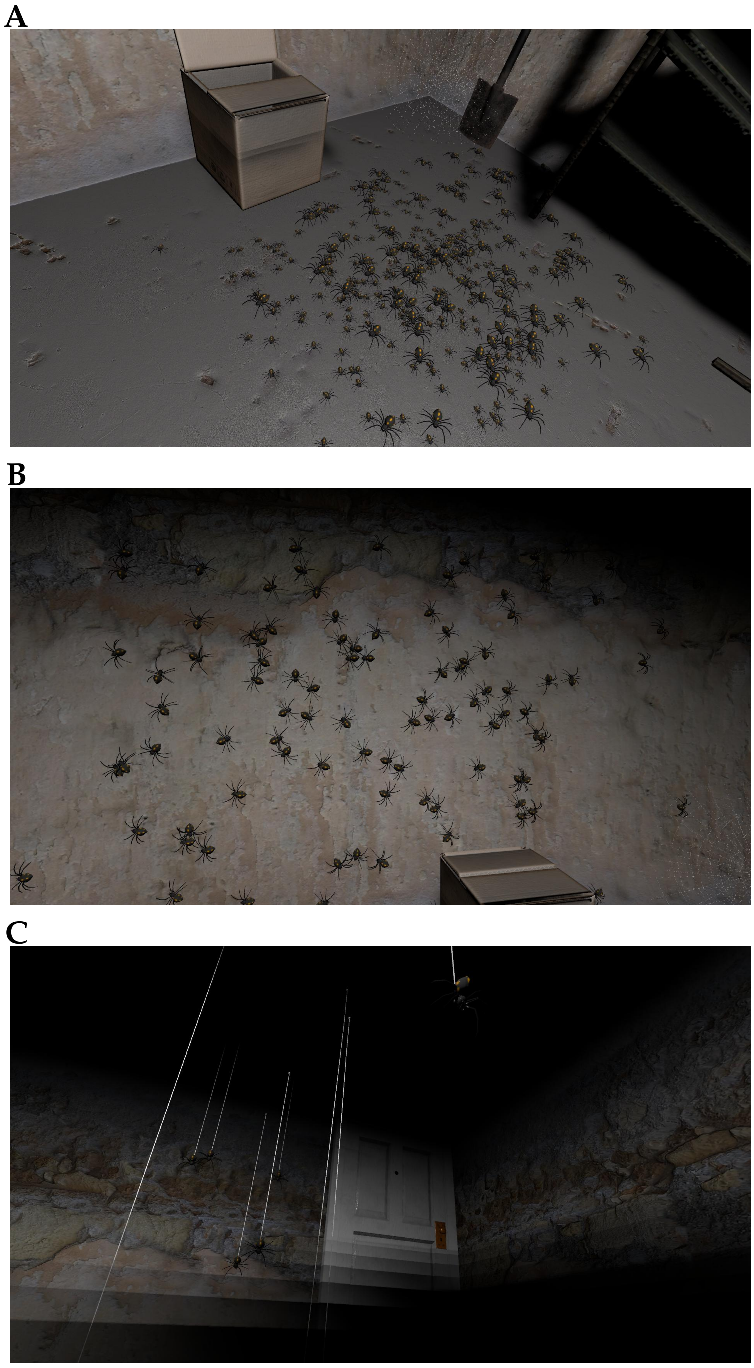


Figure 2.5: The 3 different spider stimulus types. **A**) The walking-spiders-on-the-floor stimulus is displayed. **B**) The walking-along-the-wall-spider stimulus is presented. **C**) The web-net-spider stimulus is displayed.

2.2 Pilotstudy

A pilotstudy with two subjects, who had a moderate spider fear, were performed to find out if there was any difference between the left and right frontal brain hemisphere, and if the FAA index values could be used as features. In this pilotstudy the subjects first performed a pretest, where they were for 90 seconds in the relaxed scenario and then they were confronted for 90 seconds with the spider scenario. The measurement data were then used to compute a frequency spectrum plot and an EEG topomap for both scenarios and both participants. Therefore, the data was bandpass filtered with a Butterworth filter between 1 and 40 Hz, and frequency spectrum was calculated with the Welch method, an alternative approach to calculate the power frequency spectrum. After the pretest, the subjects were gradually exposed to an increasing spider level and after reaching the maximum level, the spider confrontation level decreases again stepwise. During this test, subject gave a subjective fear level feedback, ranking from 1 ("low fear") to 4 ("high fear"). With this measurement data, different classifiers with different parameters were trained and the classifier accuracy was calculated by comparing it to the subjective feedback. According to this, the best classifier was selected for the main experiment.

2.3 Participants

For this study 13 healthy participants took part in the main experiment. One participant was excluded due to huge EEG artifacts. Therefore, a total of 12 participants (1 woman, 11 men) were used to evaluate the measurement results. All of them had normal or corrected-to-normal vision. The demographic survey revealed that the participants had an age range from 24 to 33 years, with a mean age of 28.67 years (SD=2.42). Ten out of them were right-handed and two were left-handed. Before the experiment started, all participants had to read the participant information sheet which included a description of the study in short words, an explanation of the measurement tools, rights of the participants and how the participant's data would be further used. For confirming that the participants had read this information sheet and understood their rights, they had to sign a written informed consent paper.

2.4 Experimental Setup

As head mounted device (HMD) the HP Reverb G2 Omnicept Edition (HP Development Company, California, United States) was used, which had already included several sensors like the HR sensor. Besides, it has two high-quality speakers on both sites of the VR glasses. After the participant arrived at the VR laboratory, the participant's head circumference was measured to find a fitting EEG electrode cap (Easycap GmbH, Worthsee, Germany). For positioning the cap according to the 10-20 system, the distance from nasion to inion, and from one of the preauricular points to the other, was measured to find the position of the Cz electrode. Then the electrode cap was put on the participant's head and adjusted according to this distance measurements. As soon as the cap was positioned right, the LiveAmp amplifier (Brain Products GmbH, Gilching, Germany) was switch on and a Bluetooth connection to the computer was generated. The program "BrainVision Recorders" was started and set to the impedance check mode. For reducing the electrode impedance below $20k\Omega$, the electrodes were filled with electrolyte-gel to generate a good conducting layer between scalp and electrode. Once the electrode impedance was below $20k\Omega$, both the LED on the electrode and the electrode position on the electrodes image on the computer, changed the color form red to green. After all electrodes passed the impedance check, the participants were instructed to produce signal artifacts on purpose to see if all electrodes were setup correctly and to show the participants how different kind of noise signals disturb the target EEG signals. Therefore, they produce EMG and electrooculogram (EOG) artifacts by grinding teeth, blink several times in a sequence, roll their eyes to the left or to the right, and swallowing several times. In the next step, the HMD was put onto the participant and the Unity app was started. The participant was given some time to make them familiar with the VR setting and to look around in the VR environment. Then, the participant was positioned in a way that the looking direction was towards the edge where the VR cardboard and the VR shelf was set, because there the VR spiders will be appearing in the experiment. At that moment, the experiment python script was started, which sends out a LSL Marker stream to mark the exact time points of the experiment paradigm and to communicate to the VR environment in Unity. The EEG signals, HR signal and the LSL event markers were recorded by the software "LabRecorder". During the experiment the participants were asked to avoid the previous demonstrated EEG artifacts as good as possible. Figure 2.6 shows how the whole EEG-VR setup looked like.

Figure 2.6: The experimental setup, with the EEG cap and the HP Reverb G2 Omnicept Edition VR glasses.

2.5 Experimental Design

In figure 2.7 the timeline of the experiment can be seen. First, the State-Trait Anxiety Inventory (STAI) questionnaire should be filled out to specify the general anxiety level of the participant. Then, the Fear of Spider Questionnaire (FSQ), a more specific test about the specific fear of spiders, should be completed by the participant. And the last questionnaire to be filled out was the Brief Mood Introspection Scale (BMIS) to rate the current participant's mood. As a next step, the pretest was carried out to get EEG and HR values for the relaxed and spider stimulated case. After completion of the pretest, a python script was used for determining the FAA index values of the frontal channels and the mean HR. These values were further used for training a SVM classifier which was implemented in the main experiment python script. This script then decided on the latest 30 second measurement data if the VR stimulus should be increased or decreased in the main experiment.

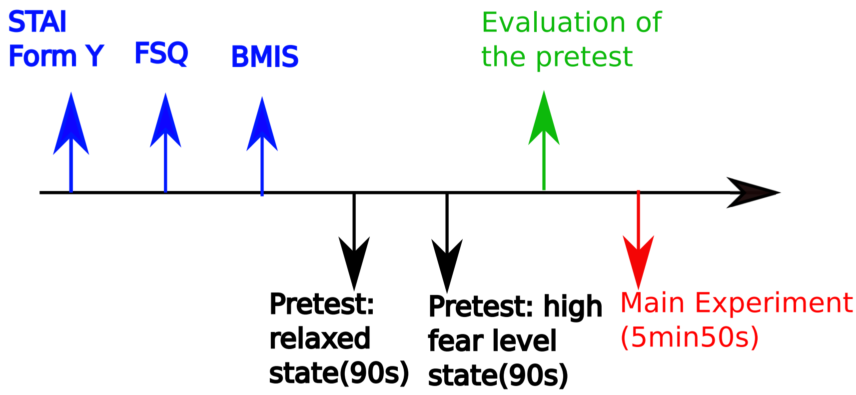


Figure 2.7: The experimental timeline.

2.5.1 Questionnaires

The STAI questionnaire, developed from Spielberger et al. (1983), measured the general anxiety level of a subject. Therefore, it made a distinction between the state anxiety, the anxiety feeling which the subject had at the temporary moment, and the trait anxiety, the anxiety feeling which the subject had in a general, daily basis. It consists of 40 questions in total, 20 questions for each anxiety type, which were rated in a 4 point Likert scale. The score range for each anxiety type ranged from 20 to 80 points. For categorizing the different groups out of this inventory, the general classification (Kayikcioglu et al., 2017) as “no or low anxiety” (20-37 points), “moderate anxiety” (38-44 points), and “high anxiety” (45-80 points) could be used. For assessment of the occurrence of arachnophobia in the participant, the FSQ score were used. This questionnaire was a 7-point scale questionnaire with a total of 18 questions from Szymanski and O'Donohue (1995). For obtaining the FSQ score, all points of the items were added up. The FSQ did not involve a norm score for the phobic and non-phobic group population, but in the study of Cochrane, D. Barnes-Holmes, and Y. Barnes-Holmes (2008) they divided their participants in three groups according to the FSQ score. Therefore, the low-fear group has a score below 33, the mid-fear group has a score between 33 and 50, and a score above 50 was used for the high-fear group. The mid-fear FSQ score was used in this thesis as a cut-off value to categorize the participants in a spider fear group and a control group population, therefore, if the FSQ-score was above 33, the participant was assigned to the spider fear group. The BMIS (Mayer and Gaschke, 1988) is a mood scale test which ask the participant to rate 16 adjectives, describing the mood, in a four-point “Meddis” response scale ranging from "definitely do not feel" to "definitely feel". This scale was useful to see if a specific mood has influence on the measurement results. This test was than subdivide into four subscores: Pleasant-Unpleasant, Arousal-Calm, Positive-Tired, and Negative-Relaxed Mood. Each of these four subscales contained a different set of adjective items. How these subscales were obtained can be read in Mayer and Cavallaro (2019). Furthermore, the overall mood should be scaled at the end of the BMIS at a scale from -10 to 10.

2.5.2 Pretest

In the pretest, the physiological measurements should be taken at two different states, the relaxed state and the high spider fear state. In the relaxed state the VR environment was the normal scene, where no VR spider stimuli were present. The measurement of relaxed state was initiated by the marker "Relax_Phase" and this state lasted for 90 seconds. Then the marker stream sent the "Spider_Scene" marker event, and with this, the scene changed to the fearful scene. After 5 seconds another marker, the "Spider_Stimulus" marker, was sent to Unity, which made the VR spiders appear in all three stimulus types. More precisely, 100 walking spiders on the floor, 100 walking-along-the-wall-spiders and 5 web-net-spiders appeared in the VR environment. All of them were scaled to the largest main level spider scale to evoke the strongest fear response. This high fear state also lasted for 90 seconds, and after that, the marker "End_Measurement" marked the end of the pretest. Then, to process the measured data, the python script "prestudy.py" was executed, which split the data in 30 seconds segments and applied some signal processing steps. At the end, the script calculated the FAA index values for the electrode pairs $F3/F4$, $F7/F8$, $FC5/FC6$, and $FT9/FT10$, and the mean HR for each of the 30 seconds epochs. These values are saved in a python list and finally saved as a "parameter.txt" text file, which contains the features of all 6 epochs.

2.5.3 Main Experiment

A total of five VR stimulus levels were used in the main experiment, where each increasing level was introducing a new amount of spiders of larger size in the VR environment for all three spider stimulus types. A SVM classifier had to determine according to the FAA scores and mean HR value if the VR stimulus level should be increased, decreased, or stay the same. At the beginning of the main experiment, the Unity application was again started. Furthermore, the python script "svm_classify" was executed, which took the features from the "parameter.txt" file and trained the SVM classifier. The SVM model was imported from the package scikit-learn (Pedregosa et al., 2011), a free machine learning library for Python. A polynomial kernel was used as kernel function with a degree of 8. Additionally, to this python script execution, the LabRecorder also was started to record the EEG, HR, and marker stream. In the python script, a "Spider_Scene" marker was sent out to change the VR environment form the normal to the fearful scene. The VR stimulus level 1 was the starting level, where 10 small spiders appeared for both the walking-on-floor-spider and the walking-along-the-wall-spider stimulus type, and 1 web-net-spider was hanging from the ceiling. Now, a loop was implemented with 10 iterations. In one iteration, the program was pulling the last 30 seconds stream data of the EEG and HR measurement. Then a beep tone was introduced to the participant's HDM speakers through the python package module "playsound"(Taylor Marks, 2021), which indicated that the participant should now give a subjective rating of the current fear level by raising the hand with a specific number of raised fingers. Generally, one finger was the sign for "No Fear", two fingers for "Little Fear", three fingers for "Medium/Moderate Fear", and four fingers for "High Fear". These finger signs were preferred over an acoustic message, since any acoustic signal from the participant would have caused high artifacts in the EEG signals. The participant was given 5 seconds for this subjective fear level rating and this rating was noted by the researcher. Then, the python script executed the signal processing steps, calculated the classification features and predicted with these features if the VR stimulus level should be increased, decreased, or not be changed. The desired classifier behavior in response to the user's subjective fear level rating is also displayed in figure 2.8. So, if the user gave a rating of "No Fear" or "Low Fear", the classifier should response with an increase in stimulus. Whereas a "Moderate Fear" or "High Fear" rating should be responded with a decrease in stimulus. If the classifier responds with "Keep Stimulus" then it is also rated as correct if the participant give a "Low Fear" or "Moderate Fear" feedback.

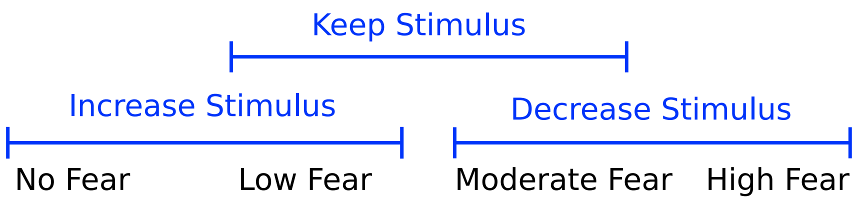


Figure 2.8: The desired classifier response (in blue) in dependency of the subjective fear level rating of the participant (in black).

This prediction depended on the sample distance to the SVM model hyperplane, meaning if the current features were near the pretest relaxed state feature space or the pretest high spider fear level state feature space. Therefore, if the distance function gave back a value below -0.5, meaning the sample features belonging to the relaxed state class, then the VR stimulus level would be increased by sending a "Increase_Stimulus" marker. And if the function returned a value above 0.5, meaning the sample features belonging to the fear state class, then the VR stimulus level would be decreased by sending a "Decrease_Stimulus" marker. A value between the margin of -0.5 and 0.5 would not trigger any marker transmission, and therefore, the stimulus level will stay the same for the next iteration. An increase in the VR stimulus level caused an introduction of a new spider wave, where the VR spider scale was increased by 10%. In contrary, a decrease in the VR stimulus level caused the disappearance of the introduced VR spiders from the previous level. The calculated features and prediction probability values from each iteration were appended in a python list to be saved at the end of the experiment as a text file. After the 10 iterations, the marker stream transmits the "End_Measurement" marker, initiating the end of the main experiment.

2.6 Signal Acquisition

For EEG measurement a 32 active (Ag-AgCl) electrode channel system was used according to the international $10 - 20$ system. Figure 2.9 shows the 32 electrode positions on the cap. As ground electrode the FpZ electrode was used, and the FCz electrode served as reference electrode. The EEG signal has a sampling rate of $500Hz$, and the LiveAmp wireless amplifier (Brain Products GmbH, Gilching, Germany) was amplifying the signal and transmitting it to the laptop with the receiver USB stick via Bluetooth. There the signal was recognized from the software "BrainVision Recorder". In this software there is an impedance view, where the electrode impedance value of each electrode can be observed. Therefore, the electrodes were filled with gel until the electrode impedance was below $20k\Omega$. Furthermore, the software "BrainVisionRDA" converts the EEG signal into an LSL stream, which can then be recorded by the program "LSLRecorder" in a XDF format with all the other streams, like the HR stream and the Marker stream.
The HR signal was directly measured by the VR glasses which had an in-build HR optical sensor via a photoplethysmogram (PPG) sensor (Fig.2.10). This PPG sensor illuminated the skin with light coming from two green light-emitting Diodes (LEDs), and detected the amount of light which was reflected and not absorbed by

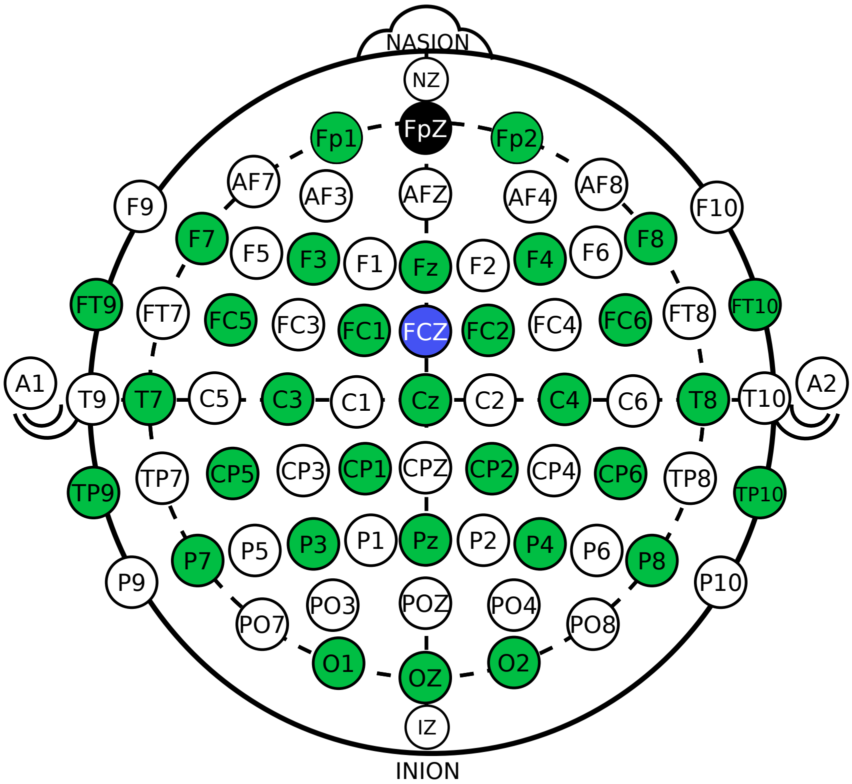


Figure 2.9: The positions of the 32 electrodes on the electrode cap according the 10-20 system. The used electrodes for this study are highlighted in green. The ground electrode is marked in black and the reference electrode in blue.

the bypassing blood via a photodetector (Solé Morillo et al., 2022). Therefore, the PPG signal waveform depicted the pulse wave of the circulatory system. Out of this detected PPG signal, a processing algorithm, which was similar to the algorithm described by Siegel et al., 2021, was applied for calculating the peak to peak interval, and furthermore the HR. The HR was measured automatically every 5 seconds, where it could measure a HR range from 40 to 350 beats-per-minute (bpm).

Figure 2.10: The PPG sensor for HR measurement with the 2 green LEDs and the photo-sensor

2.7 EEG Pre-Processing

The signal pre-processing was proceeded by a python script with the appropriate libraries. First, the training data for the SVM algorithm, which were obtained by the pretest experiment beforehand, were loaded into the script. Then, the SVM was trained to these data to get the best matching decision boundary. Afterward, the streams for the physiological signal streams were read in and the actual EEG signal processing began. The EEG signal processing steps can be seen in figure 2.11. As first step, a bandpass filter (Butterworth filter with order 4) was applied with a high-pass of $40Hz$ and a low-pass of $1Hz$, to avoid aliasing effects and to limit the frequency range. Secondly, a re-referencing was done by calculating the average over all channels and subtracting it of each channel. With help of the Welch method (L. Zhao and He, 2013), the EEG time signal was divided in segments of length $5f_s$ and an overlap of 50%, a Hann window was applied to the segments, and the Fourier Transform of each segment was calculated to get the power frequency spectrum. These spectra were then averaged together to obtain a power frequency spectrum with smoothed out noise artifacts. The last step was to calculate the FAA index value. Therefore, the average power in the alpha band, from $8Hz$ to $13Hz$, for the channels $F3, F4, F7, F8, Fc5, Fc6, FT9$ and $FT10$ was determined. Then, each opposite channel pair was taken, and the natural logarithm of the left spectrum power was subtracted from the natural logarithm of the right spectrum power to obtain the FAA index value. The formula can also be seen in equation 2.1. These values and the average HR were given to the SVM model to predict the fear class.

$$FAA = ln(alpha\ power\ right\ channel) - ln(alpha\ power\ left\ channel) \tag{2.1}$$

Figure 2.11: The EEG signal processing chain. The epoching (organe) was only performed in the pretest, not in the main experiment.

2.8 Data Analysis

For further analysis, specific features of the measurement data and the SVM classification output were used to generate plots. From the pretest, the alpha frequency power of the frontal channels, the FAA index values of the $F3/F4$, $F7/8$, $FC5/FC6$, $FT9/FT10$ electrode pair, and the average HR are saved in a .txt file for both scenarios, relaxed and spider fear scenario. In the main experiment, additional to the features of the pretest, the SVM hyperplane distance value and the current VR spider level are also saved in a .txt file for all 10 epochs. Measurement plots and statistical tests are then performed by the programing language R (R Core Team, Vienna, Austria) in the editor RStudio (RStudio Team, Boston, MA).

2.8.1 Subjective Measures

The mean and the standard deviation for each questionnaire were calculated and written into a table. An independent 2-group t-test was executed for each questionnaire, determining any significant difference between the score distribution of the groups. Aside from that, correlation plots between FSQ score and STAI-S/STAI-T were generated, and a regression line was fitted to the data points.

2.8.2 Pretest Analysis

From the pretest measurement data, FAA index group plots were generated to compare the non-fear group with the fear group. For these plots, a box plot for each group, and for each VR scenario, the relaxed scenario and the spider fear scenario, was generated and put together in one plot. Additionally, the alpha frequency power plots for the the electrode pairs were added on top, to compare the power change between the two scenarios within the group. Beside these FAA index plots, a HR group difference plot was also created in the same style as the FAA index plots. For determining if the observed feature difference between these two groups were significant, an independent 2-group t-test was performed, and a paired Student's t-test to compare the difference of the two scenarios within the group. For seeing any individual feature changes from the relaxed scenario to the spider scenario, appropriate plots with the individual FAA index value and HR value changes for each participant were created. Furthermore, different FAA-FSQ fear rating correlation plots were included to see any correlation between these two values. Therefore, a linear regression line was fitted to the data of each group.

2.8.3 Main Experiment Analysis

In the main experiment, feature development plots over the different VR spider level were generated for the FAA index values and the HR values of the two groups. Therefore, to have some statistically equality, only the first feature values for each VR spider level were taken into account for generating a box plot. Which means that if the participant repeated a VR level twice or more, only the feature values of the first time in this level were used for statistical analysis. A linear regression over the feature mean values and the level index was performed, to receive a regression equation. Individual feature-level development plots for the spider fear group were also added for detection of individual trends over the VR levels. In the end, the accuracy of the SVM classifier for both groups should be calculated by dividing the amount of correctly classified fear levels from the total amount of levels within the group.

3 Results

3.1 Pilotstudy

The frequency spectrum plots for the two pilotstudy participants are shown in figure 3.1 and figure 3.3 respectively. There, participant 1 showed an increased brain activity in the alpha frequency spectrum of the frontal channels from the relaxed to the spider scenario. This can also be seen from the corresponding topoplot in figure 3.2. In the higher frequency bands the difference is not so much visible for participant 1. The frequency spectrum for participant 2, showed a general increase of brain activity in the higher frequency bands for the spider scenario. Especially, the frequency spectrum of the frontal channels has a higher beta frequency activity for the spider scenario. The topoplot of participant 2 in figure 3.4 also shows that the alpha frequency activity decreased from the relaxed scenario to the spider scenario. Additionally, there is more alpha frequency activity on the left frontal side compared with the right frontal side. In the table 3.1 the different FAA index values for the different frontal channels are compared between the two scenarios. For participant 1 only the channel pair $F3/F4$ decrease in a more negative FAA index value from the relax to the spider scenario, whereas for participant 2 the $F3/F4$, $F7/8$, and $FT9/FT10$ FAA index value change to a more negative value for the spider scenario. Table 3.2 compares the accuracy of different SVM classifier kernels applied to the test measurement data of participant 1 and 2. The polynomial kernel with degree 8 reaches the highest accuracy with 80%, therefore for the main test this kernel was finally used for training the SVM classifier.

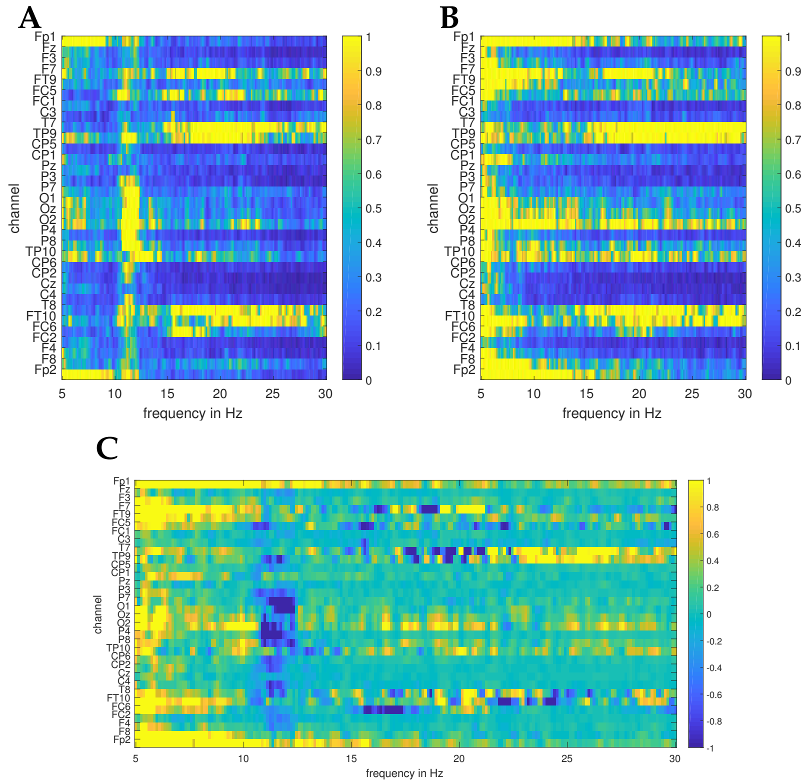


Figure 3.1: Frequency spectrum plot from pilotstudy-testperson 1 for **A**) relax scenario and **B**) spider scenario. **C**) The frequency spectrum plot of the diffence between spider and relax frequency plot is shown.

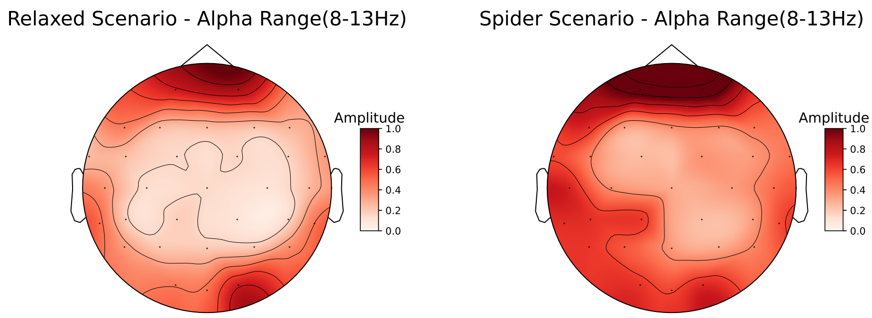


Figure 3.2: Topoplot from pilotstudy-testperson 1 for relax scenario (left) and spider scenario (right).

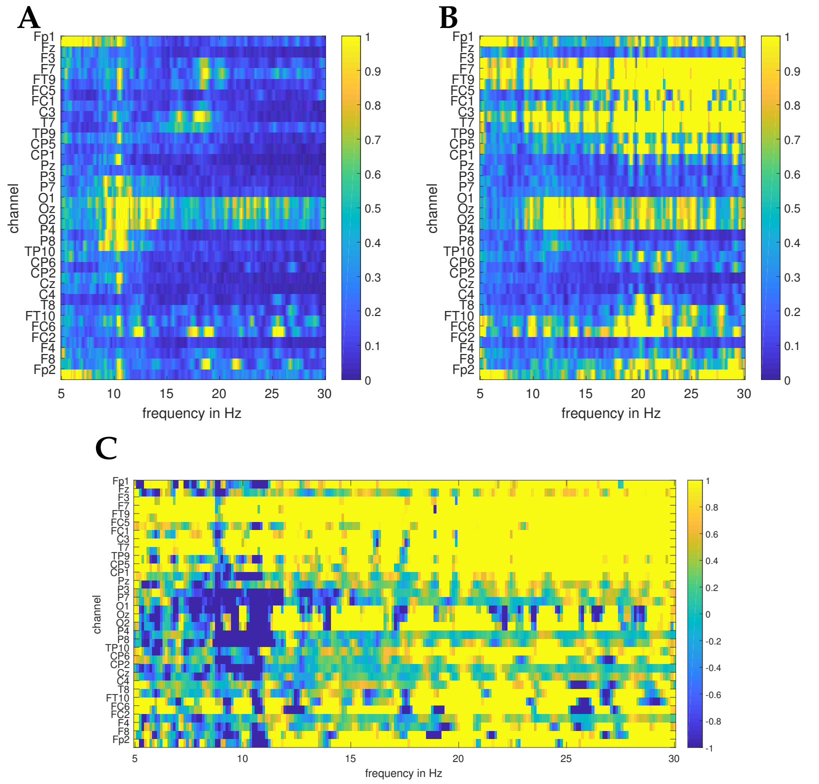


Figure 3.3: Frequency spectrum plot from pilotstudy-testperson 2 for **A**) relax scenario and **B**) spider scenario. **C**) The frequency spectrum plot of the diffence between spider and relax frequency plot is shown.

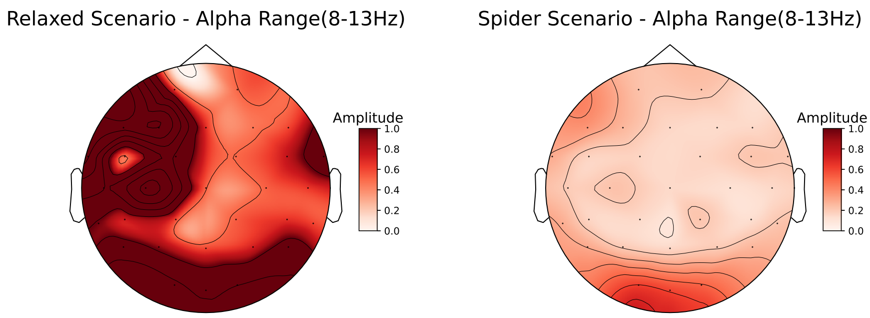


Figure 3.4: Topoplot from pilotstudy-testperson 2 for relax scenario (left) and spider scenario (right).

Table 3.1: FAA index values from the pilotstudy test.

Participant	Channels	FAA in relaxed state	FAA in spider state
1	$F3/F4$	0.04	-0.16
	$F7/F8$	-0.31	-0.20
	$FC5/FC6$	-0.51	-0.31
	$FT9/FT10$	0.37	0.01
2	$F3/F4$	0.15	-2.03
	$F7/F8$	0.16	-1.64
	$FC5/FC6$	1.83	0.56
	$FT9/FT10$	0.45	-1.28

Table 3.2: Classifier accuracy for the pilotstudy.

SVM Classifier Kernel	Mean Accuracy (%)
Linear	70
Poly (degree 1)	25
Poly (degree 2)	25
Poly (degree 3)	70
Poly (degree 4)	75
Poly (degree 5)	70
Poly (degree 6)	70
Poly (degree 7)	70
Poly (degree 8)	80
Poly (degree 9)	75
Poly (degree 10)	75
Sigmoid	30
RBF	30

3.2 Subjective Measures

Table 3.3 shows the mean scores and the corresponding standard deviation for each questionnaire for the control group and the spider fear group separately. Furthermore the results of the group comparisons were indicated by the p-values. There was a significant difference in the STAI questionnaire for the STAI-S test

Table 3.3: Main statistics of the questionnaires for the STAI-S, STAI-T, FSQ and BMIS.

	Non-fear group (n=7) Mean (SD)	Spider-fear group (n=5) Mean (SD)	p
STAI-S	28.14 (6.67)	35.40 (3.36)	0.0347*
STAI-T	34.57 (7.98)	38.20 (2.17)	0.2886
FSQ	21.86 (4.38)	47.40 (5.03)	0.00002**
BMIS Pleasant-Unpleasant	55.14 (4.91)	46.20 (7.69)	0.060
BMIS Arousal-Calm	26.43 (3.26)	28.80 (3.11)	0.234
BMIS Positive-Tired	23.43 (3.55)	19.60 (1.34)	0.031*
BMIS Negative-Relaxed	7.71 (2.06)	12.60 (4.33)	0.064
BMIS Overall Mood	7.43 (1.51)	7.00 (0.71)	0.528

[t=−2.47, df=9.26, p=0.035]. In the STAI-T test there was no significant difference between the two groups [t=−1.15, df=7.19, p=0.289]. Furthermore, the spider fear group had a significantly much higher FSQ score than the control group [t=−9.15, df=7.94, p=0.00002]. The BMIS test showed no significant difference for the subscales Pleasant-Unpleasant [t=2.29, df=6.31, p=0.060], Arousal-Calm [t=−1.28, df=9.02, p=0.234], and Negative-Relaxed [t=−2.34, df=5.30, p=0.064]. Only the subscale Positive-Tired revealed a significant difference between these two groups [t=2.60, df=8.15, p=0.031]. The overall mood value had also no significant difference [t=0.66, df=8.98, p=0.528]. In figure 3.5 the correlation of the FSQ score and the STAI-S/STAI-T score was plotted in a scatter plot, and a regression line was fitted to the data points. The regression equation for the FSQ and STAI-S plot was:

$$FSQ = -6.39 + 1.25 * STAI - S \tag{3.1}$$

The Pearson correlation coefficient of these two variables was $r = 0.585$ [p=0.045]. For FSQ and STAI-T the regression line was:

$$FSQ = 4.84 + 0.77 * STAI - T \tag{3.2}$$

And the Pearson correlation gave a r value of $r = 0.349$ [p=0.266].

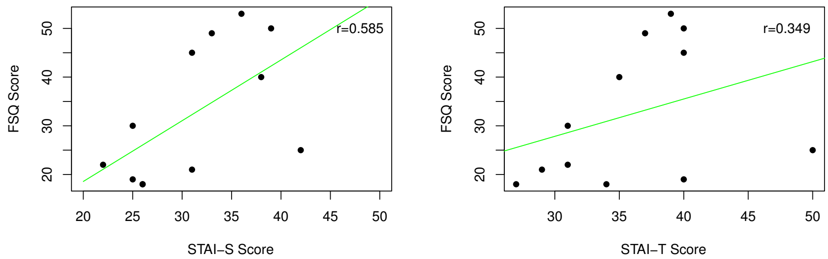
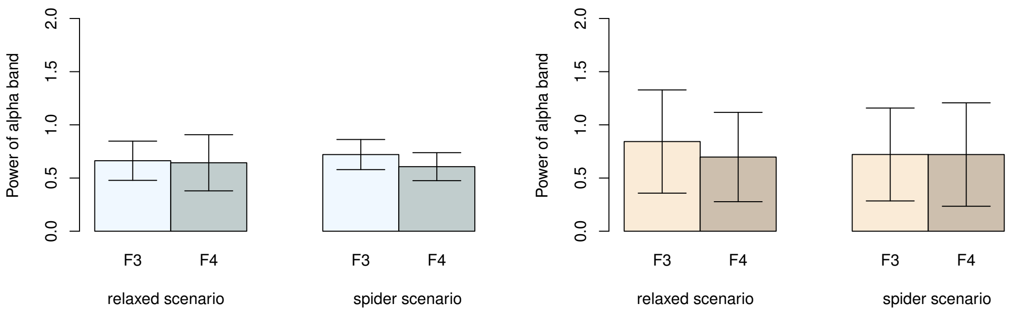


Figure 3.5: Scatter plot of FSQ scale and STAI scale with the corresponding correlation value "r".

3.3 Pretest

Figure 3.6 shows the alpha frequency power for the channels $F3$ and $F4$. For the control group the $F3$ and $F4$ alpha power was nearly the same for both VR scenarios, which gives a mean FAA index value of 0.05 with a range of -0.34 to 0.24 for the normal scenario, and a mean value of -0.06 with a range of -0.42 to 0.17 for the spider scenario. The paired t-test showed a significant difference [t=2.78, df=6, p=0.032] for the control group between these two scenarios. The spider fear group had a little bit higher $F3$ alpha power than $F4$ alpha power in the relaxed scenario resulting in a negative mean FAA index value of -0.21 (range=$[-0.41; -0.02]$). For the spider scenario the alpha $F3$ and $F4$ frequency power was the same for the spider fear group. Therefore, the FAA index value increased for the spider fear group from the relaxed to the spider scenario with a mean FAA index value of 0.04 (range=$[-0.19; 0.14]$). Again, there is no significant difference in the paired t-test [t=-2.17, df=4, p=0.096]. By comparing the $F3/F4$ FAA index values in the relaxed scenario for both groups, there was a statically significant difference between the two groups [t=2.37, df=9.08, p=0.042]. In contrast, comparing the $F3/F4$ FAA index values in the spider fear scenario for both groups showed that there is no significant difference between these two groups [t=-1.00, df=10.00, p=0.342]. Also, the $F7$ alpha frequency power (Fig. 3.7) was rising at the spider scenario for the control group, which was reflected in a more negative FAA index value from the normal scenario with a mean FAA index value of 0.02 (range=$[-0.18; 0.25]$) to the spider scenario with a mean value of -0.15 (range=$[-0.22; 0.01]$). The statistical test showed no significant difference between the two scenarios for the control group [t=2.54, df=6, p=0.044]. For the spider fear group, both alpha frequency channel powers were decreasing in the spider scenario. The mean FAA index value was -0.29, with the values ranging from -0.41 to -0.15 for the normal scenario, and a mean FAA value of -0.22 with ranging values from -0.51 to -0.04. Comparing these two scenarios for the spider fear group with each other showed no significant change [t=-0.97, df=4, p=0.386]. Again, comparing the $F7/F8$ FAA index values in the relaxed scenario for both groups, there was a clear significant difference between the two groups [t=3.38, df=9.95, p=0.007]. However, for the spider fear scenario, there is no significant difference of the $F7/F8$ FAA index values between these groups [t=0.73, df=4.88, p=0.499]. The mean power for $FC5$ and $FC6$ control group channels (Fig. 3.8) were staying the same, with a FAA mean value of 0.07 (range=$[-0.33; 0.50]$) for the normal scene and a mean value of 0.12 (range=$[-0.34; 1.01]$) for the spider scene. No significant difference was revealed by the paired t-test between the scenarios for the $FC5/FC4$ channel FAA index values [t=-0.44, df=6, p=0.678]. For the spider fear group there was a slightly increase for both alpha channel powers at the spider scenario. The spider fear group has a FAA index mean value of 0.32 (range=$[-0.16; 1.08]$) for the normal scene and a FAA index mean value of 0.31 (range=$[-0.40; 1.51]$) for the spider scene. Comparing these two VR scenarios with each other for the $FC5/FC6$ FAA values of the spider fear group gave no significant difference [t=0.04, df=4, p=0.968]. The t-test for the $FC5/FC6$ FAA index values difference between the groups in the relaxed scenario, showed no significant difference [t=-0.98, df=6.03, p=0.364]. For the spider fear scenario, it was the same output [t=-0.46, df=6.10, p=0.662]. At figure 3.9, the mean $FT9$ alpha power was a little bit higher than the $FT10$ power in the relaxed scenario, and for the spider scenario the mean $FT10$ alpha power was a little bit higher for the control group. The FAA mean value was -0.28 (range=$[-1.00; 0.35]$) for the normal scenario and -0.13 (range=$[-0.83; 0.32]$) for the spider scenario. No significant change was revealed by the paired t-test [t=-1.68, df=6, p=0.144]. Furthermore, for the spider fear group the mean $FT9$ alpha power had a little higher value than the counter mean $FT10$ power in the relaxed scenario, which decreased to the same $FT10$ level in the spider scenario. Therefore, the mean FAA index value increased from a mean value of -0.14 (range=$[-0.29; 0.02]$) for the normal scenario to -0.07 (range=$[-0.40; 0.28]$) for the spider scenario. The paired-test showed again no significant difference between the spider fear group's $FT9/FT10$ FAA index values for two VR scenarios [t=-1.09, df=4, p=0.335]. Comparing the statistical difference between the $FT9/FT10$ FAA index values at the relaxed scenario for the two groups, did not show any significant difference [t=-0.73, df=6.93, p=0.490]. There was also no significant difference between the $FT9/FT10$ FAA index values at the spider scenario [t=-0.31, df=9.97, p=0.764]. The HR box plots showed no big difference, comparing both groups and both scenarios. In the relaxed scenario the control group had a mean HR value of 68.00 (range=[45.67; 84.83]) and in the spider scenario a mean HR value of 67.44 (range=[45.94; 84.17]). Furthermore, the paired t-test revealed no significant difference between the HR values of the control group [t=0.40, df=6, p=0.702]. The spider fear group had a mean HR value of 69.16 (range=[53.72; 82.17]) for the normal scenario and a mean value of 69.37 (range=[52.67; 89.11]) for the spider scenario. The paired t-test showed that there is no significant difference between the spider fear group's HR value of the relaxed and spider fear scenario [t=−0.12, df=4, p=0.913]. Comparing the two groups statistically with each other, revealed no significant difference [t=−0.15, df=9.19, p=0.886] of the HR values in the relaxed scenario, and no significant difference [t=−0.23, df=7.22, p=0.827] in the spider fear scenario. The individual FAA index value and HR plots (Fig. 3.11) shows how the feature values change on an individual level for each participant. Four of five participants in the spider fear group had a visible $F3/F4$ FAA index value increase from the relaxed to the spider scenario. There is also an increase in the $F7/F8$ FAA index value for 4 spider group participants. In the individual HR plot, only one spider fear group participants shows an increase of the HR from the relaxed scenario to the spider scenario. There is no clear trend visible in the other plots for the spider fear group. Furthermore, for the control group there is a visible decrease in the $F3/F4$ FAA index value plot for 2 out of 7 participants. Three participants of the control group also had a notable decrease in the $F7/F8$ FAA index value. For the other individual line plots, there is also no trend detectable. Figure 3.12 shows the relationship of FSQ score and the measured FAA index and HR value. The control group had a correlation value of $r = 0.678$ [$p = 0.094$] between $F3/F4$ FAA index value and FSQ score, and the spider fear group had an value of $r = 0.441$ [$p = 0.457$]. Correlation value between $F7/F8$ FAA index value and FSQ score was $r = -0.016$ [$p = 0.972$] for the control group and $r = 0.784$ [$p = 0.116$] for the spider fear group. In the $FC5/FC6$ plot, the correlation value for the control group was $r = -0.100$ [$p = 0.831$] and $r = 0.489$ [$p = 0.403$] for the spider fear group. Furthermore, the control group's correlation between $FT9/FT10$ FAA index value and FSQ score was $r = 0.103$ [$p = 0.826$] and the spider fear group's correlation value was $r = 0.719$ [$p = 0.171$]. And finally, the correlation between The HR value and FSQ score for the control group was $r = -0.071$ [$p = 0.880$], and for the spider fear group it was $r = -0.927$ [$p = 0.023$].



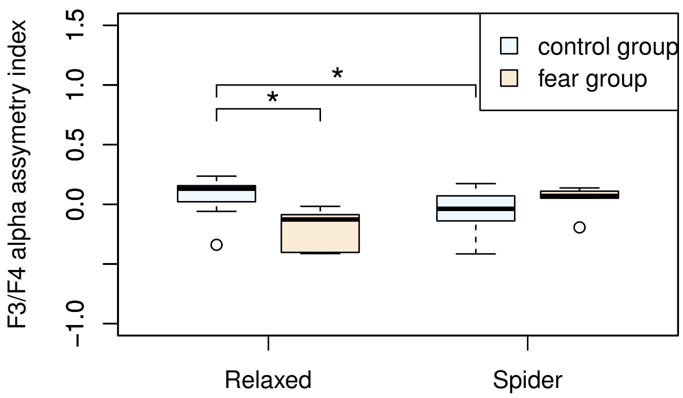


Figure 3.6: Upper left plot shows the alpha frequency power of the channels $F3$ and $F4$ for both scenarios, measured at the control group. The upper right plot shows the same but measured at the spider fear group. The bottom plot displays the box plots of the FAA index values form the channel pair $F3$ and $F4$ for both groups and both VR scenarios. $^*p < 0.05$.

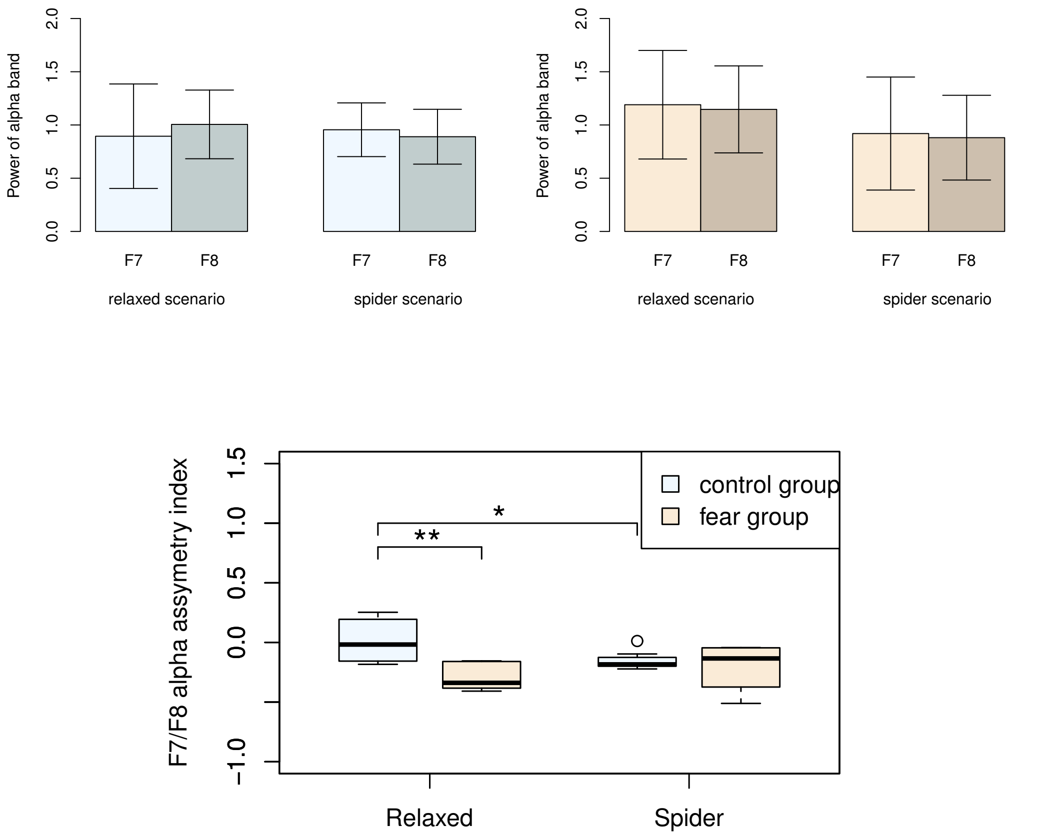
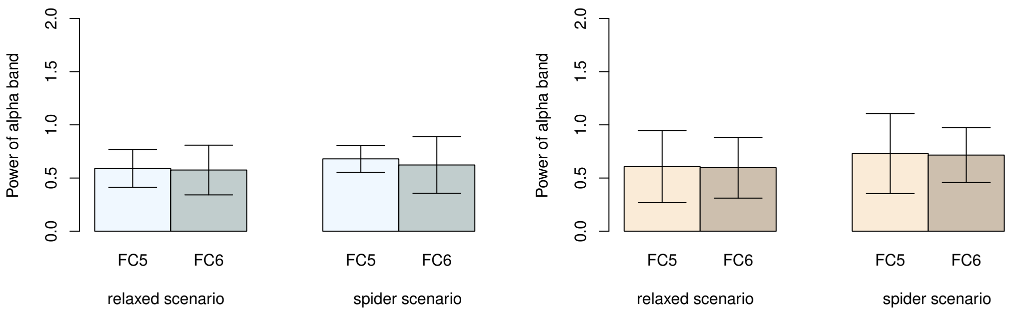


Figure 3.7: Upper left plot shows the alpha frequency power of the channels *F7* and *F8* for both scenarios, measured at the control group. The upper right plot shows the same but measured at the spider fear group. The bottom plot displays the box plots of the FAA index values form the channel pair *F7* and *F8* for both groups and both VR scenarios. $^{*}p < 0.05$ and $^{**}p < 0.01$.



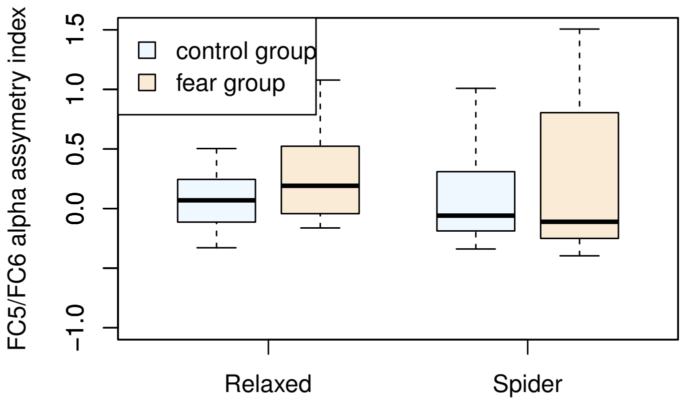


Figure 3.8: Upper left plot shows the alpha frequency power of the channels *FC*5 and *FC*6 for both scenarios, measured at the control group. The upper right plot shows the same but measured at the spider fear group. The bottom plot displays the box plots of the FAA index values form the channel pair *FC*5 and *FC*6 for both groups and both VR scenarios.

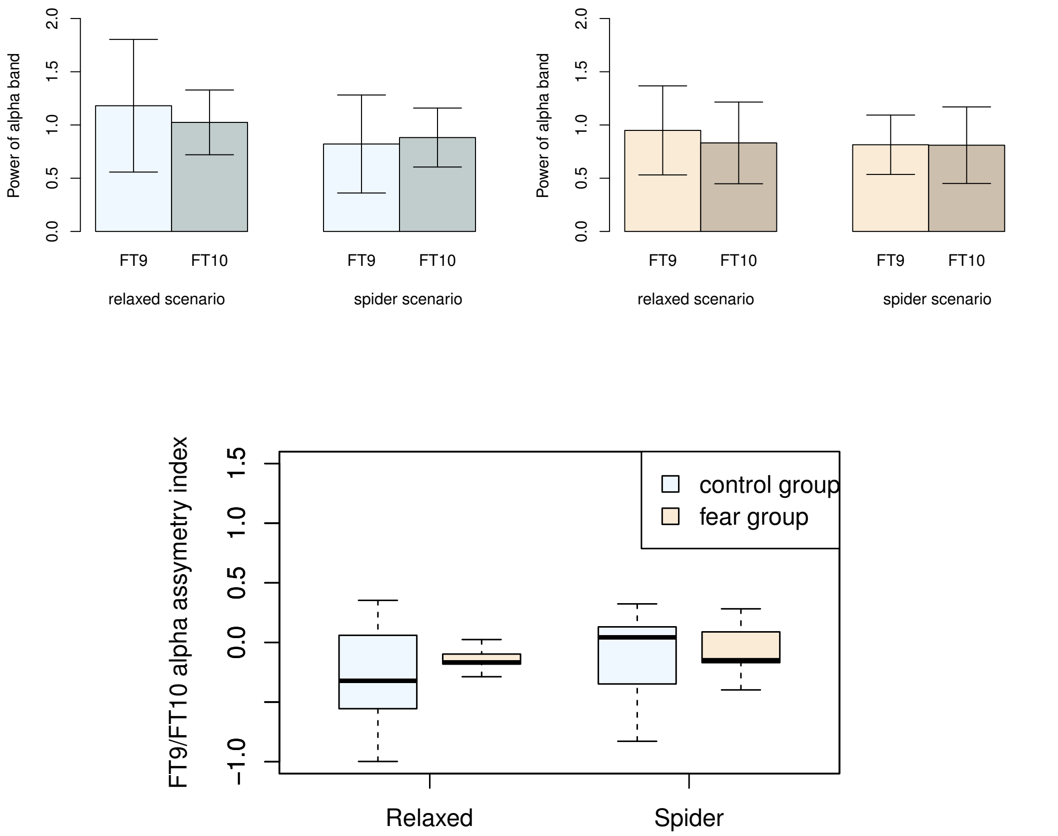


Figure 3.9: Upper left plot shows the alpha frequency power of the channels *FT*9 and *FT*10 for both scenarios, measured at the control group. The upper right plot shows the same but measured at the spider fear group. The bottom plot displays the box plots of the FAA index values form the channel pair *FT*9 and *FT*10 for both groups and both VR scenarios.

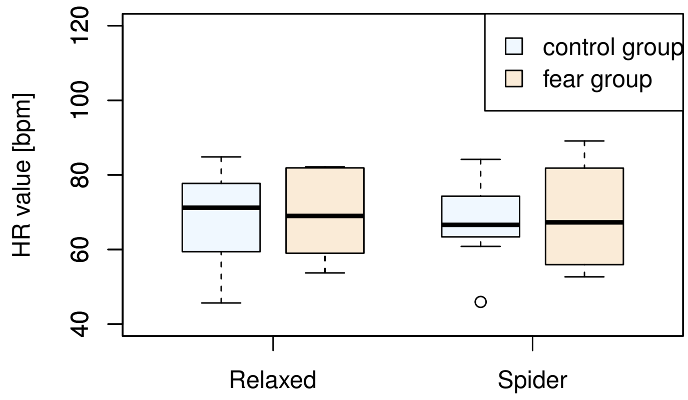


Figure 3.10: The box plot shows the HR values for both groups and both VR scenarios.

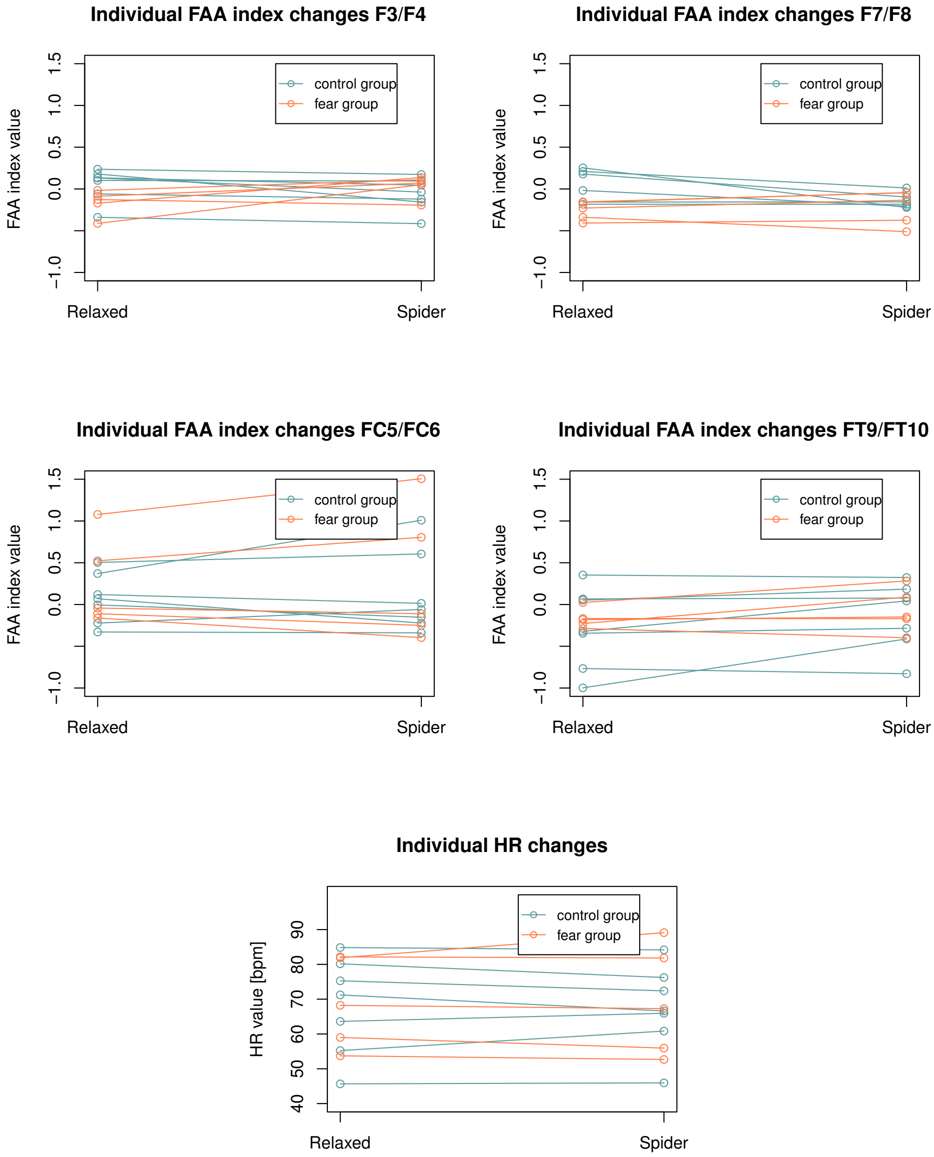


Figure 3.11: Individual FAA index value plots and HR value plot.

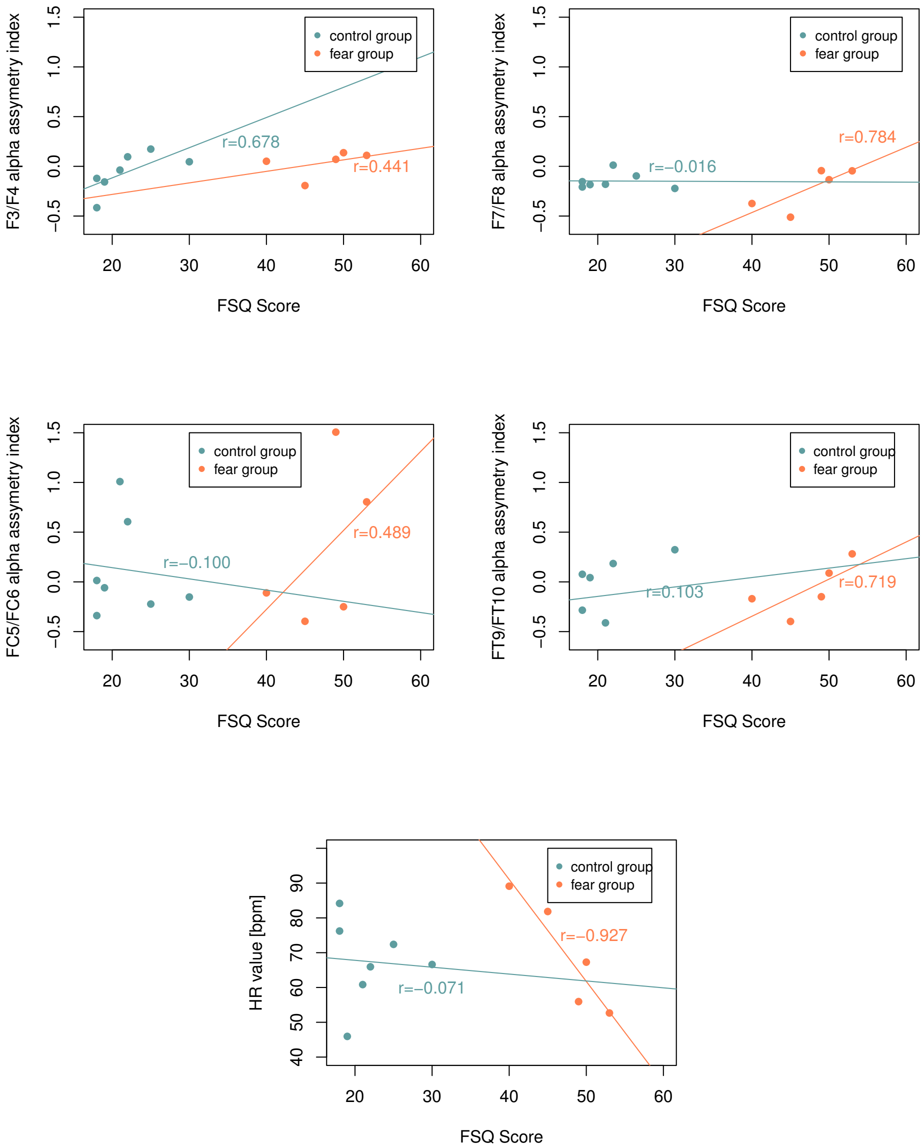


Figure 3.12: Correlation plots of FAA index values and FSQ score, and HR value and FSQ score.

3.4 Main Experiment

In figure 3.13, the FAA index box plot change of the channel pair $F3/F4$ with the rising stimulus level is plotted for the control group and spider fear group. By doing a linear regression, the line equation for the control group is:

$$FAA_{F3/F4,control}(level) = -0.048 - 0.029 * level \tag{3.3}$$

The spider fear group had an equation which was:

$$FAA_{F3/F4,fear}(level) = -0.104 - 0.019 * level \tag{3.4}$$

By doing linear regression for the channel pair $F7/F8$ (Fig.3.14), we obtain a control group line equation of:

$$FAA_{F7/F8,control}(level) = -0.099 - 0.038 * level \tag{3.5}$$

And for the spider fear group, the regression line equation looked like:

$$FAA_{F7/F8,fear}(level) = -0.132 - 0.043 * level \tag{3.6}$$

The channel pair $FC5/FC6$ in figure 3.15 had a linear regression line equation of:

$$FAA_{FC5/FC6,control}(level) = 0.041 - 0.052 * level \tag{3.7}$$

As for the spider fear group, the equation looked like:

$$FAA_{FC5/FC6,fear}(level) = 0.588 - 0.119 * level \tag{3.8}$$

Furthermore, the linear regression of the $FT9/FT10$ channel pair (Fig.3.16) gave out an equation of:

$$FAA_{FT9/FT10,control}(level) = -0.034 - 0.051 * level \tag{3.9}$$

And for the spider fear group:

$$FAA_{FT9/FT10,fear}(level) = 0.062 - 0.022 * level \tag{3.10}$$

Analysis of HR-level plot (Fig.3.17) resulted in a control group's regression line of:

$$HR_{control}(level) = 70.940bpm - 0.083bpm * level \tag{3.11}$$

And for the spider group the linear regression calculated a line of:

$$HR_{fear}(level) = 70.543bpm - 0.582bpm * level \tag{3.12}$$

The individual feature-level development plot for the spider fear group (Fig.3.18-3.22) revealed that there is no general trend visible. Nevertheless, in figure 3.18 at least one participant's $F3/F4$ FAA index curve visibly increases from level 2 to 4, and subsequently a decrease from level 4 to 5. In figure 3.20, one participant showed a clear, continuous decrease of the $FC5/FC6$ FAA index value from level 1 to 4. The individual HR-level development plot showed that two participants had a decrease in HR from the first to the second level. The classifier achieved an accuracy rate of 65.71% for classifying the right fear level of the control group participants, and an accuracy rate of 50% for the spider fear group.

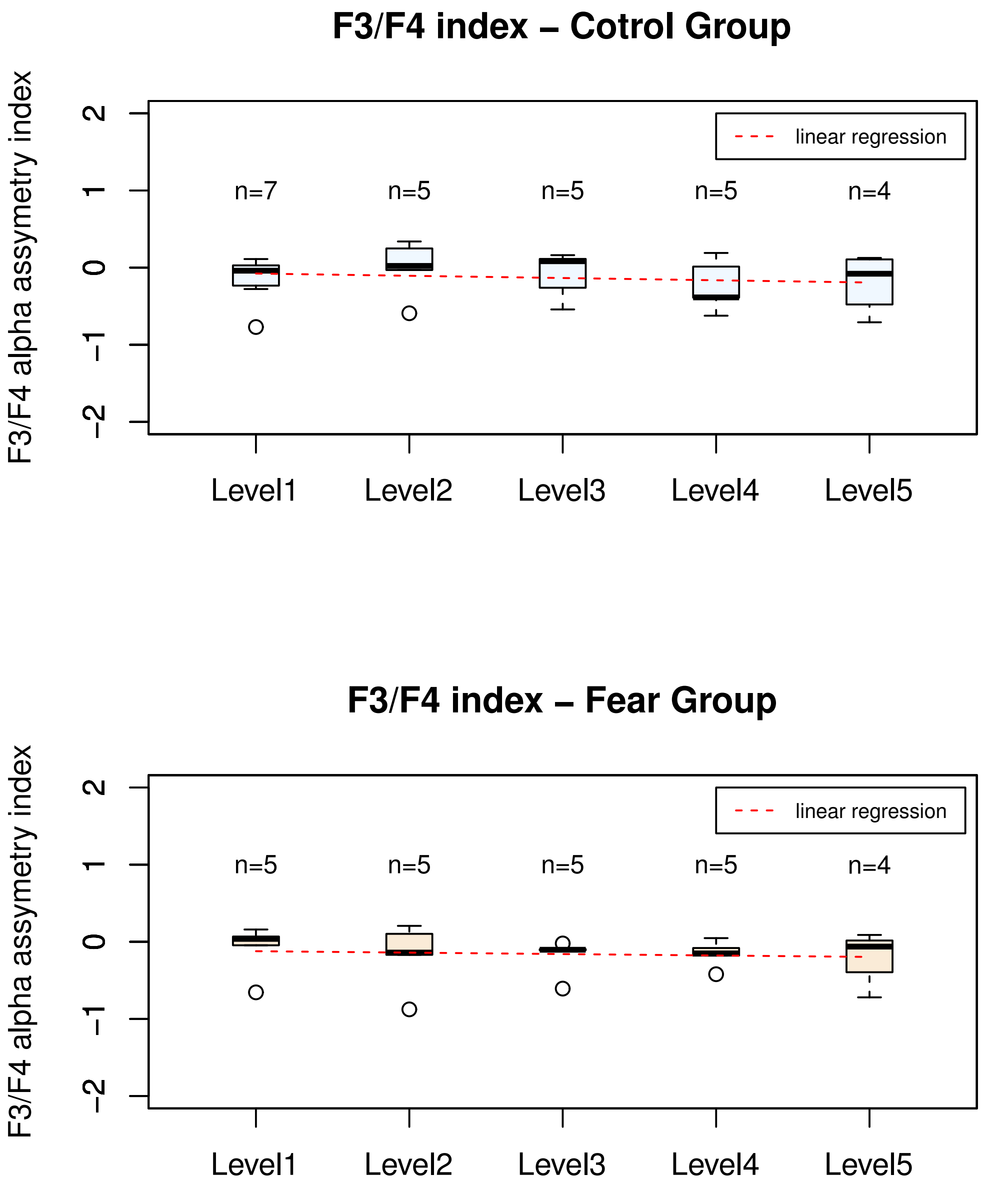


Figure 3.13: Box plots for the FAA index values for the channel pair *F*3 and *F*4 at each level.

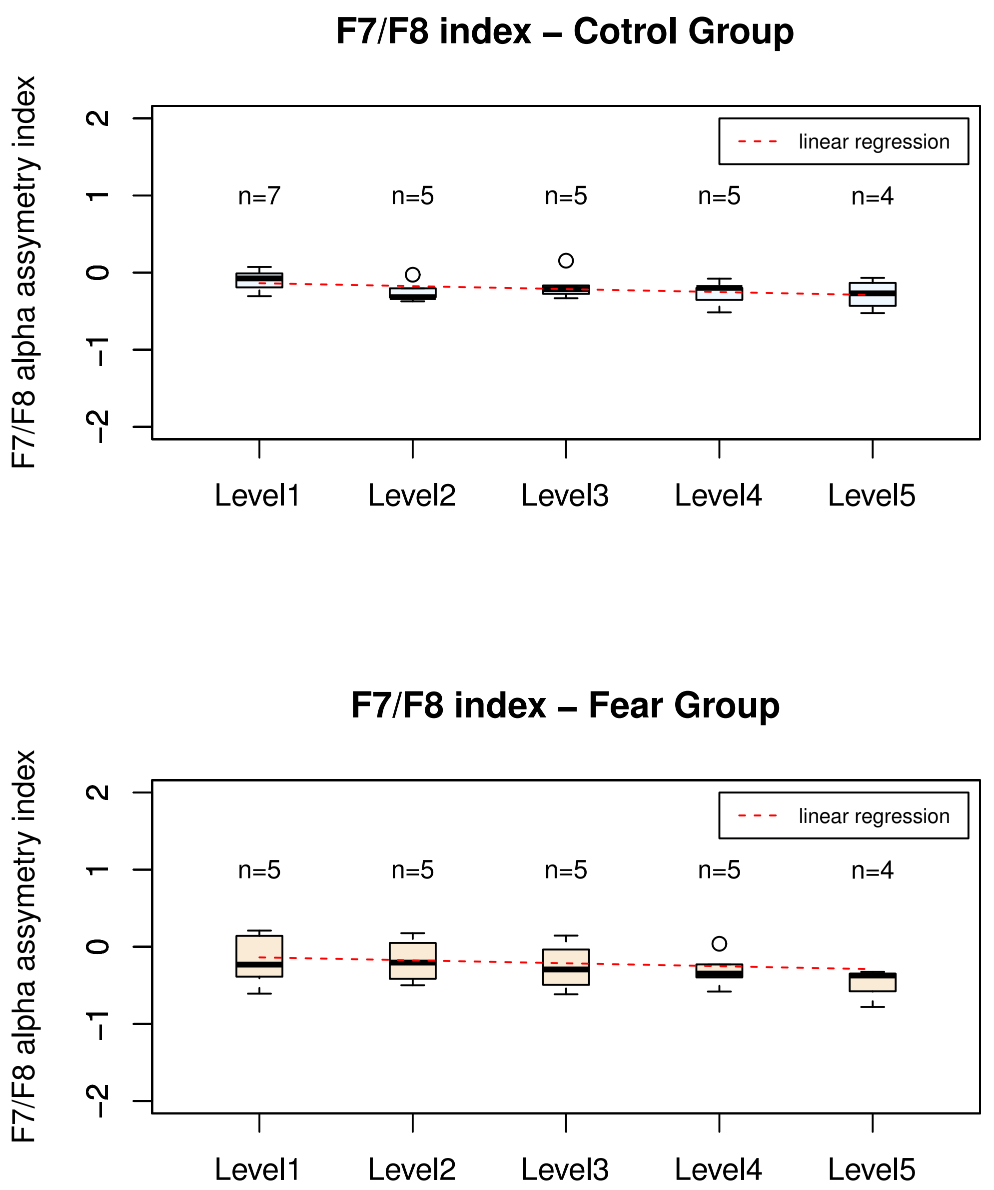


Figure 3.14: Box plots for the FAA index values for the channel pair *F7* and *F8* at each level.

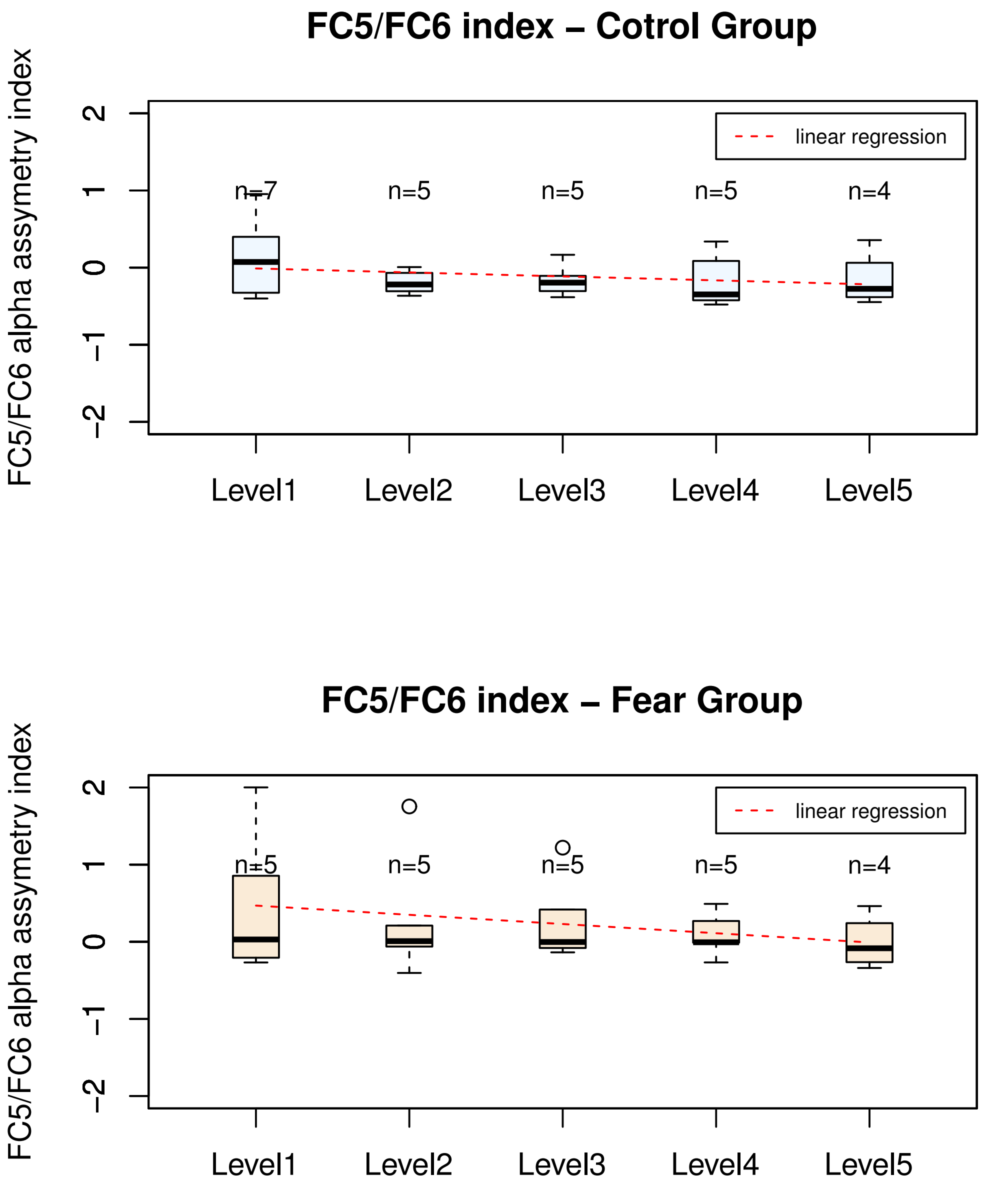
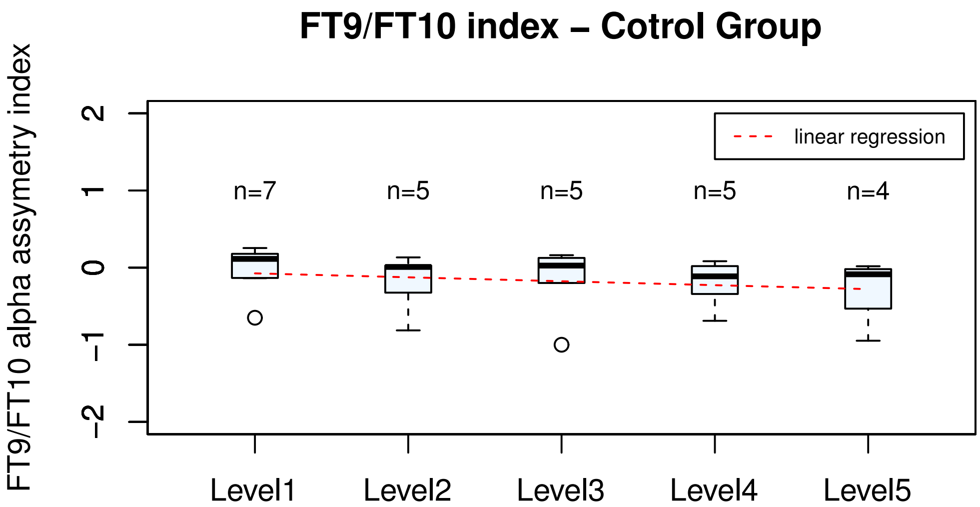


Figure 3.15: Box plots for the FAA index values for the channel pair *FC*5 and *FC*6 at each level.



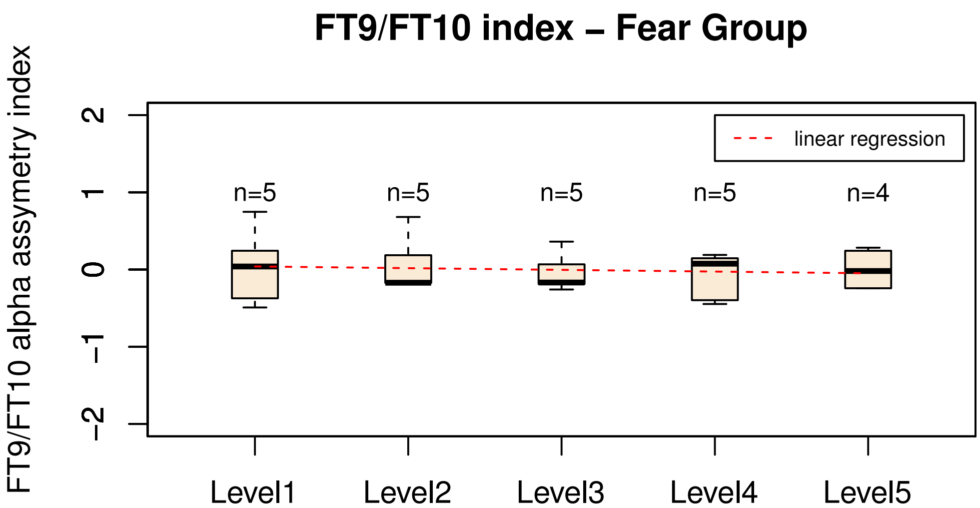


Figure 3.16: Box plots for the FAA index values for the channel pair *FT*9 and *FT*10 at each level.

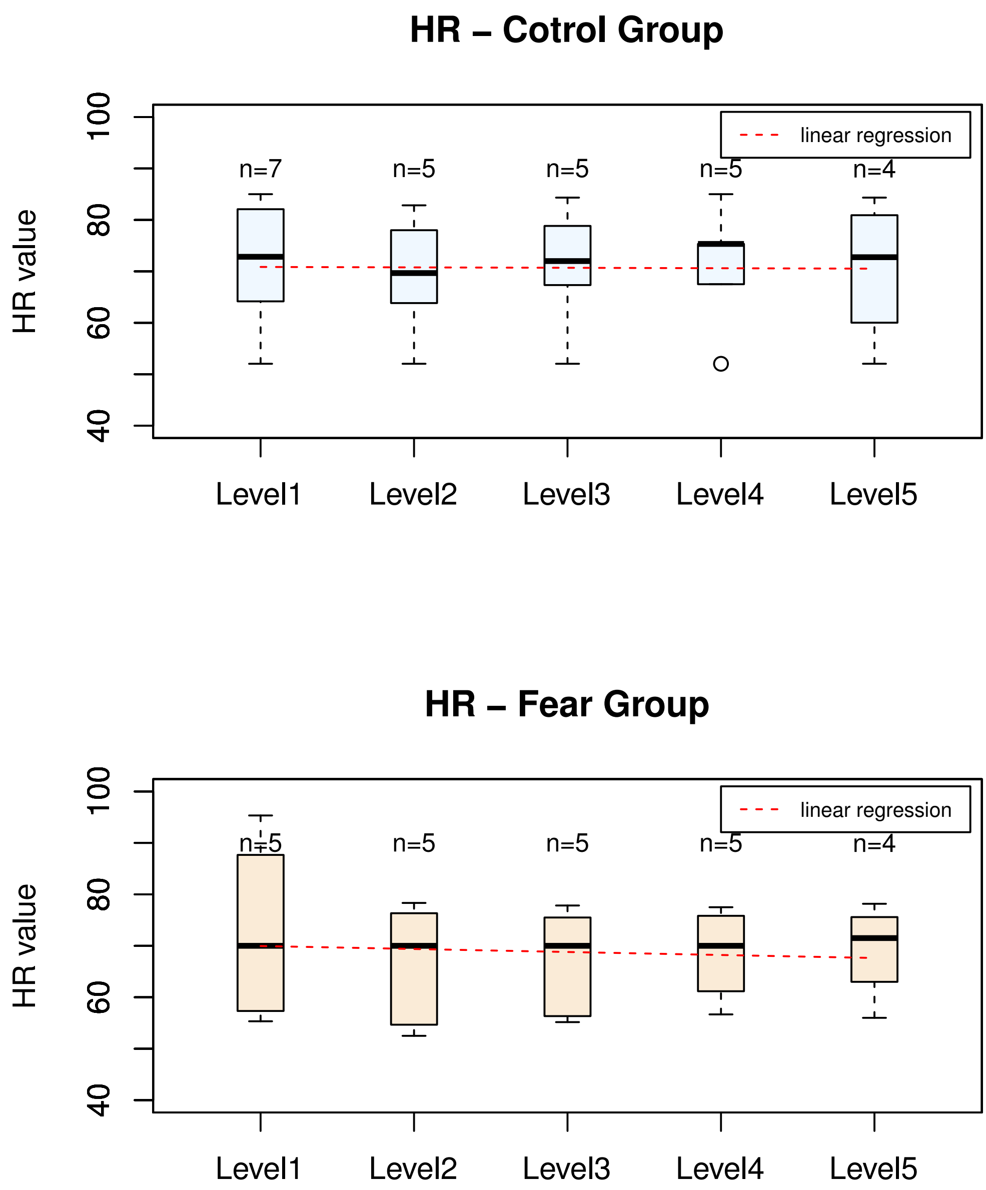


Figure 3.17: Box plots for the HR values at each level.

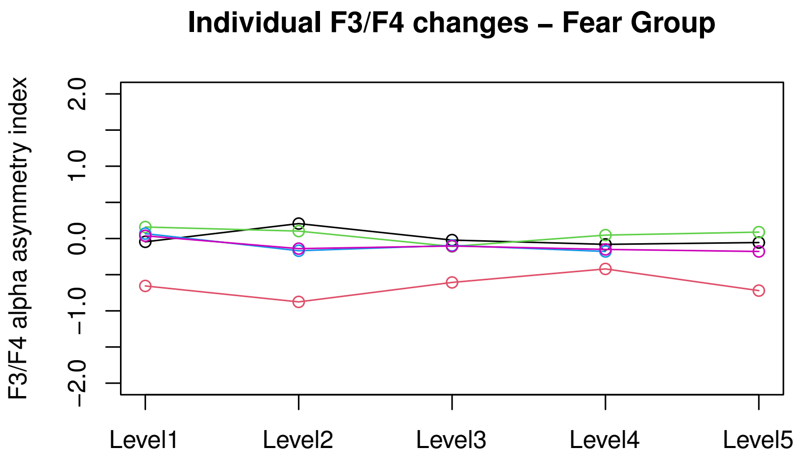


Figure 3.18: Individual $F3/F4$ alpha asymmetry index value change for the spider fear group according to the VR spider level.

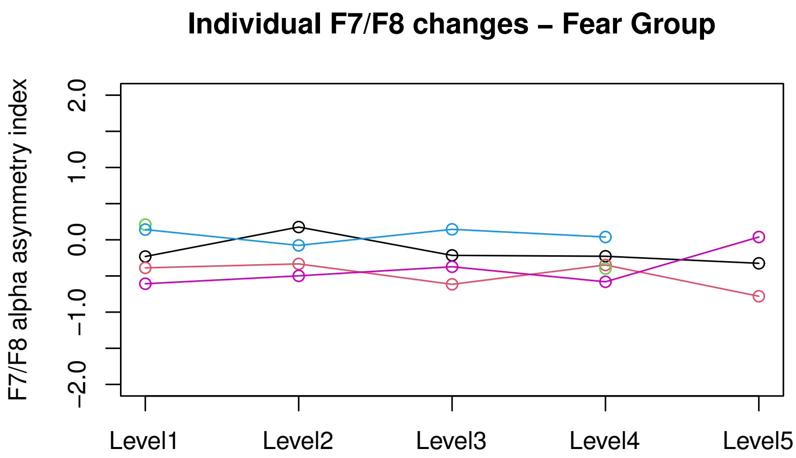


Figure 3.19: Individual $F7/F8$ alpha asymmetry index value change for the spider fear group according to the VR spider level.

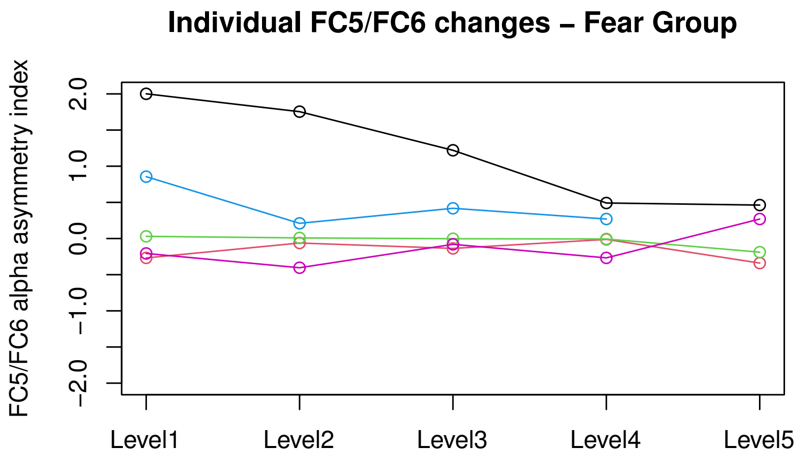


Figure 3.20: Individual $FC5/FC6$ index value change for the spider fear group according to the VR spider level.

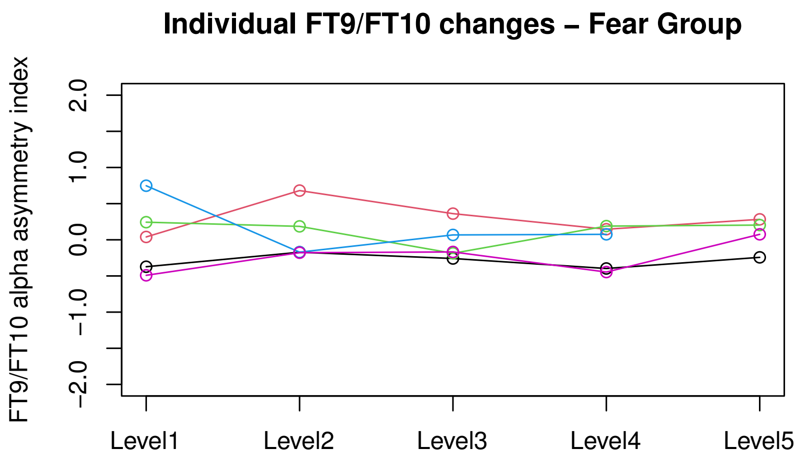


Figure 3.21: Individual $FT9/FT10$ alpha asymmetry index value change for the spider fear group according to the VR spider level.

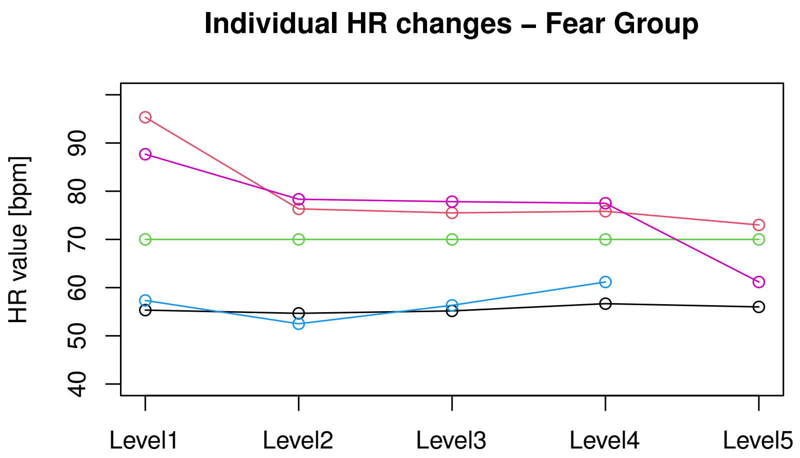


Figure 3.22: Individual HR value change for the spider fear group according to the VR spider level.

4 Discussion

The goal of this study was to develop a neuroadaptive system for arachnophobia exposure therapy. This was done by correctly classifying the fear level of the participant by means of frontal FAA index values out of the EEG measurements and the HR value. Therefore, a SVM classifier was trained with data coming from the pretest. Afterward, in the main experiment this classifier should be able to detect the corresponding participant's fear level for the past 30 seconds time window, and increase, decrease, or keep the current VR spider level according to this. The expectation was that subjects in the spider fear group would have a more negative FAA index value in the frontal channels during the spider scenario compared to the relaxed scenario, due to the approach-withdrawal theory, which states that fear as a negative, withdrawal emotion should be processed in the right frontal hemisphere. In contrary, the expectation on the control group was that the FAA index values between the spider and relaxed VR scenario would be not significant different from each other, since the fear level should be the same. For analyzing these statements, several FAA index box plots for each frontal channel pair were constructed out of the pretest measurements. Additionally, to see any potentially occurring trend of the FAA index values and HR value course over the VR spider level, a level-based feature value box plots figure was generated and analyzed.

4.1 Pilotstudy

To clarify any effect on the frontal channels and on the corresponding FAA index values, a pretest with two subjects was conducted. For analysis, the frequency spectrum for both scenarios and the difference between these two are plotted in one figure, and the topoplot of the alpha frequency range for both scenarios are plotted in another figure. For participant 1 there is a general increase of alpha activity during the spider scenario for most of the EEG channels (Fig. 3.1 and Fig. 3.2). This increase in alpha frequency spectrum was unexpected since a decrease in alpha frequency is correlated with a higher brain activity. And higher brain activity was expected for the spider scenario because of a fear processing especially in the frontal brain areas. Nevertheless, there is also a frequency power increase in the beta band for most of the channels as can be seen in the difference frequency spectrum plot in figure 3.1, which is also an indicator of higher brain activity in these areas. Furthermore, participant 2 shows a brain activity shift to the higher frequency bands from the relaxed to the spider scenario (Fig. 3.3). In the topoplot (Fig.3.4) the decrease in brain activity in the alpha frequency band is visible. Nevertheless, comparing the FAA index values of the frontal channel pairs for both VR scenarios, participant 2 has a clear decrease to negative values for the channel pairs $F3/F4$, $F7/F8$, and $FT9/FT10$, which is in agreement with the approach-withdrawal theory. For participant 1 this effect is not visible at all. There only the channel pair $F3/F4$ shows a small shift to a negative FAA index value for the spider scenario. All in all, the findings of the pilotstudy proved that the FAA index value features from the frontal channels are different enough for being used as training data for the fear level classifier for the main experiment.

4.2 Subjective Measures

The FSQ showed significant higher values for the spider fear group. They were all still below the spider phobic boundary, which lies according to Muris and Merckelbach (1996) by around 89 points. And also the STAI-S questionnaire revealed a significant difference between the spider fear group and the control group. It indicated that participants from the spider fear group had in general a higher state anxiety before the VR experience, which could come from the fact that all of them already knew that they will be confronted with VR spider in this study, and therefore, felt already some tension and discomfort. The correlation plots in figure 3.5 also showed, that there is a high correlation between FSQ and STAI-S score. Therefore, it can be said that participants with a higher fear of spiders also have a general higher state anxiety before the VR spider confrontation. In the BMIS questionnaire only the "Positive-Tired" subcategory was significant different between the two groups, where the control group had higher values, indicating that they had a more positive mood compared to the spider fear group.

4.3 Pretest

The pretest analysis of the FAA index value changes from the relaxed to the spider VR scenario showed for both groups that only the channel pairs $F3/F4$ and $F7/F8$ there is a significant change visible. The control group's FAA index values for these channel pairs were decreasing when they experienced the VR spider pretest scenario, but the decrease was not very big to say that there was a real effect coming from the VR spider confrontation. This observation is in line with the hypothesis that the FAA index values for the control group will be approximately the same for both scenarios. In the other channel pairs, $FC5/FC6$ and $FT9/FT10$, the measured FAA index values had no visible changes between the two scenarios, and additionally, the $FC5/FC6$ and $FT9/FT10$ FAA index values had a much higher spread as for the other FAA index values. Looking at the individual FAA index plot (Fig.3.11) especially three participants of the control group experienced a decrease of the $F3/F4$ value, and four of them for the $F7/F8$ value, the other control group participant's FAA index values did not change from one scenario to the other, confirming the expectation. Analyzing the FAA index development for the spider fear group revealed that only for the channel pair $F3/F4$ there is a visible FAA index value change detectable from the relaxed to the spider VR scenario. The mean $F3/F4$ FAA index value increased by an amount of 0.25 to a positive value. This observation is in contrast with the study hypothesis, where the expectation was contrary to the outcome. Meaning, a more negative FAA index value during the spider confrontation was expected for the spider fear group. Interviewing the participants after the VR spider experiment showed that most of the participants in the spider fear group tried to play down their emotion during the VR spider confrontation by keep telling themselves that the situation was not real, and that the VR spider was not that scary. Some even tried to imagine that they are in a more positive related environment, like on the beach during a sunny day. This cognitive reappraisal strategy could be the reason for the FAA index shift to a more positive value, and therefore, an increase in the left hemispheric activity. Choi et al. (2016) have investigated how such emotional regulation strategies like cognitive reappraisal influence the FAA index value. They found out that there is an increase in left frontal hemispheric activity of the participants during watching negative related images from the ISAP set if they were instructed to apply reappraisal strategy in comparison to just watching the images without applying any emotional regulation strategy. Furthermore, in their study they observed a positive correlation between the FAA index value and the emotional regulation questionnaire (ERQ), which is used to quantify the usage of emotional regulation strategies in the daily life of the participants, especially for male participants. Meaning, subjects who are used to apply reappraisal strategies for negative situations, have in general also a more positive FAA index value in the reappraisal situation. Parvaz et al. (2012) also observed an increase in left hemispheric cognitive activity in participants who were instructed to down-regulate their emotional response to unpleasant pictures from the IAPS by changing the meaning of the picture or view it in another perspective compared to the instruction to just watch the pictures. Figure 3.11 also confirms that 4 out of 5 participants showed an increase from the relaxed scene $F3/F4$ FAA index value to the spider scene $F3/F4$ FAA index value. Interestingly, figure 3.12 makes the impression as if with higher FSQ score, the fear group participants had also a higher FAA index value, which would be in agreement with the assumption that if the participant had a higher subjective spider fear rating then they also respond with a higher FAA index value. Apparently, these results are not significant since the participant number in the fear group is only five, and therefore, only on a visible inspection of the correlation plots, this trend can be seen. Inspecting how the VR spider confrontation has an effect on the HR (Fig.3.10 and Fig.3.11), no changes could be observed between relaxed and spider scene for both groups. This non-changing HR was rather unexpected, since according to several other studies (Cisler, Olatunji, and Lohr, 2009), a fearful situation as the VR spider confrontation should normally trigger an increase in HR at least for the spider fear group. Possible explanation for these non-changing HR values could be that since the participant were sitting in a relaxed position and aware that these spiders are only virtually present, the VR fear confrontation maybe did not have an effect on the measured HR. Additionally, the before mentioned reappraisal strategy, which was unintentionally applied by some participants, could compensate the normal increase of HR.

4.4 Main Experiment

The regression analysis of the feature development over the levels, did not show any significant change for any of the two groups. Only by inspecting the plots (Fig.3.13-3.17) visually, some small trends to more negative FAA index values with increasing stimulus level for the channel pairs $F3/F4$ and $F7/F8$ of the spider fear group appear. Which is what we would expect, since a stronger stimulus confrontation, in form of a higher amount of spiders and also an increase in their size, should also cause a higher activation of the right frontal hemisphere, and furthermore, a more negative FAA index value. However, due the small sample size in the spider fear group, it is not possible to confirm this hypothesis statistically. On the other hand, the non-changing feature development with increasing stimulus level for the control group, was matching the expectation, since higher stimulus levels should still not evoke any fear response in the control group. Furthermore, also the individual feature-level development plots (Fig.3.18-3.22) of the spider fear group did not show any general trend development of the features over the increasing stimulus levels. The SVM classifier achieved an accuracy rate of 50% for the spider fear group, which is still higher than the chance level of 33.33%. It could be assumed, that the accuracy rate of the classifier for people with real arachnophobia would be higher, since the fear response should be even higher for these, and therefore, resulting in a more distinguishable set of classifier features. This has to be proven in future studies, to see if this neuroadaptive VRET can be used for treatment of arachnophobia. Interestingly, the classifier accuracy rate of 65.71% for the control group is higher than for the spider fear group. Expected was the other way around, due to the hypothesis that the VR relaxed scenario and the VR spider scenario would evoke the same FAA index values and the same HR value for the control group. This discrepancy could be derived from a surprising effect at the initial VR spider scenario at the pretest. The participant of the control group did not know exactly how the VR spiders look like and how they were interacting with them. Even some of them were expecting a jump scare. This uncertainty could have evoked a little change of the measured features for the training data at the VR spider scenario. Since in the main experiment, this uncertainty was not present anymore, nearly all fear class levels were classified as "relaxed state" class. This together with the subjective fear rating in the control group, which was most of the time either "no fear" or "low fear", could be the reason for a quite high accuracy rate for the control group.

4.5 Limitations and future directions

One limitation of this study is the small sample size of participants. Therefore, the statistical validity is very poor and no clear significant observation could be declined. Nevertheless, the focus of the study was on the development of the VR environment and the study design. Additionally, there is a high amount of male participants compared to female participants, but according to Schmitt and Müri (2009), women are much more likely to have a spider phobia than men, therefore, would be desirable to increase the amount of female participants. Another point which has to be taken into account, is that none of the participant had a real arachnophobia, which implies that a therapeutic usage as VRET of this spider VR therapy would most probably have more distinguishable classifier features for the relaxed and spider scenario. Since the before mentioned reappraisal strategy was given as potential reason for the observed more positive shift of the FAA index values for the spider fear group, a questionnaire, like the ERQ, which assess how much someone uses emotional regulation strategies like reappraisal in the daily life, could be added to the study design. This will then give a better picture if this reappraisal strategy is really correlated with a positive FAA index shift for the spider scenario. Additionally, to control that they participants do not look away from the VR spider stimuli, and by this interfering with the measurements, an eye tracking device could also be added to the experiment setup. One limitation of this study is the small sample size of participants. Therefore, the statistical validity is very poor and no clear significant observation could be declined. Nevertheless, the focus of the study was on the development of the VR environment and the study design. Additionally, there is a high amount of male participants compared to female participants, but according to Schmitt and Müri (2009), women are much more likely to have a spider phobia than men, therefore, would be desirable to increase the amount of female participants. Another point which has to be taken into account, is that none of the participant had a real arachnophobia, which implies that a therapeutic usage as VRET of this spider VR therapy would most probably have more distinguishable classifier features for the relaxed and spider scenario. Since the before mentioned reappraisal strategy was given as potential reason for the observed more positive shift of the FAA index values for the spider fear group, a questionnaire, like the ERQ, which assess how much someone uses emotional regulation strategies like reappraisal in the daily life, could be added to the study design. This will then give a better picture if this reappraisal strategy is really correlated with a positive FAA index shift for the spider scenario. Additionally, to control that they participants do not look away from the VR spider stimuli, and by this interfering with the measurements, an eye tracking device could also be added to the experiment setup. Furthermore, the expected FAA shift to a more negative value could also be only visible for participant with a real arachnophobia, due to the disability to apply an emotional regulation strategy. These points can be used to assign a future follow-up study, where this spider VRET should be tested on subjects with arachnophobia, and furthermore, assess the effectiveness of the VRET by applying the VRET on several sessions and assessing the process of the participants viva the Behavior Approach Test (BAT) at the beginning of the therapy and at the post-therapy test. Some of the participants in the spider fear group also reported in the post experiment talk that they had found the VR environment not realistic enough to evoke a feeling of fear. For implementing a more realistic stimulation environment, usage of an augmented reality (AR) environment can be an alternative option. AR gives the user a higher feeling of presence since only a few objects are virtually generated, otherwise the user can see all the real objects in the room and the movements of the own limbs. Juan et al. (2005) for example have generated a AR environment by visualizing virtual moving spiders with the right transformation in the vicinity of marker plates. The spiders could then visually crawl over the user's hand. Other alternative options for creating a more realistic feeling could be to introduce a more multimodal sensory stimulation. Up to now there is only the visual stimulus by watching the VR spiders and the acoustic stimulus from the crawling sound of the spiders. An additional stimulus could be provided by the haptic sense by using an ultrasonic feedback system like Brice et al. (2021) have used in their study. They were able to give a sensational feeling as if the spider was really crawling on the participant's hand, by an ultrasonic transducer which produced a haptic sensation by sending out ultrasound waves synchronized with the spider movement in the VR and with the size of the spider. The hand position was tracked by using Leap Motion hand tracker which additionally visualizes the participant's hand in the VR. Or Kurscheidt et al. (2019) have added a vibrotactile feedback in form of an arm-sleeve with vibration motors to their AR exposure therapy system. Therefore, they were able to let the participants feel how a virtual spider was crawling along their arms by controlling the vibration motors in synchronization to the spider movement.

4.6 Conclusion

The purpose of this study was to generate a neuroadaptive virtual environment in form of a VRET for people with arachnophobia. Therefore, the SVM classifier should detect the fear level of the participant, and according to the classified fear level, the VR environment should automatically adjust the VR spider fear level. As training features the classifier used the FAA index values from the frontal EEG channels and the HR signal, which were obtained during the pretest, where the participant first entered the relaxed VR scenario to receive the training data for the relaxed state, and afterward experienced the spider VR scenario to obtain training data for the fear state. Analysis of this pretest showed that there was a shift of the $F3/F4$ and $F7/F8$ FAA index values to more positive values for the spider VR scenario. This was in contrast to the hypothesis, that according to the approach-withdrawal theory, there should be a shift to more negative values for the FAA index values of the spider fear group, since emotion of fear evokes a higher activity in the right frontal hemisphere. This disagreement could be explained through the emotional reappraisal strategy, applied by some participants in the spider fear group. For the control group there was only a small feature change visible when comparing the two pretest scenarios. This was in line with the hypothesis that for the control group the two VR scenarios should evoke approximately the same FAA index values and HR value, since the VR spiders should not trigger any high fear response for the participants in this group.

In the main experiment the trained classifier took out the last 30 seconds of measurement data, did a online classification of the fear level, and sent out the matching marker to the VR environment. Participant had the instruction to give a subjective rating of the fear level every time they heard a beep sound, which indicated the end of the 30 second level. This rating was used to calculate the accuracy of the SVM classifier. The feature-level development plots showed that the features over the increasing levels did not change significantly for both groups. This outcome was against the expectation, that there would be at least a change for FAA index values of the spider fear group to more negative values, due to the assumption that a higher fear stimulus would trigger a higher fear level, and therefore, cause an increase in activity in the right frontal hemisphere. All in all, the classifier reached a higher accuracy rate of 65.71% for the control group and 50% for the spider fear group. This high accuracy rate for the control group was rather unexpected, which may come from the fact, that in the pretest, the control group participants were surprised of how the VR spider scenario looked like. Therefore, this surprising effect may have caused this distinguishable change in the FFA index values. Since this surprising effect was not any more there in the main experiment and also through the low subjective fear rating in this group for each level, the accuracy rate achieved an acceptable rate. For the spider fear group, the accuracy rate was at least over the chance level of 33.33%, but still could be better.

In conclusion, the results showed that there is a distinguishable, measurable difference in the FAA index values from the EEG measurement when participants in the spider fear group are confronted with VR spiders. Nevertheless, it was not clear if there is any significant effect from increasing the VR spider stimulus in the higher levels. Future studies should increase the number of participants to see if there is some statistically difference of FAA index values within the levels. Additionally, a study with real phobic participants should be conducted to see if the withdrawal effect in form of a shift of FAA index values to more negative values, is present for people with arachnophobia.

Bibliography

[prism bucket] (2015). *Animated Spider*. URL: https://assetstore.unity.com/packages/3d/characters/animals/insects/animated-spider-22986.

A dog's life software (2016). *18 High Resolution Wall Textures*. URL: https://assetstore.unity.com/packages/2d/textures-materials/brick/18-high-resolution-wall-textures-12567.

Albakri, Ghaida, Rahma Bouaziz, Wallaa Alharthi, Slim Kammoun, Mohammed Al-Sarem, Faisal Saeed, and Mohammed Hadwan (2022). "Phobia exposure therapy using virtual and augmented reality: a systematic review." In: *Applied Sciences* 12.3, p. 1672.

ANRUVAL_3D_MODELS (2018). *Wooden Chairs 2 Variations*. URL: https://assetstore.unity.com/packages/3d/props/furniture/wooden-chairs-2-variations-125757.

Apicella, Andrea, Simone Barbato, Luis Alberto Barradas Chacn, Giovanni D'Errico, Lucio Tommaso De Paolis, Luigi Maffei, Patrizia Massaro, Giovanna Mastrati, Nicola Moccaldi, Andrea Pollastro, and Selina C. Wriessenegger (2023). "Electroencephalography correlates of fear of heights in a virtual reality environment." In: *Acta IMEKO* 12.2, pp. 1–7.

Balan, Oana, Gabriela Moise, Alin Moldoveanu, Florica Moldoveanu, and Marius Leordeanu (2019). "Automatic adaptation of exposure intensity in VR acrophobia therapy, based on deep neural networks." In:

Basbasse, Yasmin, Julian Packheiser, Jutta Peterburs, Christopher Maymon, Onur Guentuerkuen, Gina Grimshaw, and Sebastian Ocklenburg (2022). "Walk the Plank! Using mobile EEG to investigate emotional lateralization of immersive fear in virtual reality." In: *bioRxivs*, pp. 2022–08.

Brice, Daniel, Zara Gibson, Fintan McGuinness, and Karen Rafferty (2021). "Using ultrasonic haptics within an immersive spider exposure environment to provide a multi-sensorial experience." In: *Frontiers in Virtual Reality* 2, p. 707731.

Carl, Emily, Aliza T Stein, Andrew Levihn-Coon, Jamie R Pogue, Barbara Rothbaum, Paul Emmelkamp, Gordon JG Asmundson, Per Carlbring, and Mark B Powers (2019). "Virtual reality exposure therapy for anxiety and related disorders: A meta-analysis of randomized controlled trials." In: *Journal of anxiety disorders* 61, pp. 27–36.

Chang, Eunhee, Hyun Taek Kim, and Byounghyun Yoo (2020). "Virtual reality sickness: a review of causes and measurements." In: *International Journal of Human–Computer Interaction* 36.17, pp. 1658–1682.

Choi, Damee, Takahiro Sekiya, Natsumi Minote, and Shigeki Watanuki (2016). "Relative left frontal activity in reappraisal and suppression of negative emotion: Evidence from frontal alpha asymmetry (FAA)." In: *International Journal of Psychophysiology* 109, pp. 37–44.

Cisler, Josh M, Bunmi O Olatunji, and Jeffrey M Lohr (2009). "Disgust, fear, and the anxiety disorders: A critical review." In: *Clinical psychology review* 29.1, pp. 34–46.

Cochrane, Andy, Dermot Barnes-Holmes, and Yvonne Barnes-Holmes (2008). "The perceived-threat behavioral approach test (PT-BAT): Measuring avoidance in high-, mid-, and low-spider-fearful participants." In: *The Psychological Record* 58.4, pp. 585–596.

Davidson, Richard J., John R. Marshall, Andrew J. Tomarken, and Jeffrey B. Henriques (2000). "While a phobic waits: Regional brain electrical and autonomic activity in social phobics during anticipation of public speaking." In: *Biological psychiatry* 47.2, pp. 85–95.

Davidson, Richard J. and Andrew J. Tomarken (1989). "Laterality and emotion: An electrophysiological approach." In: *Handbook of neuropsychology* 3, pp. 419–441.

Denisova, Alena and Paul Cairns (2015). "First person vs. third person perspective in digital games: do player preferences affect immersion?" In: *Proceedings of the 33rd annual ACM conference on human factors in computing systems*, pp. 145–148.

Harmon-Jones, Eddie (2003). "Clarifying the emotive functions of asymmetrical frontal cortical activity." In: *Psychophysiology* 40.6, pp. 838–848.

Harmon-Jones, Eddie and John JB Allen (1998). "Anger and frontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence." In: *Journal of personality and social psychology* 74.5, p. 1310.

Houssein, Essam H., Asmaa Hammad, and Abdelmgeid A. Ali (2022). "Human emotion recognition from EEG-based brain–computer interface using machine learning: a comprehensive review." In: *Neural Computing and Applications* 34.15, pp. 12527–12557.

ISBIT GAMES (2015a). *First Person Lover - Female Character and Clothes Pack*. URL: https://assetstore.unity.com/packages/3d/characters/humanoids/first-person-lover-female-character-and-clothes-pack-41056.

ISBIT GAMES (2015b). *First Person Lover - Male Character and Clothes Pack*. URL: https://assetstore.unity.com/packages/3d/characters/humanoids/first-person-lover-male-character-and-clothes-pack-40848.

James Lowart (2021). *Pipe constructor*. URL: https://assetstore.unity.com/packages/3d/environments/industrial/pipe-constructor-186974.

Juan, M Carmen, Mariano Alcaniz, Carlos Monserrat, Cristina Botella, Rosa Marıa Baños, and Belen Guerrero (2005). "Using augmented reality to treat phobias." In: *IEEE computer graphics and applications* 25.6, pp. 31–37.

Kayikcioglu, Ozcan, Sinan Bilgin, Goktug Seymenoglu, and Artuner Deveci (2017). "State and trait anxiety scores of patients receiving intravitreal injections." In: *Biomedicine hub* 2.2, pp. 1–5.

Kisker, Joanna, Leon Lange, Kira Flinkenflügel, Michael Kaup, Nils Laberweiler, Falk Tetenborg, Paula Ott, Christopher Gundler, Thomas Gruber, Roman Osinsky, and Bejamin Schöne (2021). "Authentic fear responses in virtual reality: a Mobile EEG study on affective, behavioral and electrophysiological correlates of fear." In: *Frontiers in Virtual Reality* 2, p. 716318.

KrazyFX (2015). *Fire Extinguisher*. URL: https://assetstore.unity.com/packages/3d/props/fire-extinguisher-21147.

Kurscheidt, Maximilian, Vitaliy Ostapchuck, Friederike Sottek, Sebastian Felix Rauh, and Gerrit Meixner (2019). "Augmented reality exposure therapy with tactile feedback for small animal phobia: hardware concept and user study design." In: *2019 IEEE International Conference on Healthcare Informatics (ICHI)*. IEEE, pp. 1–7.

Linowes, Jonathan (2020). *Unity 2020 Virtual Reality Projects: Learn VR development by building immersive applications and games with Unity 2019.4 and later versions*. Packt Publishing Ltd.

Mayer, John D and Rachael Cavallaro (2019). "Brief mood introspection scale (BMIS): Technical and scoring manual." In:

Mayer, John D and Yvonne N Gaschke (1988). "The experience and meta-experience of mood." In: *Journal of personality and social psychology* 55.1, p. 102.

Mouri, Fatima Islam, Camilo E Valderrama, and Sergio G Camorlinga (2023). "Identifying relevant asymmetry features of EEG for emotion processing." In: *Frontiers in Psychology* 14.

Muris, Peter and Harald Merckelbach (1996). "A comparison of two spider fear questionnaires." In: *Journal of behavior therapy and experimental psychiatry* 27.3, pp. 241–244.

MyNameIsVoo (2016). *Pallet*. URL: https://assetstore.unity.com/packages/3d/props/pallet-66603.

NEKCOM Entertainment (2014). *Wooden table and chair*. URL: https://assetstore.unity.com/packages/3d/props/furniture/wooden-table-and-chair-18996.

Parvaz, Muhammad A, Annmarie MacNamara, Rita Z Goldstein, and Greg Hajcak (2012). "Event-related induced frontal alpha as a marker of lateral prefrontal cortex activation during cognitive reappraisal." In: *Cognitive, Affective, & Behavioral Neuroscience* 12, pp. 730–740.

Pedregosa, F., G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot, and E. Duchesnay (2011). "Scikit-learn: Machine Learning in Python." In: *Journal of Machine Learning Research* 12, pp. 2825–2830.

Pixabay (2022a). *10-pasos-de-arana-spider-steps-47018.mps*. URL: https://cdn.pixabay.com/audio/2022/03/10/audio_320adf0662.mp3?filename=10-pasos-de-arana-spider-steps-47018.mp3.

Pixabay (2022b). *spider-chattering-87558.mps*. URL: https://cdn.pixabay.com/audio/2022/03/15/audio_d0209e2cc7.mp3?filename=spider-chattering-87558.mp3.

Pixel Games (2015). *Shelf*. URL: https://assetstore.unity.com/packages/3d/props/interior/shelf-646.

PolyWorkshop (2015). *Cardboard Boxes Pack*. URL: https://assetstore.unity.com/packages/3d/props/cardboard-boxes-pack-30695.

Rabe, Sirko, Tanja Zoellner, Andrë Beauducel, Andreas Maercker, and Anke Karl (2008). "Changes in brain electrical activity after cognitive behavioral therapy for posttraumatic stress disorder in patients injured in motor vehicle accidents." In: *Psychosomatic medicine* 70.1, pp. 13–19.

RRFreelance (2018). *Sledge Hammer*. URL: https://assetstore.unity.com/packages/3d/props/tools/sledge-hammer-20498.

Safikhani, Saeed, Johanna Pirker, and Selina C. Wriessnegger (2021). "Virtual Reality Applications for the Treatment of Anxiety and Mental Disorders." In: *2021 7th International Conference of the Immersive Learning Research Network (iLRN)*. IEEE, pp. 1–8.

Schmitt, Wolfgang J. and René M. Müri (2009). "Neurobiologie der Spinnenphobie." In: *Schweizer Archiv für Neurologie und Psychiatrie* 160.8, pp. 352–355.

Sergi Nicolás (2018). *Rusty Black Shovel*. URL: https://assetstore.unity.com/packages/3d/props/tools/rusty-black-shovel-73088.

Siegel, E. H., J. Wei, A. Gomes, M. Oliviera, P. Sundaramoorthy, K. Smathers, M. Vankipuram, S. Ghosh, H. Horii, J. Bailenson, and R. Ballagas (2021). *HP Omnicept cognitive load database (HPO-CLD)–developing a multimodal inference engine for detecting real-time mental workload in VR*. Tech. rep. Technical Report.

Simple Forge (2017). *PBR Barrels*. URL: https://assetstore.unity.com/packages/3d/props/industrial/pbr-barrels-83508.

Solé Morillo, Ángel, Joan Lambert Cause, Vlad-Eusebiu Baciu, Bruno da Silva, Juan C. Garcia-Naranjo, and Johan Stiens (2022). "PPG EduKit: An Adjustable Photoplethysmography Evaluation System for Educational Activities." In: *Sensors* 22.4, p. 1389.

Spielberger, C. D., R. L. Gorsuch, R. Lushene, P. R. Vagg, and G. A. Jacobs (1983). "Manual for the State-Trait Anxiety Inventory; Palo Alto, CA, Ed." In: *Palo Alto: Spielberger*.

Szymanski, Jeff and William O'Donohue (1995). "Fear of spiders questionnaire." In: *Journal of behavior therapy and experimental psychiatry* 26.1, pp. 31–34.

Taylor Marks (2021). *playsound*. URL: https://github.com/TaylorSMarks/playsound.

Tim H. (2018). *Tim's Horror Assets - The Bloody Door*. URL: https://assetstore.unity.com/packages/3d/props/interior/tim-s-horror-assets-the-bloody-door-70847.

Wang, Jiang and Mei Wang (2021). "Review of the emotional feature extraction and classification using EEG signals." In: *Cognitive robotics* 1, pp. 29–40.

Wiedemann, Georg, Paul Pauli, Wilhelm Dengler, Wemer Lutzenberger, Niels Birbaumer, and Gerhard Buchkremer (1999). "Frontal brain asymmetry as a biological substrate of emotions in patients with panic disorders." In: *Archives of general psychiatry* 56.1, pp. 78–84.

Zhao, Guozhen, Yulin Zhang, Yan Ge, Yan Zheng, Xianghong Sun, and Kan Zhang (2018). "Asymmetric hemisphere activation in tenderness: evidence from EEG signals." In: *Scientific reports* 8.1, p. 8029.

Zhao, Li and Yang He (2013). "Power spectrum estimation of the welch method based on imagery EEG." In: *Applied Mechanics and Materials* 278, pp. 1260–1264.

Appendix

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

public class MovingSpider : MonoBehaviour
{
    public float speed = 2;
    public float direction_var = 1f;
    public string animation_trigger_walk;
    public string animation_trigger_idle;
    public AudioClip walkClip;
    public AudioClip idleClip;

    private Vector3 target = new Vector3(0f, 0f, 0f);
    private Animator spider_animation = null;
    private float Sec = 0.0f;
    private bool SetWalkTrigger = false;
    private AudioSource soundEffect;


    void Start()
    {
        spider_animation = GetComponent<Animator>();
        float x = Random.Range(0.0f,-2.0f);
        float z = Random.Range(0.0f,2.0f);
        target = new Vector3(x, 0.0f, z);
        soundEffect = GetComponent<AudioSource>();
        Sec = Random.Range(0.0f,5.0f);
    }

    void Update()
    {
        if(spider_animation != null)
        {
            if(Sec <= 10.00f)
            {
                if(SetWalkTrigger == false)
                {
                   spider_animation.SetTrigger(animation_trigger_walk);
                   soundEffect.clip = walkClip;
                   soundEffect.Play();
                }
                SetWalkTrigger = true;
                Sec += 1*Time.deltaTime;
                MoveToTarget();
                float dist = Vector3.Distance(transform.position, target);
                if(dist<0.1f)
                {
                    spider_animation.SetTrigger(animation_trigger_idle);
                    soundEffect.Stop();
                    soundEffect.clip = idleClip;
                    soundEffect.Play();
                    Sec = 10.1f;
                    SetWalkTrigger = false;
                }

            }
            else
            {
                if(SetWalkTrigger == true)
                {
                    spider_animation.SetTrigger(animation_trigger_idle);
                    soundEffect.Stop();
                    soundEffect.clip = idleClip;
                    soundEffect.Play();
                    SetWalkTrigger = false;
                }
                Sec += 1*Time.deltaTime;
                if(Sec > 20)
                {
                    Sec = Random.Range(0.0f,5.0f);;
                    float x = Random.Range(0.0f,-2.0f);
                    float z = Random.Range(0.0f,2.0f);
                    target = new Vector3(x, 0.0f, z);
```

```
                }
            }
        }

    }

    void MoveToTarget()
    {
        Vector3 direction = (target - transform.position).normalized;
        Quaternion lookRotation = Quaternion.LookRotation(direction_var*direction);
        transform.rotation = Quaternion.Slerp(transform.rotation, lookRotation,
                Time.deltaTime * speed * 7);
        transform.position = Vector3.MoveTowards(transform.position, target, speed *
                Time.deltaTime);
    }
}
```

Listing 1: MovingSpider C# Script

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

public class ClimbingSpider : MonoBehaviour
{
    public float speed = 2;
    public float direction_var = 1f;
    public string animation_trigger_walk;
    public string animation_trigger_idle;
    public AudioClip walkClip;
    public AudioClip idleClip;

    private Vector3 target = new Vector3(0f, 0f, 0f);
    private Animator spider_animation = null;
    private float Sec = 0.0f;
    private bool SetWalkTrigger = false;
    private AudioSource soundEffect;


    void Start()
    {
        spider_animation = GetComponent<Animator>();
        float y = Random.Range(0.0f,2.5f);
        float z = Random.Range(-1.5f,2.3f);
        target = new Vector3(-2.5f, y, z);
        soundEffect = GetComponent<AudioSource>();
        Sec = Random.Range(0.0f,5.0f);
    }

    void Update()
    {
        if(spider_animation != null)
        {
            if(Sec <= 15.00f)
            {
                if(SetWalkTrigger == false)
                {
                   spider_animation.SetTrigger(animation_trigger_walk);
                   soundEffect.clip = walkClip;
                   soundEffect.Play();
                }
                SetWalkTrigger = true;
                Sec += 1*Time.deltaTime;
                MoveToTarget();
                float dist = Vector3.Distance(transform.position, target);
                if(dist<0.1f)
                {
                    spider_animation.SetTrigger(animation_trigger_idle);
                    soundEffect.Stop();
                    soundEffect.clip = idleClip;
                    soundEffect.Play();
                    Sec = 15.1f;
                    SetWalkTrigger = false;
                }
```

```

            }
            else
            {
                if(SetWalkTrigger == true)
                {
                    spider_animation.SetTrigger(animation_trigger_idle);
                    soundEffect.Stop();
                    soundEffect.clip = idleClip;
                    soundEffect.Play();
                    SetWalkTrigger = false;
                }
                Sec += 1*Time.deltaTime;
                if(Sec > 20)
                {
                    Sec = Random.Range(0.0f,5.0f);;
                    float y = Random.Range(0.0f,2.5f);
                    float z = Random.Range(-1.5f,2.3f);
                    target = new Vector3(-2.5f, y, z);
                }
            }
        }

    }

    void MoveToTarget()
    {
        Vector3 direction = (target - transform.position).normalized;
        Quaternion lookRotation = Quaternion.LookRotation(direction_var*direction, new
               Vector3(1.0f, 0.0f, 0.0f));
        transform.rotation = Quaternion.Slerp(transform.rotation, lookRotation,
               Time.deltaTime * speed * 7);
        transform.position = Vector3.MoveTowards(transform.position, target, speed *
               Time.deltaTime);
    }
}
```

Listing 2: ClimbingSpider C# Script

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

public class GetSpiderEnv : MonoBehaviour
{
    public GameObject BlackSpiderPrefab;
    public GameObject SpiderPrefab;
    public GameObject ClimbWallSpiderPrefab;
    public GameObject WebSpiderPrefab;
    private Vector3 StartPosition;
    private Vector3 StartPositionWall;
    private Vector3 StartPositionCeiling;

    public GameObject GoodShell;
    public GameObject BrokenShell;
    public GameObject GoodPallet;
    public GameObject BrokenPallet;
    public GameObject GoodWall;
    public GameObject BrokenWall;
    public GameObject NormalLight;
    public GameObject FlickeringLight;
    public GameObject Barrel;
    public Material RustyMat;
    public GameObject maleHead;
    public GameObject femaleHead;
    public GameObject SpiderWebCollection;

    private int StimulusLevel = 0;
    private float spider_size = 0.002f;
    private int spider_amount = 1;


    void Start()
    {
```

```
        maleHead.transform.localScale = new Vector3(0.01f, 0.01f, 0.01f);
        femaleHead.transform.localScale = new Vector3(0.01f, 0.01f, 0.01f);
        StartPosition = new Vector3(-2.42f,0.0f,2.42f);
        StartPositionWall = new Vector3(-2.5f,0.25f,0.8f);
    }

    void Update()
    {
        //Setup the Spider Environment
        if (GlobalVariableSpiderScene.TriggerSpiderEvironment == true)
        {
            GoodShell.SetActive(false);
            BrokenShell.SetActive(true);
            GoodPallet.SetActive(false);
            BrokenPallet.SetActive(true);
            GoodWall.SetActive(false);
            BrokenWall.SetActive(true);
            SpiderWebCollection.SetActive(true);
            NormalLight.SetActive(false);
            FlickeringLight.SetActive(true);
            Barrel.GetComponent<MeshRenderer>().material = RustyMat;
        }
        //Pretest Spider Stimuli
        if (GlobalVariableSpiderScene.TriggerSpiderStimulus == true)
        {
            for (int i=0;i<100;i++)
            {
                GameObject newSpider = Instantiate(SpiderPrefab, StartPosition, Quaternion.identity) as GameObject;
                newSpider.transform.localScale = new Vector3(0.02f, 0.02f, 0.02f);

            }
            for (int i=0;i<100;i++)
            {
                GameObject newClimbWallSpider = Instantiate(ClimbWallSpiderPrefab, StartPositionWall, Quaternion.identity) as GameObject;
                newClimbWallSpider.transform.localScale = new Vector3(0.02f, 0.02f, 0.02f);
            }
            for (int i=0;i<5;i++)
            {
                float x = Random.Range(-2.2f,-1.0f);
                float y = Random.Range(0.8f,1.5f);
                float z = Random.Range(-1.3f,1.8f);
                StartPositionCeiling = new Vector3(x, y, z);
                Instantiate(WebSpiderPrefab, StartPositionCeiling, Quaternion.identity);
            }
        }
        //Main Test with Stimulus Levels to increase the Level
        if (GlobalVariableSpiderScene.IncreaseSpiderStimulus == true && StimulusLevel < 5)
        {
            StimulusLevel += 1;
            spider_size = StimulusLevel * 0.008f;
            spider_amount = StimulusLevel * 5;

            for (int i=0;i<spider_amount;i++)
            {
                GameObject newSpider = Instantiate(SpiderPrefab, StartPosition, Quaternion.identity) as GameObject;
                newSpider.transform.localScale = new Vector3(spider_size, spider_size, spider_size);
                newSpider.tag = "Level"+StimulusLevel.ToString();

            }
            for (int i=0;i<spider_amount;i++)
            {
                GameObject newClimbWallSpider = Instantiate(ClimbWallSpiderPrefab, StartPositionWall, Quaternion.identity) as GameObject;
                newClimbWallSpider.transform.localScale = new Vector3(spider_size, spider_size, spider_size);
                newClimbWallSpider.tag = "Level"+StimulusLevel.ToString();
            }
            for (int i=0;i<1;i++)
            {
                float x = Random.Range(-2.2f,-1.0f);
                float y = Random.Range(0.8f,1.5f);
```

```
                float z = Random.Range(-1.3f,1.8f);
                StartPositionCeiling = new Vector3(x, y, z);
                GameObject newWebSpider = Instantiate(WebSpiderPrefab, StartPositionCeiling,
                       Quaternion.identity) as GameObject;
                newWebSpider.tag = "Level"+StimulusLevel.ToString();
            }
            GlobalVariableSpiderScene.IncreaseSpiderStimulus = false;
        }
        //Main Test with Stimulus Levels to decrease the Level
        if (GlobalVariableSpiderScene.DecreaseSpiderStimulus == true && StimulusLevel > 0)
        {
            GameObject[] destroySpiders =
                   GameObject.FindGameObjectsWithTag("Level"+StimulusLevel.ToString());
            foreach(GameObject destroySpider in destroySpiders)
                Destroy(destroySpider);
            StimulusLevel -= 1;
            GlobalVariableSpiderScene.DecreaseSpiderStimulus = false;
        }
        //Emergency Stop Key to return to normal rest environment
        if (Input.GetKey("1"))
        {
            GoodShell.SetActive(true);
            BrokenShell.SetActive(false);
            GoodPallet.SetActive(true);
            BrokenPallet.SetActive(false);
            GoodWall.SetActive(true);
            BrokenWall.SetActive(false);
            SpiderWebCollection.SetActive(false);
            NormalLight.SetActive(true);
            FlickeringLight.SetActive(false);
            Barrel.GetComponent<MeshRenderer>().material = RustyMat;

            Object[] allObjects = FindObjectsOfType(typeof(GameObject));
            foreach(GameObject obj in allObjects) {
                if(obj.transform.name == "spider(Clone)") {
                Destroy(obj);
                }
                if(obj.transform.name == "ClimbWallSpider(Clone)") {
                Destroy(obj);
                }
                if(obj.transform.name == "WebNetSpider(Clone)") {
                Destroy(obj);
                }
                if(obj.transform.name == "WebNetSpider(Clone)") {
                Destroy(obj);
                }
                if(obj.transform.name == "smallspider(Clone)") {
                Destroy(obj);
                }
                GlobalVariableSpiderScene.TriggerSpiderEvironment = false;
            }
        }
    }
}
```

Listing 3: getSpiderEnv C# Script