**TALLINN UNIVERSITY OF TECHNOLOGY**

School of Business and Governance

Department of Business Administration

**Cristofer Angel Franco**

# EEG SIGNAL RECOGNITION TECHNOLOGY IN COGNITIVE STRESS CONDITION AND FUTURE APPLICATIONS AS EVOLUTION OF ERGONOMIC SYSTEMS AND PREVENTION OF WORKING NEGATIVE CONDITIONS

Master of Work and Organizational Psychology Thesis

HVWM11/12 Work and Organizational Psychology

Supervisor: Liina Randmann PhD

Tallinn

2018

# TABLE OF CONTENTS

# ABSTRACT


EEG signal recognition technology in cognitive stress condition. Future applications as evolution of ergonomic systems and prevention of working negative conditions.

Cristofer Angel Franco

New digital technologies are changing the work environment day by day. The electroencephalographic reading systems that until recently were only used for studies and scientific discoveries, now are beginning to be studied and used as a method to improve human-machine communication, proof of this effective communication is the existence of helmets suitable for leisure activities that allow the control of small mechanical systems, as well as growing researches on the use of these helmets in highly technological work environments.

The new technologies also cause that the tasks that must be done are increasingly specialized and require increasingly complex control systems, scientific branches such as ergonomics make many efforts to create work environments that improve the quality of life and reduce the cognitive effort and the physical demand of the job task.

The reading of human brain signals opens the door to the possibility of knowing in an empirical and objective way the psychophysiological condition of people. throughout the present work it will be demonstrated how it is possible, through the use of an EEG reading helmet, to record the fluctuation of brain waves of a subject and the stress factor that it presents while performing a cognitively stressful activity.

Although this type of technology requires a significant evolution, it is now possible to theorize about its future function as a transforming agent of the working environment. This work presents the possibility of using EEG systems to monitor the worker's status during their working day and use this information in real time to modify their work environment according to their psychophysiological needs, always keeping the worker's energy levels at their optimum.


Keywords: Stress, EEG, Brain Computer Interaction (BCI).

# ABBREVIATIONS LIST

BCI: Brain Computer Interaction

SA: Situational Awareness

EEG: Electroencephalography

PSD: Power Spectral Density

μV: Microvolt

HMIi: Human-Machine Interaction Interface

HMI: Human-Machine Interaction

HMi: Human-Machine Interface

Hz: Hertz

# 1. INTRODUCTION

Work environments become more technological as new systems emerge that improve the effectiveness of results or facilitate the work reducing the workers workload. Digital technology has greatly increased the ability to connect and exchange information, the person's work can be automatically encoded and sent to multiple computers across the globe to be used as a piece in other projects. The ergonomics and the actual worker environment leaves the manual or physical work to the machines, in that way, the worker mostly only has to worry about take decisions and press the correct activators when it is necessary.

Digital technology has turned the work tools into intelligent tools that automate everything that can be automated, however, the process of exchanging human-machine information remains unchanged. The tools improve with the technology, but next to the ease of use also increases the complexity or the number of possibilities that allow, making the decision process or the work environment itself a more complex situation.

A new technology is appearing and recently showing itself as a viable alternative to the current human-machine information exchange process, this technology is known as brain computer interaction (BCI) and allows the elimination of the process of pressing buttons or levers to interact with the machine. The BCI system subjugates the movement or the machine actions to the operator's own thought. Through an EEG system (electroencephalographic) it is possible to read the brain waves fluctuations and codify them as machine actions, resulting for example in the movement of a robot or a prosthetic hand.

Another capacity presented by the BCI system is the ability to read the mental state of the subject, emotions such as stress, fear or calm show EEG signals before the person is aware of them and can subjectively refer these conditions. The emotional reading capacity of the BCI systems opens the door to the effective prevention of negative or altered states of workers, warning on the beginning of states of stress or fatigue before they are harmful. Thanks to this early warning, it would be possible to modify the work environment according to the needs of the worker.

A work environment where this technology would be very beneficial, and in which experiments and discoveries on BCI systems are already being carried out, is in the aeronautical sector, the large number of working hours, the extremely technological environment that it already has and the potential catastrophes that can occur due to human failures make to this sector one of the most benefited if this technology would be implemented.

This paper presents the correlation between brain waves and stress (following what has been done in previous experiments), creates a baseline for future experiments focused on fatigue, and also show how these results (within the theoretical framework) can be implemented in the future.

Due to limitations of time and resources, finally it has only been possible to measure stress in a theoretical work environment for aircraft pilots. However, the theoretical framework is focused on showing how with a greater number of resources and a quantitative improvement in the technology is possible to use these systems to connect the work environment whit the worker psychophysiological needs, allowing to modify the environment with the intention to anticipate stress and / or fatigue episodes.

Therefore, this work can be divided according to its objectives into two parts:

- The practical objective is to demonstrate how it is actually possible to measure stress objectively thanks to the BCI technology and therefore theorize (with a prior theoretical basis) the possibility of measuring other emotions or mental states. To carry out the experiment the following hypothesis was formulated: The signal strength of the parietal alpha wave will decrease and the frontal theta will rise as the stress in the subject increases.
- The theoretical objective is to elevate the practical experiment results to a new future ergonomics system, with the BCI system as a modifying center of the working environment, it would be possible to prevent acute episodes or periods of stress or fatigue.

The experiment has been carried out through three tests designed to resemble the actions that a pilot must perform in their common work environment. These tests were performed on ten subjects through the use of a computer and an EEG reader helmet.

The restrictions of time and resources precluded the experimentation with more subjects, as well as the implementation of the fatigue factor, since this factor required more personal volunteers time. The resulting data had to pass through multiple processes for refinement and exposure, however, at the end several of these processes did not appear to be sufficiently refined to show significant utility.

Below is written a detailed review of each chapter of the theoretical body:

Chapter one shows in a generalized way the current knowledge about stress and fatigue, as well as the importance of these concepts in current societies.

The second chapter is necessary as part of the theoretical approach, to show the importance and usefulness of a BCI system in aeronautics, and why specifically this work is focused on aeronautics.

In the third chapter the relationship between the worker's environment and his physical-psychic state is shown, emphasizing the possibility of modifying the environment to modify the worker's status.

The fourth chapter is the theoretical basis for the practical experiment that will be described in the methodological section. In this chapter is described the EEG reading system and the brain waves.

The fifth chapter is the basis of the theoretical part and serves as a bridge between this part and the practical part, as it shows the operation of the HMi systems and how these could be used in aircraft cabins as a frame for the BCI system.

Part of chapter six could be included inside the methodological part, since it explains the qualities of the EEG reading helmet that is used for the experiment (Emotiv insight). The rest of this chapter shows how this technology is viable for daily use in a more or less comfortable way.

Finally, I would like to thank Schon Z.Y. Liang Cheng and the DR. Rosa M. Arnaldo Valdés, members of the Polytechnic University of Madrid (aerospace systems department) for their indispensable help collecting experimental data and invaluable advices about the operationalization and data correction. I would also like to thank my tutor Liina Randmann for helping me to focus on my goals and clarify my ideas

# 2. LITERATURE REVIEW, THEORETICAL BACKGROUND

## 2.1. Fatigue and stress. Psycho-physiological approach

The concept of stress has many different meanings and has been shaped by multiple theories during investigations. In this work I am using the definition of Miller and Smith (1993): "Stress is the state of dynamic tension created when you respond to perceive demands and pressures from outside and from within yourself". It is important to remember that the stressors can be internal or external, and even real or imagined. However, regardless of their nature, these stressors have something in common: they exceed the perception of the person's self-capacity. That means that the same stressor may or may not cause stress to a person depending on his ability to face or fix the stressor.

Stress can also be divided into two opposite categories – eustress and distress. The first one has positive character and the second one – negative character for body or mind of the person. While there are exceptions in the extremes (things that the body or mind are not able to do), in general the solution of this dichotomy depends exclusively on the person, because he is exactly who will decide how to act: to suffer the stress in a negative and exhaustible way or, otherwise, take it as something positive and strengthening.

At first glance the eustress may seem something really positive and what should be applied or enhanced to the workers, and to an extent it is. But in spite of that, it should be clarified that the body does not distinguish between the two types at the physiological level (Homan, W.J 2002). Physical and mental demands, whether conceptualized by the person as positively or negatively, burden the body with the same state of tension.

Acute stress causes adrenaline rush in the bloodstream increasing the energy level, breathing and heart rate, as well as blood sugar level. This energetic increase allows us to think and act quickly in return for an over-physiological effort. This kind of stress is a very useful state to end conflicts where exists any immediate solution, but he main problem is normally caused by the situations where the solution is extended in time or does not have any direct solution. In this case the produced energy will stay at its abnormally high level and, as a result, long-lasting stress will overload the body and the psyche of the person. Demand level of current work methodologies generate large amounts of continued stress which affects the body in this way.

However, there is another big problem, and it is one of the most studied ones in work and social psychology – fatigue. It is a common situation when the person is not able to do more than permits his body or mind without forcing himself. In this case the overexertion produced leads to a drastic decline of the energy level. There are studies that demonstrate that from twenty to thirty per cent of the population of Europe and United States suffer essentially from the fatigue (Ishii, A. 2014). It is caused by our current rhythm of life, which requires frequently a constant energy wear, and not only requires it but our  high level society itself    the constant energy flow do not come just from the outside requirements, our already highly evolved society has accustomed us to a constant stimulation, therefore, leaving aside the efforts required by our daily tasks, whether work or studies, even during our free time we are used to keeping our mind or body active thanks to new technologies.

Fatigue unlike stress, has a physical component that normally covers the visibility of fatigue as a psychological element. Like all other emotional processes, it is impossible to separate physical fatigue from mental fatigue due to its close correlation, which leads the general public to consider fatigue at work as a physical problem that is solved with rest. However, as I mentioned before, it is not work in its physical-practical nature the only source of stress and fatigue, but often our emotions and considerations about work and its peculiarities continue to cause fatigue even when we are resting or doing a totally independent activity.

The human being is a network that connects all aspects of his daily life in his psyche, in the same way that the neural network connects cognitive processes, that is why it is not possible to simply forget about an activity for the mere fact of stopping to make it. The information is saved as experience and returns when it is remembered, which in turn brings us a sample of the effects that brought with it when was experienced (Ishii, A. 2015). Therefore, the simple rest, either by withdrawals or holidays is not enough to eliminate the state of fatigue completely, because remembering that state and the situation that creates it generates moderate levels of fatigue in the person (Ishii, A. 2015).

If the fatigue in a state that already require a rest can not be completely eliminated, as the memory of that activity reinforces fatigue, it is clear that observe, predict and minimize fatigue at low levels is an action that reports greater benefit that solve the problem once it has already emerged.

Fatigue is, therefore, a common problem in the general population and more specifically, in the worker. Fatigue in a prolonged state over time can cause sick leave and work disability, which generates consequences for employees, such as decreased monetary income or social loneliness and logically consequences for employers, in the form of reduced productivity and decompensation of the work groups. In addition, it is associated with a wide range of somatic conditions and mental problems such as depression or anxiety, some common effects are: Decreased visual acuity, numbed mind, stubbornness, irresponsibility, errors of judgment, loss of memory, lack of organization, indifference and irascibility (Ma, J. 2014).

Fatigue and stress are two symptoms difficult to diagnose because it depends largely on the personal perception of the sufferer (Genova, H.M. 2013), the eustress and the fatigue produced by an activity on which we are proud are positive experiences, however, in the end is the decision of the person to identify their own state as something positive or negative.

Being such a subjective situation is really difficult to diagnose properly (Andrea, H. 2002) and what is even more difficult, do it at the right time. Since, being such a subjectively idea, professionals can only see and work on it when the situation it escapes the person's control and becomes so big that it is clearly visible.

When this lack of control happens, the next step is usually indicated with rest, however, as I mentioned before, although removing the person from work or from the root that causes stress and fatigue reduces the problem noticeably, it can not be said as a solution, for the experience of a situation so acute (and commonly delayed in time) remains etched and reappears again when the person experiences situations that remind him the environment that caused the symptom.

The studies and the advances on the conformation of the brain have allowed us to see that this re-experimentation is not only something emotional but that the neuronal conditioning makes the people who have experienced high levels of fatigue and stress experience it strongly (Ishii, A. 2015) since his neural network is already predisposed to maintain the synaptic connections produced by the acute situation.

There are psychometric tests of different types that are widely used in the discovery and treatment of fatigue in workers, however recent studies have identified some types of these tests as limited, since these test adequately indicated the levels of fatigue perceived by the subject and their environment, however in some subjects who scored negative in these tests scored positive in psycho-physiological tests, which showed that many people who did not report subjective fatigue did suffer at a physiological level (Ma, J. 2014), the same happened with mental overwork and stress.

The flow of energy of a person can be perceived empirically and many studies have been done on when it is more powerful, because it decreases, the consequences of its fluctuation or ways of controlling it. To identify the optimal level of excitement, energetic potential or attention that a person must have to carry out a task in its best physical and mental state, we can use the model of Yerkes-Dodson (Figure 1.) (Homan, W.J. 2002), in whose left vertex is the lack of energy or boredom and in its right vertex the excess of energy or anxiety (panic).

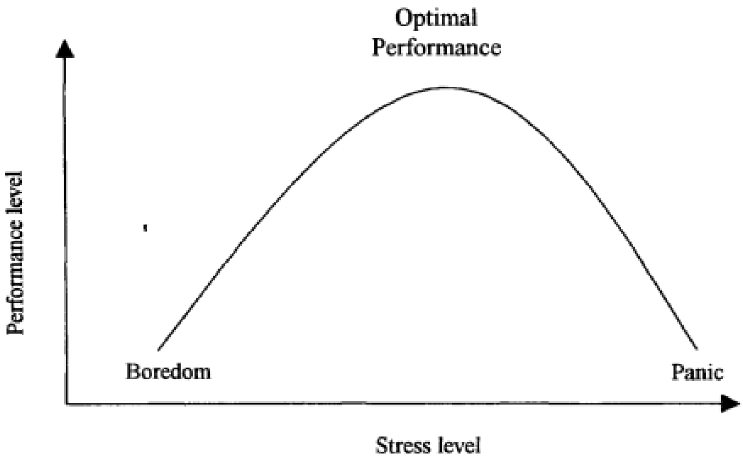


Figure 1. Yerkes-Dodson model
Source: Homan, W. J. (2002)

The stress would be located logically in the right vertex, since it is the result of an overstressed energy caused by an excessively demanding task while the fatigue would be located in the left vertex, but unlike boredom which is a state in which energy is not used despite being inside the person, fatigue is a state of complete lack of energy as a result of being burned by over-exertion.

Although fatigue is a natural state caused by continuous over exertion and therefore is not an exclusive consequence of stress, by definition and if the appropriate measures are not taken it is common that fatigue is the symptomatic state that follows stress. This very narrow consequence facilitates the limitation of the effects of fatigue when the state of stress is identified in a person, because by limiting the stressors to which this person is exposed, the continual demand and the physical and mental requirements that would lead to exhaustion and greater fatigue are also limited.

## 2.2. Evolution and importance of the aeronautical industry

The ease of communication and online navigation networks are not the only ones responsible for the growing global multiculturalism. Intercultural tourism has been a constant in the history of humanity, and since the creation of the concept of tourism this has been increasing thanks to the evolution of transport means, as well as its ease form of use and the publicity, these means of transport currently allow to cross great distances with a lower economic cost than ever.

With this panorama, mass tourism has been reached, a term that encompasses the idea of the exponential increase that international tourism has suffered since the eighties. This tourism has not only grown in quantity but also in distance and speed, the current cost of production of the most common mass travel means as trains, large ocean liners, and mainly airplanes, makes of the competition between companies that carry these services so high that currently the possibility of international and intercontinental travel has been extended to the general public. This is reflected in the estimates that dictate that in the period between 1995 and 2020 international tourism will grow by 175 percent (Hernandez, J.A. 2007).

The speed limits reached by the new engines allows the planes to make trips without stops, before, the turboprop engines required regular stops to refuel, this greatly increased the security of aircraft, since landings and take-offs were the most likely to suffer accidents (Hernandez, J.A. 2007). This increase in speed and safety also affected the work days of the pilots and their relationship with the machinery of their job,

The democratization of air transport and the competitiveness among the booming aeronautical tourism companies led to the creation of certain modern initiatives and methodologies that limited the cost for companies and for users. Regarding the airplanes, a single aircraft model was used by each companies, as far as possible, this facilitated and accelerated the learning of mechanics and pilots.

The configuration of the aircraft also changed, changing the most parts of the spaces and reducing the difference between classes, this advantage also affected the cabins of pilots whose configuration change provided more space in the cabin and allowed an increase in the size of the control panels.

This generalization of the aeronautical tourism and the increasing competitiveness also caused a change in the paradigm of the education of the pilots, as well as an increase in the demand to them, since the security of the airplane depends for the most part on the maintenance of the aircraft and the capabilities of the pilots. The new pilots, have more difficulties when it comes to adapting to the situation in the cabin because leaving aside the intrinsic stress of the weight of responsibilities (which can not be practiced in simulators) the altitude and the consequent reduction of atmospheric pressure are conditions physiological long-term strenuous (Legeza, E.2005).

These conditions, which cause long-term altered states, are the most dangerous for pilots because it is not permitted for them to get into the cabin of an airplane if they are under the influence of an illness or are being medicated with assets that generate contraindications, these situations give us an idea of the high degree of demand that pilots carry with them and the pressure that this produces in their daily lives.

Currently, pilots are taught the interaction with the instruments of the cabin, with the aim of preventing accidents or errors caused by a poor human-machine communication or by the lack of coordination among workers, they are also taught notions of human resources, or operational communication, with the intention that make an effective communication system with their colleagues in the cabin (Toppi, J. 2016), with the hostesses in case it is necessary a close cooperation and even with the operators in charge of the maintenance of the airplane thus preventing possible conflicts between the state of the airplane or the instruments and preconceived ideas of the pilot.

Pilots are exposed to physical and mental fatigue due to noise and light fluctuation of the cabin, vibration and sudden movements, pressure changes, long-duration flights and irregular work schedules and lack of sleep or jetlag, these factors are enhanced by the aforementioned decrease in pressure and the low atmosphere that cause in the non-experienced people a physiological change that makes even more difficult the correct functioning of the brain, fatigue is in fact, one of the greatest cause of accidents in flight (Ma, J. 2014).

## 2.3. Environment as a modifier of energy activation

Many studies on sustained attention, arousal and fatigue are made with the intention of demonstrating how it is possible to use the environment and modify it to maintain stable levels of attention, from these experiments we can see how some colors favor attention, as well as the variation of colors itself already reduces tedium and boredom, this same thing happens with sound and in general with the whole environment of the person. The relationship between a monotonous environment, with little stimulation and the progressive decrease of attention is well known, in the same way that an overstimulating environment hinders the conscious attention towards a certain point and with time it can generate stress.

Using the aforementioned Yerkes-Dodson model graph and the findings on sustained, selective and focused attention, we can observe how the environment can become a big problem when discriminating stimuli or making decisions and organizing both, attention and order of realization. More specifically, during a mid-flight crisis, the pilot must deal, apart from the stress and mental load of the event itself, with multiple sound and visual alarms and with an immense number of activators in his work panel (Figure.2), in addition to having to work synergistically with his cabin partner.

Figure. 2 Cockpit of a Jetstream 31
Source: Internet, see references

In the same way during the long periods of time in flight in which the activity of the pilots becomes routine, the general conditions of the cabin facilitate calmness, with a faint light, without sounds, beyond that caused by one's own airplane and comfortable temperature. The levels of attention of the pilots may decline because the environment facilitates it with the intention of not keeping the pilots over stimulated and then being less agile by the fatigue caused by the previous stimulation.

Throughout the evolution of aeronautics, many experiments have been carried out with the intention of limiting the symptoms caused by long periods of flight, these recommended measures can prevent future problems thanks to specific diets, periodic rest periods, physical exercises or sleeping schedules in function of the direction of travel. Although these measures facilitate the correct physical and mental functioning of the pilot, it does not reduce the burden of fatigue nor regulate the correct state of attention depending on the situation.

One can conclude then, that an over-stimulated environment is good in a certain way during long-term calm situations, it is negative during crises, on the other hand, environment low on stimulation are negative in these long-term situations, but positive in a certain way in situations of danger where concentration and order are required. Therefore, with the intention of maintaining the energetic level and the attention of the pilots in a suitable point as long as possible and depending on the situation in which it is, a modifiable environment is necessary, this new system could alter the space of the cabin depending on the needs of the situation and the pilot.

## 2.4. Cerebral waves, EEG reading systems

In this work a methodology of recognition of the brain's electrical activity of the subjects was used, more precisely, electroencephalography (EEG) methods. The EEG is a recording technique, in general non-invasive, that relies on the use of electrodes along the skull, above the scalp of the subject. The EEG measures the voltage fluctuations caused by the ion exchange between the neurons brain and the excitations in the dendrites of the neurons caused by electric currents, this allows to record the spontaneous electrical activity and its fluctuations.

The signal received through the EEG technique is quantified according to the potential difference over time between the active electrode and the reference electrode, adding to these a third "land" electrode used to measure the voltage difference between the two principal electrodes.

Because it is a non-invasive technique it is by far the most commonly used electric signal engraving technique, however, because of this, the signal obtained by actual technologies is a poor quality signal, since it must pass through the skull, scalp and hair layer of the subject. Therefore, the signals are weak and of poor quality, so they are difficult to acquire, we also have to take into account the ease with which this system is affected by the background noise, either from the environment with the environmental electricity or in the subject's own brain.

The amplitudes of voltages of the EEG signal are between 1 μV (microvolt) and 100 μV peak-to-peak at low frequencies (0.5 Hz to 100 Hz) on the cranial surface. The odes result of the variation between the electric potentials are recognized according to their speed (frequency), to which adding the time factor allows us to classify them in Hertz, the frequencies of the EEG are divided into five groups, also related to the mental condition of the subject and the cognitive requirement of the task (Das, T.2017):

Delta (δ) 0.5 Hz - 4 Hz. Associated with light sleep or meditation with low requirement.

Theta (θ) 4 Hz - 8 Hz. Associated with deep relaxation states with low performance.

Alpha (α) 8 Hz - 12 Hz. Associated with mental coordination, mental preparation (Patten, T.M. 2012) and relaxed alertness with an average performance level.

Beta (β) 13 Hz - 40 Hz. Associated with problem solving, decision making and concentrated mental activity with high performance.

Gamma (γ) 40 Hz - 100 Hz. Associated with cognitive functions such as learning or memorization with high performance.

Of all these types of waves, only alpha and thetas will be studied.

Alpha activity is less than 10 µV peak-to-peak and increases in the posterior part (occipital region) of the brain, it is a very weak signal and it is difficult to register. In contrast, theta activity is less than 100 µV peak-to-peak and is very strong on the central region (parietal region) of the brain, so it will be easier to obtain reliable results from it.

The amplitude of the alpha wave increases when the eyes are closed and the body is relaxed and also decreases when the eyes are open or mental effort is being made. These rhythms are usually associated with visual processing in the occipital region as well as with functions related to memory (13Nicolas, L.F. 2012). Evidence has also been found of an inverse relationship with mental effort, which causes a suppression in the rhythm of alpha waves, especially in the frontal region of the brain (Maksimenko, V. A. 2017).

The frequency of frontal theta wave activity increases with the difficulty and effort required by mental operations, and is related to the focus of attention, learning, mental processing and memory effort (Saputra, R. 2017).

In previous studies (Borghini, G. 2014), the correlation between the PSD (Power Spectral Density) and the EEG signals with the difficulty and complexity of the task has already been described. More specifically, it has been found that the electroencephalographic PSD signal in the frontal theta band (4-8 Hz) increases, meanwhile the signal in the alpha parietal band (8-12 Hz) decreases when the mental workload and the complexity of the task increase.

With this previous information and because the literature that relates stress and brain waves has not yet been very developed, it is possible to use these fluctuations of the waves that have already been studied in specific cognitive processes (Usanova, L.D. 2011) and hypothesize their relationship with the state of stress. In general, the alpha wave decreases with brain activation and mental effort while the theta wave has a direct relationship with mental processing and working memory.

## 2.5. HMI-Brain Computer Interaction

It is called human machine interaction interfaces (HMIi) to the medium by which human and machine exchange information and relates human, machine and environment. In the most common human-machine interaction models, the person receives the information that the machine emits, then the person processes it in the brain, makes a decision and locomotive reacts with an action consistent with the flow of information. The category of HMIi is divided into two sections, which are:

- Human-machine interface (HMi) which deals with the output or input design of the machine itself. These designs are generated based on the utility of the machine with the intention of being as functional as possible and improve its synergy with the human.
- Human-machine interaction (HMI) that is treated, as its own name indicates, the interaction in the form of bidirectional communication.

Although the HMi in the analog machines is based almost exclusively on the simple and direct configuration of the signals of the physical interface, when dealing with a digital machine with the capacity to respond to an input with two or more outputs the form in the that these information outputs are presented has the capability to influence human decision making.

In conversations between people, the order of importance given by the different types of information, the way in which it is presented (in a visual, auditory, etc.) and the complexity, alter the communication system and the messages, since the human brain tends to fill in the gaps in the information received with its own information, in the form of previous experiences or future deductions. Therefore, when it is designing an HMi for a specific system, it must be taken into account what information it will exchange in the future with its user, as well as the specific type of user to whom it is addressed, for this purpose there are some principles that facilitate effective interaction human-machine (Deng, L.2016):

1. The cognitive or learning ability of the machine must be goal oriented. The HMi must be designed in line with the experiences and knowledge of the users in order to generate valid answers and reduce the learning and memorization time of the machine and the human.

2. The design must flow with the task for which it is programmed. In order to reduce the work effort of the human being, the machine must emit the information quickly, easily understood and according to the task it performs.
3. The HMi must have the modular capacity necessary to match the variable cognitive strategies of the user. The mental condition of the user can vary over time, as well as their work strategies, the machine must have the ability to adapt itself to the user's thinking method.
4. The machine must organize the information output according to the situational requirements. With the intention of facilitating the decision making of the user, the machine must prioritize or minimize the signals used for the information exchange according to the needs of the situation.

Following with the wake of the alarm and thanks to the new technologies of scanning and brain signal collection, certain characteristics that until recently were exclusive of the human-machine physical or manual interaction are currently beginning to be studied as possible applications of brain computer interface (BCI) This is a hardware and software communication system that allows a user's brain activity to take control and manage a computer or an external device.

Because the basis of the BCI is to allow the interaction between the user and their environment without it needing to use their peripheral nerves or their muscles, thanks to the use of the signals generated by the electroencephalographic activity, it is easy to recognize that their principal use, and the reason why this technology began to be studied, is to allow the mobility of people with neuromuscular problems or to generate highly functional prostheses that replace lost limbs. The improvement in mobility is currently used as the main reason for studying the BCI, although methods for its use in leisure are also emerging, such as the control of small drones thanks to portable EEG systems connected to a processor such as a mobile phone or a laptop.

Due to the complexity of the brain and the little and imprecise information that is currently available about the relationship of its functioning with the cognition or the will, the BCI has been generally rejected for serious scientific investigations, which limited the research from brain activity to the analysis of neurological disorders and the exploration of brain functions (Nicolas, L.F.2012). However, BCI research streams are currently gaining strength thanks to modern signal detection systems that provide clearer and more accurate information, had started great interest on a big part of the scientific community by the possible uses of this new technology.

However, of all the new options that this technology has opened to researchers there is one that due to its complexity has been left aside, this is the reading of the emotions and the mental state of the user, since it has not been enough investigated the real relationship between the signals of the brain and the different emotional states.

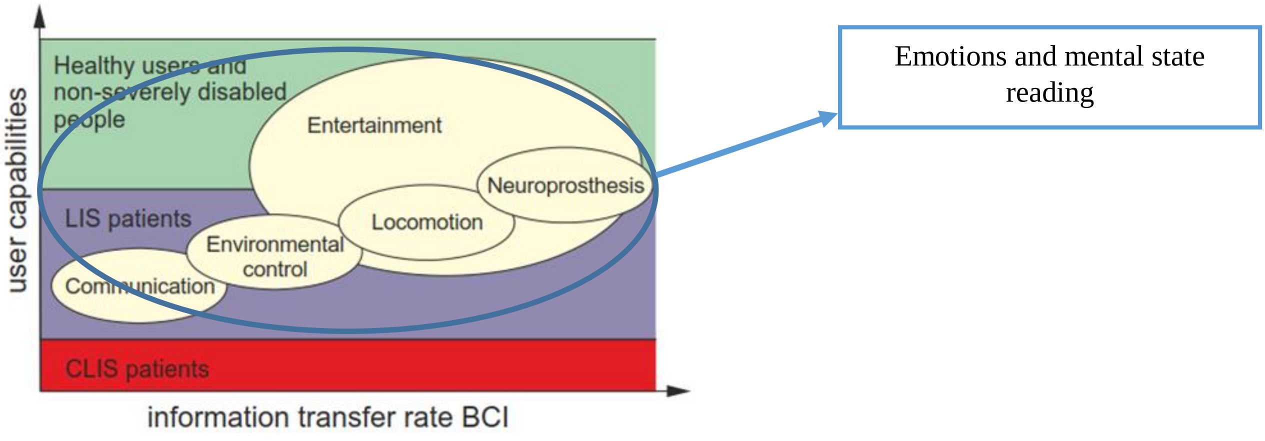


Figure 3. Fields of use of BCI systems depending on user mobility. *LIS: people with diminished motor capacity *CLIS: people without any motor control ability, severe brain palsy. Source: Nicolas Alonso, L.F (2012) *modified

The ergonomics in the design is a punctual act in the creation of a tool that, although it is necessary for an optimal functioning in its relationship with the operator, is not enough when introducing it into a modular and changing environment such as the emotional or cognitive state of the human being. To solve this problem and thanks to the use of the BCI we can create environmental ergonomics (based on the design of the ecological interface), it can use the EEG signals to observe the needs of the operator before he is aware of them (as it was commented before regarding the subjectivity of fatigue). About the function that could have in the commercial aeronautics, environmental ergonomics could change the situation in the cabin, either through light, sound or ergonomic configurations, as well as the configuration of a modular control panel to adapt to the psychophysiological state of the operator, thus maintaining optimal energy levels.

The most widely currently used HMI systems, are created with the intention of facilitate the assessment of the situation by the operator, however, in order to going a step further and improve human-machine interaction turning it into a bidirectional channel of information and answers exchange, the creation of self-evaluation capacity is necessary. Unlike the machine, the operator already has the ability to evaluate their own actions and those of the machine, so it can be said that regardless of the recognition capacity or action that the machine owns thanks to the BCI systems, it will always be behind in the resolution of multilayer or modular situations, because this require a response to a situation created by a previously taken machine decision (Gonzalez, 2013).

In order to do the HMI function completely, it is necessary for the machine to be able to understand the situation in which the operator is located, but it also needs to understand the situation that the machine has created. The ability to learn from one's own actions and to evaluate past decisions in something that is currently possible for a machine, in an aircraft cabin using a BCI system to improve environmental ergonomics and decision-making in crisis processes, the machine itself needs to be able to understand the environment as a result of their own actions, with this in mind, it is possible that the machine learns over time that the action of the multiple options it has, generates a better psychophysiological state in the pilot according to the situation and therefore generate a personalized profile that improves the skills of each pilot in specific and mitigate their weaknesses.

So far I have focused exclusively on the information from the cockpit and the pilot itself, however, the truth is, that in the current HMi airplanes, this is not the most important, because even the training to become, a pilot prioritize the information received from outside, such as altitude, speed, position; with the intention of preventing crisis situations. In general aviation 85% and 90% of accidents are caused by inexperienced pilots who have made a bad decision due to problems related to situational awareness (SA) (Golebiowski, W.2008).

The SA is based on the collection of external signals for self-location and the prevention of future crises related to the atmospheric environment or aircraft crossings. A correct SA is achieved thanks to an advanced driving assistance system, this system is composed of a set of tools that identify the environment and offer information to the pilot to stay in a comfort zone that facilitates the avoidance of future crises. Unlike other vehicles such cars, on airplanes it is more important to give information much before of the crisis situation since the maneuverability of the airplane makes it more difficult to make decisions and carry out the relevant actions to avoid disaster (Alvarado, P.2010).

Must be taken into account that information excess may exceed the attention capacity or redirect it towards less important stimuli and block the decision-making process, that is, for example, an alarm that is fulfilling the function of attracting attention to a situation may require so many cognitive resources that the user can not concentrate on the situation to which the alarm refers (MA, X. 2012). The more stimuli exist in a discrimination task, or the more complex these are, the higher is the rate of blindness to the objective stimulus (Giraudet, L.2015), throughout aeronautical history have been a significant number of accidents related to aviation and caused for lack of reaction or for a bad perception due to an excessive attention demand by warning stimuli.

## 2.6. EMOTIV helmet, applicability to the work environment

EEG reading devices more powerful, accurate and reliable are currently used in the medical and neuroscientific field, however, these are very expensive, large, bulky and in some cases, even invasive, needing some type of minor surgery. After these, there is another range of lower quality and cost that are commercial devices, these devices are created to be portable and functional in daily life, although the signal received is less refined than the one provide by of the big medical machines, its portability and comfort for the user make these devices an almost perfect tool for continued use in a work environment.

Within the range of possibilities for the selection of the EEG signal collection device, factors such as accessibility, cost, portability and quantity of signals were considered, with the Emotiv insight model being the best option. The Emotiv insight system consists of a high-resolution neural hull with five dry reading channels (the neurosensory system does not require contact area prior humidification), with a high electrical conductivity and which are also safe to use, in addition, this model, has two reference channels, it is wireless and communicates by radio frequency with a USB connected to a computer, which receives the signals and processes them (Lay, 2015).

The distribution of the EEG sensors is positioned to obtain optimal benefits for the HMI, these sensors are located in the prefrontal, parietal and temporal cortex with the arrangement shown in the figure 4.

Figure 4. Emotiv insight helmet
Source: Internet, see references

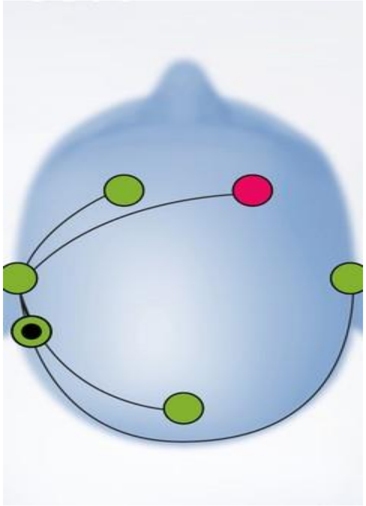

Figure 5. connection points
Source: Internet, see references

The most widespread use of this system in which it has also shown quite functional recognizing signals is in the control of mechanisms such as mobile robots (Li, Y. 2015) or prostheses in a leisure or research environment. To perform these movements Emotiv system is focused on the reading of brain waves produced by expressions or facial gestures, this is because the signals produced by these face movements are very powerful and easily discriminable from the rest of the neuronal signals (Moreno, L. 2014).

Despite this greater ease of reading, it should be noted that any type of reading and consequent mechanical control does not work at full power from the first moment a user starts using Emotiv. The systems of recognition and use of EEG helmets require learning, by the user and the machine, the machine must be calibrated for each user in a different way and this is achieved through multiple tests, in addition, the user requires training to make their signals stronger and decrease the "noise" caused by the general thinking system, that is, the user need to learn to focus on the task and amplify certain neural signals.

This difficulty of control is evident from the first moment in which a novice person puts on the Emotiv helmet, however, with training and exercises it has been shown that a person can refine their signals to the point of being able to use the associated mechanical systems, even during the presentation of distractions, it is possible to reach a level of improvement that allows to use these devices effectively in daily life (Vecchiato, G.2015).

The Emotiv device comes with its own data processing software that is divided into three different specialties, each one capable of processing emotive references, expressive references and cognitive data. The multifunctionality of the program even serves to see the user's level of attention across to the waves potential and their attentional focus, calculating the estimated position of the eyes. Therefore, its current usefulness allows knowing when the user is distracted and whit what is distracted by reading EEG signals.

Although the Emotiv device has a great capacity and a good price-quality ratio, it has several problems that make it difficult to implement it as a tool for daily work, this technology is still too newly today and although it is starting to study its implementation in the not too distant future, it is still necessary to refine and enhance the reception, discriminate the signals better and, above all, make it more comfortable and accessible. The Emotiv insight device is made of a semi-rigid material, this allows to mold the "wires" that carry the connectors to attach to the user's head, however, not being fully moldable can be uncomfortable and does not conform well to all head types, apart from this, the receptors are in direct contact with the skin, so a long period of use can cause cutaneous discomfort.

It should be noted, and it is a great inconvenience, that due to the fragility of the signal, the receivers should be as close to the skull as possible which, unfortunately, prevents its use in people with long or bulky hair, since this space between the receptor and skull inhibits or weakens the signal, therefore it is currently not possible to perform experiments with this type of device in men with long hair or in the vast majority of women, which limits the feasibility and adaptation of the results to the workplace

The importance of EEG reading systems is growing with the recent currents of neurophysiological research that are taking place in the world of aeronautics, proof of this is the NINA project that is focused on using the results and innovations of neurophysiology to monitor the cognitive state of air traffic operators and identify appropriate actions to support their activity, using EEG measurements and other neurophysiological measures.

The NINA project is part of the structure of SESAR, a European initiative that coordinates and concentrates all the research and development activities related to air traffic operations. Many of the projects that SESAR is currently carrying out focus their efforts on the improvement of HMIi systems and the use of BCI systems to facilitate and speed up communication between workers and their computers.

# 3. EMPIRICAL EXPERIMENT

## 3.1. Study description

The study carried out consisted of three tests focused on attention and coordination, administered through a computer. During the tests, the subjects wear on their heads a device designed for the recognition and reading of EEG signals. Once collected, the subject's data was processed with programs specifically designed to operationalize the signal data.

All the tests were done one after another in the same session, with a small break of three minutes between each of them. The test was performed to two subjects for each day the experiment was made.

Days before the recording session in which the subjects participated, they were asked to practice the different mini-games in their personal time, in that way, the subjects was familiar with the tests before doing them. This personal practice permit the measures to be as close as possible to an already trained pilot, and the stressful effect produced by the surprise during the exercises would be eliminated.

The hypothesis of this work is based on the perceived functioning of the alpha and theta waves during previous experiments.

The hypothesis considers that the signal strength of the parietal alpha wave will decrease and the frontal theta will rise as the stress in the subject increases:

Estress ↑ = Pariethal α ↓

Estress ↑ = Frontal θ ↑

## 3.2. Sample used

The sample used for this experiment consists of ten men, all of them university students with an age between 21 and 25 years. All the subjects were volunteers and gave their personal time to carry out the experiment.

The time available for the space that was needed inside the university campus, and the subjects own availability for the testing time after their class schedule, made it impossible to match the schedules and although there was an attempt to recruit more volunteers, was impossible to perform more tests.

## 3.3. Simulation environment and tests performed

The environment has been selected to contribute to the concentration of the subject who performs the experiment, with few distractions in sight and the less environmental noise as possible. In the room whit the subject, there is only one table, a chair, a computer with the program test and a researcher who will explain the processes and will serve as an aid to the subject if during the test a problem arises (with the helmet for example). The subject is asked not to speak, and move as little as possible, in order to minimize the noise in the recorded EEG signal, caused by cognitive distractions.

The tests have been chosen with the intention to be as similar as possible to the tasks that a pilot can perform on his daily job. For this reason, three tests have been selected from the NATS website (United Kingdom aeronautical company responsible for training air traffic controllers and providing air navigation services). These tests have been created to serve as training and facilitate the recognition of various necessary cognitive skills to become a pilot or air control operator.

To strengthen the relationships between the readings and the stress factor, a regressive counter has been added to each test, which forces the subject to think and make decisions quickly.

### 3.3.1. Shape Tracking

The first test proves the ability to follow an element on the screen, with the inclusion of different levels of progressive difficulty. In each level, an element in yellow is presented at the beginning, after that, the highlighted element will return to its normal color and all the elements will begin to move around the screen. When they stop moving, the subject have to click to indicate where the yellow element that had to follow is at that moment. As the level of difficulty increases, the elements present on the screen will move faster, thus complicating their tracking. The game ends when the subject mistakes elements or the countdown ends.

In this study, level 1 has been labeled as not very stressful, and the maximum level at which each subject has arrived before failing is labeled as highly stressful.

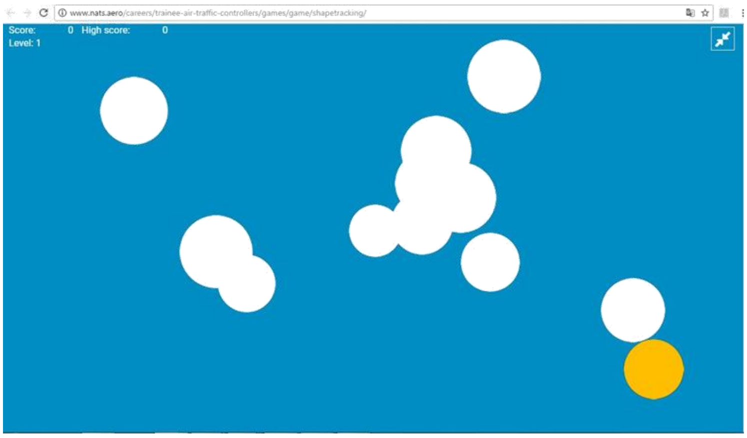


Figure 6. test 1, Shape Tracking
Source: Internet, see references

### 3.3.2. Landing Game

The second test consists in guide airplanes to arrive safe on the track, thanks to the signal of a radar, this exercise tests the conscience and the coordination of each person.

The test starts with two planes on the screen (yellow dots) constantly moving, which must be guided to the track clicking on the arrows that are shown around each plane. Once these two are landed, three more planes are presented and so on in each stage. This exercise ends when one of the planes crash with another plane or when the stipulated time ends.

The beginning of the test will be studied as a condition of low stress, and the last step in which a larger set of aircraft is added, as a condition of high stress.

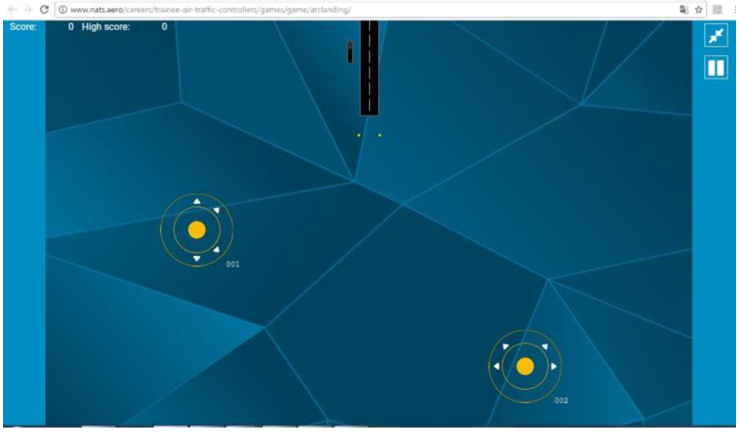


Figure 7. test 2, ATC Landing Game
Source: Internet, see references

### 3.3.3. Gateway Game

In the third and final test it is necessary to organize several airplanes in a safe way, this exercise allows to test the conscience and the subject coordination.

In this test the subject has to guide the planes in their ways to cross three doors in the direction indicated by their arrows and according to the order of door numbers. After they have passed through these doors, the planes must be directed to a last door in the lower left corner, which is the exit door.

As in the previous test, it starts with two planes, and once the two have passed through the exit door, three other planes appear, and so on. The level of difficulty increases as there are more planes on the screen and the time limit is reduced. In addition, at higher levels, planes of different colors may also appear, which correspond to different altitude levels, so that planes of different colors can be crossed on the screen (they are at different altitudes and therefore do not crash). In the same way as before, the beginning of the test will be considered as a low-level stressor, and the last presentation of airplanes sets as a high-stress condition.

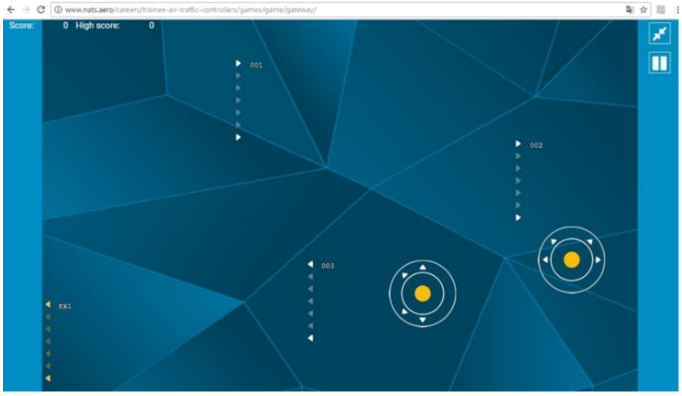

Figure 8. test 3, Gateway Game
Source: Internet, see references

### 3.4. Measurement equipment

The device called Emotiv Insight is used for EEG measurements. In this case, the Emotiv Xavier SDK, 'Software Development Kit', consists of an Emotiv Insight helmet, a USB wireless receiver and a signal reception and conversion application. The helmet captures the signals of the cerebral waves (EEG). After being converted to digital form, the brain waves are processed, and the results are transmitted wirelessly to the USB receiver. The software application collects the data packets from the USB device and processes them to display, analyze, and record, upload to the cloud and download recorded sessions from the cloud.

The Emotiv Insight helmet is designed for general use in the BCI research field and self-assessment. The software used for the registration of the EEG signals is Pure.EEG.

In the main panel of the application the contact quality of each sensor is shown according to the color it has (being the green the ideal quality), it also shows the battery level and the progress of the EEG signals in real time for each channel, as shown in Figure 9.

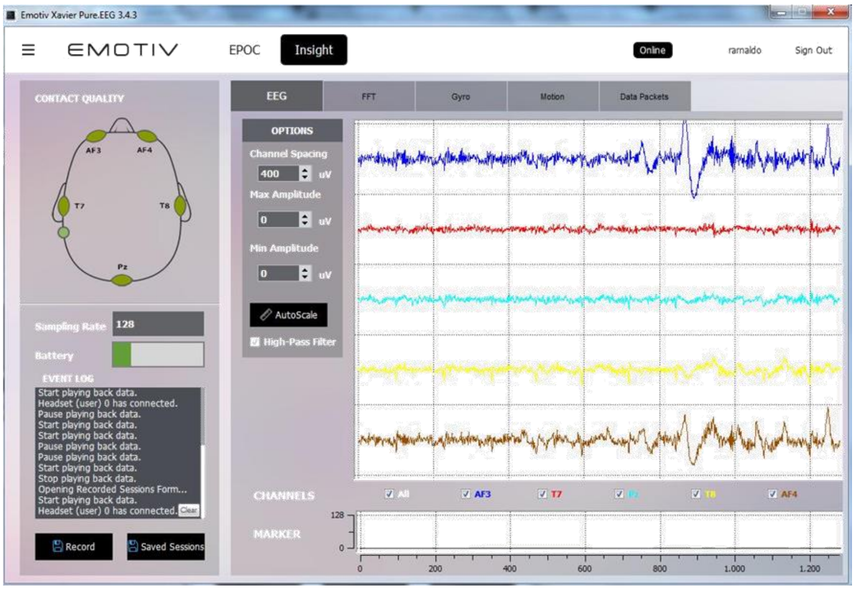


Figure 9. Emotiv Xavier Pure.EEG

For this study only signals received from points F3, F4 and PZ has been used. The first two has been used to measure the Theta wave signal, while the third point serve to receive the signal from the Alpha waves.

After investigating which is the most appropriate software for the treatment of the data, it was concluded that the most appropriate tool is Matlab through a toolbox called EEGLAB, with functions and algorithms specific for EEG signals.

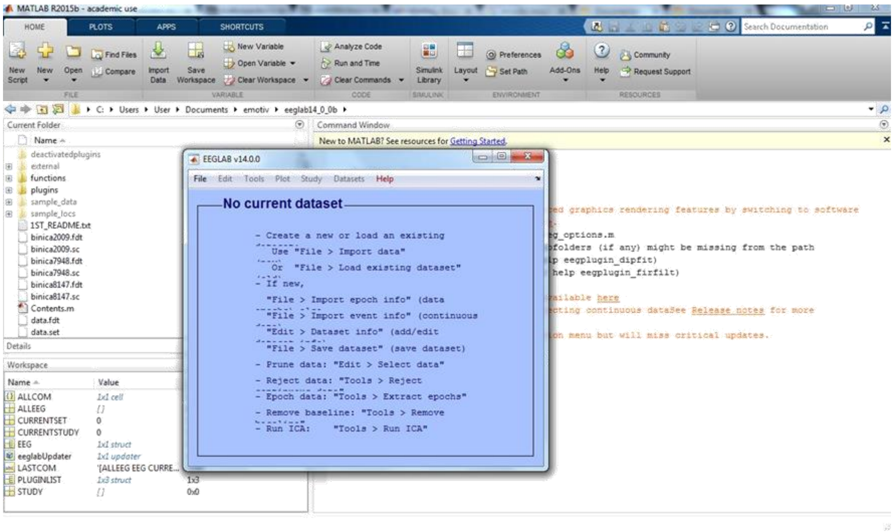


Figure 10. EEGLAB principal screen

## 3.5. Signal processing and data noise purge

As it was already mentioned in the theoretical review section, the EEG record shows a large amount of data in a single result. Much of the information included in the recorded EEG signal is unnecessary for this study, such as information resulting from muscular movements, eye movements, respiration, pulse, electrodes, skin resistance, sweat, etc.

To solve the problem of mixed information, is necessary a transformation of the raw data obtained from the experiment. Whit this goal in mind, in this part of the process was used ICA, 'Independent Component Analysis', a computational method to separate a signal into independent subcomponents. It is designed for multi-channel EEG recordings and allows remove a wide variety of artifacts (noise) from EEG records by eliminating contributions from artificial sources in the sensors. In this way it is possible to detect, separate and eliminate effectively the ocular activity (main responsible for useless information in this experiment) on EEG records (Tzyy-Ping Jung, 2000).

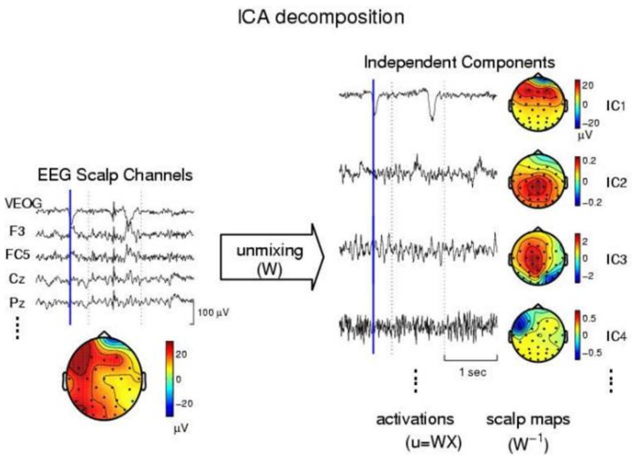


Figure 11. ICA Method Schema

The noise produced by eye blinking especially affects the signal recorded by the front sensors F3 and F4. They are easy to identify, since they are represented as peaks distributed periodically.

To eliminate these artefacts from the EEGLAB program, is possible use the RUNICA algorithm, which one allows separating the EEG signal into independent components, one of this component will be the eye blinking dividing the signal into independent components.

In fig 12. it can be observed how component 2 produces constant peaks that can be identified with the blinking

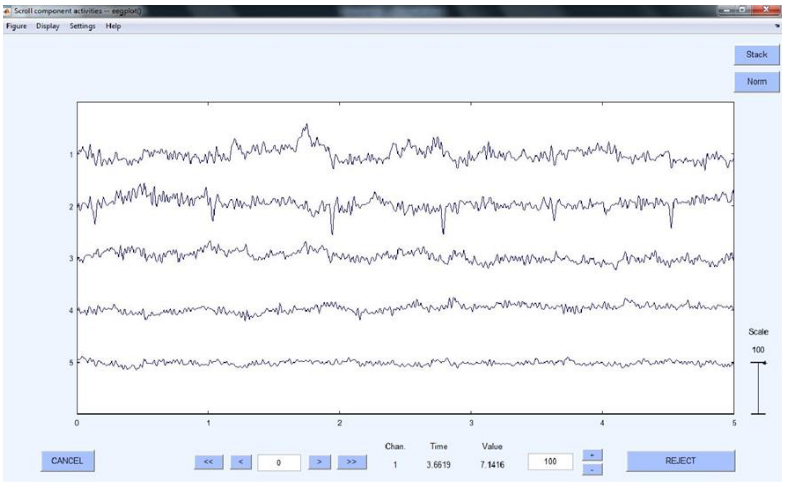


Figure 12. Signal graph divided into independent components.

Once a "clean" signal is achieved, the next step is to filter the signal in order to obtain the searched frequency bands, in this experiment the theta band (4-7 Hz) and the alpha band (8 -12 Hz). Once we have the waves signal we want to study, we can perform the last processing, which consists of taking out the PSD (Power Spectral Density) for the alpha and theta waves. The PSDs of the waves and their variation during the tests will be the data used as a experiment final result.

To get the values of PSD in the theta band and make a correct analysis, it is necessary to divide the EEG signal in times of 2 seconds, overlapping 0.125 seconds, according to the sources (Gianluca Borghini, November 2014) thanks to this division the program give a PSD numerical value for each event.

## 3.6. Result tables PSD

Although the number of recorded sessions was ten (one for each subject), a total of four subjects have been evaluated because the rest presented inconsistent data when trying to analyze them, such as a PSD that is too high or even negative, as a result of having registered the data with bad contact sensors or with the subject too distracted, these situations seem to have filled the signal of noise and very pronounced energetic peaks impossible to eliminate without producing a significant information loss.

The results that have been reached are collected in tables with gross values and PSD averages. Emphasize that, to simplify the results, the next PSD written values is, in true, a calculation resulting from the 10logPSD operation. For theta band, only the PSD values of channels F3 and F4 was collected, and for the alpha band, only was used the PSD values of the Pz channel.

Table 1. Results of four channels PSD values of subject 1 in all test variants

| | | **Subject 1** | | | |
|---|---|---|---|---|---|
| | | **PSD Average values** | | | |
| | | **F3** | **F4** | **Frontal theta PSD average** | **Parietal Alpha PSD** |
| **Low stressful load** | **Test1** | **6.20** | **7.69** | **6.95** | **3.10** |
| | **Test 2** | **11.83** | **8.21** | **10.2** | **4.76** |
| | **Test 3** | **9.39** | **9.95** | **9.67** | **4.78** |
| **High stressful load** | **Test1** | **10.23** | **8.31** | **9.27** | **4.13** |
| | **Test 2** | **12.36** | **10.21** | **11.28** | **4.37** |
| | **Test 3** | **10.63** | **12.39** | **11.51** | **3.64** |

Table 2. Results of four channels PSD values of subject 2 in all test variants

| | | **Subject 2** | | | |
|---|---|---|---|---|---|
| | | **PSD Average values** | | | |
| | | **F3** | **F4** | **Frontal theta PSD average** | **Parietal Alpha PSD** |
| **Low stressful load** | **Test1** | **6.37** | **9.94** | **8.15** | **7.12** |
| | **Test 2** | **7.82** | **8.73** | **8.27** | **6.96** |
| | **Test 3** | **10.49** | **9.92** | **10.20** | **5.36** |
| **High stressful load** | **Test1** | **9.63** | **10.65** | **10.14** | **7.16** |
| | **Test 2** | **8.48** | **9** | **8.74** | **6.60** |
| | **Test 3** | **14.93** | **12.17** | **13.55** | **7.11** |

Table 3. Results of four channels PSD values of subject 3 in all test variants

| | | Subject 3 | | | |
|---|---|---|---|---|---|
| | | **PSD Average values** | | | |
| | | **F3** | **F4** | **Frontal theta PSD average** | **Parietal Alpha PSD** |
| **Low stressful load** | **Test1** | **4.69** | **5.39** | **5.04** | **5.25** |
| | **Test 2** | **7.26** | **5.31** | **6.28** | **6.54** |
| | **Test 3** | **11.43** | **12.28** | **11.86** | **7.22** |
| **High stressful load** | **Test1** | **7.40** | **11.02** | **9.21** | **5.79** |
| | **Test 2** | **10.14** | **5.94** | **8.04** | **7.22** |
| | **Test 3** | **11.61** | **12.96** | **12.28** | **4.75** |

Table 4. Results of four channels PSD values of subject 4 in all test variants

| | | Subject 4 | | | |
|---|---|---|---|---|---|
| | | **PSD Average values** | | | |
| | | **F3** | **F4** | **Frontal theta PSD average** | **Parietal Alpha PSD** |
| **Low stressful load** | **Test1** | **4.68** | **8.61** | **6.64** | **5.09** |
| | **Test 2** | **5.21** | **7.21** | **6.21** | **2.81** |
| | **Test 3** | **7.56** | **6.59** | **7.07** | **3.83** |
| **High stressful load** | **Test1** | **6.29** | **6.07** | **6.18** | **2.77** |
| | **Test 2** | **8.08** | **7.84** | **7.96** | **2.82** |
| | **Test 3** | **9.11** | **9.13** | **9.12** | **3.63** |

Table 5. PSD average values of the subjects for the two types of waves in the two stress conditions

| | All subjects PSD average | | | | | |
|---|---|---|---|---|---|---|
| | 1 Test | | 2 Test | | 3 Test | |
| | Frontal Theta | Parietal Alpha | Frontal Theta | Parietal Alpha | Frontal Theta | Parietal Alpha |
| Low stressful load | 6.70 | 5.14 | 7.70 | 5.27 | 9.70 | 5.30 |
| High stressful load | 8.70 | 4.96 | 9.01 | 5.25 | 11.62 | 4.78 |

- The conclusions derived from the results shown in the previous numerical tables will be exposed in the graphic tables section

## 3.7. Graphic tables

### 3.7.1. Theta PSD

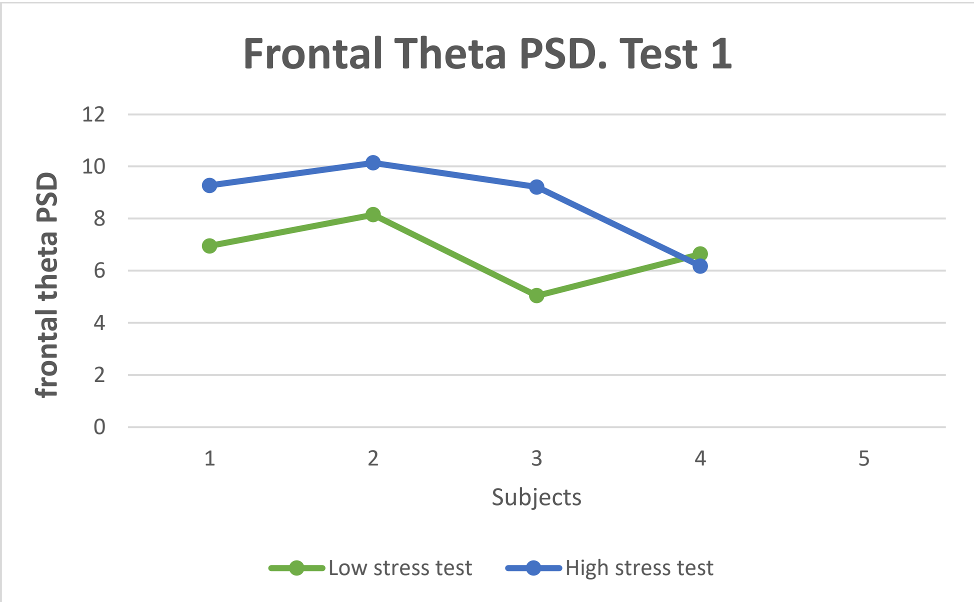


Figure 13. Frontal Theta PSD. Test 1

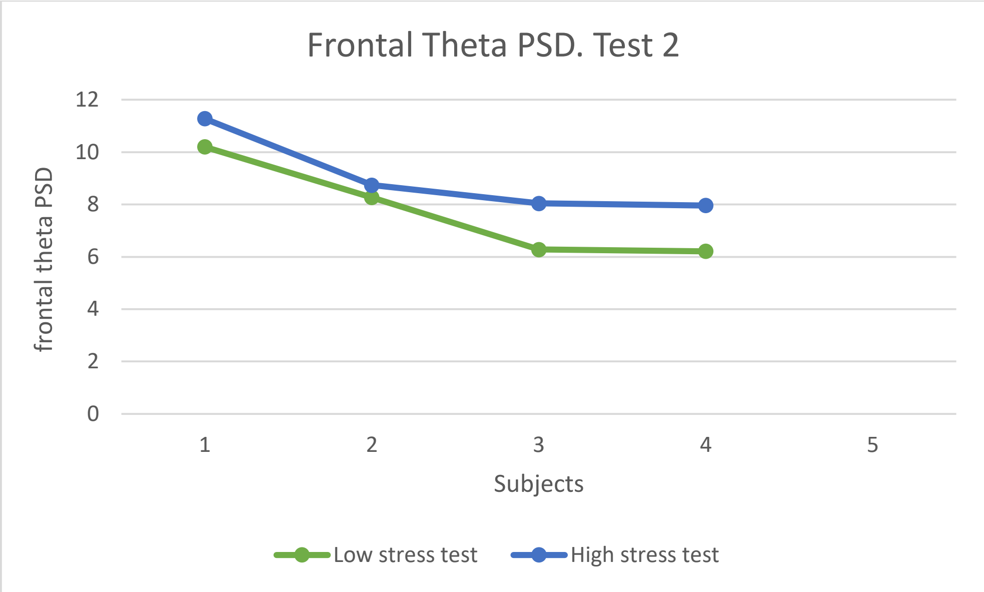


Figure 14. Frontal Theta PSD. Test 2

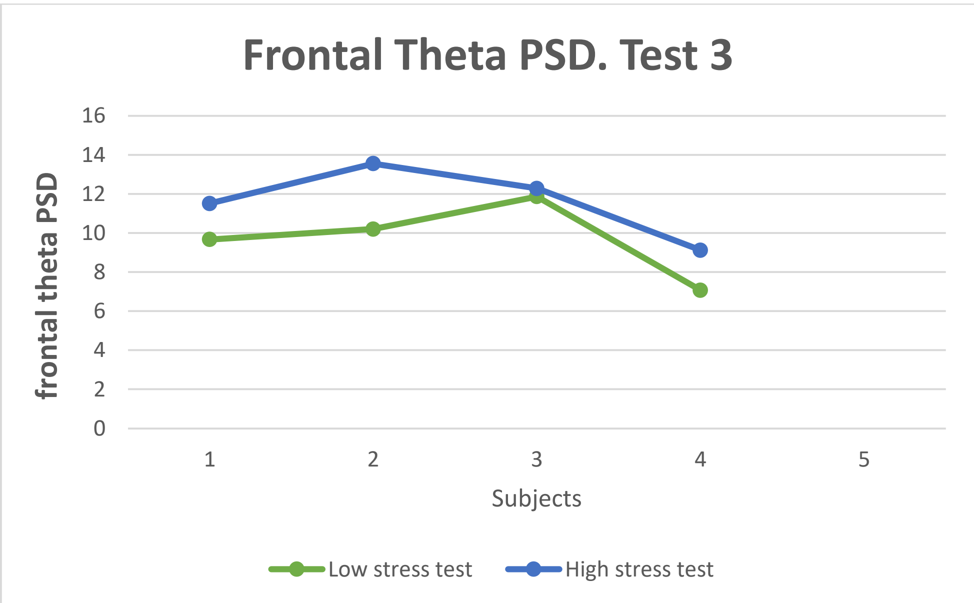


Fig 15. Frontal Theta PSD. Test 3

1. During the beginning of test three, the subject three showed clear signs of nervousness, which could explain the little variation between the two stress conditions, since the low stress condition seems to show a higher level than expected.
2. It is possible that the results of subject four in the first test were taken under the influence of a distraction factor, the subject showed a certain lack of concentration and several distractions during this test.
3. PSD under high stress conditions is maintained at all times above PSD for low stress conditions (except for subject four in test one). These results confirm that theta wave values grow as the stressors increase.
4. For each subject, the PSD variation becomes smaller as the tests session progress, that is, there is more variation in the test one than in the three.

### 3.7.2. Alpha PSD

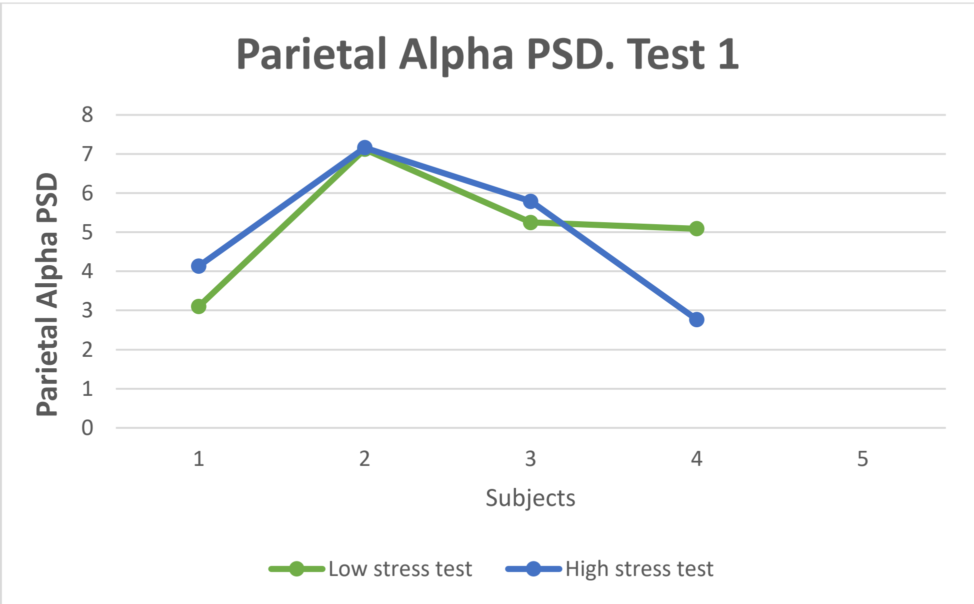


Figure 16. Parietal Alpha

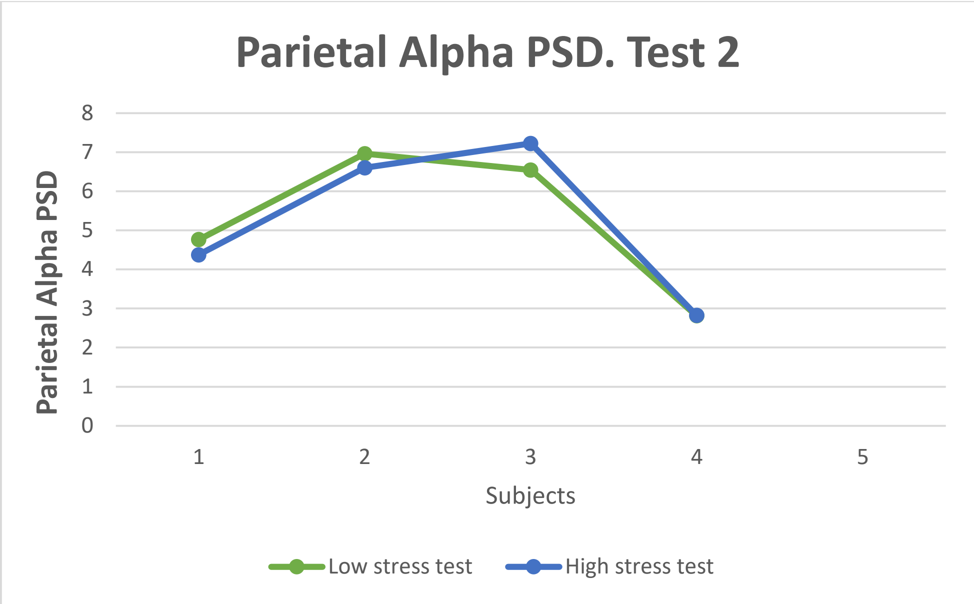


Figure 17. Parietal Alpha PSD. Test 2

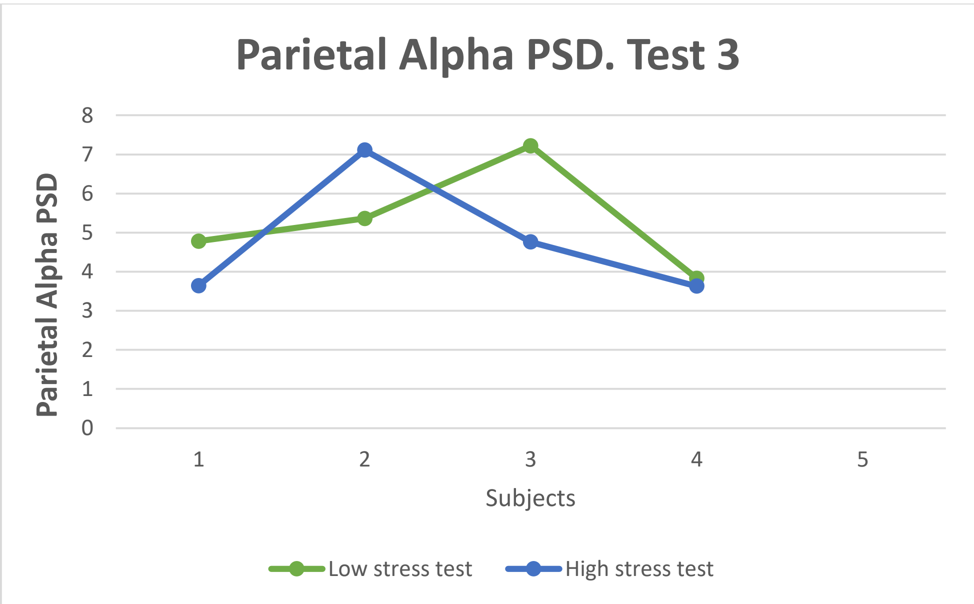


Figure 18. Parietal Alpha PSD. Test 3

1. The PSD graphs corresponding to tests one, test two and in a certain way test three, follow a very similar pattern.
2. The graph of subject four in test one seems to confirm the distraction factor, since his results for low stress are equally discrepant.

3. The results for the alpha parietal PSD can not systematically confirm that the alpha waves fall as the stressor increases, since at several points an increase can be observed. However, this may be due to certain problems related to the PZ sensor which, at times, showed low contact quality.

### 3.7.3. Comparison between tests

The following graphs show the comparison between the averages obtained from the four subjects in each test.

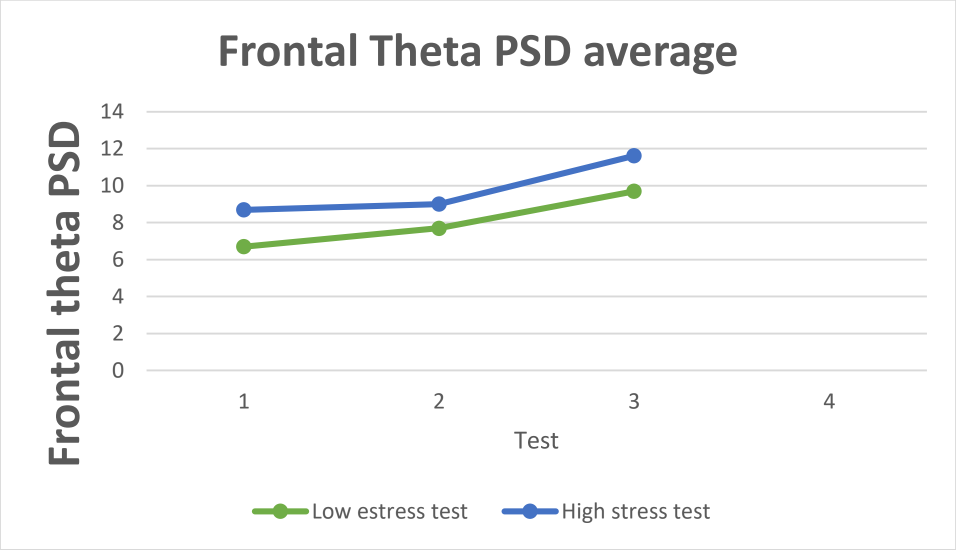


Fig 19. Frontal Theta PSD average

1. Test three was considered the most difficult and stressful, since it contained more elements and actions to perform, the PSD theta frontal value corroborates this difficulty.
2. Test three is the one that most faithfully corresponds to the set of tasks that a pilot or an air traffic controller must perform.
3. The average of the front theta PSD of each test is higher in all cases comparing it whit the tests with low stress load, in addition, a very homogenous tendency can be observed between the two situations.

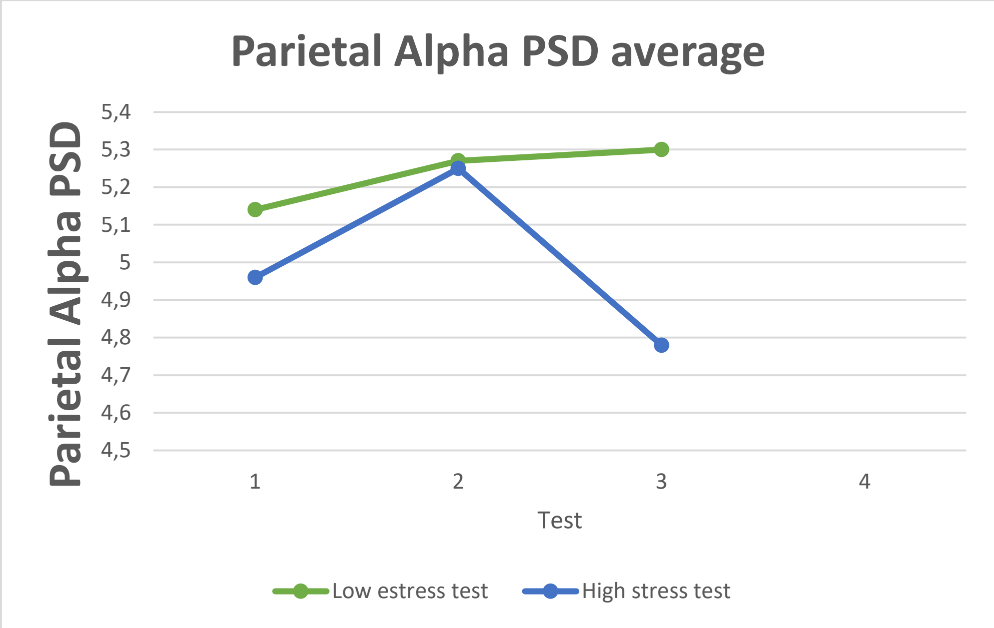


Figure 20. Parietal Alpha PSD average

1. It can be observed a little difference between the average values of the different tests, although the difference increases under high stress conditions.
2. The average values of PSD in both stress conditions for the different tests are around five, decreasing only a few tenths for high levels.
3. The measures of parietal alpha PSD seems unable to draw conclusive statements, contrary to what has happened in the case of the PSD theta frontal.

## 3.8. Limitations

Throughout the realization of this experiment several important limitations should be brought out that were not planned at first, due to lack of time or resources, the tests could not be done with pilots in appropriate environments (official simulators), so in order to make exercises similar to those that the pilots themselves use in their work training, three tests have been selected, each one corresponds whit a task that a commercial flight pilot would face. Each of them has different levels of difficulty that will be described later.

Although add several levels of difficulty allows to use the EEG readings to measure the effort and stress during its performance, the limitation of time and sessions makes it impossible to read and study the situations and the signals related to fatigue in the subjects. The basic idea was to make measurements of the subjects before the tests and few minutes after the completion and confront these results in order to see the differences between fatigue signals, however, it was not possible to find volunteers with the time necessary for this part of the experiment.

As previously mentioned before, another of the limitations is related to the EEG signal, since it records brain activity as a whole and it is difficult to identify brain activity that is only related to stress. Although it is possible to eliminate some noises, such as blinking, thanks to the fact that they are easily recognizable during the processing of the resulting data, the lack of an empirical indicator of the stress signal makes difficult to discriminate.

# 4. DISCUSSION

## 4.1. Practical discussion

The results of this experiment have not fully confirmed the initial hypotheses. Could be caused by external problems or by errors during the realization of the experiments, such as specific failures in the Emotiv helmet or subjects distractions.

The PSD recorded at the F3 and F4 receptors confirms the hypothesis that the theta wave increases in the prefrontal cortex when the subjects stress increases. However, the data collected from the PZ sensor negates the hypothesis that the alpha wave decreases as the subjects stress increases.

The reason why alpha waves have not followed the expected results may be is caused by the low amplitude of these waves, because unlike tetha waves, which have an amplitude of 100 μV peak-to-peak, alpha waves only have an amplitude of 10 μV peak-to-peak. The signal weakness of the alpha waves makes them much harder to measure compared to theta, although this weakness can be fixed in part thanks to more powerful BCI systems, it is undeniable that we are facing one of current major problems for the implementation of BCI systems in everyday life.

It should also be mentioned that several efforts were made during the signal processing phase that turned out to be unclear or directly useless. Many of the actions that are advised for the signal processing, show as result an almost equal visually signal or otherwise, eliminate certain signal variations that could be important to relate that signal with stress.

With the intention of delimiting stress, or any other cognitive signal, it would be indispensable in future experiments to use more signal points (helmet receptors) as well as the study of other brain waves, since, if we consider all types of waves, it is possible to differentiate in a better way, emotions such as the stress or cognitive functions such as attention or distracting thoughts.

The experiment carried out in this work serves as a small addition to previously performed experiments on the identification of cognitive states through BCI systems, confirming the previous results that it is possible to use these booming technologies as a method to identify altered states of consciousness that could cause future errors in decision-making in crisis situations. These results also serve to show that is possible avoid the great difficulty that bring the diagnosis of these altered states, through early physiological detection and avoiding the use of subjective tests.

Certain paradigms and studies have previously shown the correlation between several negative emotions and neural systems (Ishii, A. 2015), however there is not so much literature references regarding experiments focused on the use of EEG engraving techniques to study emotions or the conscience, since the EEG reading is usually considered too complex (Nicolas, L. 2012), because this technique does not discriminate the received signal, and the relation of the EEG signal with the real state of the subject has not yet been sufficiently studied. For all the above reasons, it is clear that this research field needs to focus its efforts on identifying specific signals with references emotional states.

Finally, it is necessary to say that the results of this experiment have been conditioned by the novelty, because, although the subjects had already practiced the tests before performing them in the experimentation session, these subjects had no previous experience with BCI systems and the system itself had not been calibrated in any way to suit each subject. For the effective implementation of this technology in the work environment it will be necessary for workers to refine their skills with this tool through training while the software and hardware of each tool must be calibrated for their final operator.

## 4.2. Theoretical discussion.

Stress and fatigue are common problems in today's advanced societies, proof of this is the effort that psychology and other sciences currently put into solving or minimizing the damage caused by these physical-psychical states, however, it is easy to observe that the resources destined to solve these so generalized problems, can be minimized if we works in the elimination of stress or fatigue before these arise in the person, in the same way as the symptoms of a physiological disease decrease depending on how quickly the disease is diagnosed and treated.

Aeronautics is a sector in clear expansion since the seventies, currently the most widely used means of mass transport and one of the sectors where technology advances fastest, it is therefore, a good place to start research on new methods of prevent anomalous states of consciousness. The cockpit of an airplane is a propitious place for the implementation of human-machine technology, since its current interface is extremely complex and the work periods are usually very broad, these two situations would benefit greatly from a system that would allow the cabin adjust itself to the worker needs, either by modifying the space to increase or decrease the arousal or modifying the control panels to focus the efforts of the pilot in what matters depending on the situation.

Still have many unknowns about the relationship between the mind and the brain, about the relationship between consciousness and observable electrical signals, however, more and more studies (and the implementation of EEG reading helmets in the market) show that even with this short actual knowledge it is possible to use these signals effectively.

Ergonomics and the correct design of workplaces have always been one of the main objectives of the work and organizational psychology, as well as other scientific branches, many studies identify how workers behave according to the stimuli received, as well as the way in which the control panels are designed. Many work accidents are caused, in part by a design that makes difficult or impossible for the worker to attend or reach the tool that would have prevented that accident. The BCI is the technological evolution of the HMi, greatly improving bidirectional communication between the worker and his work environment.

Although the brain signal recognition technology is still far from being able to be implemented safely in the workplace, the truth is that it is improving very quickly due to the great possibilities offered and the interest of big companies in the improvement of this technology. The EEG reading helmets are still far from being really functional, but their ergonomics and reading capacity (as was demonstrated in this experiment) already show a forecast of how useful and satisfactory could be the use of this technology in a near future.

# CONCLUSIONS

To serve as summary of the work presented, I will expose the three keys on which it is based and which have been developed throughout this work:

- HMi and ergonomics. Ergonomics is a science that advances parallel with the changes happened on jobs, one of the most important branches about work environments with a high technological burden is the HMi. How to place the activators, to what give more importance and what colors or alarms to use are part of the HMi design that, in the case of computers and other digital environments must be added the modular factor, this factor is the possibility of creating the control panels by layers that can change depending on the needs or decisions made by the operator.

- The use of EEG systems to read psychophysiological states. As already mentioned before, the EEG technology still requires great advances, however it is undeniable that the possibility of controlling automatisms with the human mind is highly intriguing and a future to which technology will inevitably end up arriving. Outside the more practical or technological use, the possibility of "read" the human brain is an objective to which science is directed, know the relationship between the brain and the mind, can open the way to understand the functioning of the brain in a deep way and ultimately can allow us to understand the functioning of the human *psyche* itself.

- The elimination or reduction of the effects caused by stress or fatigue states through early prevention. It is widely known that stress, fatigue and other symptoms or related or causal syndromes are the main psycho-emotional problems of adults in first world societies. Although their importance is enormous and their propagation even greater, efforts to correct these problems are usually palliative, since normally large-scale prevention would require deeply changes in labor systems and in the general social organization. Since these negative states are intrinsic to our social states, a more plausible way is the use of technology. Although it should be noted that all the information that technology can give us is useless if it is not willing to make concessions in favor of the health and well-being of workers.

I would finish this work without giving the importance it deserves to ethical considerations. It is true that this experiment has been carried out with all the ethical guidelines in mind, safeguarding the anonymity and the welfare of the subjects, however, it is obvious that the BCI technology is a potential ethical danger, the union of mind and machine could in the future, leave us without the only aspect of personal privacy that currently can not be violated, our mind world. This technology makes it possible to know and tax the cognitive and possibly emotional state of workers before they are even aware of these states, it is of critical importance that future experiments about BCI technology will be controlled very closely about their ethical aspects, and that future uses of these technologies must never violate personal privacy or put it at the service of companies.

I would like to point out that, although the experiment conducted in this work only vaguely shows the relationship between the state of stress and brain signals (more specifically the alpha and tetha wave types) in a generic environment and with tests focused on cognitive performance, is not my intention to remain exclusively with a purely physiological reflection on the mind-brain relationship. As it has already been said before, large companies and business consortiums are using their resources to investigate how to implement the discoveries resulting from experiments with BCI technology in the aeronautical sector, from my point of view, I consider that it is the sector which, due to its characteristics, would benefit more whit this technology, since it would greatly reduce the burden on workers and could prevent major catastrophes.

Although my initial vision was to also experiment also whit fatigue and in the end I could not do it, due to various lack of resources, I considered it very important to focus a big part of this work on fatigue, since stress is widely known and easy to observe, because people usually refer to these states in early stages and the base symptomatology, excess activation, is easily recognizable. But fatigue often accumulates weight on the person without anyone noticing about their presence and it is this fatigue, this tiredness and this apathy which causes a great variety of physical and emotional disorders that could be avoided if we made the work exciting enough or relaxed enough as each person needed. The BCI technology is, for me, a small step towards this utopia.

# REFERENCES


Alvarado Mendoza, P. Angelelli, A. lindgren, A. (2010). Ecological interface design inspired human machine interface for advanced driver assistance systems. IET Intelligent Transport Systems. https://dx.doi.org/10.1049/iet-its.2009.0143.

Andrea, H. Kant, I.J. Beurskens, A.J.H.M. Metsemakers, J.F.M. Van Schayck, C.P. (2003). Associations between fatigue attributions and fatigue, health, and psychosocial work characteristics: a study among employees visiting a physician with fatigue. Occup Environ Med, 60. 99-104.

Borghini, G. Aricò, P. Graziani, I. Salinari, S. Babiloni, F. et al. (2014). Analysis of neurophysiological signals for the training and mental workload assessment of ATCos. SESAR 2014, 4th SESAR Innovation Days.

Cao, T. Wan, F. Wong, C. Cruz, J. Hu, Y. (2014). Objective evaluation of fatigue by EEG spectral analysis in steady-state visual evoked potential-based brain-computer interfaces. BioMedical Engineering OnLine, 13. 28.

Das, T. (2017). Consciousness as a Function of Brain Waves and Physical Constant Conscire. NeuroQuantology, 15. 1-6. https://dx.doi.org/10.14704/nq.2017.15.3.1047.

Deng, L. Wang, G. Yu, S. (2015). Layout Design of Human-Machine Interaction Interface of Cabin Based on Cognitive Ergonomics and GA-ACA. Hindawi Publishing Corporation Computational Intelligence and Neuroscience. http://dx.doi.org/10.1155/2016/1032139.

Figure 2. Cockpit of a Jetstream31. Accesible: https://en.wikipedia.org/wiki/Northwest_Airlink_Flight_5719 , 5 March 2018.

Figure 4. Emotiv insight. Accesible: https://www.emotiv.com/product/emotiv-insight-5-channel-mobile-eeg/ ,7 February 2018.

Figure 5. Emotiv insight contact points. Accesible: https://www.emotiv.com/insight/ ,7 February 2018.

Figures 6, 7, 8. Games used as tests. Accesible: http://www.nats.aero/careers/trainee-air-traffic-controllers/games/ , 7 February 2018.

Figure 11. ICA method schema. Accesible: http://cnl.salk.edu/~jung/artifact.html 3 March 2018.

Genova HM, Rajagopalan V, DeLuca J, Das A, Binder A, et al. (2013) Examination of Cognitive Fatigue in Multiple Sclerosis using Functional Magnetic Resonance Imaging and Diffusion Tensor Imaging. PLoS ONE 8(11): e78811. doi:10.1371/journal.pone.0078811.

Giraudet L, St-Louis M-E, Scannella S, Causse M (2015) P300 Event-Related Potential as an Indicator of Inattentional Deafness?. PLoS ONE 10 (2): e0118556. doi:10.1371/journal.pone.0118556

Golebiowski, W. Loroch, L. (2008). Possibilities of improving pilot's situational awareness through the shaping of the human-machine interface in military aircraft cockpits. Journal of KONBiN, 4. (7).55-70.

Gonzalez Calleros, J.M. Gerrero Garcia, J. Vanderdonckt, J. (2013). Advance human–machine interface automatic evaluation. *Springer-Verlag Berlin Heidelberg, 12.* 387–401. https://dx.doi.org/10.1007/s10209-013-0310-7.

Usanova, L.D. Usanova, A.D. Skripal, A.V. (2012). Analysis of Effect of Audiovisual Stimulation on Parameters of Encephalogram and Rate of Pulsation Wave Propagation in Humans. *Biomedical Engineering, 46.* 25-28.

Hernández, J. A. (2008) Turismo de masas y transporte: el gran reto del turismo del siglo XXI. Scripta Nova. Revista Electrónica de Geografía y Ciencias sociales, 12.

Homan, W. J. (2002). Stress Coping Strategies for Commercial Flight Crewmembers. Journal of Aviation/Aerospace Education & Research, 12. 15-57.

Ishii A, Karasuyama T, Kikuchi T, Tanaka M, Yamano E, Watanabe Y (2015) The Neural Mechanisms of Re-Experiencing Mental Fatigue Sensation: A Magnetoencephalography Study. PLoS ONE 10(3): e0122455. doi:10.1371/journal.pone.0122455.

Ishii A, Tanaka M, Watanabe Y (2014) The Neural Mechanisms Underlying the Decision to Rest in the Presence of Fatigue: A Magnetoencephalography Study. PLoS ONE 9(10): e109740. doi:10.1371/journal.pone.0109740.

Ishii A, Tanaka M, Watanabe Y (2014) The Neural Substrates of Self-Evaluation of Mental Fatigue: A Magnetoencephalography Study. PLoS ONE, 9.(4): e95763. doi:10.1371/journal.pone.0095763.

Jung, T.(2000). Removing electroencephalographic artifacts by blind source separation. Psychophysiology, 37. (2).

Jung, T. Makeig, S. Humphries, C. Lee, T., Mckeown, M. Iragui, V. Sejnowski, T. (2000). Removing electroencephalographic artifacts by blind source separation. Psychophysiology, 37(2), 163-178.

Lay, S.M. Pizarro, D.A. (2015). Robotic motion control with cognitive and facial detection via Emotiv EEG. Ingeniare, 23. 496-504.

Legeza, E. (2005). Working conditions in the cockpit cabin. Periodica polytechnica ser, 34. 3-18.

Li, Y. Zhou, G. Graham, D. (2016). Towards an EEG-based brain-computer interface for online robot control. Multimed Tools, 75. 7999–8017.

Ma, J. Ma R-M, Liu X-W, Bian K, Wen Z-H, et al. (2014) Workload Influence on Fatigue Related Psychological and Physiological Performance Changes of Aviators. PLoS ONE 9(2): e87121. doi:10.1371/journal.pone.0087121.

Ma, X. Yu, L.(2012). Study on the feedback information of man-machine interface. Applied Mechanics and Materials, 235. 340-344.

Maksimenko VA, Runnova AE, Zhuravlev MO, Makarov VV, Nedayvozov V, Grubov VV, et al. (2017) Visual perception affected by motivation and alertness controlled by a noninvasive brain-computer interface. PLoS ONE 12(12): e0188700. https://doi.org/10.1371/journal.pone.0188700.

Moreno-Cueva, L.A. Peña-cortes, C.A. Gonzalez-Sepulveda, H. (2015). Integration of a Neurosignals System to Detect Human Expressions in the Multimedia Material Analysis. Revista Facultad de Ingeniería, 24. 29-40. 163-78

Nicolas Alonso, L.F. Gomez Gil, J. (2012). Brain Computer Interfaces, a Review. *Sensor 12.* University of Valladolid. 1211-1279.

Patten TM, Rennie CJ, Robinson PA, Gong P (2012) Human Cortical Traveling Waves: Dynamical Properties and Correlations with Responses. PLoS ONE 7(6): e38392. https://dx.doi.org/10.1371/journal.pone.0038392.

Saputra, R. Muhamad, B.Komarudin. (2017). Stress Emotion Evaluation in Multiplayer Online Battle Arena (MOBA) Video Game Related to Gaming Rules Using Electroencephalogram (EEG). ICBBE 2017. 74-77. https://doi.org/10.1145/3168776.3168797.

Toppi J, Borghini G, Petti M, He EJ, De Giusti V, He B, et al. (2016) Investigating Cooperative Behavior in Ecological Settings: An EEG Hyperscanning Study. PLoS ONE 11(4): e0154236. doi:10.1371/journal.pone.0154236.

Vecchiatto, G. Borghini, G. Arico, P. Graciani, I. Maglione, A.G. Cherubino, P. Babiloni, F. (2015). Investigation of the effect of EEG-BCI on the simultaneous execution of flight simulation and attentional tasks. *Med Biol Eng Comput*, *54*. 1503–1513. DOI 10.1007/s11517-015-1420-6.

Website NINA Project, part of SESAR. Accesible: http://www.nina-wpe.eu/#overview , 2 February 2018.

Website SESAR European initiative. Accesible: https://www.sesarju.eu , 2 February 2018.