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Bachelor of Science

# Development and gamification of a neurofeedback application to support anxiety treatment

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*"The Man who says he can, and the man who says he can not.*
*Are both correct"*
*Confucius*

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This is just one of the first pages of a beautiful story...

# Abstract


Anxiety disorder is one of the most common mental illness, affecting 264 million people worldwide.

Current treatments are limited because they cause side effects and/or require long therapeutic periods. Neurofeedback (NFB) has been associated with the reduction of anxious symptomatology but typically uses unappealing therapeutic interventions.

In this work a game was developed, Anxiety Destroyer, using procedures of gamification adapted to the NFB, with the goal of providing a guided, immerse and efficient treatment, to be used at home. The lean method was applied to the development process by construction-measurement-learning of value propositions.

Thirty people were studied, which performed up to 8 NFB sessions for 35 minutes, totalling 185 sessions, 108 hours. Three groups of 10 individuals were created, one group with frontal alpha asymmetry (Alpha Asymmetry (ALAY)) protocol (F4-F3), another with asymmetry between AF4 and AF3 channels (AF) for hairless skin usage and another control group, with increased alpha in F4 and F3 (F+). The Beck Anxiety Inventory (BAI) was applied to assess anxiety. The Game Experience Questionnaire (GEQ) was used to evaluate game experience in different versions, which were adapted to the needs of the user.

The ALAY group significantly increased the asymmetry ($p < 0.05$) (reduction of the anxiety biomarker), with a corresponding significant reduction ($p < 0.01$) in the anxiety reported by BAI after NFB training. The AF group showed a decrease in the frontal alpha asymmetry, and the F+ a slight increase, respectively confirmed by the increase and decrease of the BAI. The GEQ did not show better gaming experience throughout sessions.

An increase of the sample size is required to confirm these results, inclusively since some individuals in the AF and F+ groups abandoned treatment because of no perceived effects. However, this study suggests the effectiveness of the gamified application in the treatment of anxiety.



**Keywords:** Neurofeedback, Anxiety, Gamification, Electroencephalography, Lean

# Resumo


A perturbação de ansiedade é das doenças mentais mais comuns, afetando 264 milhões de pessoas em todo o mundo.

Os tratamentos atuais são limitados, tendo efeitos adversos e/ou necessitando de longos períodos terapêutico. O NFB tem sido associado à redução de sintomatologia ansiosa, contudo ter recorrido a intervenções pouco estimulantes.

Neste trabalho pretendeu-se desenvolver um jogo, Anxiety Destroyer, que recorrendo a processos de gamificação adaptada ao NFB, permitisse realizar um tratamento guiado, imersivo, eficiente e de utilização domiciliária. O método lean foi aplicado ao processo de desenvolvimento, pela construção-medição-aprendizagem de propostas de valor.

Estudaram-se 30 pessoas, que realizaram até 8 sessões de NFB durante 35 minutos, totalizando 185 sessões, 108 horas. Criaram-se 3 grupos de 10 indivíduos, um grupo com protocolo de assimetria frontal (F4-F3) em alfa (ALAY), outro de assimetria entre os canais AF4 e AF3 (AF) para utilização em pele glabra e um outro de controlo, aumentado-se alfa em F4 e F3 (F+). Foi aplicada a escala de Beck (BAI) para avaliar a ansiedade. Usou-se o Game Experience Questionnaire (GEQ) para avaliar a experiência de jogo em diferentes versões, que se foram adaptando às necessidades do utilizador.

O grupo ALAY aumentou significativamente a assimetria ($p<0.05$) (redução do biomarcador de ansiedade), e correspondente redução significativa ($p<0.01$) da ansiedade reportada pelo BAI após treino por NFB. O grupo AF apresentou um decréscimo da assimetria frontal alfa, e o F+ um ligeiro aumento, confirmados pelo aumento e diminuição do BAI, respetivamente. O GEQ não mostrou uma melhor experiência de jogo ao longo das sessões.

Será necessário aumentar a amostra de estudo para se poderem confirmar estes resultados, tendo inclusive alguns indivíduos dos grupos AF e F+ abandonado o tratamento por não verem efeitos. Contudo, este estudo sugere eficácia da aplicação gamificada no tratamento da ansiedade.



**Palavras-chave:** Neurofeedback, Ansiedade, Gamificação, Eletroencefalografia

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# Acronyms

**ALAY** Alpha Asymmetry.

**ANS** Autonomic Nervous System.

**APA** American Psychological Association.

**ATP** Adenosine Triphosphate.

**BAI** Beck Anxiety Inventory.

**CBT** Cognitive-Behavioral therapy.

**EEG** Electroencephalography.

**EU** European Union.

**GEQ** Game Experience Questionnaire.

**LTP** Long-Term Potentiation.

**MVP** Minimum Viable Product.

**NFB** Neurofeedback.

**PANS** Parasympathetic Autonomic Nervous System.

**SANS** Sympathetic Autonomic Nervous System.

**SNS** Somatic Nervous System.

**STDP** Spike Time-Dependent Plasticity.

**USA** United States of America.

# Chapter 1

# Motivation

What if you could develop a tool capable of benefiting billions of people around our world, would you do that? Why not? What's more important than that? If you find something more meaningful, great, go get it! Anyway, this thesis started with a great sense of purpose, believing that something great could start with it, believing that this insignificant work could change the life of each, any and everyone that suffers, and is constrained by the greatest mind thief of this millennium, Anxiety.

## 1.1 Anxiety Incidence, Definition and impact

Anxiety is the most common neuropsychological disease worldwide together with depression [1] [2]. That is so massive that studies indicate that it can account for 264 million people across the world, a number that grew 14.9% since 2005 [2].

If we look at the European Union (EU), it was shown that the number of people that suffers from an anxiety disorder in a given year, is over 60 million, making it the most frequent psychiatric condition in the EU [3]. According to the National Institute of Mental Health, in the United States of America (USA), the prevalence of any anxiety disorder among adults is estimated to be 19.1%, and it was reported that further 31,1% of USA adults had experienced some anxiety disorder in their lives [4]. It was estimated that the burden to the economy of the USA, in a year, was between a total of $42.3 and $46.6 billion [5] [6].

The American Psychological Association (APA) defines anxiety as "*an emotion characterized by feelings of tension, worried thoughts, and physical changes*"[7], and the National Institute of Mental Health clarifies, "*but anxiety disorders involve more than temporary worry or fear. For a person with an anxiety disorder, the anxiety does not go away and can get worse over time*"[8].

Generally, people have anxiety symptoms that are below the threshold to be diagnosed with an anxiety disorder. These people are characterized by having phases, where they feel anxiety symptoms followed by extended periods where they do not suffer from it. Adverse life events and social factors trigger symptoms. People who suffer from an anxiety disorder tend to have a chronic course, recurrently having anxiety symptoms that vary in intensity along time. These symptoms last for long periods, often years, and the person with this disorder cannot get out of this worrying state [9]. According to Blaskovits, "*anxiety also have direct neurobiological consequences. Stress hormones have been linked to neuronal remodeling, excitotoxic damage and neuroanatomical changes to the hippocampus and basolateral amygdala*"[10].

The effects of anxiety in the body are extensive and can be harmful. It can vary from extreme fatigue, muscle aches, loss of libido, upset stomach, heart palpitations and chest pain with the increased risk of high blood pressure and heart disease, stomach-aches, nausea, diarrhea, depression, headaches, irritability or panic attacks [11].

When diagnosed as a disorder, if not treated anxiety has been associated to significant costs, both personal and societal, and to frequent acute and primary care visits, unemployment, decreased work productivity and impaired social relationships [12].

The anxiety disorder can be subdivided into subtypes such as generalized anxiety disorder (GAD), panic disorder and various phobia-associated disorders [8].

## 1.2 Why are current anxiety treatments not working

There are several types of treatment for anxiety, of which two are included in treatment guidelines [9] [13] [14] in both psychotherapy and psychopharmacological medication have shown efficacy in treating the three main types of anxiety, generalized anxiety, panic disorders, and social anxiety.

A rooted and lasting treatment kind of psychotherapy is labeled Cognitive-Behavioral therapy (CBT). Its primary purpose is to recognize, understand, and alter thinking and behavior patterns. In CBT, the patient is actively participating throughout recovery of his disorder, gaining a sense of control over life, and learning skills that are expected to be beneficial. This kind of therapy usually includes maintaining records between appointments and concluding homework assignments in which the treatment procedures are practical. Patients learn skills all along therapy sessions, but they must frequently practice, to see progress. Unfortunately, this kind of psychotherapeutic approach only partially reduces its disease burden, often people relapse after the conclusion of the therapy. Also, often doesn't work for everybody [15], mainly because of personality characteristics of anxious people that create barriers to therapy by not doing homework and not leaving harmful beliefs due to their excessive worry thoughts [15]. Moreover, the benefits of CBT are on average just seen after 12 to 16 weeks of treatment [16].

Regarding medication, it is useful just in short-term, since it is beneficial for alleviating the symptoms. Several possibilities differ as much in the effectiveness as in the severity of the adverse effects that can be caused [13]. These drugs affect neurotransmitters presented in the body. Different drugs affect different neurotransmitters that can lead to a more relaxed state.

There are a variety of studies which show the side effects and dangers of using medication as an answer to an anxiety disorder. According to Bystritsky, medication "*were found to increase the risk of suicidality and atypical neuroleptic agents caused tardive dyskinesia and arrhythmias [1]. All of these drugs can cause weight gain and sexual dysfunction. They also cause dependence, somnolence, motor incoordination, memory disorders, confusion and depression [17]. Because polypharmacy is becoming the rule rather than the exception, especially in complex and treatment-resistant anxiety, practitioners should be cognizant of potential drug-drug interactions* [1]".

In a recent study [18] comparing anxiety treatment by psychotherapy and medication, it has been shown that medication is more effective than psychotherapy in the short-term. However, it is important to note that there are side effects related to the taking of medication. Concerning treatment by psychotherapy, such as anxiety disorder, adverse side effects on the health of the individual are not known.

Affective psychological disorders are not generated by a single event as deficiencies in particular neurotransmitters or damage in a localized brain region, having complicated biological causes. These disorders are related to destabilization in the electrical activity within networks of brain connections that cause a shift in mood and behavior [19]. This kind of disorders can be affected by anomalies in the brain's intrinsic networks, such as Default Mode Network [20]. Treatment protocols in regions with abnormal activity have the potential to harmonize the brain's activity and mitigate the duration or severity of anxiety [15].

The most used methods to treat anxiety are insufficient. A rapid solution is paid frequently by strong side effects and a more safe way to treat anxiety involve extended periods. Moreover, the mean estimated cost to treat one patient with anxiety is 6,465$ which translates into great expenses for the healthcare system and the individuals [21].

## 1.3 Neurofeedback has recently being used at clinical procedures to treat anxiety

There are some emergent forms to treat anxiety. Between those, NFB is having a huge impact with the scientific community [22] [10] [23].

NFB is an emergent form of therapy. It uses EEG that presents real-time information about brain activity recorded from the scalp of an individual. NFB is a non-invasive method where in order to access the target EEG component that is being rewarded, individuals learn to optimize their brain activity. The objective is to "train"the brain by rewarding the person, that is doing NFB, by increasing or decreasing a particular EEG component that should be altered. For that, a NFB protocol must be applied, which is based on operant-conditioning paradigms, explained in chapter 2.1.2. The EEG components trained by an individual are generally constituted by brain waves (e.g., theta training), but it could also be ratios of brain waves (e.g., alpha/beta ratio training), or an association between different brain regions(e.g., coherence training). The repetition of NFB sessions allows the creation or reinforcement of brain connections and pathways due to the neuroplasticity of the brain [15]. These adjustments in the brain enable positive modifications in the behavior and feelings of the person [24]. NFB training has shown potential for anxiety treatment. It is possible by analyzing the EEG to determine specific biomarkers of anxiety, and the focus of NFB treatment for anxiety relies on identifying and changing those biomarkers. These biomarkers are identified by the spectral power changes of specific frequency bands. Biomarkers include theta (4-8 Hz), alpha (8-13 Hz) waves in some areas of the brain and beta (over 13 Hz), especially in the central and frontal regions of the brain [25]. Studies have shown the efficacy of the NFB practice, revealing improvements in patients suffering from anxiety disorder [26] [23] [27].

Since it is necessary to place the electrodes in a correct position, to monitor the signal quality between the electrodes and the scalp of the individual and to monitor the patient during the NFB session, there has been a necessity for the presence of a clinician/healthcare professional during the session.

## 1.4 Gaming and didactic methods in mental health

The clinical presence during NFB sessions had been necessary for the current years for treating mental disorders. However, what if:

1. The placement of the electrodes would not be a problem for the NFB session.

2. The signal quality during the session would be stable.

We would be left just with the problem of monitoring the behavior of the patient during the NFB session.

What could be an efficient solution to this problem?

Nowadays, more than 32% of the adults between 18-35 years old, allocate on an average of 22 hours per week playing games [28]. Researchers have been attentive to this growth, and games with didactic applications in medicine and education have been developed successfully [29] [30] [31]. The area of mental health has shown that it is prepared to integrate games in order to get better results in treatment [32]. Video games that are not just recreational have shown enormous potential for changing thinking and behavior [32]. Also, games are becoming to be linked with anxiety treatments with great success [33].

It seems that video games could have the potential to be applied for anxiety treatments. What if a shift of perspective would be done in order not to apply games directly to treat anxiety, but to apply games to monitor the NFB session for anxiety treatment? Giving a challenging nature of video games, they could monitor the patient's behavior during a NFB session, guiding them to achieve small objectives in order to shift their brain's abnormal patterns slowly.

Scientists have started to involve gaming with NFB. A study conducted in 2016 [34] evaluated a video game using NFB to prevent anxiety since there was a concern to create an enjoyable game for the user. The NFB game was compared to another game that doesn't use NFB but helped children overcome challenges and anxiety. Participants were just told that they were participating in a study in which both games would help with anxiety reduction. Results were surprising since although many hours were spent in the development of the game and although there were good results regarding the reduction of anxiety, there was no significant difference between one and the other game concerning the decrease of anxiety caused by both games. That was a surprising result that can have different explanations. The possibility of the NFB game containing constant challenges to face fear rather than having some fun-free time may have affected the state of flow (where individuals feel immersed in an activity) that could affect the treatment of anxiety. Another possibility for failure was the choice of the protocol and location of the electrode could not be ideal as a great NFB protocol to treat anxiety. Regardless, a game could be a great possible way to get people involved in the treatment of anxiety, and more research is needed in the use of games and NFB to prove its efficiency.

## 1.5 Connecting Neurofeedback with Gaming

Therefore the main idea for this thesis was to create a game that could join the funniness of a video game and the effectiveness of a NFB clinical session. It was expected that the video game could be more pleasant to an individual. Consequently, the motivation for the training could be higher and it could be translated in a better performance in the NFB session.

Since it was discovered a frontal right lateralization in alpha EEG from patients that suffers from anxiety, comparing to a healthy control group, it could be develop a game with NFB that resorts to a protocol that corrects this pattern of brain activity to recover this patients [10].

## 1.6 Adjusting the product to the user, the Lean process

Since the purpose was to create a product, constituted by an EEG device and the video game, it was essential to build something that could add real value to people. Not only that, but also something that could be built with the feedback collected by the users of our product.

Recently, the approach that a product should be finished before it could be offered to a user was replaced by the lean start-up movement and its iterative empirical methodology on customer validation [35] [36]. In order to increase the fast development of a product's user experience [37], this new lean approach is considered as a philosophical fusion of design thinking, lean production, and Agile development [38]. Moreover, once the Minimum Viable Product (MVP) is ready for use, the lean development cycle can start with user approval tests, in opposition to the past software development proceedings, where much user testing occur only after the conclusion of a conceivable shippable product [39]. It was Frank Robinson the first person to use the term MVP [40], regarding a functional artifact that has enough feature sets to answer the needs or resolve the pain points of the initial users of the MVP. MVP is vital to show targeted users some values that they want. It is essential to clarify the distinctive nature of this method and the Scrum model, once this method is done in sprints with a purpose of validating the usable features that the targeted people are willing to pay.

In contrast, the Scrum model is designed to build a product incrementally without wastage. In order to get the most of a MVP, it is crucial to have a balance between usability and minimalism once that is the best way to get genuine responses by the targeted people and validate each feature of the product [41]. Usability is essential concerning testing the product because people can feel frustrated if the MVP is complicated to use or is not learnable. Such negative emotions can lead to a waste of the viability test. Therefore, it was not easy to learn from an MVP that is not usually enough since the customer is less receptive to the expected value of the MVP [41].

The product that this thesis aimed to develop was evolving in the lean process in order not only to embrace a scientific purpose but also to be a real product, with real value, developed for the real needs that people are willing to pay.

## 1.7 Objectives

**General objective:**

- Develop a gamified NFB application to anxiety treatment.

**Specific Objectives:**

- Adapt the product to the users.
- Develop an appealing game for adults.
- Increased value of the game for the users over time.

# Chapter 2

# Theoretical Concepts

## 2.1 Learning Theory

Fundamentally, for this thesis is necessary that people learn behaviors, that could be translated in a reduction of anxiety. These new behaviors would be programmed into the brain as the process of learning occur.

Although learning is an intensively studied subject, it is challenging to define it. Its definition has evolved over time and authors have been proposing descriptions for learning. One of the most accepted was introduced by Gregory A. Kimble (1917–2006), which defines learning as "*a relatively permanent change in behavioral potentiality that occurs as a result of reinforced practice*. This definition is far from being generally agreed worldwide, regardless, none definition is. If we look at this definition with attention, learning is connected with a change in behavior. Thus, to be able to observe learning is necessary to measure a change in behavior. Therefore learners have won a different ability after the learning process has occurred, even if this ability is just slightly different. Also, what results from learning do not have to appear immediately after learning has occurred. The author also defines a "behavioral potentiality", that means that a particular change in behavior is an option and not an obligation and this change can occur in a later time. It is also important to clarify that a change in behavior results from practice or experience and a reinforcement is needed in order to fix this new learned ability [42].

As we have seen, in general, the experience can modify behavior as a form of leaning. Moreover, the actual process that results in a behavioral change is called conditioning by theorists. There are two types of conditioning, operant and classical, and this means that at least there are two different forms of learning. Since it is fundamental to understand the actual process of behavioral change in order to promote learning, it is crucial to understand what those two types of conditioning are [42].

### 2.1.1 Classical conditioning

As it was demonstrated in a well-recognized study among the scientific community, Ivan Pavlov showed that it is possible to condition the responses of a dog based on a present stimulus. Food that causes a natural and automatic reaction, salivation, was given to a dog, while a bell rang. The food is called the unconditioned stimuli, salivation the unconditioned response and the bell, the conditioned stimuli. After the conditioned stimuli and the unconditioned stimuli are paired for a number of occasions, what happened was that the salivation now also occurred proceeding the conditioned stimuli (the bell), without the necessity of the unconditioned stimuli (the food) be present. The entire process of learning relies on the presence of the unconditioned stimuli, that works as the reinforcement of learning. It is important to note that in classical conditioning, the learning takes place with no control of the reinforcement by the organism which is learning, in this case, the dog. It is the experimenter that determines the entire process. [43] [42].

### 2.1.2 Operant conditioning

Classical conditioning explains the association between two stimuli but does not explain the increasing or decreasing of a behavior. B.F. Skinner was considered the father of operant conditioning and studied how a behavior can be increased or decreased by either reinforcement or a punishment [44]. This kind of conditioning focuses on the association between the behavior and the consequence of that behavior. The organism that is learning must act in a specific way before the presentation of the reinforcer. For example, imagine a trainer is training his dog to give the paw when he says "paw". Every time the dog has success in his task the trainer gives him food, otherwise, the trainer withholds the food. Eventually, the dog will establish an association between the paw and the desired reward, food. The response becomes reinforced if the probability of the response changes depending on the reward or the punishment given to the response. If the reward or punishment accomplishes this objective, it is called a reinforcer.

A reinforcer is exposed to the timing of the reinforcement of behavior, that is crucial to learning, considering that delays as small as a fraction of a second can influence the conditioning by decreasing its strength [45]. Reinforcement schedules vary into two major types, continuous reinforcement (the desired behavior is reinforced each time it occurs and are acquired at a fast pace), and intermittent reinforcement (not every single occurrence of the desired response is rewarded, and it is usually acquired at a slow pace, but the response is more enduring to extinction). There are four schedules of intermittent reinforcement:

1. Fixed-ratio schedules
2. Variable-ratio schedules
3. Fixed-interval schedules

4. Variable-interval schedules

Continuous reinforcement is generally preferable when the intended response is not learned yet. As soon as the response is learned, changing to the intermittent reinforcement produces a lesser probability of the extinction of the learned behavior. For NFB, the major part of the studies has applied a continuous reinforcement schedule within sessions.

Three important terms that concern NFB, and essential for conditioning are shaping, habituation and sensitization.

- **Shaping**: In order to be efficient in the assimilation of a new behavior, successive approximations to the desired behavior should be applied. This is done in the interest of accelerating the learning process, giving positive feedback to behaviors that continuously will end in the final desired behavior [46].
- **Habituation**: This is a phenomenon that occurs when a stimulus is shown repeatedly, creating a decrease in the novelty and reducing the response to stimuli. Habituation causes the reduction of the capacity of conditioning stimuli to produce changes in the behavior [46].
- **Sensitization**: The repetitive nature is comparable with habituation, but it is an entirely different mechanism. Sensitization occurs when an individual has an amplification of awareness for a particular stimulus, and therefore he starts to attribute a negative significance to a stimuli when a stimulus was pretended to be positive or vice versa. In the beginning, he classifies the positive feedback as pleasurable, but after a while, he starts to find the supposed positive feedback as annoying or some other negative feeling that changes the feedback to negative while it should be positive [46].

This conditioning is widely applied in areas such as addiction and dependence, animal training, child behavior - parent management training, economics, praise, psychological manipulation, video games, and others [46].

#### 2.1.2.1 Neurobiology of learning

As we have seen operant and classical conditioning are the two major types of associative learning. It is necessary to understand those in order to understand the underlying mechanisms of learning. If the activity in a presynaptic neuron repeatedly originates firing of the postsynaptic neuron, a permanent alteration in the synaptic structures follows, and it will become easier to fire the postsynaptic neuron since there was a strengthening of that path, as Hebb hypothesized "neurons that fire together wire together"[47]. Contemporary literature holds that the Long-Term Potentiation (LTP) is a necessary underlying mechanism for associative learning to occur. There is a specific form of LTP that recent research has been focusing called Spike Time-Dependent Plasticity (STDP) [48]. In respect to STDP, variations in the timing of weak and intense synaptic inputs over tens of milliseconds cause modifications in synaptic transmission. There are inputs where the transmission increases since the presynaptic response enhance a postsynaptic response. In contrast, other inputs result in a reduced transmission for a "depressed"postsynaptic response. That means that STDP relies on the series of firing times of presynaptic and postsynaptic neurons.

The relationship between STDP and behavioral changes is intermediated by dopamine that is responsible for adjustments in the plasticity of corticostriatal and cortical synapses. However, opposing evidence suggests that LTP is not sufficient or even involved in the association formation [49]. This evidence arose since hippocampal synapses are selectively modified in strength all along the acquisition of classical conditioning but not of operant conditioning, whereas striatal regions are triggered all along operant conditioning but not during classical conditioning [50].

It is necessary for a human to make accurate predictions about future events in order to be ready when this expected event arrives and to adapt to the situation in the most efficient way. Thus, improving the predictions of the future is no more than learning. However, the predictions that humans make generally are not quite correct, so an error occurs in the prediction. It is called prediction errors, and are a fundamental teaching signal that is used to improve prediction accuracy. The prediction error is a key concept in associative learning. It is described as the difference among actual and expected rewards [51]. It is a measure between what would be expected of an outcome, expected signal, and what was the real outcome. This error signal is passed to the cortical and striatum areas. Dopaminergic neurons respond with short-latency plastic bursts [52] in proportion to the reward prediction error signal [53] [54]. Learning arises from the simultaneous existence of a strong presynaptic and postsynaptic activation and dopamine release [55]. According to the 'three-factor learning' which is a postulation that describes the strengthening of the synaptic transmission in those neurons, at the same time that the neurons obtain input from some event in the external surroundings, the dopaminergic input is proportional to the prediction error for the reward [56]. Therefore, on the foundation of feedback, in reaction to the salient stimuli, dopaminergic projections are capable of changing the expected behavior [47].

## 2.2 Electroencephalographic signal

The human brain operates as a conscious and unconscious control center of the body, has a strong chemical and electrical activity. In the presence of clear environmental circumstances, this activity can be identified by patterns that are replicated in particular situations and regions of the brain [57]. EEG is an electrophysiological monitoring method that registers this activity. It has a high temporal resolution, is portable, non-invasive, and is easy to use [58].

### 2.2.1 Nervous System

The Nervous System is anatomically divided into two major zones, the Peripheral Nervous System, which incorporates peripheral nerve brain and spinal cord and the Central Nervous System, which holds the brain and spinal cord [59].

In the way they carry information, there are two different kinds of neurons. The afferent motor neurons that belong to the Peripheral Nervous System respond to external stimuli bringing information to the Central Nervous System (usually sensory neurons) and efferent neurons that transfer information from the Central Nervous System to the organs. Conform to their physiological function efferent motor neurons can be part of the Autonomic Nervous System (ANS), or the Somatic Nervous System (SNS). In order to regulate physiological signals, the SNS is voluntary and enervates the skeletal muscles, and the ANS is involuntary and principally innervates glands and organs. The ANS is classified into two central units: the Sympathetic Autonomic Nervous System (SANS) and the Parasympathetic Autonomic Nervous System (PANS). Some organs are controlled by both (SANS and PANS), while others are just controlled by one of them [60].

The cerebral cortex has a thickness between 2-3 mm and consists of the peripheral layer of the brain. Different areas of the cerebral cortex are responsible for different functions such as perception, voluntary movement, and learning. Concerning anatomical disposition of the cerebral cortex, it has four lobes: the frontal lobe, temporal, parietal and occipital [61] as shown in 2.1.

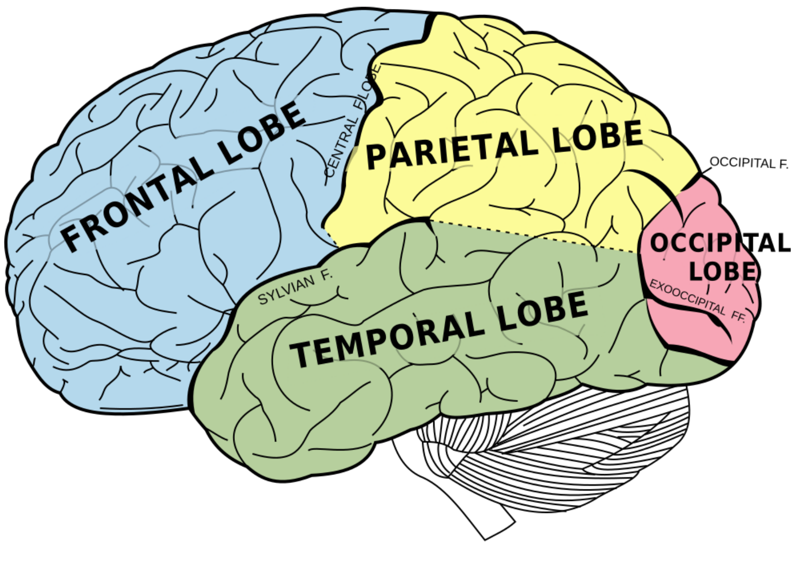


Figure 2.1: Four lobes of the cerebral cortex (adapted from [62])

The frontal cortex is predominantly activated when performing future planning, including self-management and decision-making. Some functions include forming memories, understanding and reacting to the feelings of others, forming personality and reward-seeking behavior and motivation [63].

Neurons and glial cells are part of the nervous tissue [59]. The neurons are the primary structural and functional part of the nervous system. Neurons have the function of reacting to chemical and physical stimuli, directing electrochemical impulses, and even releasing chemical regulators. While doing that, neurons support learning, the perception of sensory stimuli, control of muscles and memory [59]. Besides, not only glial cells are qualified for numerous functions necessary to the normal physiology of the nervous but also afford anatomical and functional support to neurons [59].

Neurons have different sizes and shape, but all have three major regions: the cell body, dendrites, and axon (see Figure 2.2).

The nucleus of the nerve cell is located at the cell body, while dendrites and axons are extensions of this. The transmission of the electrochemical impulses to the cell body is carried by dendrites that have a receptive area responsible for that. In turn, the axon transfers these impulses to the dendrites of the next nerve cell, preserving the electrical signal [59].

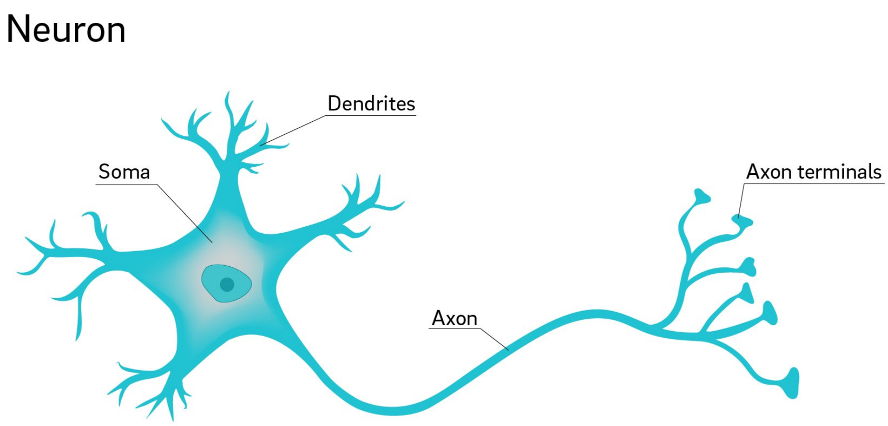


Figure 2.2: Motor Neuron Structure (adapted from [64])

### 2.2.2 Electrophysiology

#### 2.2.2.1 Membrane potential

Cells have a potential difference in the membrane. The membrane is polarized when the inside of the cell is negative compared to the outside. Thus the resting potential occurs, indicating that there is a difference in electric charge. In the case of neurons, the resting potential corresponds to -70 mV. The potential difference is the result of permeability of the cell membrane to specific ions present on both sides of the membrane (such as K+ (potassium), Na+ (sodium), Cl- (chlorine), among others), as well as the presence of proteins present on the membrane itself that influences that difference [59].

They are responsible for keeping the potential difference and the ionic concentrations of the membrane.

What allows the maintaining of the potential difference between the inside and outside of the cell is the passage of sodium and potassium ions in the cell membrane that involves the use of a sodium-potassium pump [59]. Since this process occurs against the concentration gradient and involves energy expenditure in for of Adenosine Triphosphate (ATP), it is called active transport. This pump is a transmembrane protein that concurrently carries three ions of sodium to the outside of the cell and two ions of potassium in the interior. Therefore, there is a higher concentration of sodium ions in the extracellular medium, and a higher concentration of potassium ions within the cell [59].

#### 2.2.2.2 Action potential

Although all cells have membrane potential, only a few cell types undergo an alteration of their membrane potential in response to a stimulus. As already mentioned, such changes result from the permeability of certain membranes to specific ions when stimulated. The physiology that characterizes the neurons and the cells of the muscular tissues allows to produce and to transmit these alterations through the membrane potential [59]. Potential action, or nerve impulse, can be defined as a wave of electric discharge that travels through the membrane of the neuron [65].

The action potential has two main phases: depolarization and repolarization. After stimulating the stimulation of the sodium channels, they are the first ones to be opened, causing the entry of positive charges due to Na+ ions and consequent depolarization. Then, the potassium channels open, allowing the exit of the K+ ions, producing repolarization of the membrane potential. The hyperpolarization phase is called the refractory period and is when the membrane potential becomes "more negative"than the resting potential because the potassium channels remain open after the repolarization phase ends. This prevents further depolarization from occurring while this phase lasts.

Through the analysis of figure 2.3 it is realized that, during depolarization, the membrane potential becomes "less negative"until it reaches a positive value. In the repolarization phase, the membrane potential returns to the resting state (approximately -70 mV) [66].

An action potential occurs on the membrane of an axon when depolarization reaches a certain threshold of excitation, about -55 mV for many neurons, and usually constant in each of them. Thus, the creation of an action potential depends on a stimulus sufficient to cause a change in membrane potential up to the excitation threshold. If this condition is verified, the neuron is triggered.

However, a depolarization "stronger"than the threshold of the neuron, has the same amplitude as a stimulus of the same threshold value. That is, each time an action potential is generated, its amplitude is constant and does not depend on the intensity of the stimulus. However, the higher the intensity of the stimulus, the greater the frequency of

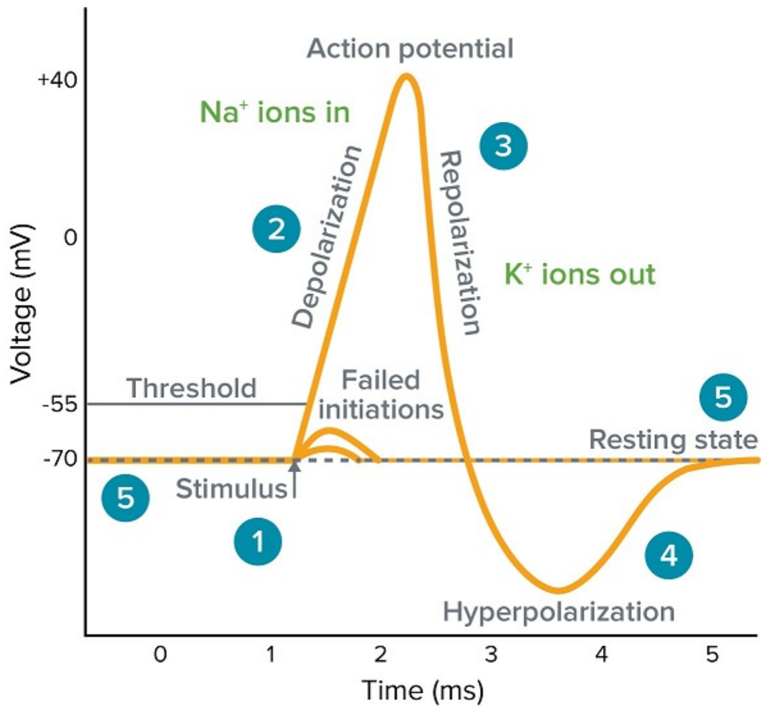


Figure 2.3: Action potential. **1.** Stimulus begins the quick shift in voltage or action potential. Enough current need be applied to the cell in order to increase the voltage above the threshold voltage to begin membrane depolarization. **2.** Depolarization is generated by fast growth in membrane potential opening of sodium channels in the cellular membrane, ending in an extensive influx of sodium ions. **3.** Membrane Repolarization appears from fast sodium channel inactivation and a huge efflux of potassium ions resulting from activated potassium channels. **4.** Hyperpolarization is a diminished membrane potential generated by the efflux of potassium ions and closing of the potassium channels. **5.** Resting state is when membrane potential returns to the resting voltage that happened before the stimulus occurred (adapted from [67])

.

the action potential until a maximum frequency value is reached [66].

Thus, the action potential follows the "all or nothing"rule: either it occurs completely or does not occur if the stimulus is below the excitation threshold (post-synaptic potential) [59].

### 2.2.3 Electroencephalogram

#### 2.2.3.1 Detection of electric currents in the scalp

The synaptic potentials produced in the cell body and dendrites of the cerebral cortex create electrical currents that can be detected by electrodes placed on the scalp. The detection of such electrical activity in the scalp is only possible thanks to the activation of a considerable amount of neurons, responsible for producing electric current flows. The electroencephalogram is the name given to the recording of these currents [59].

A detailed analysis of the information obtained by the technique of Electroencephalography allows the diagnosis of specific pathologies, namely when EEG signals are detected that deviate from the normal functioning patterns [59]. EEG analysis is used both to study the functions of normal brain activity, such as changes occurring during the sleep phase and states of emotion, such as to diagnose certain diseases, such as epilepsy, tumors, and degenerative diseases [66].

As already mentioned, in this equivalent diagnostic examination, metal electrodes and conductive means are used to detect the variation of electrical activity generated by brain structures [68].

#### 2.2.3.2 International Standard 10/20

The 10/20 System is an internationally recognized method to describe the location of the electrodes in the scalp. This method is based on the relationship between the location of the electrode and the area of the corresponding cerebral cortex and uses 21 points in total (see figure 2.4), whose nomenclature is designated according to the region in which they are located: frontal (F), frontopolar (Fp), central (C), temporal (T), posterior (P) and occipital (O). Note that the letter "z"(zero) represents the electrodes placed on the center line. The even numbers (2,4,6,8) refer to the electrodes placed in the right hemisphere, and the odd numbers (1,3,5,7) refer to the electrodes positioned in the left hemisphere [69].

### 2.2.4 EEG Typical Waves

The waves read by the equipment have specific frequencies. Those frequencies are packed into sets of frequencies and called different names. The important sets of brain waves are categorized into the delta, theta, alpha and beta waves [59] and each one describe a particular physiological function [71].

**Delta Waves 0.5-4 Hz** Delta waves are slow waves, regarding different general characteristics such as: Unawareness, deep-unconsciousness, sleep, repair, complex problem solving [71].

**Theta Waves 4-8 Hz** Theta waves are relatively slow waves, regarding different characteristics such as: Unconsciousness, creativity, insight, deep states, optimal meditative state, depression, distractibility, anxiety [71].

**Alpha Waves 8-13 Hz** Alpha are waves, regarding different characteristics such as: Deeply-relaxed, meditation, alertness and peacefulness, readiness [71].

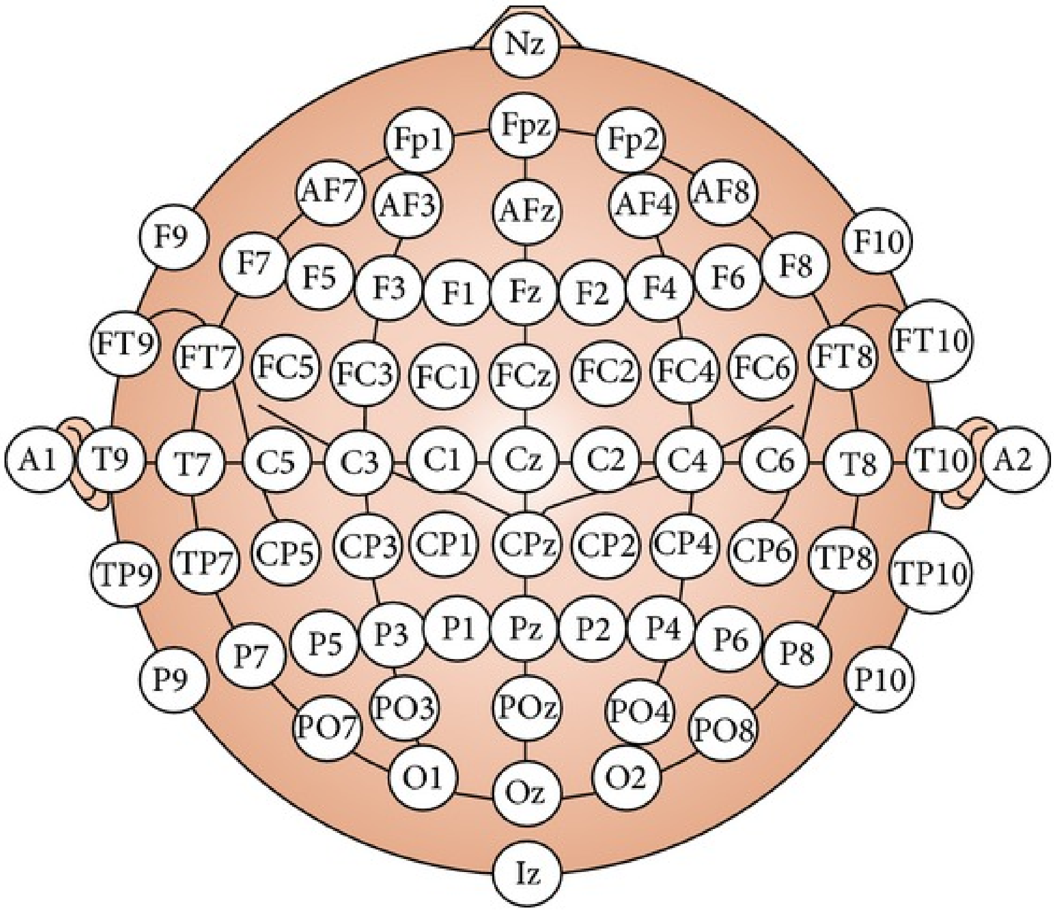


Figure 2.4: 10/20 system for positioning electrodes (adapted from [70])

**SMR (sensorimotor rhythm) 13-15 Hz** SMR are associated to the sensorimotor rhythm and labeled as low beta, regarding different characteristics such as: Mental alertness, physical relaxation [71].

**Beta Waves 15-20 Hz** Beta are relatively fast waves, regarding characteristics such as: Thinking, focusing, sustained attention, tension, alertness, excitement [71].

**High Beta Waves 20-32 Hz** High Beta are fast waves, regarding characteristics such as: Intensity, hyperalertness, anxiety [71].

**Gamma Waves 32-100 Hz or 40 Hz** Gamma are swift waves. Different authors defend different ranges, but in general, vary from 32 Hz to 40 Hz or 100 Hz. They are associated with characteristics such as: Learning, cognitive processing, problem-solving tasks, mental sharpness, brain activity, organize the brain [71].

## 2.3 Neurofeedback

### 2.3.1 Basic Setup of neurofeedback

According to Huster *et al*, the process of doing neurofeedback is generally divided into five stages. Starting with the brain signal acquisition, followed by signal preprocessing, feature extraction, generation of a feedback signal and the final step, adaptive learning.

**1. Acquisition of Brain Signals** Generally, the most used real-time functional neuroimaging methods underly the same representation of neural activation. The three well-known methods to directly measure the extracellular field potential, are electroencephalography (EEG), magnetoencephalography (MEG) and electrocorticography (ECoG) [47]. These methods have a high temporal resolution (about 1 ms). These non-invasive methods, EEG and MEG, can collect information from all the cortex, nevertheless they have a poor spatial resolution, 5 $cm^2$ [72] and 10 $mm^2$ [73]. Conversely, measurements taken from ECoG, which is measured at the surface of cortex have a spatial resolution of just about 5 $mm^2$. EEG is the most used recording method for neurofeedback. EEG has the advantage of being portable and low-cost equipment [47].

One of the other most used techniques for the acquisition of brain signal, is the functional magnetic resonance imaging (fMRI), in contrast to EEG, exploits the fact that neural activity and some characteristics of cerebral blood flow are connected. This modality is based on an hemodynamic process alternately to the electric process that EEG uses. Relying on blood-oxygen-level-dependent (BOLD) contrast, where there exists a difference in magnetization between oxygen-rich that gets greater contrast than oxygen-poor blood which has a lower signal. Fundamentally, regional metalization of glucose and oxygen are related to increased neural activity. A local increment typically overcompensates the oxygen consumption in the flow of oxygenated blood. This reflects the metabolic demands of the underlying neural activity, and it is not so closely related to an action potential, instead is more related to postsynaptic activity and field potentials [74] [75]. This method has a relatively low response to blood oxygenation of neural activity and is called haemodynamic response function (HRF). fMRI is a method that detects HRF as the BOLD signal in the brain, and after the stimulus is triggered there exists peaks in HRF at about 5 seconds. This method has an exceptional spatial resolution that is typical of up to $2mm^3$ [76], unfortunately, it lacks in temporal resolution. fMRI and MEG are not portable and expensive since they need more-sophisticated machinery with shielded areas and are priced appropriately.

**2. Preprocessing of recorded signals** In real-time analysis, the signal that derives from these methods is frequently converted to the frequency domain and then it is decomposed into different frequencies. These frequencies were already referred to in 2.2.4. Generally, it is necessary to filter the signal since there are artifacts that appear on the signal that comes from different sources than not the brain. These artifacts can be caused by other

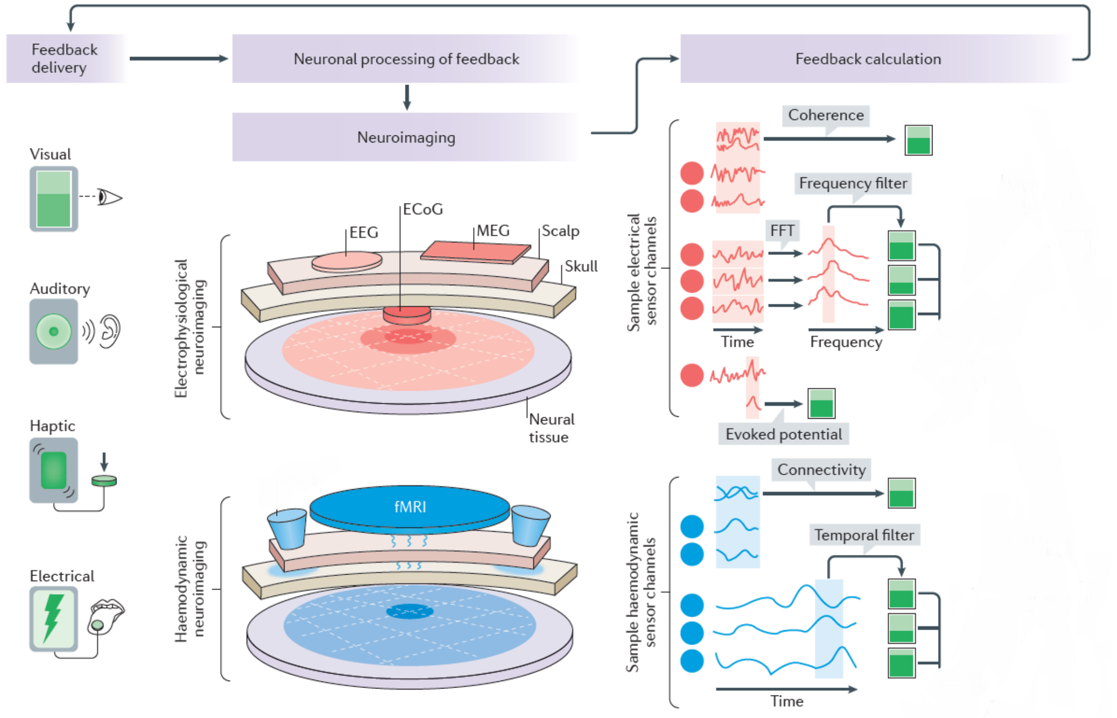


Figure 2.5: Overview of the neurofeedback process (adapted from [47])

electrical equipment, changes in the impedance of the electrodes of physiological origin, such as cardiac, muscular and specifically eye movement. We have been able to remove a significant part of the first type of noise by placing a filter that rejects 50 Hz [77]. As for the signal of cardiac activity can be avoided by careful placement of the electrodes. Muscle activity usually exists in frequencies higher than EEG frequencies (> 30 cycles per second). In any case, care must be taken to warn the user not to grind their teeth or move their head to avoid this type of noise effectively. However, the ocular movement turns out to be an artifact impossible to avoid. Most of the procedures for rejection of this type of artifact use the detection of suspected high activity (greater than 75 microvolts). Its elimination is relevant since eye movements usually generate activity that is abnormal in the EEG [77]. This kind of preprocessing of the recorded signal is important for one being able to get valid data before feature extraction successfully.

**3. Feature Extraction** This turns out to be a critical step since it is responsible for optimizing the performance of the interface through the specific characteristic that we want to extract from the signal. Many techniques can be used, such as Independent Component Analysis (ICA), Principal Component Analysis (PCA), Fourier Transform, or Wavelet. However, most studies only extract the power of a given frequency band after Fourier transform is calculated the preprocessing and segmentation of the data. Then the comparison for each segment of the power value with the power of the baseline of the same frequency is made. This baseline is obtained from the NFB training pre-session [77].

Another widely used method is qEEG, referring to quantitative electroencephalography. In this method after placing 2 or more electrodes in a particular region, they are real-time calculations in order to compare the characteristic of interest with a normative database according to age being extracted the difference between both [78].

Regarding anxiety, studies have recurred to the qEEG method with regularity [78]. However, the training of the frontal asymmetry of the alpha waves seems to be the most successful [23]. This signal characteristic is collected by subtracting the F4 channel from the F3 channel, alpha waves of the 10/20 system.

**4. Feedback Signals** Once a signal characteristic is selected, it is necessary to send this information to the participant in order to close the learning cycle. This is because in NFB training the modification of brain processes in real time is the ultimate goal of the procedure. Thus, how the feedback signal is presented to the user is crucial. The most common forms have been the binaural presentation of the tone whose frequencies change according to the characteristic of interest, as well as the presentation of colored squares that are changing color [79]. Recently, games have been developed to interact with the player for the signal presentation [34]. This kind of feedback will be reviewed later (2.4.1).

**5. Learner characteristics** Finally, it is essential to understand what factors allow participants to succeed in NFB training. Learning to control the brain is the primary objective, and it can be achieved through contingent feedback, rewards and conceivably by verbal instructions and mental strategies that are suggested to the participant by the experimenter [47]. It should be noted that there is no single formula in the best way for the participant to approach training. However, factors such as positive thinking rather than using negative mental strategies are linked to greater success. Participants described some strategies they used to imagine colored rectangles or sing to themselves a song [79].

### 2.3.2 Neurofeedback Specificities

There are two significant concerns regarding the NFB training method to be applied since its choice determines what will be altered and how it will be altered.

#### 2.3.2.1 Band-frequency specificity

The training result is inherently dependent on the chosen frequency band. That is, changing the training band will produce different results [80]. Therefore, it is necessary to know what it will be trained, and what frequency range is associated with that feature.

#### 2.3.2.2 Topographical specificity

The training result is dependent on the spatial placement of the electrodes, which relates the localization of a cognitive function to the behavior expected to change [80]. Regardless, it is known the precise location where electrodes should be placed, but there is insufficient information about what is the distance to which is acceptable to place the electrode from the original correct position. This is an important question since the electrode captures information from all the brain, but it gets more information as the closer it is to the electrode. It remains to discover if some protocols could be done in different but near places in the brain.

### 2.3.3 Neurofeedback Learning Nature

#### 2.3.3.1 Neuroplasticity

At the layer of large cells assemblies, there is enormous evidence that exists specific neural changes from NFB training. It was seen that although non-invasive methods do not are so specific and precise, there are undeniable neuroplastic changes cause by structural changes in grey matter volume and white matter connectivity resulting from various forms of skill training [81] [82]. Ghaziri *et al.* also found this evidence in their study, since, after one week of NFB training of beta waves in the areas of the frontal and parietal region of the brain, increments in grey matter volume and fractional anisotropy in white matter pathways were identified. The structural alterations were linked to considerable enhancement in auditory and visual attention following training [83]. Moreover, the continuation of functional reorganization of the brain after ending the train, confirms neuroplasticity.

#### 2.3.3.2 Brain Regions Associated to the Neurofeedback Process

There is a collection of evidence [84] [85] [86] [87] [88] pointing to fundamental brain regions that are implicated in the itself process of NFB. In the course of generalized NFB, when feedback exhibited visually, the posterior parietal cortex (PPC), anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (dlPFC) and anterior insular cortex (AIC) are activated. Besides, lateral occipital cortex (LOC) is fundamental to regulate attention in the visual signal [89]. Two deep brain regions have the ability to regulate different regions in the brain necessary for the learning through NFB to occur, the thalamus and basal ganglia. Moreover, two complexes are involved in performing executive tasks, like imagery [90], they are the PPC [91] and the dlPFC [92]. They connect with the thalamus to regulate cortical arousal [93]. It is interesting that there are specific parts in the salience network, the AIC, and ACC, that is in control of feedback, rewards and conscious perception [94] [95] [87], whereas, the ventral striatum(VC) is responsible for the processing of unconscious reward [84]. It is known that the dorsal striatum (DS) is directly responsible for the process of learning in NFB. In summary, NFB involves a reward processing network, a control network and a learning network, composed of respectively by the group of AIC, ACC and VS, the group of the thalamus, dlPFC, LOC and PPC and finally the DS shown in the Fig. 2.6.

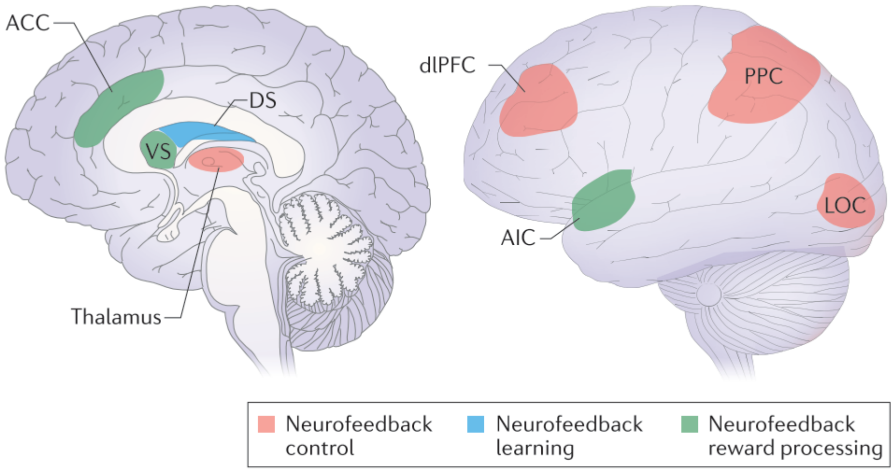


Figure 2.6: Brain regions involved in the process of neurofeedback leaning (adapted from [47])

### 2.3.4 Neurofeedback Learning Perspectives

To increase the probability of differences in neuroplasticity and therefore new originated abilities with NFB it is critical to look at different aspects of the training. Accordingly, it is necessary to be aware of significant aspects of training like, what is suppose to happen during and between sessions, to baseline increments along the practices and other instructions.

#### 2.3.4.1 Between Sessions

Individuals are expected to have difficulty achieving results in the first phase. After this phase, an increase in growth rate of NFB learning is expected until a session where the user reaches a plateau [80].

#### 2.3.4.2 During Session

The studies related to skill development within the same session are not conclusive since there are many factors to be taken into account, many depending on the context of each training [80].

#### 2.3.4.3 Instructions

Previous results suggest that experimenter should not give exact instructions for the training since the non-specific use of mental imagery enables more effective learning [96] [97].

#### 2.3.4.4 Baseline increments

As the purpose of this training is to change the EEG tone of an individual, it is expected that it will have direct implications in the pre-training baseline between sessions [96].

### 2.3.5 Neurofeedback Protocols for Anxiety

Several NFB protocols showed effective results in the treatment of anxiety. Among those protocols, because of its efficacy in the treatment, the following stand out:

- **Beta(F3) alpha/theta ratio (Pz)**:

  This protocol was used recently, by Cheon, Koo, and Choi (2016), during the extended period of 8 weeks and with the participation of 20 adult patients. The practices were divided following the later weeks in the first half, increasing of beta at F3 for 30 minutes, and the second half the increase of alpha/theta ratio at Pz for the same period. Significantly improved symptoms were reported [98].

- **Alpha/theta ratio (F3)**:

  One example of the use of this protocol is in the study of Sadjadi & Hashemian, 2014, where they provided NFB training during 20 sessions to 24 children from 7 to 12 years old. In this protocol is rewarded the increase of alpha/theta ratio, this means that as greater the alpha and as lower the theta the better. The location F3 of the 10/20 system (section 2.2.3.2) was used. The results showed that people who practiced active NFB treatment had less anxiety than people who underwent sham treatment [99].

- **qEEG**:

  Walker, 2009 also reported results from a qEEG protocol at the detection of abnormalities and its correction in 19 patients [100]. That protocol had good results by the increase of generalized alpha and theta was.

- **ALAY**:

  ALAY is one of the most common NFB protocols for the treatment of anxiety. The alpha power difference between the F4 and F3 channels of the 10/20 system (2.2.3.2) is effectively used. Recently, Menella and Palomba (2017) applied this protocol with effective results in 32 healthy students. In just 5 NFB session of 45 minutes, they had significant results in the reducing of anxiety. Moreover, it resulted in clinical benefits presented after six months of the NFB training [23].

## 2.4 Gamification

Having reviewed essential concepts for the application of NFB, it is now necessary to talk about the point of view of the final consumer, through the development of a pleasant environment that encourages the will to train with the use of gamification.

Deterding et al. in 2011 defined gamification "as the use of game design elements in non-game contexts"[101]. The idea is to apply game design elements in non-game contexts in order to stimulate and increase user activity and retention. Making a distinction between gameful design and gamification is important. Whereas they have the same extension of phenomena, the purpose behind them is different, the gameful design has a goal to design for great playability, and gamification aims to just use game design elements as a design strategy [101]. Gamification has attracted researchers [101], because there is a large use of "gamified"applications for large audiences ranging across finance, productivity sustainability entertainment media, education, and health, that potentially indicates fresh, appealing lines of inquiry and data sources for game research and human-computer interaction.

### 2.4.1 Video Games and Play Loyalty

Video games have been growing enormously recently, Lee and Larose (2007) reported that in 2005, retail sales in computer games market reached $US 10.5 billion [102] and Przybylski, Ryan *et al.* (2009) stated that it is even bigger than Hollywood [103].

The users of a video game, demonstrate to have play loyalty (PL) when they play it repeatedly. Flow theory [104] is reported to be the essential construct to explain this subjective experience that takes to PL [105]. This is no more than a state where one reflects the optimum experience of the individual where it feels an enormous excitement and sense of accomplishment. Csíkszentmihályi described flow as a complex construct with eight distinct elements. They refer to the experience that should be intrinsically rewarding, there should be an excellent coupling between the skills of an individual and the challenges conferred by an activity, should contain a considerable amount of concentration and a sense of personal control, support explicit and instant feedback and have clear goals. This is a state that automatically refers to the course of an activity for a considerable period without the perceived passing of that time (Su, Chiang, James Lee, & Chang, 2016). This state consists of perceived enjoyment (PE) and attention focus (AF). In a recent study [106] it was identified that the interactions between man and machine, which result in the interaction between the game and the player, have a tremendously positive influence on PE and AF. Indicating that the interface between the player and the computer and how much better the sound effects are facilitates the creation of an immersive experience in the game itself and ultimately the increase of the PL. Also, the skill and challenge have the same positive relationship in immersion, where the skill refers to the feeling that the player has mastery, while the challenge refers to the events that comprise an obstacle slightly above the current capabilities of the player. In this way, all these factors are decisive for the success of a game, since the same is only possible if there is enough PL.

# Chapter 3

# Methodology

## 3.1 Product Pre-Requirements

- Portability
- User friendliness
- Simple design
- Affordable in cost
- Real time communication between the computer and the player
- Stimulating sound effects
- Challenging game
- Allowing the use of new skills gained during training
- Minimizing the number of channels necessary for the treatment

## 3.2 Equipments available for EEG

There are several possible types of equipment, and solutions to measure EEG. Therefore various aspects needed to be considered when choosing the right equipment. Possible solutions vary according to different characteristics, such as the number of channels to be read, the sampling rate, wireless connectivity, the operational autonomy, the weight, on-board data storage, accelerometry, if medical certified, price and setup time. In the 3.1 and 3.2 below we can see 10 different equipment.

| | Neuroelectrics Enobio 32 | Emotiv Epoc | OpenBCI Cyton | ABM B-Alert X24 | Brain Products ActiCHamp |
|---|---|---|---|---|---|
| **Number of channels** | 32 | 14 | 16 | 24 | Up to 160 |
| **Sampling rate** | 500Hz | 128Hz | 250Hz | 256Hz | 100kHz |
| **Communication** | Bluetooth / WiFi | Proprietary wireless | Bluetooth / RFDuino radio | Bluetooth | Wired |
| **Operating time** | 14 hours | 12 hours | 24 hours | 6 hours Bluetooth / 16 hours SD card | Unlimited (wired) |
| **Weight** | 65g | 125g | 260g | 110g | 1.1kg |
| **Onboard storage** | Yes | No | Yes | Yes | Yes |
| **Accelerometer** | Yes | Yes | Yes | Yes | Yes |
| **Medically certified** | CE / FDA investigational | No | No | No | No |
| **Price** | $$ | $ | $ | $$ | $$$ |

Figure 3.1: EEG comparison between 5 different equipments that measures EEG signal part 1 (adapted from [107])

For the purpose of this specific Neurofeedback training, it was important to just read specific channels, F4, F3, AF4, and AF3. All equipment match the requirements. The sampling rate according to the Nyquist frequency [108] should be at least two times the maximum frequency of interest. In this case, alpha waves until 13 Hz are studied, so the minimum sampling rate required is 26 Hz. Since beta waves were also acquired and reach 30 Hz, according to the Nyquist frequency, a minimum of at least 60 Hz of sampling rate is required. All equipment that is being compared complies with the minimum sampling rate. There's no pre-required communication for this protocol. However, a wired connection should be avoided, since it should be good to match an eventual product used by people at home that would be simply to use, avoiding cables. Brain Products ActiCHamp and Biosemi are not adequate for this aim. Considering the fact that in this study we will use the equipment for a non-stop extended period, the EEG should operate for at least 8 hours straight. We can exclude from the list, three pieces of equipment among which figures, AntNeuroego and mBrainTrain Smarting. The weight is significant when the machine stands in the head of the patient since it could interfere with players performance, so the lighter, the better. Nevertheless, it is difficult to quantify an exact weight that would be proper for equipment to be used for 40 minutes in the head of an individual so that no consideration will be given regarding this parameter. Onboard Storage could facilitate the collecting process, but it's not a major deciding factor. The accelerometer is an instrument that quantifies movement. It is essential to reduce the noise since it can be detected if the user is moving and "how much"he's moving. This attribute is shared by all the equipment listed above. Price is an essential component for

| | AntNeuro eego | BioSemi | g.tec nautilus | Cognionics Mobile 72 | mBrainTrain Smarting |
|---|---|---|---|---|---|
| Number of channels | 64 | 256 | 64 | 72 | 24 |
| Sampling rate | 2048Hz | 2-16kHz | 500Hz | 500-1000Hz | 250-500Hz |
| Wireless | Yes (Bluetooth / WiFi) | No | Yes (Bluetooth) | Yes (Bluetooth) | Yes (Bluetooth) |
| Operating time | 6 hours | 5 hours (or unlimited when wired) | 10 hours | 6 hours Bluetooth / 10 hours SD card | 5 hours |
| Weight | 500g | 1.1kg | 360g | 250g | 60g |
| Onboard storage | Yes | No | Yes | Yes | No |
| Accelerometer | Yes | Yes | Yes | Yes | Yes |
| Medically certified | CE | No | No | No | No |
| Price | $$ | $$$ | $$ | $$ | $$ |

Figure 3.2: EEG comparison between 5 different equipments that measures EEG signal part 2 (adapted from [107])

this research and a future product. Emotiv Epoc and OpenBCI Cyton, are the cheapest among the listed equipment. Another Crucial characteristic that is not present in the previous table is the setup time. Because it was expected to do eight sessions with 30 individuals, that results in 240 sessions, and the setup time is fundamental to reduce the sessions time by hours. Between the listed, Emotiv Epoc stands out the others, since the setup time is approximately 3-5 minutes [109], and the others usually extend to more than 15 minutes.

Weighing all the preselected features, it was concluded that the Emotiv Epoc is the best option for this research. The reasons behind it are the fact that it was not excluded in any category, and it has the advantage of the low price, the small weight, and especially the Setup Time, that made the **Emotiv EPOC+ the best option for this research.**

It was used the Emotiv EPOC+ wireless headset [9]. This headset has 14 electrodes located at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4 following the International Standard 10/20 (see 2.2.3.2). This equipment has a sampling rate of 128 Hz, the bandwidth is 0.2-45 Hz, and the digital notch filters are at 50 Hz and 60 Hz. Since it was chosen the ALAY protocol (see 2.3.5), it would be necessary for electrodes locating at F4 and F3 positions, which the Emotiv EPOC+ have.


Figure 3.3: EEG equipment Emotiv EPOC+(adapted from [110])

## 3.3 Game integrated development environment

Game integrated development environment (IDE), is a specialized platform that allows programmers to access a multitude of tools for creating video games. They are useful tools not only because they allow to manipulate objects in a relatively simple way, and they are not difficult to learn.

In order to create a video game, there are several renowned Game IDE platforms, among them, are three described below.

### 3.3.1 Unity3D©

Unity3D©is the most popular platform for developers, with a robust community and there is a free licensing that covers the majority of the content which is very helpful for programmers not accustomed with a platform. Another important factor regarding this platform is the fact that Unity's visual editing tools are excellent, but regarding time-consuming of the processing events, it is not that great since the compilers are not well optimized.

### 3.3.2 Unreal©

Unreal©is a powerful engine to work on a sophisticated game, is easy to work with the interface and it gives the possibility to design impressive graphics. However, it has a massive learning curve to start working. Another important aspect is that it is better to work in teams, because of its complexity and it generates many data, even in smaller games.

### 3.3.3 Cry Engine©

Cry Engine©is a full source code engine with great graphics, visuals, and sounds. These attributes are possible considering their great visual and audio tools, namely *FlowGraph* for the visuals, and *Fmod* for the sounds. Nevertheless, Cry Engine©does not support 2D game creation and has a steep learning curve.

**The Game IDE chosen was Unity 3D©.** Considering the smaller learning curve comparing to the other options, the strong support community and the great edition tools, Unity was recognised to be the best option. Therefore, "Anxiety Destroyer"was built in Unity, using C# as the programming language.

## 3.4 Feedback Tool, Anxiety Destroyer

Firstly it is essential to address the fact that since the game could be commercialized the code will not be shown during the present thesis.

The game, Anxiety Destroyer, was developed step-by-step, in total, four main versions and 11 subversions were developed, encompassing, eight levels + 1 test level, each with different characteristics.

The basis of the game was to build some procedure where the data is read from the EEG, and an initial baseline was calculated. The player should compete against himself in order to overcome his previous baseline. If he overcomes the baseline, a reward should be given. Otherwise, he receives a punishment. More than this, the initial idea encompassed a process of competition, where the difficulty of the baseline should be recalculated and increased. The first MVP (described in section 1.6), just had a single background with three horizontal bars and a spaceship that could move up and down, that was the version 0 of Anxiety Destroyer.

In the next subsection will be described each version of the game. In each version will be discussed several topics as "What were the needs?", "Description of this version", "Game mechanics", "How it relates to NFB learning?"and "Feedback from sessions". "What were the needs?"corresponds to the needs assessed with all users that played the previous version or gave feedback even not playing the game, the assessment was done by mouth and saved in a document that had to correct aspects for future versions. "Description of this version"is a description of why it had been necessary the development of this version and the elements of the game present in the version. "How it relates to NFB learning?"is about why each element and mechanic was built since the objective was to produce learning, for reducing anxiety. "Feedback from sessions"is a resume of the feedback given by players at the end of each of the 185 sessions of the game.

### 3.4.1 Version 0

This version of the game was not for collect user physiological data. It just served to test a scenario and see what the users wanted.

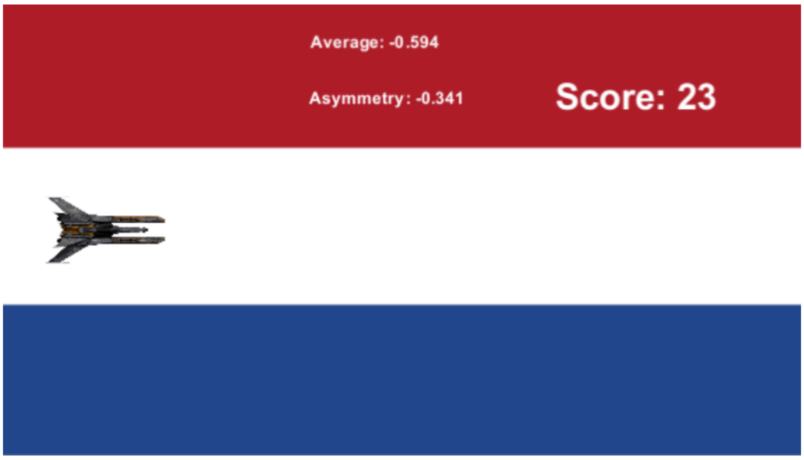


Figure 3.4: **Version 0 of Anxiety Destroyer**. **Average** is the baseline value of the F4-F3 asymmetry. **Asymmetry** is the current value of the F4-F3 asymmetry. **Score** is the current number of points.

- **What were the needs?**
  - A tool to guide the session
  - A challenging game design to get people involved
  - Better game playability
- **Description of this version:**

  This version served mainly to test the game playability of the NFB system in the control of the ship. A scene was built with a spaceship that could move up and down the screen. The game scene was divided into three horizontal bars as it can be seen at fig.3.4. When the player is in the red bar, he gets one point per second, instead if he is in the blue bar the player loses one point per second and if the player is in the white bar he neither wins nor loses points. The total amount of points cannot be smaller than zero It can be seen in the *Score* screen element. *Average* and *Asymmetry* elements were not for players. Instead, they were designed to the game programmer understand if the game mechanics were functioning correctly.
- **Game mechanics:**

  One of the elements in the screenplay is the *Average*. It represents the average of the selected signal feature in the last minute. Alpha power between 8-13 Hz at right (F4), left(F3) sites were collected through Emotiv SDK, where the average band power for a specific channel from the latest epoch had 0.5 seconds step size and 2 seconds window size. At the beginning of the session the *Average* value is set at -1, this value refreshes every minute. The three signal features were used in different sessions. The element *Asymmetry* was a representation of the instant value of the selected signal feature. The movement of the spaceship was proportional to the value of *Asymmetry-Average*. If the result is positive, the spaceship moves up, if the result is negative, it moves down, and if it is zero, there's no movement.

- **How it relates to NFB learning?**

  Note that a reinforcer is either a reward or a punishment, according to the objective. It can be visualized in a table format the following explanation of each one of the NFB leaning mechanisms at Table 3.1.

  - **Reinforcers :** The rewards are fundamental to build through operant conditioning (see 2.1.2) the desired behavior. In this case increase F4-F3, for that purpose were integrated two different game mechanisms. The *Score* reinforce the player to get the spaceship at the red bar (by rewarding him) instead of the blue bar (by punishing him) with respectively the increment and decrease of the score. Another mechanism was the upward movement of the spaceship that is in itself associated with a positive outcome. Conversely the downward of the spaceship is an adverse outcome.
  - **Shaping:** Since the game updates the baseline (*Average*) every minute, adapting to the player's mental state, it functions has successive approximations to the desired behavioral (get a high level of F4-F3). Regardless in this version, it does not result in perfect shaping since if the player diminished his desired behavior for a minute, the baseline adapts to that state and the previous baseline was higher than the actual baseline.

- **Feedback from sessions:** The game was tested with different players. The playability has undergone changes through the sessions, mainly the intensity of movement in the spaceship in order to get a fluid movement of the spaceship and not an approximation of binary upward and downward movement. Players were interested in playing this game with the brain since it was something new to them. They complain about the "game always remains the same", they wanted more interaction.

### 3.4.2 Version 1

This version was not developed fully before testing. Instead, each new game element and new mechanic in the game was tested, but for simplicity, it will be described the final version of version 1. The graphics of the game were taken from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce [111].

Before the first Level of this new game started, a cross (see Fig.3.5) were shown to the player for 3 minutes.

Table 3.1: It is represented several elements of the game that corresponds to different NFB mechanisms. Each line represents an element of the game, and each column is specific to a different NFB learning mechanism.

| | Shaping | Habituation | Sensitization | Reward | Punishment |
|---|---|---|---|---|---|
| Ship Sounds | x | | | x | x |
| Background environment | | x | x | | |
| Asteroids | | x | | x | x |
| Music | | x | x | | |
| Score | x | | | x | |
| Points per asteroid | | x | | x | |
| Points to level up | | | | x | |
| Points to level down | | | | | x |
| Lowering speed | x | | | | |
| Baseline | x | | | | |
| Spaceship movements | | | | x | x |

Figure 3.5: Anxiety Destroyer: Cross. **Score** is the figure showed to the players before the game starts.

- **What were the needs?**
  - A challenging game
  - Novelty in the game
  - A feedback tool that determines the performance of the player during a session.
  - Monitoring the NFB session
- **Description of this version:**

Starting from the spaceship idea, the game was developed to be a spaceship that takes off from Earth and has to travel through different layers of the atmosphere. The traveling through different layers would create novelty in the game and functioned as a guide to the session since in each level the baseline was different. Seven different levels of the game were created, from troposphere to exosphere.

This version had different zones from the previous one. Each zone is a horizontal bar, and each zone represents a different number of points per second. The distribution of points per second, relative to the zone and level can be seen at Table 3.2.

The only game mechanics that remained constant along all levels were the spaceship sounds. A specific sound for the spaceship rise and another specific sound for the spaceship descent were created.


Figure 3.6: **Anxiety Destroyer: 5 different zones in the game.** The screenplay was divided in 5 zones, each one representing different mechanics.

- **Level 1**

  The game starts at the Troposphere, first layer of the atmosphere (Fig. 3.7). There are 3 screen elements, *Score*, *Level Up*, and *Level Down*. *Score* in this version can increase, but can't decrease. The other two elements are in the screen to inform the player about how many points left to get in a higher level or a lower level. *Level Up* is about how many points are needed to get to a higher level, in contrast, *Level Down* is about how many points are left to get in a lower level. The game starts with 240 points to *Level Up*, and 0 points to

Table 3.2: The number of points per second gained. Each line represents a different zone of the map, and each column represents the game level.

| | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Level 7 |
|---|---|---|---|---|---|---|---|
| Zone 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Zone 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Zone 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zone 4 | 0 | -1 | -1 | -1 | -1 | -1 | -1 |
| Zone 5 | -1 | -1 | -2 | -2 | -2 | -2 | -2 |

level down. As it can be seen at Table 3.2 the distribution of points per second at the level 1 is 2 for zone 1, 1 for zone 2, 0 for zones 3 and 4 and finally -1 for zone 5. The descent rate of the ship is 0.2 of the upward rate (see Table 3.3), note that the upward velocity rate never changes along all levels since it has been adjusted to give the player pleasant playability. The music for this level was considered to be relaxing.


Figure 3.7: Anxiety Destroyer: Level 1. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

– **Level** 2

When the spaceship gets 0 points to level up in the level 1, it goes to the second level of Anxiety Destroyer, and the spaceship rises to Stratosphere (Fig. 3.8). When the player moves to that level, he won 15 extra points in order to not level down again by losing just a single point. Therefore, when he arrives at the second level he has 15 points to *Level Down* and 225 points to *Level Up*, this

Table 3.3: There are represented different characteristics of levels, the spaceship speed and the size of the asteroids. At the lowering speed line, it is represented the relationship between the lowering speed against the upload speed, lowering speed/upload speed. At the Asteroid size line, it is representation if asteroids are appearing in the level and if yes, the size of them.

| | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Level 7 | Level 8 |
|---|---|---|---|---|---|---|---|---|
| Lowering speed | 0.2 | 0.4 | 0.6 | 0.8 | 1 | 1 | 1 | 1 |
| Asteroid size | None | None | Small | Medium | Big | Giant | Giant | None |

mechanism is the same across levels. What is different for the player about the previous level, is the distribution of points per second in each zone, and the descent rate and the music. As can be seen in Table 3.2 the distribution of points per second at the level 2 is 2 for zone 1, 1 for zone 2, 0 for zones 3, -1 for zone 5 and the difference is in zone 4 where the value changed from 0 to -1, so difficulty increased. The descent rate of the ship in this level is 0,4 of the upward rate (see Table 3.3) in contrast with the previous level where it was 0,2. The music for this level was considered to be relaxing but with a higher rhythm.


Figure 3.8: Anxiety Destroyer: Level 1. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

- **Level 3**

  After the player reaches the 0 points to level up in the level 2, he/she goes to the third level of Anxiety Destroyer, and the spaceship rises to Mesosphere

(Fig. 3.8). The distribution of points per second in each zone, the descent rate, and the music was changed from the previous level as it can be seen in Table 3.2 the distribution of points per second at the level 3 maintains from the level 2 except the number of points per second at the zone 5, where the player loses 2 points per second instead of 1. The descent rate also increases difficult at this level, since it goes from o.4 times the upward rate to 0.6 (see Table 3.3). The music for this level was considered to have a higher rhythm than the previous level.


Figure 3.9: Anxiety Destroyer: Level 3. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

– **Level 4**

  When the spaceship starts to move up to level 4, it does not reach another atmospheric layer. Instead, it reaches the Kármán Line. The Kármán Line is defined as being the limit agreed to be the end of the terrestrial atmosphere, and the start of external space, 100 km above the sea level (Fig. 3.10). The distribution of points per second in each zone now starts to be the same from the previous level. The changes are in the descent rate, that changes from 0.6 of the upward rate to 0.8 (see Table 3.3) and the music that becomes not so relaxing and more moderate.

– **Level 5**

  In the next level, the player arrives at Aurora. It is not another atmospheric layer but is the zone where the aurora borealis manifests itself and is where the field of aeronautics change to the field of astronautics, it can be seen in the screenplay (see 3.11) by the static appearance of a space shuttle. In this


Figure 3.10: Anxiety Destroyer: Level 4. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

zone it is necessary for any vehicle to move in velocity above the orbital speed, which is 24.000 km/h, to can get aerodynamic sustenance. The changes in this level relative to the previous are in the descent rate, that now is the same as the upward rate, and the music got a higher pace.


Figure 3.11: Anxiety Destroyer: Level 5. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

- **Level 6**

Now the player is almost arising to the top of this version of the game. The spaceship arrives at the Thermosphere, where orbits the space station and some satellites 3.12. In this level just the music varies to a more agitated one comparing to the previous level music.


Figure 3.12: Anxiety Destroyer: Level 6. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

- **Level 7**

  Since it was not expected that no one could arrive Mars at the first sessions of the game and in order to build this MVP as soon as possible, this version of Anxiety Destroyer ended with the Exosphere level. The Exosphere is known as the most exterior layer of Earth where atmosphere and external space are mutually coexisting. This level has no difference relative to the previous one.

- **How it relates to NFB learning?**

  The relationship between game elements and the NFB learning mechanisms are clearly visualized at Table 3.1.

  - **Reinforcers :** Additional reinforcers were added here, whereas *Score* were changed since the feedback collected from the players of the previous version pointed to an inefficient way the Score was being processed since it just divided the map into 3 zones. In version 0 of the game the *Score* could increase and decrease, that led to sessions where users had great performances and ended with really poor *Scores*. This happened considering that some players passed much time earning points and by becoming tired at the end of the session, they just got in the zone 5 unable to get out of that zone causing the loss of all their


Figure 3.13: Anxiety Destroyer: Level 7. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.

points. This should not have happened since it was very demotivating and not translate the overall performance of the player. To overcome this barrier were implemented 3 game elements already addressed in the description of this version, the new *Score* element, the *Level Up* element and the *Level Down* element. Therefore, *Score*, functions as a positive reinforcer (reward), since it just can increase and not decrease what reinforces the desired behavior and not punishes the player until a point where it demoralizes him. The punishment element is a lot softer by the appearance of *Level Down* points to get in the inferior level. *Level Up* points were introduced to motivate the player to be in the next level and inform him about his current state in the game. Relatively to the *Score*, two more zones were added in regards to the previous version in order to give more novelty to the game. It was implemented a huge difference in gameplay since the new players were excessively punished when they were learning the basics of the game which led to demoralizing behaviors, reported by them at the end of each session. Therefore the first level of the game just punished the players when they were at zone 5 and just with one point per second. As long as the player was becoming better and moving up levels, the punishment increased in zones 4 and 5, adapting the punishment to the game experience. Another element that was implemented considering the reinforcement effect were the *Spaceship Sounds*. Every time the player moved up the spaceship send out a considered pleasant sound of a spaceship movement, reported by the users at the end of the sessions, in contrast, when the player moved down the spaceship send out a considered unpleasant sound of a spaceship movement.

- **Shaping:** One crucial aspect of the game that was implemented and served as the major shaping mechanism and was designed to guide the players behavioral along the session was the adaptive baseline. The baseline mechanism hugely changed from the previous version. The first baseline started to be calculated in the first minute of the game. The first-minute baseline was programmed to be the average of last minute where the player saw a cross. When the first minute of the game ended, the new baseline was created. From there on, each level has a new baseline, not constrained with time, just constrained by the level where the player was. In Level 2, the baseline is the average of the specific NFB training that the player was doing, in the Level one, in Level 3, it was the average of Level 2, and it goes on. Every time the player level up, a new baseline for that level was calculated. This process allowed players to experience a shaping mechanism since as time goes on, and the player gets more relaxed, the difficulty of move the spaceship in the upward direction increases, considering that as more relaxed as a player is, more difficult is to him to relax even more and move the spaceship in an upward direction. The ship sounds functioned as a shaping mechanism too since it indicates to the player if he is getting closer to the top of the screen or the bottom down of the screen. The lowering speed that was introduced in the game description part changed across levels, the speed that the player moved down was increasing as the level increases too. That allowed the player to do the desired behavior by adapting the punishment along levels.
- **Habituation:** This is a new concept of NFB learning mechanisms addressed in this version of the game (see Chapter 2.1.2). In order to not create a decrease in the novelty and consequently reduce of the response to a stimulus, the changing of the screenplay between levels and the changing of the music played in each level was implemented. Therefore, different stimuli were generated to avoid habituation.
- **Sensitization:** Another new concept of NFB learning mechanisms was addressed in this version of the game (see Chapter 2.1.2). The background environment and the music was changing between levels in order to avoid sensitization, which means that the player would start to attribute a different significance to what would be supposed from the stimuli.

• **Feedback from sessions:** The game was tested with 30 players. The participants of the study were asked for feedback at the end of the session. Usually, they liked the game and were fascinated by the possibility of playing a game with their brains. The playability has undergone changes through the sessions, mainly the intensity of movement in the spaceship in order to get a fluid movement of the spaceship and not an approximation of binary upward and downward movement. Players were interested in playing this game with the brain since it was something new to them.

They complained about the "game always remains the same", they wanted more interaction as well as they don't win more points in the upper levels, the difference of score was just by the time spent in the upper zones independently of the level, and they quickly, after leveling up, got down to the previous level.

### 3.4.3 Version 2

The version 2 was developed during the collecting data phase of this project. Through the feedback of users from the previous versions, it was possible to maintain the positive aspects for the users and change the negative aspects of the game.

- **What were the needs?**
  - A substantial increase of novelty in the game
  - Rewarding the players according to their level.
- **Description of this version:**

  The version 2 of Anxiety Destroyer had some changes done to the NFB algorithm and user interacting components were added during the game, asteroids. The extra score given to the players when they level up was changed from 15 extra points to 20 extra points. Therefore, when they arrive the next level, *Level Up* has 220 points and *Level Down* 20 points.

  In the following text, it will be explained how the introduction of asteroids in the game was made. Asteroids are not present in the first two levels of Anxiety Destroyer, so let's start with the third level.

  - **Level 3**

    When the player reaches the level 3 he can see asteroids in the game. The condition for the appearance of an asteroid is the spaceship be in the highest place of zone 1 for 3 seconds. If that condition is met, an asteroid appears (see Fig. 3.14)from the right side of the screen. The position of the asteroid always appears from middle to bottom of the screen and moves in the left direction at the same vertical position. Then two conditions can occur:

    1. The player hit the asteroid.
    2. The player does not collide with the asteroid.

    If the first condition is met, the player automatically levels down, with the same *Score*, *Level Up* and *Level Down* points, adapting the baseline to the new level. Instead, if the second condition is met the player wins 15 points at level 3. A message with the number of points won appears in the screen for 3 seconds (see Fig. 3.15). These points vary according to the level (see Table 3.4) as well as the size of the asteroid (see Table 3.3).


Figure 3.14: Anxiety Destroyer: Level 3. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down. The asteroid is shown in a time frame when it was moving form right to left.


Figure 3.15: Anxiety Destroyer: Level 3. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down. The points won by the avoidance of an asteroid are shown in green, and stay in the screen for 3 seconds.

– **Level 4**

The same asteroids mechanisms were implemented in level 4 as well as the subsequent levels of this game including the level down if an asteroid hit the player. The changes are in size (see Fig. 3.16) and the number of points per asteroid won. In this level, the size of the asteroids was bigger, and now the player won 30 points per asteroid (see Table 3.4).


Figure 3.16: Anxiety Destroyer: Level 4. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down. The asteroid is shown in a time frame when it was moving form right to left.

- **Level 5**

  At level five the asteroids become even more prominent (see Fig. 3.17), and the number of points won per asteroid were 45 (see Table 3.4).


Figure 3.17: Anxiety Destroyer: Level 5. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down.The asteroid is shown in a time frame when it was moving form right to left.

– **Level 6**

This is the level where asteroids have their largest size (see Fig. 3.18). The number of points won per asteroid were 60 (see Table 3.4).


Figure 3.18: Anxiety Destroyer: Level 6. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down. The asteroid is shown in a time frame when it was moving form right to left.

– **Level 7**

At this level the size of the asteroid maintained from the previous level (see Fig. 3.19) but the player won 75 points if he could avoid the asteroid (see Table 3.4).

Table 3.4: In white, it is represented the number of points per second that a player wins in each zone of the map and each level. In green, it is represented the number of points that the player wins per asteroid.

| | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Level 7 |
|---|---|---|---|---|---|---|---|
| Zone 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Zone 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Zone 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zone 4 | 0 | -1 | -1 | -1 | -1 | -1 | -1 |
| Zone 5 | -1 | -1 | -2 | -2 | -2 | -2 | -2 |
| Asteroids | 0 | 0 | 15 | 30 | 45 | 60 | 75 |

| |
|---|
| Implemented in version 1 |
| Implemented in version 2 |

- **How it relates to NFB learning?**


Figure 3.19: Anxiety Destroyer: Level 7. **Score** is the actual number of points. **Level up** is the number of points left to level up. **Level Down** is the number of points left to level down. The asteroid is shown in a time frame when it was moving form right to left.

The relationship between game elements and the NFB learning mechanisms can be seen with the extra element visualized in Table 3.1.

- **Reinforcers :** The asteroids functioned as a stressor game element with the objective of getting the player anxious and put him in a situation where he had to deal with it. If the player avoided the asteroid, therefore it was given points to him, reinforcing positively the way he could deal with the stressor. Consequently, they train his brain to deal with stressors in real life, and how to deal with that stressor element. If they got hit by the asteroid it was given to they a negative reinforcer, forcing they to level down, punishing them for getting out of his initial position, when the asteroid appeared, the top of the screenplay, falling against the asteroid that where positioned from the middle to the lower part of the screen. It is important to note that concerning NFB learning by reinforcers, there was an incongruous mechanism concerning asteroids which would be difficult to avoid. This incongruous is originated by the fact that, the stressor, the asteroid appears when the player is at the top of the screen for 3 seconds straight. Therefore, the asteroid could be interpreted as a punishment for the desired behavior. Conversely, since the players liked the introduction of more novelty in the game by asteroids that effect could have been a little bit mitigated.
- **Shaping:** Since every time the player moves up to the next level the baseline was adjusted, that adjustment could decrease and not increase as intended since the player could reach a higher level and the average of the metrics read

in the brain decrease. To prevent that situation, the algorithm was changed to adjust the baseline of the level just if the new baseline was higher than the previous one (see Table 3.1).

- **Habituation:** The asteroids are an aspect of the game to avoid habituation of being in the zone 5, thus the appearance of the asteroid added novelty to the game when the player was situated at this zone of the screen.

- **Feedback from sessions:** The participants of the study referred to as positive the changes made to this new version. Regardless, they wanted even more novelty in the game, they complained about music playlist along with the levels and the fact that if they hit an asteroid, no other asteroid appear during the session, even if they were at the top of the screen for an extended period. This was caused not in purpose but due to a bug in the game.

### 3.4.4 Version 3

The developments in the game that lead to the version 3 of Anxiety Destroyer were predominately concerned with the increase of the novelty in the game and with the final of the game, arriving Mars.

- **What were the needs?**
  - Changes in the music playlist
  - An increase of novelty in the game

- **Description of this version:**

  Nothing was removed from the previous version except some music were replaced. The music playlist was changed in order to give players a better experience and immersion during the game, adapting the playlist to the needs of the game. Some video clips were added to the game for the same purpose. When the player stated the game, he saw a video clip of a spaceship countdown to the takeoff, and the taking off itself from Earth. The last level was added, and when the player arrives at this ultimate level, he saw a video clip of a spaceship seeing Mars. If after 35 minutes from the beginning of the session the player is at level 8, it automatically appears a video clip of a spaceship arriving Mars, the player wins 600 points, and the game ends (see Table 3.5). This last level, level 8, can be seen in Fig. 3.20. This level has the same game elements as previous levels, but the asteroids were not included in this level since, if the player hit an asteroid he could not arrive Mars, and it could be very frustrating for the player.

- **How it relates to NFB learning?**

  The only mechanism that relates to the NFB learning itself from the changes done in for this version was designed as a form of a reinforcer.


Figure 3.20: Last level of Anxiety Destroyer

Table 3.5: In white, it is represented the number of points gained per second in each level and each zone. In green, it is represented the number of points that the player wins per asteroid. In blue it was included the last level of the game and also a line with the number of points won if the player finishes the game and arrive in Mars.

| | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Level 7 | Level 8 |
|---|---|---|---|---|---|---|---|---|
| Zone 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Zone 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Zone 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Zone 4 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| Zone 5 | -1 | -1 | -2 | -2 | -2 | -2 | -2 | -2 |
| Asteroids | 0 | 0 | 15 | 30 | 45 | 60 | 75 | 0 |
| Arriving Mars | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 600 |

| |
|---|
| Implemented in version 1 |
| Implemented in version 2 |
| Implemented in version 3 |

– **Reinforcer :** When the player arrives Mars, he automatically wins 600 points, giving him a huge reinforcement for the fantastic session that he did.

It was described critical processes of the NFB learning, that had been applied to the game as long as the interconnection of them and the game, which had been given the maximum attention in order to obtain the maximum efficiency of the training. These concepts and their interconnection become more relevant since the purpose of this application are to monitor and guide the entire session, and therefore the application of these mechanisms was fundamental.

## 3.5 Lean Method applied in the process

As already have been seen, the Lean method, described in Chapter 1.6, was applied during the execution of the project, that intended to unify the business and scientific world. Engineering is the application of science to find solutions to problems, but if no one cares about the problems, it would be a waste of time for an engineer to work in a problem that he thought it was relevant, or he thought that he had the specific solution, without really taking care about what people really want. The business field, specifically, the lean process was used in this thesis to deal with that issue. Of course, this is like doing a time-frequency analysis, if we want a better resolution in time we have to give up some resolution in frequency and vice-versa. Therefore, it is necessary to find a balance between the both to get to a sweet spot. In this project, this was done by creating the version 0 before starting collecting data for the study, which happened in version 1, 2 and 3. There were eight sessions in total, changing two times the version, at the same session across all participants of the study. The version changed at session 4 and 7. Every participant played the same version from session 1 to 3, then changed to version 2, from session 4-6, then changed again to version 3, session 7-8 (see Table 3.6). For scientific method to occur we should maintain the conditions as possible as we can, whereas in the lean process with have to perform the cycle hypothesis-test-validation with the users as fast as we can, so this was the believed to be the sweet spot found for this project knowing that the primary objective was to create a useful solution.

Table 3.6: There are marked which session of the study corresponds to each version of the game.

| | Version 1 | Version 2 | Version 3 |
|---|---|---|---|
| Session 1 | x | | |
| Session 2 | x | | |
| Session 3 | x | | |
| Session 4 | | x | |
| Session 5 | | x | |
| Session 6 | | x | |
| Session 7 | | | x |
| Session 8 | | | x |

## 3.6 Performance Measurement

In order to know the performance of the product, it was necessary to measure specific metrics related to anxiety, game experience, and game performance. Objective and subjective measures were taken in order to complement each other.

### 3.6.1 Objective Measurements

#### 3.6.1.1 Physiological Measurements

**F4-F3** One biomarker of anxiety is the alpha asymmetry between F4 and F3. The protocol that works with that region is the ALAY. It was chosen given the fact that it needs a small number of electrodes comparing to other protocols, which is useful from a business perspective, reducing the costs of treatment. Moreover, NFB aimed at increasing alpha activity has been, previously employed to reduce stress and anxiety symptoms [112] [23], due to the positive association of alpha power with states of relaxation and low arousal, with excellent efficacy.

**AF4-AF3** In order to use ALAY protocol, it is known the location where the electrodes should be positioned, but there is insufficient information about what range of distance it is acceptable to place the electrodes from the original position. It is an important question, since the electrodes capture information from the brain, but usually with higher intensity the smaller the distance to the electrode. It remains to find from what range of distance could be applied to this protocol, and how would vary the efficiency of the training, with the distance. Considering that in a business perspective, the placement of electrodes in the hairless skin would reduce the costs due to the facility of reading biological data, it was chosen to use another metric, the alpha asymmetry between AF4 and AF3 of the International Standard 10/20 referred in Section 2.2.3.2.

**F4+F3** There is the need to have a control group for this experience. It is the standard to which comparisons are made in an experiment. Therefore, the perfect way to do that would be creating a sham that would perform the same metrics as the not sham group. It was thought about the possibility of playing a video clip of the game while the players tried to play Anxiety Destroyer, when in fact they just saw a video clip previously recorded. That hypothesis was excluded since it would be most likely to people abandon the experiment before doing the eight sessions by not seeing any effect and not being paid to the experiment. In order to work around this problem, it was chosen to use the sum of the alpha waves of the frontal position (F4+F3) for the control group since a recent study showed an almost no change in anxiety during a NFB protocol of 5 sessions in region Fz [23]. Since with Emotiv Epoc + there is not possible to perform the protocol in region Fz, it was chosen to perform the protocol at increasing both regions, F4 and F3. It was known that alpha waves are related to relaxing states (see 2.2.4), so it was expected that participants would reduce their anxiety while playing the game but with small effect. In that way, this was not the perfect control group, but it should be a useful group in order to validate the another two NFB protocols.

#### 3.6.1.2 Gaming Measurements

It would be necessary to measure the performance of the users in each session, regarding game performance which was designed to translate the NFB training performance.

**Score** Score was believed to be a useful metric to measure it since it measures the amount of time the player is performing the desired behavior since points are given concerning time (seconds).

### 3.6.2 Subjective Measurements

#### 3.6.2.1 Anxiety Related Measurements

**Beck Anxiety Inventory (BAI)** The Beck Anxiety Inventory (Beck, Epstein, Brown & Sterr, 1988; translated and adapted by Pinto-Gouveia & Fonseca, 1995) [113] was constructed to address the need to differentiate anxiety from depression adequately. It consists of 21 items and is self-response. Each item describes a typical symptom of anxiety and the participant is asked to respond according to how much they have been troubled by each of the symptoms during the last week. The responses correspond to 4 degrees of frequency (absent, mild, moderate, and severe). The obtained values are analyzed in order to obtain a total score that can vary between 0 and 63. The inventory has good psychometric characteristics, being essential to mention that it has a high internal consistency, which means that the questionnaire is a good representation of the reality. This inventory can be consulted in annexes, see Annex II.

**PANAS** The original Positive and Negative Affect Scale developed by Watson, Clark and Tellegen's (1988) was translated and adapted for the Portuguese population by Galinha and Pais-Ribeiro (2005) [114], evaluating the affective dimension (trait or state) of subjective well-being, Positive Affect (PA) and Negative Affect (NA). It consists of 20 items, 10 with positive valence (items 1, 3, 5, 8, 10, 11, 13, 15, 17, 19) and 10 with negative valence (items 2, 4, 6, 7, 9, 12 , 14, 16, 18, 20). Each item is answered on a Likert scale of 1 (nothing or very slightly) to 5 (extremely). This scale can be consulted in annexes, see Annex III .

**Others**

#### 3.6.2.2 Gaming Experience Measurements

**The Game Experience Questionnaire** GEQ was [115], to measure the experience of the player between versions. It was used just the in-game and post-game modules of GEQ. The core and social presence modules were discarded in this study for two reasons, first since the social presence module does not apply to the present study and the second to shorten the overall test duration since the core module was too extensive. The modules used contains the following dimensions: competence, sensory and imaginative immersion, flow, tension, challenge, negative affect, positive affect, positive experience, negative experience, tiredness, returning to reality. These are each measured using two to six items per dimension (31 in total), each on 1-to-5 disagree-agree response Likert-scales. Moreover, flow, immersion competence, positive affect appear to have some empirical support [116]. Since there is not a translated Portuguese version, GEQ had to be translated. This questionnaire was used to measure the experience during the game. It was expected that the experience could increase between versions since the game was adapted according to user needs. GEQ was applied in session 3, 6 and 8 for participants who wanted to answer it. GEQ was not an obligation of the study since this study already had many metrics to answer, that could lead to participants to quit due to its extensive questionnaires. This questionnaire can be consulted in annexes, see Annex IV.

## 3.7 Participants

Thirty healthy and free from medication adults aged between 18-35 years old (M age= 26.2, SD = 4.5), 20 women and ten men, from three different Portuguese cities, Lisboa, Caldas da Rainha, and Torres Novas were enrolled. This study included only right-handed people, as handedness influences the asymmetrical alpha activity [117]. Exclusion criteria were: previous chronic neurological or mental diseases, head injury, and the use of medication that are known that influence EEG, such as antidepressants or tranquilizers. Participants were randomly selected to get a NFB training intended either to enhance frontal alpha asymmetry (i.e., F4-F3; ALAY group; N = 10), to increase alpha asymmetry between the frontal and pre-frontal region (i.e., AF4-AF3; AF group; N = 10) or to increase frontal alpha activity(i.e., F4+F3; F+ group or active group; N=10). Note that after starting to get a tendency of AF group to decrease F4-F3 along sessions, posterior new participants that had a starting BAI score 15 or more, which represents a moderate or higher state of anxiety, and were randomly selected to AF group, were assigned to randomly change to one of the other two groups since existed the possibility of the AF training worsen their condition. Participants were told that it was a scientific study that could help to reduce their anxiety. The present study was carried out with the adequate understanding and written consent of the participants in accordance with the Ethical Committee of the Faculty of science and technology of the Universidade Nova de Lisboa. The informed consent that presented and signed by participants at the beginning of the study can be consulted in annexes, see Annex I as long as the official approval of the Ethics committee that can be seen at the same Annex.

Table 3.7: Demographics and pre-training log-transformed alpha power at the three different groups(F4-F3, AF4-AF3 and F4+F3).

| Variables | ALAY group (N=10) | AF group (N=10) | F+ group (N=10) |
|---|---|---|---|
| **Demographics** | | | |
| Age(years) | 26.9(4.9) | 26.6(5.2) | 25(3.3) |
| **Alpha power (mV2/Hz) pre-training** | | | |
| F4-F3 | -0.18(1.2) | 0.82(1.5) | -0.03(0.5) |
| AF4-AF3 | -0.04(2.0) | 0.22(0.4) | 0.29(0.8) |
| F4+F3 | 1.9(1.2) | 2.02(2.5) | 1.03(0.5) |

Notes: Data are M (SD). F4 = right frontal zone; F3 = left frontal zone; AF4= right between pre-frontal and frontal zone; AF3 = right between pre-frontal and frontal zone

## 3.8 Procedure

A biomedical engineer student ran the entire procedure with the supervision of a neuropsychologist expert in NFB and EEG procedures and the help of a psychologist for data revision, and it can be seen the experimental protocol at Annex V. The procedure made up of 8 sessions (performed in a period that could not exceed three months, normally biweekly but adapted to the participants' schedules). Each session lasted about 45 minutes (35 minutes for the session and 10 minutes for EEG procedures of inserting and calibrating the equipment). During the first session, upon arrival at the laboratory in Lisbon, or mini-laboratories in Caldas da Rainha and Torres Novas with approximated the same conditions participants received general information about the experimental procedures and read and signed an informed consent form. Note that the distribution by the city was random. In order to get the status information and check the exclusion criteria, a short semi-structured interview was conducted. Then, participants sat on a suitable armchair, where a psychophysiological assessment was carried out, including psychological questionnaires administration and electrophysiological recordings in resting conditions, by seeing a white cross in a black screen for 1 minute and a half, followed by a moving cross that changed its position from each 30 seconds until reaching the 3 minutes mark in total. The cross procedure happened during all the sessions immediately before the game started. In the initial session before the cross visualization procedure, participants were assigned to ALAY group, AF group or F+ group, accordingly to what had mentioned in section 3.7. Then participants underwent 8 NFB sessions, some of them abandoned the training before the end of the eight sessions. At the beginning of each session, some strategies of how to approach the game were given according to the experimental protocol, that can be consulted at Annex V. The GEQ was applied at the end of sessions 3, 6 and eight if the participant did not mind doing it. At the beginning and the end of each session electrodes state conditions of connection were assessed and if F4 or F3 located electrodes were in adverse conditions, the data was rejected. Moreover at the end of each session participants were asked for verbal feedback about the game, what they liked and what they did not like. In the last session, the first assessments were reproduced, to assess the subjective effects of the training.

## 3.9 Statistics

Alpha power between 8-13 Hz at right (F4), left(F3), and between frontal and prefrontal right (AF4) and left (AF3) sites were collected through Emotiv SDK.

Alpha asymmetry from the cross procedure between 30 seconds and 2 minutes and a half in each session was calculated subtracting alpha power at F3 from F4 (F4-F3) and the subtraction of AF4 and AF3(AF4-AF3). The sum of alpha power in frontal zones was calculated by adding F4 and F3 (F4+F3). Analysis of variance (ANOVA) with Group (ALAY, AF, and F+) as a between-subjects factor was used to compare the three groups regarding age, game score, asymmetries, frontal alpha power in total. Changes in resting frontal alpha asymmetry were evaluated running an ANOVA as long as a linear regression with Group as a between-subjects factor and Time (number of the session) as a within-subjects factor. It is important to notice since not all individual finished the total number of sessions that ALAY group in total made 75 sessions, AF group made 57 sessions, and F+ group made 52 sessions. The main factors of participants quitting the sessions were both the lack of results in the training and the lack of time. Separate ANOVAs with Group as a between-subjects factor and Time as a within-subjects factor was conducted on each subjective measure, namely the PANAS NA and PA scores, BAI and GEQ. p-values, $R^2$ (measure of adjustment of the linear regression, in relation to the observed values) and $B$ (unstandardized beta) are reported. Main interactions and effects were admitted to be significant if $p < 0.05$. SPSS 25.0 software (IBM SPSS STATISTICS 25) was used for statistical analysis.

## 3.10 Electrophysiological recordings

EEG signals were recorded in a standardized fashion using a computerized recording system (Emotiv). Electrophysiological signals were registered for 3 minutes, while individuals were asked to fixate a white cross on a black screen to reduce eye-movement for the first minute and a half. Then appeared a moving cross that changed his position every 30 seconds until reach 3 minutes in total, in order to get the attention of the participant. EEG was obtained from 4 active scalp electrodes using Emotiv EPOC+ (see section 3.2). The EEG sites were F3, F4, AF4, and AF3 with two references (CMS/DRL references at P3/P4). The Emotiv sampling rate is 2048 Hz internally downsampled to 128 samples per second. Its bandwidth is 0.16-43 Hz with digital notch filters at 50 Hz and 60 Hz and a built-in digital fifth order Sinc filter.

## 3.11 Neurofeedback training

At the beginning of each training session, at rest and with eyes open, a 3-minute baseline registration was taken, in order to set the baseline of the frontal alpha asymmetry, with other secondary measures such as AF4-AF3 and F4+F3 baselines. Alpha power (8-13 Hz) at right (F4), left (F3), right (AF4) and left (AF3) was extracted. The average band power for each channel from the latest epoch with 0.5 seconds step size and 2 seconds hamming window size was extracted during all process. The baseline values were used to calculate the threshold for the first minute of the game according to the protocol used. The game started as it was already explained (see section 3.4). The difference in alpha power between right and left (F4 - F3) for ALAY group, the sum (F4+F3) for F+ group or the difference in alpha power between AF4 position and AF3 (AF4-AF3) for AF group, was then computed and compared against the threshold value established for the baseline.

## 3.12 Signal Processing

The reproducibility, fundamental in the scientific environment, for this study was questioned since there was a problem with the research version of Emotiv. The present study had a license to access raw data from Emotiv EPOC+ equipment, but a problem with Emotiv SDK version inhibit it to use raw data. That problem was tried to solve for two months, but Emotiv only solved it after that period, that was no longer at the beginning of the investigation, and therefore no raw data could be collected. Despite being a significant limitation, the primary objective of this study was not related to the reproducibility of this study, but the validation of this product as effective in the treatment of anxiety.

Chapter 4

# Results and Discussion

## 4.1 Characteristics of the participants between groups

It was applied a one-way ANOVA to see statistical differences between groups before the NFB training, where F represents the variation between sample means / variation within the samples and p is the p-value as the degree of marginal significance within a statistical hypothesis test characterizing the probability of the happening of a given event. [118]. ANOVA yielded differences for sex ($F_{(2,7)} = 25.14$ , p=0.00), but no group differences for age ($F_{(2,7)} = 0.51$, p=0.61), for F4-F3 ($F_{(2,7)} = 2.22$, $p = 0.13$), for AF4-AF3 ($F_{(2,7)} = 0.19$, $p = 0.83$), and for F4+F3 ($F_{(2,7)} = 1.11$, $p = 0.35$). The descriptive statistic for each group are reported at Table 3.7 on page 51.

## 4.2 Anxiety Destroyer gaming metrics

The ANOVA and linear regression coefficients were analyzed for each group in the game performance, translated by *Score*, where $B$ represents the slope of the line between the predictor variable and the dependent variable. A significant Score x Session interaction emerged for ALAY group ($F_{(2,7)} = 15.41$, $p < 0.001$, $B = 67.80$), for AF group ($F_{(2,7)} = 5.29$, $p < 0.05$, $B = 47.63$) and F+ group ($F_{(2,7)} = 8.84$, $p < 0.01$, $B = 61.58$) (see Table 4.1). As it can be in Figure 4.1, all groups increased the score from the first to the last session with a definite tendency.

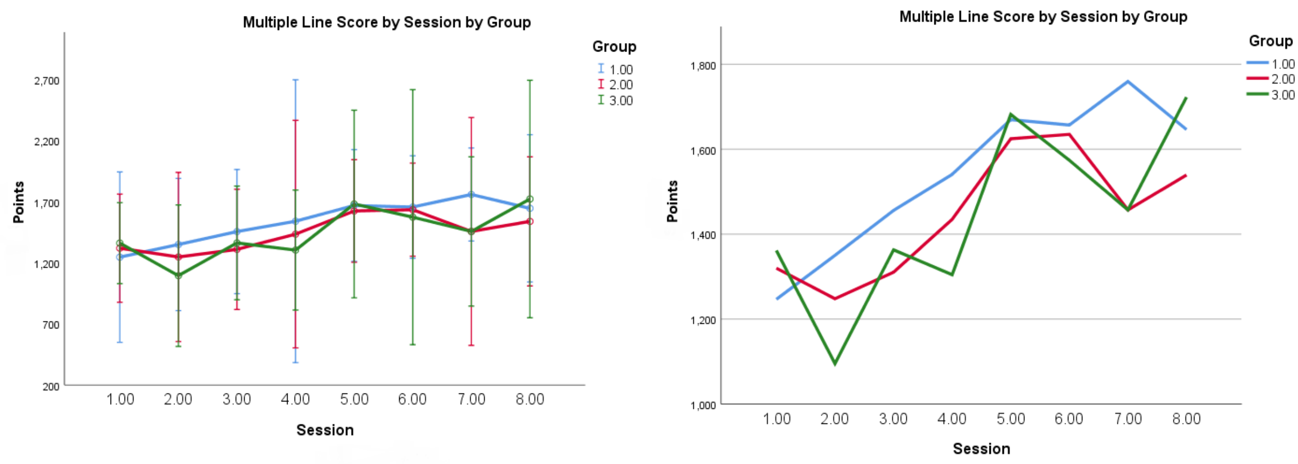


Figure 4.1: **Changes in each session in the number of points (*Score*).** At the left side it can be seen the error bars representing the standard error of the mean, while at the right side, for a cleaner visualization, the error bars were removed.

Table 4.1: Statistical analysis of *Score* from the game. ANOVA and Linear regression coefficients on *Score* from all sessions in ALAY group, AF group and F+ group and in all groups together.

| Variables | All groups (N=30) | ALAY group (N = 10) | AF group (N = 10) | F+ group (N = 10) |
|---|---|---|---|---|
| ***p-value*** | <0.001 | <0.001 | <0.05 | <0.01 |
| $R^2$ | 0.17 | 0.20 | 0.10 | 0.16 |
| ***B*** | 62.15 | 67.80 | 47.63 | 61.58 |

Notes: ANOVA = analysis of variance; $R^2$ = measure of adjustment of the linear regression, in relation to the observed values; $B$ = (unstandardized beta) slope of the line between the predictor variable and the dependent variable.

## 4.3 Effects of Neurofeedback on EEG measures

### 4.3.1 F4 - F3

ANOVA and its coefficients were analyzed for each group of the frontal alpha asymmetry, where $B$ represents the slope of the line between the predictor variable and the dependent variable. A significant F4-F3 x Session interaction emerged for the ALAY group ($F_{(2,7)} = 4.10$, $p < 0.05$, $B = 0.11$), no further significance was found in other groups, AF group ($F_{(2,7)} = 1.88$, $p = 0.18$, $B = -0.10$) and F+ group ($F_{(2,7)} = 0.32$, $p = 0.58$, $B = 0.2$) (see Table 4.2). As it can be seen at Figure 4.2, the ALAY group started with the lower absolute alpha power of F4-F3, and finished with the higher, in contrast to the AF group that started with the highest difference of F4 and F3 in absolute alpha power and finished with the lowest.

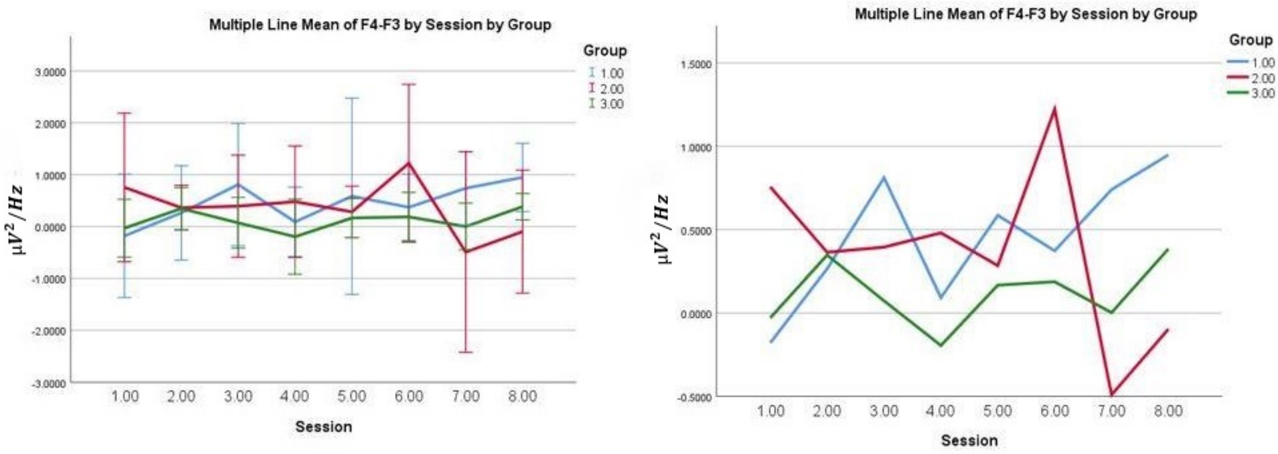


Figure 4.2: **Changes in each session on frontal alpha asymmetry, showing the absolute alpha power of F4-F3.** At the left side it can be seen the error bars representing the standard error of the mean, while at the right side, for a cleaner visualization, the error bars were removed.

Table 4.2: Statistical significance of ALAY group in frontal alpha asymmetry. ANOVA and Linear regression coefficients on F4-F3 alpha asymmetry from all sessions in ALAY group, AF group and F+ group.

| Variables | ALAY group (N=10) | AF group (N=10) | F+ group (N=10) |
|---|---|---|---|
| **p-value** | <0.05 | 0.18 | 0.58 |
| $R^2$ | 0.05 | 0.03 | 0.01 |
| ***B*** | 0.11 | -0.10 | 0.02 |

Notes: ANOVA = analysis of variance; $R^2$ = measure of adjustment of the linear regression, in relation to the observed values; $B$ = (unstandardized beta) slope of the line between the predictor variable and the dependent variable.

### 4.3.2 AF4 - AF3

It was analyzed the ANOVA and her coefficients for each group of the AF position of alpha asymmetry. No significant AF4-AF3 x Session interaction emerged. For ALAY group ($F_{(2,7)} = 0.27$, p = 0.61, $B = 0.05$), AF group ($F_{(2,7)} = 0.23$, p = 0.64, $B = 0.03$) and F+ group ($F_{(2,7)} = 0.04$, p = 0.85, $B = 0.01$) (see Table 4.3). As it can be seen at Figure 4.3, there is not a clear tendency for the difference in absolute alpha power between AF4 and Af3 along sessions for any group.

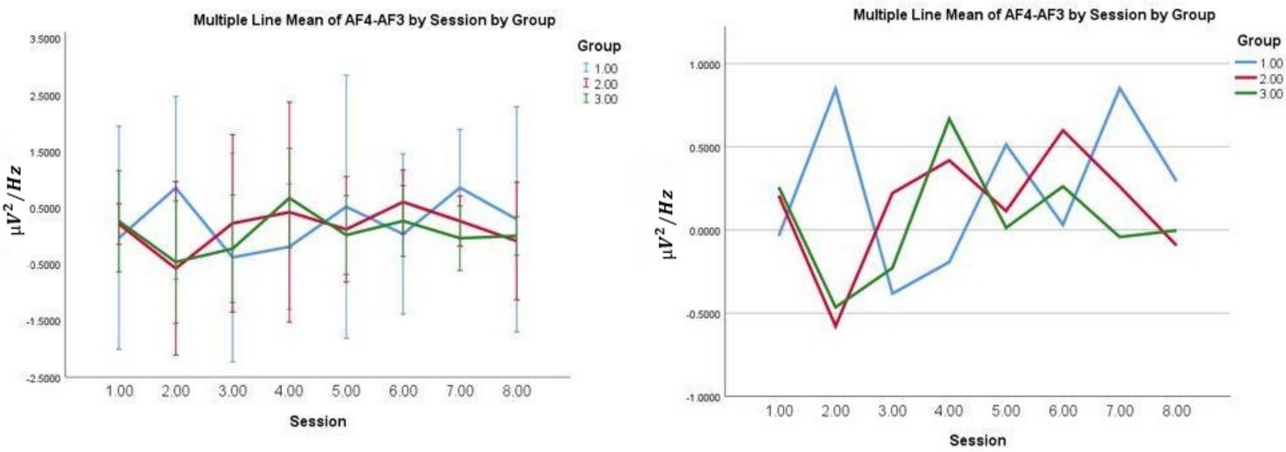


Figure 4.3: **Changes in each session on AF region of alpha asymmetry, showing the absolute alpha power at AF4-AF3.** At the left side it can be seen the error bars representing the standard error of the mean, while at the right side, for a cleaner visualization, the error bars were removed.

Table 4.3: ANOVA and Linear regression coefficients on AF4-AF3 alpha asymmetry from all sessions in ALAY group, AF group and F+ group.

| Variables | ALAY group (N=10) | AF group (N=10) | F+ group (N=10) |
|---|---|---|---|
| **p-value** | 0.61 | 0.64 | 0.85 |
| $R^2$ | 0.004 | 0.004 | 0.001 |
| ***B*** | 0.05 | 0.03 | 0.01 |

Notes: ANOVA = analysis of variance; $R^2$ = measure of adjustment of the linear regression, in relation to the observed values; $B$ = (unstandardized beta) slope of the line between the predictor variable and the dependent variable.

### 4.3.3 F4 + F3

It was analyzed the ANOVA and her coefficients for each group of frontal alpha at F4 and F3 channels. A significant F4+F3 x Session interaction emerged for ALAY group ($F_{(2,7)}$ = 16.88, $p < 0.001$, $B = 0.45$), AF group ($F_{(2,7)}$ = 10.41, $p < 0.01$, $B = 0.46$) and F+ group ($F_{(2,7)}$ = 6.92, $p < 0.05$, $B = 0.15$) (see Table 4.4). As it can be seen at Figure 4.4, the group that was training the increasing of alpha at F4 and F3 had the lower increase in that metric over the sessions, contrary to the other two groups who were not training specifically that metric.

### 4.3.4 Score changing results

In Fig 4.5 the global mean for all groups was analyzed at the same time of F4-F3, translated by the average alpha band power over sessions. The three lowest values correspond to the introduction of a new version in the game. Moreover, it was analyzed using by

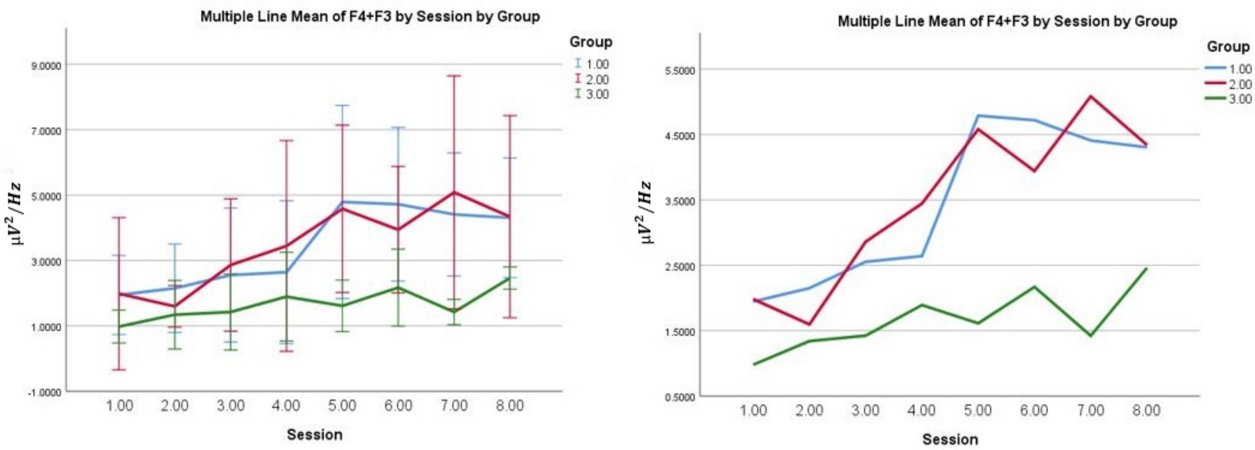


Figure 4.4: **Changes in each session on AF region of alpha asymmetry, showing the absolute alpha power of F4 summed by the absolute alpha power of F3.** At the left side it can be seen the error bars representing the standard error of the mean, while at the right side, for a cleaner visualization, the error bars were removed.

Table 4.4: ANOVA and Linear regression coefficients on F4+F3 alpha asymmetry from all sessions in ALAY group, AF group and F+ group.

| Variables | ALAY group (N=10) | AF group (N=10) | F+ group (N=10) |
|---|---|---|---|
| **p-value** | <0.001 | <0.01 | <0.05 |
| $R^2$ | 0.19 | 0.16 | 0.12 |
| ***B*** | 0.45 | 0.46 | 0.15 |

Notes: ANOVA = analysis of variance; $R^2$ = measure of adjustment of the linear regression, in relation to the observed values; $B$ = (unstandardized beta) slope of the line between the predictor variable and the dependent variable.

the same principle, the AF4-AF3 and F4+F3 metrics where the previous pattern was not found (see Figure 4.6).

## 4.4 Effects of neurofeedback on affect

Wilcoxon, Non-parametric test relating two samples for each group, was used to test for differences between Pre-training to Post-training, regarding the score in BAI scale, PANAS PA Score, and PANAS NA Score (Table 4.5). From BAI, a significant Score relationship emerged for ALAY group ($p < 0.05$) with a decrease in the mean Score from Pre-training to Post-training of 20.20 to 12.13. From PANAS NA Score, two significant results emerged, one for ALAY group ($p<0.05$) and a decrease in the mean score from 1.99 to 1.60, and the other for F+ group ($p<0.05$) and a decrease in the mean score of 1.69 to 1.60.

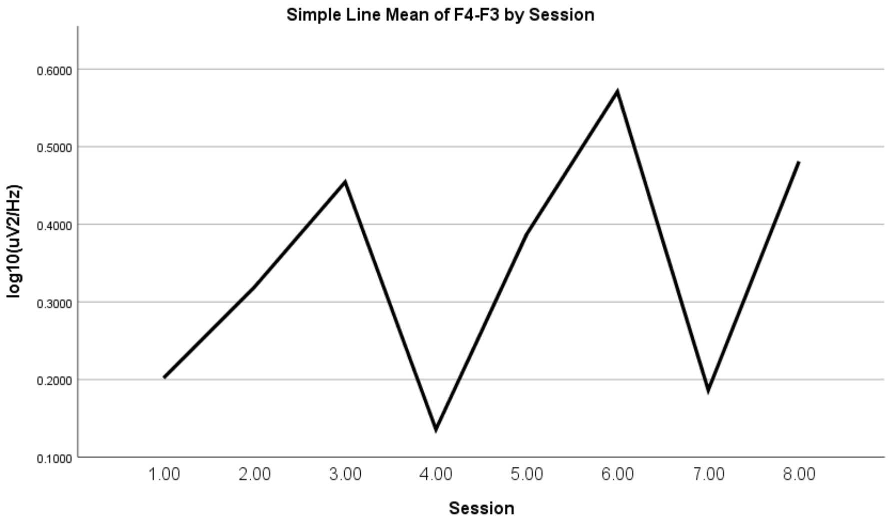


Figure 4.5: Session-by-session changes in frontal region of absolute alpha power at F4-F3. The 3 lower values correspond to the first session where a new version was applied.

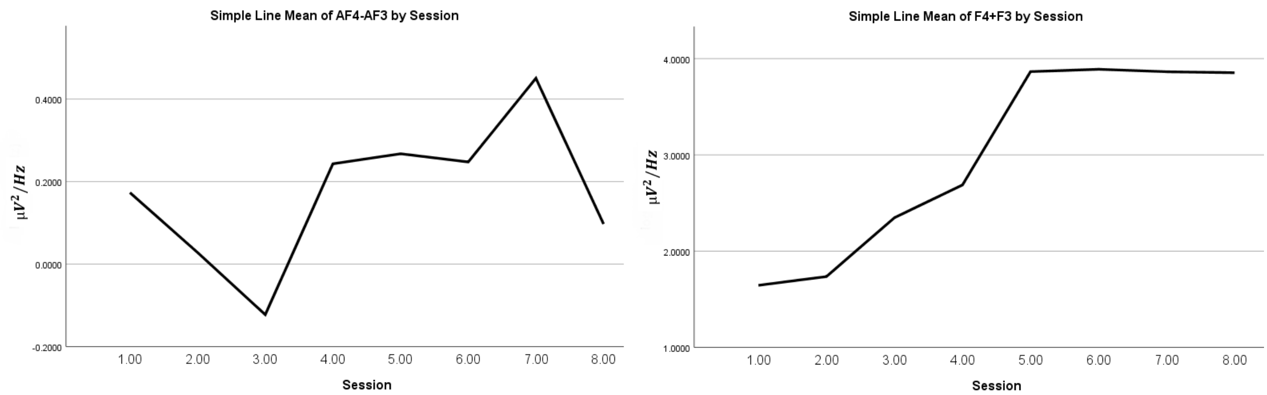


Figure 4.6: **S**ession-by-session changes at absolute alpha power at AF4-AF3 and F4+F3. No visible relation between the first session of each new version and alpha power.

Table 4.5: Wilcoxon Non-parametric test relating 2 samples on Beck Anxiety Inventory, PANAS Positive Affect Score and PANAS Negative Affect Score regarding to ALAY group, AF group and F+ group.

| Variables | Pre-training | Post-training | *p* |
|---|---|---|---|
| **BAI** | | | |
| ALAY group | 20.20 (15.57) | 12.13 (10.11) | <0.05 |
| AF group | 13.82 (9.91) | 9.33 (6.95) | 0.75 |
| F+ group | 13.25 (8.45) | 9.83 (4.88) | 0.08 |
| **PANAS Positive Affect Score** | | | |
| ALAY group | 2.83 (0.71) | 2.70 (0.69) | 0.53 |
| AF group | 2.92 (0.64) | 3.13 (0.50) | 0.83 |
| F+ group | 3.01 (0.73) | 3.22 (0.24) | 0.89 |
| **PANAS Negative Affect Score** | | | |
| ALAY group | 1.99 (0.59) | 1.60 (0.79) | <0.05 |
| AF group | 1.96 (0.60) | 1.31 (0.25) | 0.07 |
| F+ group | 1.69 (0.54) | 1.60 (0.26) | <0.05 |

Notes: Data are *M (SD)*; ANOVA = analysis of variance; PANAS = Positive and Negative Affect Schedule; BAI = Beck Anxiety Inventory;

### 4.4.1 Game Experience Questionnaire

After scoring each one of the 11 categories given by GEQ, it was computed the simple mean and standard deviation between versions of the game across all groups. The GEQ was not divided into the three different groups because the number of participants in this questionnaire was too low in version 3 (N=8), and it would not be a representative sample. The most meaningful insights from this table appear to be the slightly increase in Competence from version 1 to version 3 (M(v1) = 1.78 to M(v3) = 1.94), the little decrease in flow across sessions (M(v1) = 2, M(v2) = 1.96 M(v3) = 1.81), the growth of Tension (M(v1) = 0.80, M(v2) = 1.00, M(v3) = 1.13), the decrease of Negative affect (M(v1) = 1.50, M(v2) = 1.36, M(v3) = 1.31), also the decrease of Positive affect (M(v1) = 2.13, M(v2) = 2.11, M(v3) = 1.94) and the decrease of Tiredness (M(v1) = 1.05, M(v2) = 0.82, M(v3) = 0.63) (see Table 4.6).

Table 4.6: Simple mean and standard deviation of the GEQ measured and compared between versions. Scores were given from 0 to 4, and it depends upon each variable if a high value is a good or an adverse outcome for good player experience.

| Variables | Version 1 (N = 20) | Version 2 (N = 14) | Version 3 (N = 8) |
|---|---|---|---|
| Competence | 1.78 (0.72) | 1.96 (0.80) | 1.94 (0.82) |
| Sensory and Imaginative Immersion | 2.00 (0.81) | 1.90 (0.88) | 2.06 (0.98) |
| Flow | 2.00 (0.79) | 1.96 (0.80) | 1.81 (1.22) |
| Tension | 0.80 (0.80) | 1.00 (0.88) | 1.13 (0.74) |
| Challenge | 2.55 (0.86) | 2.36 (0.91) | 2.81 (0.84) |
| Negative affect | 1.50 (0.99) | 1.36 (1.06) | 1.31 (0.88) |
| Positive affect | 2.13 (0.67) | 2.11 (0.90) | 1.94 (0.62) |
| Positive experience | 1.48 (0.72) | 1.48 (0.86) | 1.54 (0.79) |
| Negative experience | 0.36 (0.35) | 0.42 (0.43) | 0.46 (0.39) |
| Tiredness | 1.05 (1.05) | 0.82 (0.87) | 0.63 (0.83) |
| Returning to reality | 0.52 (0.68) | 0.48 (0.60) | 0.54 (0.83) |

Notes: Data are *M (SD)*

## 4.5 Discussion

The efficacy of the NFB training in frontal alpha asymmetry in increasing the frontal alpha asymmetry (F4 and F3) were confirmed by the present findings, in accordance to earlier research [23] [119] [120]. More importantly, to our knowledge, this is the first study to report the efficacy of a gamified NFB application for anxiety treatment.

The success of this tool in reducing anxiety was dependent on the ability of the player to learn how to play the game. So if the player did not learn to play the game, the process of NFB was not possible. The results presented in Table 4.1 are conclusive, the players of all groups learned to play the game, tending to obtain higher scores along sessions. Moreover, it is clear that different groups had different learning experiences, while in average the ALAY group scored more 62.15 points per session, F+ group scored in average 61.58 points per session and AF group seemed to be the group that had more difficulty in learning how to play the game, earning in average just 47.63 points per session. In relation to the game, it seems that NFB learning mechanisms applied to the game functioned.

The self-report measures showed a significant decrease in BAI score emerged from pre to post-training for the ALAY group, but not for other groups, while the decrease of the score was almost two times the decrease of the score in other groups. Moreover, the ALAY group started the training with a mean value of 20.20 and according to this scale, individuals that scores between 16-25 points, have moderate anxiety, meaning that they usually have physical side effects of anxiety and may need professional help to evaluate their condition to reduce anxiety. The ALAY group ended the training with a mean value of 12.13, and again, according to this scale, this is considered mild anxiety (between 8-15 points), one step below the previous one, and according to the scale, those individuals have relatively normal effects of anxiety and don't need professional help. It could be derived from many factors, but in average the ALAY group transitioned from a situation where it would be significantly recommended professional help to a situation where there is no such need. Note that individuals of the ALAY group participated in 75 sessions in total while individuals of F+ group just did 52 in total (AF group did 57 sessions), so it is strongly possible that this has influenced not getting a significant value ($p = 0.08$), but it is close to having statistical significance ($p < 0.05$). Based on that, it seems clear that ALAY group performed better than the active control group F+, even taking into account the initial values, since while ALAY group decrease approximately 8 points in the BAI score, the F+ group decrease less than 3.5 points (see Table 4.5). About PANAS two significant results emerged from the ALAY group in the decrease of Negative Affect Score and the F+ group too. Notice that the decrease in the Negative Affect Score in the ALAY group was approximately four times the decrease in the F+ group, although the different starting points between these two groups could influence this result.

Not only the subjective metrics support the evidence of the efficacy of this tool, the objective measures are in accordance. As far as the frontal alpha asymmetry, described as a biomarker of anxiety, is concerned, a significant increase in this asymmetry (F4-F3) emerged along the sessions for the ALAY group, but not for other groups. The F+ group had less 23 sessions in total but it was not expected that the p-value change from 0.58 to less than 0.05 in those remaining sessions, in contrast, the p-value of the AF group showed a trend to decrease and with 18 more sessions it could decrease to less than 0.05. Comparing to F+ group, ALAY group showed efficacy in increasing asymmetry related to the reduction of the anxiety biomarker which translates into a decrease in anxiety.

These results are aligned with the initial objectives. These objectives referred to an increase in frontal alpha asymmetry that would be associated with a reduction of anxiety and negative affect through the NFB training with a gamified application.

The AF group was an interesting experiment in this thesis. We tried to understand what happens if we put the electrodes not in frontal position but between frontal and prefrontal positions, and the results although they are not significant, they seem conclusive that the AF4-AF3 protocol can't be used since that even if the p-value would be significant, the unstandardized beta is negative, in module almost equal to the unstandardized beta of ALAY group.

It seems that the the training in AF4 and AF3 positions is in congruence with the training in the FP zones, thus it was expectable that we could get better results from this tool from changing the protocol from AF4-AF3 to AF3-AF4.

It was interesting to identify that the protocol that was increasing in an explicit way alpha waves at F4 and F3, F4+F3, was the protocol that had the worst result of all in increasing alpha power in those positions (see Fig. 4.4). This result suggests that there are protocols that implicitly can perform better by raising alpha power than protocols that explicitly are focused on raising alpha power.

Nonetheless, the linear correlation between changes in frontal alpha asymmetry and changes in affective measures did emerge, the capability model of individual differences in frontal asymmetry, [121] suggests that the approach of motivational tendencies, as exhibited by frontal alpha asymmetry, are more effectively recognized through an emotional challenge, instead of in resting conditions as it had been performed in this work. That could have brought a more clear distinction in anxiety for this present study. Moreover, it can be seen that for the ALAY group the influence of different sessions in the total metric of the frontal alpha asymmetry was just 5%, ($R^2 = 0.05$). Therefore, if the participant instead of looking to a cross for 3 minutes was participating in a challenging emotional activity, $R^2$ should be greater. Frontal alpha asymmetry during emotional tasks has been reported to predict affect and mood better than frontal alpha asymmetry at rest [121] [122].

The data collected from GEQ were inconsistent with one of the objective of increasing value of the game for the user over time. We tried to measure it through the application of GEQ. It was expected that:

- **Competence grows throughout the versions**
- Sensory and Imaginative Immersion grows throughout the versions ×
- **Flow grows throughout the versions** ×
- Tension decreases throughout the versions ×
- Challenge decreases throughout the versions ×
- Negative affect decreases throughout the versions
- Positive affect grows throughout the versions ×
- **Positive experience grows throughout the versions**

- **Negative experience decreases throughout the versions** ×
- **Tiredness decreases throughout the versions**

In bold are the most relevant items to and the "×"means that the condition was not observed. Since most of the expected conditions were not meet, the GEQ suggests that the players did not find the game enjoyable throughout versions. Conversely, 3 out of 5 of the most important conditions to classify the play loyalty, were met. Since the players gave positive feedback along the changes in Anxiety Destroyer, two factors could cause these results. Firstly, the fact the changes between versions were not that significant to make a leap in the game experience, secondly, we were comparing results that come from different session numbers. It is normal that the eighth time that the player played a similar game is less exciting from the first time he played it.

An unexpected result emerged from Fig. 4.5, where the three smaller values of the mean of F4-F3 metric between all participant corresponds to the introduction of a new version of the game. Moreover, the mean is growing session by session except in those transitions of versions, a pronounced decrease was observed. That pronounced decrease is even more suspicious since, at the beginning of each one of those sessions, participants were told that the version changed and that all the changes were explained before they see the cross for 3 minutes where this data were collected. This strongly suggests that saw changing of the version worked as a stressor and biased the metrics. That effect is not seen in the AF4-AF3 metric either F4+F3 metric since they are not identified as a biomarker of anxiety.

Overall, the present results suggest that the training could have an impact in reducing anxiety symptoms in training with an interactive game tool. Surprisingly, so far not many studies assessed the effects of frontal alpha asymmetry NFB on anxiety symptoms. Results from the present study lay the foundations for wider testing of the frontal alpha asymmetry protocol with different feedback tools in order to enhance users performance.

The present findings ought to be interpreted in light of some limitations. Firstly, no raw data was collected and processed step-by-step, in order to guarantee the study reproducibility. Although using Emotiv Epoc+, that reproducibility could be achieved, but the main focus of this work was on the developing of a new tool that could help anxious people. Therefore, even the code was not given, since this aims to be a product to be in the market. Secondly, self-report measures were only collected at pre- and post-training, thus not allowing for a session-by-session correlation between EEG and subjective measures of affect. Another limitation in this work was that it included different uncontrolled variables along the process that could undermine the results. Along with that variables are, the different "laboratories"used for different participants, different hours of the day that each participant realized the training, the inclusion of 3 game versions instead of just one, the groups had a different number of sessions in total and some equipment failures during sessions. Notice that some of these limitations were consciously designed before the NFB training started in order to integrate the business and science fields.

Although, the main aim of this work was to build a gamified application that confirmed the effectiveness of training on alpha asymmetry, as the first step approaching future, engaging gamified applications. Evidence for the practice effectiveness with a gamified application adds to the research in this area, proposing that future investigations ought to consider day-by-day variations in populations with other types of feedback tools, including gamified tools, and to attest the permanence of the effect throughout follow-up evaluations.

# Chapter 5

# Conclusions and Future work

Current treatments for anxiety are limited because they cause side effects and/or require long therapeutic periods and NFB typically uses unappealing therapeutic interventions.

Consequently the primary objective for this NFB work was to develop a gamified NFB application to anxiety treatment that could be an interactive and compelling way of doing NFB.

This project was divided into different milestones, starting with learning C# necessary to work with an integrated development environment for building games, Unity. The next step was the developing of the game integrated with an NFB application. After the product was tested, the trials were carried out, and finally, the data was analyzed.

The creation of this NFB gamified application was made in congruence with the lean process by performing the cycle hypothesis-test-validation. The product was designed to be a minimum viable product, that successfully engaged the initial users and collected feedback for future developments.

The game was tested with users until it reached, as considered by users, an appealing version to start the real trials for data collection. In this phase the game was continuously developed, having three versions during the data collection. In total 11 different subversions were developed. Nevertheless, GEQ was applied to measure the experience of players along different versions, and the results were incongruent with the positive feedback received by players.

Thirty people were studied, which performed up to 8 NFB sessions of 35 minutes each, totaling 185 sessions, 108 hours. They were divided into three groups with different NFB protocols, but playing the same game, Anxiety Destroyer, that was developed during the development phase. Among the groups were the ALAY group, with a protocol that intended to increase frontal alpha asymmetry, AF group, with a protocol to increase the asymmetry between AF4 and AF3, and the active control group that was increasing alpha waves in F4 and F3. Some of the outcomes of the study were:

- Players of all groups validated the learning nature of Anxiety Destroyer by increasing the score significantly along sessions. ALAY group could learn strategies to apply in the game in order to score points better than other groups.
- A significant increase of alpha frontal asymmetry was observed for the ALAY group between sessions, supported by the BAI scale and PANAS on NA. Compared to the active control group it was much more efficient in anxiety treatment.
- It is not possible to treat anxiety by applying a protocol defined as the asymmetry between AF4 and AF3, (AF4-AF3), the results suggested the opposite effect, and eventually AF3-AF4.
- Training alpha asymmetry in frontal or between frontal and pre-frontal zones is more efficient in increasing alpha waves than training specifically the increase of alpha waves in F4 and F3 regions.
- Different forms of Neurofeedback vary in the efficacy of changing what was intended with the protocol. Some protocols can be applied during eight sessions without visible results while others significantly change the neuroplasticity of the brain.

The major limitation of this study caused by technical problems, was the no collection of raw data important in order to guarantee the study reproducibility. Although, the main focus of this work was on the developing of a new tool that could help anxious people.

Nevertheless, there are some perspectives of possible improvements and future work that mainly focus on the following aspects:

- There were some potential meaningful insights in data that were not analyzed. Specifically, the individual analysis of F3, F4, AF4, and AF3 alone could bring new relevant information. We know that prevalent right-sided frontal activity has been linked with heightened vigilance for threat [123] [124], heightened negative affect and withdrawal tendencies [125], and anxiety symptoms [124], but it would be valuable to account for specific values of frontal alpha power in each channel, especially F4.
- Complementary analysis not only in location but in frontal asymmetry in other EEG bands could reveal extended consequences in beta and theta bands since it has been earlier published that the results of the frontal alpha asymmetry NFB prolonged to the beta band [120]. Some studies confirmed that both alpha and beta bands are inversely correlated with the activation of the underlying neural structures, as measured by fMRI at rest [126]. Accordingly, it can be considered that differences in

alpha and beta power indicate a related training-induced alteration. Nevertheless, it was published that a correlation between BOLD changes and alpha/beta bands are independent of each other, perhaps mirroring distinct underlying processes [127]. There is a need to address this explicitly in future work, examining how training-related modifications act in diverse EEG bands for this kind of NFB.

- It is crucial to attest the efficiency of this NFB gaming tool and compare in future studies to other currently used NFB systems that do not make use of a game to manage the session.

The primary objective for this work was achieved, the development of a gamified NFB application to anxiety treatment. The tool was adapted to users, that could enjoy from an appealing game for adults based in the feedback gave by them, both correspond to specific objectives. The only specific objective that apparently was not successfully achieved was the increased value of the game for the user over time, although it seems the method used to measure it was not ideal. Regardless, the product pre-requirements were meet.

To conclude this chapter not only of this thesis, but also of my life, it is necessary to say that, this work started with a great sense of purpose and is being ended with a great sense of fulfillment for the work done, for the people that I had the opportunity to meet, for the people that admired the game, for the people that gave negative feedback along the process and especially for the scientifically validated efficient tool. The gamified NFB application which makes use of a game, named Anxiety Destroyer since it was designed to be an initial step in the process of involving people to utterly destroy this abominable plague, Anxiety.

"Estava cética ao início mas afinal até em mim que por norma sou super stressada funciona!"

Subject 3, ALAY group

"O sistema de pontos oferece uma motivação extra para o jogador, motivando-o a querer fazer sempre melhor. Os asteróides (devido ao sistema de pontos) são o melhor exemplo de como o sistema de pontos pode motivar e premiar a capacidade do jogador em conseguir controlar a ansiedade e aumentar a concentração/foco."

Subject 7, ALAY group

"O objectivo do jogo é simples e claro: concentrar e concentrar cada vez melhor, eliminando a ansiedade. E o jogo atinge esse objectivo."

Subject 25, ALAY group

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Annex I

# Annex 1. Informed consent form and its approval

For this study, it was asked to the Ethics Committee of the Faculty of Sciences and Technology of Universidade Nova de Lisboa for his consent. After its approval, it was given to each participant of the study an informed consent form before the first session of the game. The informed consent form and the approval of the study by the Ethics Committee are shown below.

### I.0.1 Informed consent form

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA
Departamento de Física

## Formulário de Consentimento Informado

**Título do projeto:**

Desenvolvimento de uma aplicação com recurso ao *Neurofeedback* para tratamento de ansiedade em jovens adultos.

**Investigador(a):**

*Estudo organizado pelo Instituto de Biofísica e Engenharia Biomédica da Faculdade de Ciências da Universidade de Lisboa em Colaboração com a Faculdade de Ciências e Tecnologias da Universidade Nova de Lisboa.*

Pedro Silva, Departamento de Física, FCT UNL

pe.silva@campus.fct.unl.pt

**Introdução:**

Esta breve explicação descreve o objetivo, procedimentos, riscos e precauções da experiência. Sinta-se à vontade para colocar dúvidas sobre alguma expressão ou procedimento que não compreender.

A sua participação é voluntária; é livre de retirar o seu consentimento a qualquer momento sem necessitar de motivo e sem qualquer penalização.

**Objetivo do estudo:**

O projeto pretende comparar diferentes técnicas para o tratamento de ansiedade assim como o desenvolvimento de um jogo com recurso ao *Neurofeedback*. As técnicas utilizadas serão o *Neurofeedback* e a Psicoterapia. Relativamente ao *Neurofeedback*, será analisado através de um exame eletroencefalográfico e a um sistema de feedback de uma característica do seu sinal cerebral fornecido ao utilizador através de um jogo virtual interativo.

1

Figure I.1: **Informed consent form (first page).**

**Descrição dos procedimentos deste estudo:**

Ao concordar com o presente estudo, ser-lhe-ão propostos os seguintes passos:

-Completar um questionário anónimo com finalidade de compreender o seu nível de ansiedade quer no início quer no final do estudo;

-Efetuar treinos bissemanais de no máximo 45 minutos durante 6 semanas.

-Colocar o dispositivo EMOTIV EPOC+ ou o equipamento EmoBit (ambos de leitura de sinal cerebral).

-Ouvir a explicação do paradigma da aplicação e algumas formas de a controlar.

-Proceder à calibração, 15 minutos, e iniciar a sessão de *Neurofeedback* de 30 minutos de jogo com recurso ao *Neurofeedback*.

-Obter o maior número de pontos possível no jogo a cada sessão.

Pode, no entanto, pedir um intervalo a qualquer momento.

**Riscos de participar no estudo:**

Não existem riscos expectáveis para pessoas com condição física e neurológica estáveis.

**Confidencialidade:**

A sua atividade cerebral será gravada, através de um dispositivo próprio que será colocado na sua cabeça, sendo que os sensores estarão húmidos para permitir a leitura do equipamento.

Todos os dados e resultados de medidas indiretas podem ser usados para efeitos de investigação e publicação. Os dados serão anonimizados e podem ser publicados no âmbito de investigação.

**Direito de questionar e ser esclarecido:**

Tem o direito de inquirir acerca deste estudo e de obter as respetivas respostas antes, durante ou depois da experiência.

2

Figure I.2: **Informed consent form (second page).**

**Consentimento:**

Li, ou foi-me lida a informação acima mencionada. Tive oportunidade de apresentar as minhas dúvidas sobre o estudo e todas as questões foram respondidas de forma satisfatória.

Eu concordo voluntariamente ser participante deste estudo e declaro que desconheço ter algum transtorno neurológico, assim como alguma doença mental crónica, ou estar a tomar qualquer tipo de medicação que perturbe o funcionamento normal do exame eletroencefalográfico.

*Grupo de estudo a que pertenço:* ______________________________

*Nome do Participante:* ______________________________ *Data:*__________

*Assinatura do participante:*______________________________ *Data:*__________

*Assinatura do(a) investigador(a):*__________________________ *Data:*__________

*Em caso de solicitação, uma cópia deste formulário pode ser fornecida ao participante.*

3

Figure I.3: **Informed consent form (third page)**

## I.0.2 Consent from the Ethics Committee

FACULDADE DE
CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

PARECER

**Título: "Desenvolvimento de uma aplicação com recurso ao *Neurofeedback* para tratamento de ansiedade em jovens adultos"**

O parecer da Comissão de Ética da FCT é positivo. O projeto está completo e cumpre as regras de boa prática de investigação.

Alguns comentários, que não alteram o parecer positivo do ponto de vista da Ética para poder ser realizado a investigação, a saber:

1 – Na introdução é importante fazer referência ao Conceito geral de Neurofeedback 2 – Dispositivo EMOTIV EPOC – beneficiaria de ser caraterizado, na introdução.
No consentimento informado será importante explicitar melhor, também, alguns pontos:

a) Ao referir – "realizar consultas de psicoterapia durante um período de pelo menos 6 horas" – é importante explicitar que são várias consultas de psicoterapia e que o total de horas é de pelo menos 6 h. (pode parecer redundante, mas em matéria de informação e consentimento informado é necessário ser bem explícito)
b) Na página 2, ponto 2 "Grupo de psicoterapia"
Onde está ..."Concordar com o presente estudo", deve estar "ao concordar em participar no presente estudo" . O consentimento é para participar no estudo.
c) Ainda neste ponto dois, fica confuso a separação em itens diferentes, "colocar o dispositivo EMOTIV EPOC ...." E "realizar um exame eletroencefalográfico....", porque a colocação do dispositivo é para registar o traçado eletroencefalográfico (EEG).
d) Seria também importante referir claramente que todos os participantes, seja qual for o grupo em que estejam incluídos, fazem testes e registo de 2 EEG.

Caparica, 15 de outubro de 2018

Manuel Nunes da Ponte

Figure I.4: **Consent given by the ethics committee for this study.**

Annex II

# Annex 2. Beck Anxiety Inventory

In order to evaluate the anxiety of each that participated in the study, BAI was given as a form to measure anxiety subjectively. The questionnaire is shown above.

**ESCALA DE ANSIEDADE DE BECK**

**(BECK-A)**

Data: ____ / _____ / _______ Checado por: ____________________

Abaixo temos uma lista de sintomas comuns à ansiedade. Favor preencher cada item da lista cuidadosamente. Indique agora os sintomas que você apresentou durante A ÚLTIMA SEMANA INCLUINDO HOJE. Marque com um X os espaços correspondentes a cada sintoma.

| | 0 | 1 | 2 | 4 |
|---|---|---|---|---|
| | Ausente | Suave, não me incomoda muito | Moderado, é desagradável mas consigo suportar | Severo, quase não consigo suportar |
| 1. Dormência ou formigamento | | | | |
| 2. Sensações de calor | | | | |
| 3. Tremor nas pernas | | | | |
| 4. Incapaz de relaxar | | | | |
| 5. Medo de acontecimentos ruins | | | | |
| 6. Confuso ou delirante | | | | |
| 7. Coração batendo forte e rápido | | | | |
| 8. Inseguro (a) | | | | |
| 9. Apavorado (a) | | | | |
| 10. Nervoso (a) | | | | |
| 11. Sensação de sufocamento | | | | |
| 12. Tremor nas mãos | | | | |
| 13. Trêmulo (a) | | | | |
| 14. Medo de perder o controle | | | | |
| 15. Dificuldade de respirar | | | | |
| 16. Medo de morrer | | | | |
| 17. Assustado (a) | | | | |
| 18. Indigestão ou desconforto abdominal | | | | |
| 19. Desmaios | | | | |
| 20. Rubor facial | | | | |
| 21. Sudorese (não devido ao calor) | | | | |

Desenvolvido por: BECK, A.T.: EPSTEIN. N.; et al. An Inventory for measuring clinical anxiety: psychometric properties. J. Consult. Clin. Psychol. 1988; 56:893-897.

Figure II.1: **Beck Anxiety Inventory, composed with 21 questions and with possible four answers for each question.**

Annex III

# Annex 3. Positive and Negative Affects Scale

PANAS was used as a form of subjectively measure anxiety by measuring the positive and negative affects. The entire questionnaire is shown bellow.

**PANAS** *Positive and Negative Affect Schedule* (PANAS; Watson, Clark & Tellegen, 1988)

**Esta escala consiste num conjunto de palavras que descrevem diferentes sentimentos e emoções. Leia cada palavra e marque a resposta adequada no espaço anterior à palavra. Indique em que medida sentiu cada uma das emoções. Inserir aqui as instruções de tempo de resposta adequada*:**

**1** Nada ou muito Ligeiramente **2** Um Pouco **3** Moderadamente **4** Bastante **5** Extremamente

___ Interessado
___ Perturbado
___ Excitado
___ Atormentado
___ Agradavelmente surpreendido
___ Culpado
___ Assustado
___ Caloroso
___ Repulsa
___ Entusiasmado

___ Orgulhoso
___ Irritado
___ Encantado
___ Remorsos
___ Inspirado
___ Nervoso
___ Determinado
___ Trémulo
___ Activo
___ Amedrontado

***** *Tempos de resposta utilizados pelos autores:***
- agora, ou seja, neste momento;
- hoje;
- durante os últimos dias;
- durante a última semana;
- durante as últimas semanas;
- durante o último ano;
- geralmente, ou seja, em média

Figure III.1: **Positive and Negative Affects Scale that contains 20 questions with five possible answers to each question.**

Annex IV

# Annex 4. Game Experience Questionnaire

GEQ was applied to measure the experience of the players that played the game Anxiety Destroyer. The questionnaire is shown below.

## Questionário de Experiência de Jogo

## No jogo:

Por favor, indique como você se sentiu ao jogar o jogo para cada um dos itens, na seguinte escala:

| de modo nenhum | levemente | moderadamente | bastante | extremamente |
|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 |
| < > | < > | < > | < > | < > |

1 Eu estava interessado(a) na história do jogo

2 Eu senti-me bem sucedido(a)

3 Eu senti-me aborrecido(a)

4 Eu achei impressionante

5 Eu esqueci tudo à minha volta

6 Eu senti-me frustrado(a)

7 Eu achei-o cansativo

8 Eu senti-me irritável

9 Eu senti-me habilidoso(a)

10 Eu senti-me completamente absorvido(a)

11 Eu senti-me contente

12 Eu senti-me desafiado(a)

13 Eu tive de me esforçar muito

14 Eu senti-me bem

Figure IV.1: **Game Experience Questionnaire (first page )that includes in total 31 questions with five different possible answers.**

## Módulo pós jogo

Por favor, indique como se sentiu depois de terminar o jogo para cada um dos itens, na seguinte escala:

| de modo nenhum | levemente | moderadamente | bastante | extremamente |
|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 |
| < > | < > | < > | < > | < > |

1 Eu senti-me revigorado(a)

2 Eu senti-me mal

3 Eu achei difícil voltar à realidade

4 Eu senti-me culpado(a)

5 Senti-o como sendo uma vitória

6 Eu achei-o uma perda de tempo

7 Eu senti-me energizado(a)

8 Eu senti-me satisfeito(a)

9 Eu senti-me desorientado(a)

10 Eu senti-me exausto(a)

11 Eu senti que podia ter feito coisas mais úteis

12 Eu senti-me poderoso(a)

13 Eu senti-me cansado(a)

14 Eu senti-me arrependido(a)

15 Eu senti-me envergonhado(a)

16 Eu senti-me orgulhoso(a)

17 Eu tive a sensação de ter voltado de uma jornada/viagem

Figure IV.2: **Game Experience Questionnaire (first page )that includes in total 31 questions with five different possible answers.**

Annex V

# Annex 5. Experimental Protocol

In bellow is shown the experimental protocol used at each session of the present study. The protocol gives a step by step orientation to the person responsible for the experience.

# Protocolo Experimental

## Material:

- Emotiv Epoc+.
- Computador Portátil.

## Procedimento Experimental:

- Fornecer três questionários para o paciente preencher.
  - Edinburgh Handedness Inventory (http://zhanglab.wdfiles.com/local--files/survey/handedness.html). (Apenas na primeira sessão).
  - PANAS (*Positive and Negative Affect Schedule)* (Na primeira e última sessão).
  - Inventário *Beck* de ansiedade (Na primeira e última sessão).
- Abrir a pasta "*Anxiety Destroyer_Data*" e verificar se existe algum ficheiro com o nome "*AverageBandPowers*". Caso exista, transferi-lo para o ambiente de trabalho.
- Seguir uma de duas instruções em baixo:
  - Colocar cerca de 5 gotas em cada sensor do equipamento *Emotiv Epoc+* de uma solução própria presente na caixa do dispositivo. (Primeira e última sessão)
  - Colocar cerca de 5 gotas nos sensores que irão afetar o jogo, ou F3 e F4 ou AF3 e AF4. (Todas as sessões excluindo a primeira e a última).
- Colocar o equipamento Emotiv Epoc+ na cabeça do paciente.
- Abrir o programa *Emotiv Xavier ControlPanel*.
- Ligar o equipamento Emotiv Epoc+.
- Seguir o *Quick Start Guide* que vem com o dispositivo para a aquisição correta do sinal.
- Abrir o jogo Anxiety Destroyer.
- Informar que não é permitido mexer no equipamento, caso haja algum problema, pedir ajuda ao técnico que estará perto do local.
- Informar o paciente sobre as regras do jogo: (Apenas nas duas primeiras sessões).
  - "Terá de comandar uma nave espacial com a sua mente de forma a conseguir chegar a Marte. Para conseguir ter sucesso na sua missão terá de combater a sua ansiedade, de forma a conseguir responder aos desafios desta missão da forma mais calma e relaxada possível. Caso o consiga, ao final da meia hora de jogo se conseguir estar perto de Marte poderá aterrar no Planeta Vermelho".
  - O objetivo do jogo é acumular o maior número de pontos possível, "Score".
  - Caso ao final da meia hora de jogo, esteja no último nível, chegará a Marte.
  - O Score aumenta, mas não diminui.
  - O Mapa de jogo está dividido em zonas que variam dependendo do nível de jogo.
  - Existem diversos níveis de jogo.
    - A subida e descida de nível está dependente do tempo que o jogador passa, quer na área superior do mapa (para subir de nível), quer na área inferior do mapa (para descer de nível).

Figure V.1: **Experimental protocol (fist page) written in Portuguese since the executers of the protocol speak Portuguese.**

- No geral quanto mais acima se encontrar no mapa mais pontos fará.
- Caso esteja numa zona de meio para baixo, não serão descontados pontos, no entanto, poderão ser somados um outro tipo de pontos que o fazem descer para um nível inferior.

- Transmitir ao paciente sobre possíveis formas de relaxamento, de forma a reduzir a ansiedade, sendo que cada pessoa terá a sua forma de lidar com a mesma: (Apenas nas primeiras duas sessões)
    - Observar tensão no corpo e relaxar essas zonas.
    - Imaginar o seu cérebro a relaxar.
    - Visualizar eventos positivos.
    - Entre outras possíveis técnicas.
- Comunicar que durante o jogo o jogador deverá estar o mais parado possível, de uma forma que seja confortável.
- Informar que o jogo terá a duração de meia hora mais 5 minutos iniciais de aquisição de sinal. Caso seja necessário poderá pedir ao técnico para fazer uma pequena pausa durante o jogo.
- Indicar que os primeiros 5 minutos serão para aquisição de sinal e que o individuo deverá olhar para as cruzes que vão surgindo no ecrã.
- Voltar a relembrar que não é permitido mexer no equipamento.
- Começar o jogo.
- Ao final de 35 minutos o jogo irá terminar automaticamente.
- Retirar o equipamento da cabeça do individuo.
- Pedir se o jogador se não se importa de preencher um questionário para avaliação do jogo, e entregar-lhe o inquérito.
- Alterar o nome do ficheiro Excel criado na pasta "Anxiety Destroyer_Data", de "AverageBandPowers" para o nome com o número do sujeito e o número da sessão. Ex "Sub4_Ses5".
- Transferir o ficheiro com o novo nome para a pasta "Dados Anxiety Destroyer"

Figure V.2: **Experimental protocol (second page) written in Portuguese since the executers of the protocol speak Portuguese.**