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EVALUATION OF ELECTROPHYSIOLOGICAL PARAMETERS OF DAZZLING EFFECT

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ABSTRACT

The dazzling effect, characterized by temporary vision impairment caused by intense light exposure, poses significant risks in scenarios requiring high concentration, such as driving a car in a highway or landing a plane. This dissertation explores the impact of dazzle on cognitive performance by analysing brain activity using electroencephalography (EEG). EEG is a non-invasive method that measures the brain's electrical activity by amplifying and recording spontaneous biological potentials from the scalp, making it a tool adaptable to multiple research protocols. In this study, EEG is utilized for its potential as a highly reliable technique to detect changes in concentration by evaluating electrophysiological parameters during dazzling events. Studies indicate that when individuals engaged in tasks requiring high concentration are exposed to dazzle, they report discomfort and experience impairment. This is reflected in their performance through slower reaction times, reduced task speed, and a noticeable loss of focus, all of which can be measured using EEG.

Participants performed N-Back Tasks, a well-known method to measure cognitive workload, while being exposed to intermittent white light bursts. EEG data was collected to assess variations in concentration levels, reaction times, and task performance by analysing brain wave activity. The study aims to explore the dazzling effect primarily in terms of its impact on concentration. The results are expected to show that dazzling disrupts cognitive focus, slows reaction times, and impairs participants' task performance. Ultimately, the findings of this dissertation support future research in this area, given the scarcity of publicly available information. This limitation largely stems from the topic's frequent investigation within military settings, where detailed data are typically restricted.

Keywords: Dazzling effect, EEG, Concentration, Cognitive workload.

RESUMO

O efeito de encadeamento, caracterizado por uma perda temporária de visão causada pela exposição a uma luz intensa, representa riscos significativos em cenários que exigem alta concentração, como conduzir um carro numa autoestrada ou aterrar um avião. Esta dissertação explora o impacto do encadeamento no desempenho cognitivo, analisando a atividade cerebral através da eletroencefalografia (EEG). O EEG é um método não invasivo que mede a atividade elétrica do cérebro, amplificando e registando potenciais biológicos do couro cabeludo, tornando-o uma ferramenta adaptável a vários protocolos de pesquisa. Neste estudo, o EEG é utilizado pelo seu potencial como uma técnica altamente confiável para detetar alterações na concentração, avaliando parâmetros eletrofisiológicos durante eventos de encadeamento. Estudos indicam que, quando indivíduos a realizar tarefas que exigem alta concentração são expostos a uma fonte de luz ofuscante, relatam desconforto e confusão. Isso reflete-se no seu desempenho através de tempos de reação mais lentos, velocidade reduzida na realização da tarefa e uma perda notável de concentração, e tudo isso pode ser medido usando o EEG.

Os participantes realizaram tarefas N-Back, enquanto eram expostos a luz branca intermitente que os encadeia. Os dados do EEG foram recolhidos para avaliar variações nos níveis de concentração, tempos de reação e desempenho da tarefa, analisando a atividade das ondas cerebrais. O estudo visa explorar o efeito do encadeamento, principalmente em termos do seu impacto na concentração. Espera-se que os resultados mostrem que o encadeamento perturba o foco cognitivo, aumenta os tempos de reação e prejudica o desempenho das tarefas dos participantes. As conclusões desta dissertação podem apoiar futuras pesquisas nesta área, dada a escassez de informações disponíveis ao público. Esta investigação decorre em grande parte em contextos militares, onde os dados detalhados são normalmente restritos.

Palavras-chave: encadeamento, EEG, concentração, desempenho cognitivo

LIST OF ACRONYMS

EEG – Electroencephalography

MDE – Maximum Dazzle Exposure

NODD – Nominal Ocular Dazzle Distance

FFT – Fast Fourier Transform

LED – Light-Emitting Diode

HID – High-Intensity Discharge

EOG – Electrooculography

LDR – Light-Dependent Resistor

ERP – Event-Related Potential

ICA – Independent Component Analysis

FWHM – Full Width at Half Maximum

FIGURE LIST

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1. INTRODUCTION

In this chapter, the motivation and objectives of this dissertation are presented, providing context for the study by introducing the concept of dazzling effect and explaining how it can impair human concentration and performance, which can be measured using EEG.

1.1. Motivation

The dazzling effect refers to the temporary vision impairment caused when light enters the field of vision, leading to a blinding sensation. This phenomenon is of extreme relevance, as it can result in severe accidents, including car crashes and plane incidents. Understanding the dazzling effect and how it affects concentration, is the key towards developing countermeasures to mitigate its impact during tasks that demand high levels of mental focus, as it is proven that concentration can be significantly affected by this visual disruption. (Santos, Pinto Coelho, et al., 2019).

When individuals engaged in tasks that require high concentration are affected by dazzle, they report discomfort and impairment and show signs of reduced focus, such as slower reaction times and reduced speed while doing the task. These effects suggest a transient alteration in neural processing, which can be measured using electroencephalography (EEG) (Lee et al., 2017).

1.2. Objective

The objective of this dissertation is to investigate whether exposure to dazzling light truly affects cognitive performance and concentration levels. To explore this, brain activity was recorded through EEG while participants performed an N-back task: a well-established working memory test in which individuals must identify matching stimuli. This task was chosen because it effectively induces cognitive load on participants, without it being too complicated to confuse them. The first N-back task was conducted without any dazzling stimulus, allowing participants to become familiar with the procedure and task rules. Subsequently, two additional N-back tasks were performed while participants were exposed to intermittent light stimuli, with EEG data recorded throughout all sessions. By analysing these EEG signals, this study aims to determine how, and to what extent, dazzling light influences concentration and cognitive performance.

1.3. Document Structure

This dissertation is structured into seven main chapters, each of which develops key information necessary to address the research topic:

- Chapter 1: Introduction. This chapter provides context for the study, outlining the motivation, objectives, and overall purpose of the dissertation.
- Chapter 2: Background Theory. This chapter presents the theoretical foundations relevant to the topic, including the principles behind the dazzling effect caused by white light and laser light. It also introduces the basics of EEG, as well as the main concepts related to data acquisition and preprocessing.
- Chapter 3: Literature Review. This chapter offers a simple review of existing studies that have investigated the effects of light dazzling using EEG. The aim is to establish a theoretical and methodological baseline to support the development of this dissertation's experimental approach.
- Chapter 4: Methods. This chapter describes in detail the workflow of data acquisition, the materials and equipment used, and the steps followed for data processing and analysis.
- Chapter 5: Results. This chapter presents the collected data, along with a detailed analysis and discussion of the findings.
- Chapter 6: Limitations and Future Perspectives. This chapter discusses the main limitations encountered during the study and proposes potential directions for future research. It also suggests how the methodology or experimental setup could be improved in future work to better understand the cognitive effects of dazzling light.
- Chapter 7: Conclusion. This chapter summarizes the main findings and conclusions of the dissertation, relating them to the initial objectives.

2. BACKGROUND THEORY

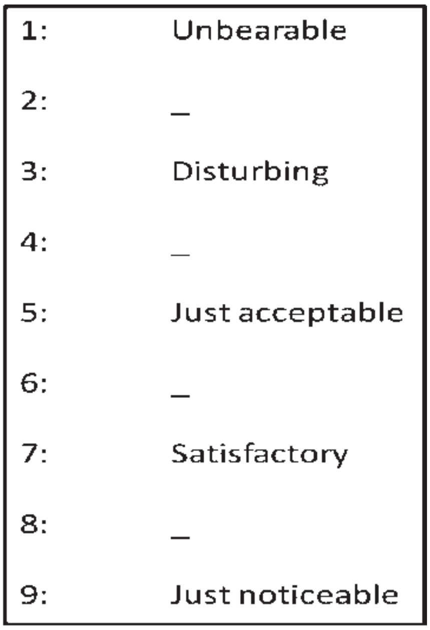
In this chapter, a comprehensive overview of the background theory related to the dazzling effect will be presented, focusing on how it influences concentration, as well as basic information about EEG and why this technique is ideal to study the dazzling effect and measuring concentration levels.

2.1. Dazzling Effect

Many people have experienced the blinding effect that occurs, particularly at night, when light hits their field of vision and causes temporary vision impairment. This phenomenon is known as the dazzling effect, and it is influenced by age, eye health, eye colour, distance from the light source, its brightness, and the angle between the light source and the person's line of sight. This dazzling effect impairs vision and can disrupt concentration (Coelho et al., 2016)(Santos, Pinto Coelho, et al., 2019). This phenomenon is particularly concerning, as it can cause visual interference that may lead to catastrophic accidents, for instance, blinding a driver who is at high speed on a highway or a pilot during take-off or landing of the plane.

In the literature, dazzling studies are often paired with the concept of glare. Glare can be subdivided into disability glare and discomfort glare. Disability glare refers to the reduction in visibility caused by scattered light within the eye, which disables aspects of the visual task, affecting visual detection and resolution. Laser dazzling can be considered disability glare that is caused by a laser source (Lee et al., 2017).

Discomfort glare is the sensation of discomfort that results from a glare source within the field of vision. The physiological and psychophysical origins of discomfort glare are still uncertain. Since vision remains unaffected, the experience is subjective and is typically measured through subjective rating scales. To test it, participants look towards a light source and rate its level of annoyance. Although there is no universal standard for the rating scale, the nine-point DeBoer scale (Figure 1.1) is the most widely used for public lighting studies. Its ratings range from "unbearable" (1/9), "disturbing" (3/9), "just acceptable" (5/9), "satisfactory" (7/9), to "just noticeable" (9/9). Discomfort glare varies from one person to the other, tending to be more severe for older adults (Santos, Coelho, et al., 2019).



1: Unbearable
2: _
3: Disturbing
4: _
5: Just acceptable
6: _
7: Satisfactory
8: _
9: Just noticeable

Figure 2.1 – DeBoer scale (Sammarco et al., 2010)

Awareness of laser dazzle (Figure 2.2) has increased with the easier access to handheld lasers with visible wavelengths and power levels far surpassing those of traditional presentation pointers. The surge in reported dazzle incidents in civil aviation is driving research into studying the potential effects of the dazzling effect on vision and task performance, as well as methods of protection against such incidents (Williamson & McLin, 2015).

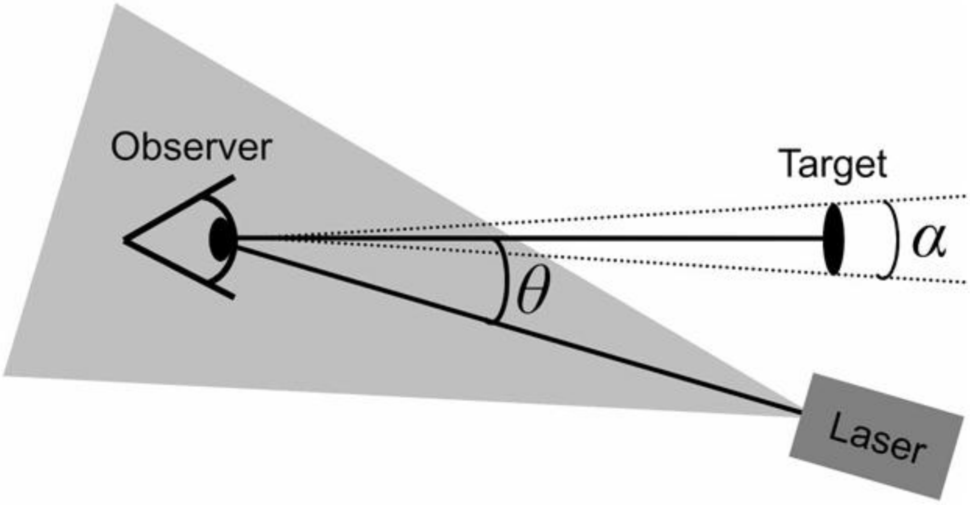


Figure 2.2 - Schematic illustration of a laser dazzle scenario (Williamson & McLin, 2015)

The dazzling effect triggers an instinctive avoidance response to protect the eyes from potential overexposure, that can lead to temporary blindness or even retinal damage (Williamson & McLin, 2015)(Santos, Coelho, et al., 2019). However, the retina does not contain pain receptors that could alert individuals of such hazards. Instead, the rapid contraction of the iris causes the pupil to constrict excessively, resulting in a condition known as pupillary spasm and this discomfort triggers the avoidance reaction. Light from the visual environment enters the eye through the pupil and is focused onto the retina, forming an image. Additional light can also enter the eye through transillumination via the iris and sclera. Some of this light is absorbed by photoreceptor pigments and other pigments such as melanin. But, before this light reaches the retina, it interacts with several scattering structures within the eye, including the cornea, lens, and the fundus of the retina. This interaction produces a phenomenon known as intraocular scatter. The scattering effect diffuses the light across the retina, effectively spreading the illumination and directing photons at angles that extend beyond the retinal image of the original light source. Understanding these processes is crucial for developing strategies to mitigate glare and enhance visual clarity in bright conditions (Williamson & McLin, 2015)(Santos, Coelho, et al., 2019).

To evaluate the safety of lasers in these situations, Williamson & McLin (2015), introduced the concepts of Maximum Dazzle Exposure (MDE) and Nominal Ocular Dazzle Distance (NODD). MDE represents the human threshold laser irradiance below which a specific target can be detected, while NODD is used to determine the minimum distance from a laser system required for visual detection of a target. Calculated MDE values can establish exposure limits to ensure that people can continue to perform their duties despite the presence of laser dazzle, and these values can help define the requirements for laser dazzle systems by indicating the irradiance necessary to produce this specific effect. Similarly, NODD calculations can determine safety distances around laser systems, allowing individuals to operate without their performance being hindered by laser dazzle. Besides dazzle conditions, one should guarantee that eye hazard regulations are met and that the irradiance at the eye fulfils the defined exposure limits.

To study the effect of dazzle in the brain, EEG could potentially be one of the most reliable techniques for detecting changes in concentration (Lee et al., 2017). However, measuring the concentration of a participant is very challenging, because it’s influenced by numerous factors (like the participant’s fatigue, medication, drowsiness, and mental effort). Nonetheless, there have been successful attempts to measure concentration levels relative to a baseline (Santos, Pinto Coelho, et al., 2019). These methods often employ cognitive load tasks, such as the N-back task, digit span task, or math problems. It is known that concentration is affected by the light’s dazzle effect. When participants, who are engaged in tasks requiring concentration, are affected by dazzle, report feelings of discomfort and impairment, and exhibit indirect signs of reduced concentration, such as slower reaction times and lower speeds, then these observations could imply a transient neural disruption that can be measured and quantified objectively with an EEG (Santos, Pinto Coelho, et al., 2019).

2.2. Electroencephalography

EEG is a non-invasive method for measuring the electrical activity of the brain, by amplifying and recording the brain's spontaneous biological potentials from the scalp, with a broad and diverse range of applications (Li et al., 2021). By placing electrodes on the scalp, it is possible to record voltage potentials that result from the postsynaptic currents between our neurons. The versatility and accessibility of the technique, along with continuous advancements in signal processing, enables EEG to consistently deliver new innovations and breakthroughs in the field of neuroscience (Biasiucci et al., 2019).

The technology used to record EEG signals consists of a combination of electrodes made from conductive material and specialized amplifiers:

Electrodes

- Modern EEG electrodes are designed to be well-tolerated by individuals across all age groups. In most cases, the effectiveness of the electrodes is enhanced by using electrolytic gels, which improve the conductivity between the electrode and the skin (Biasiucci et al., 2019). These gels help to reduce impedance, ensuring that the electrical signals from the brain are accurately captured and transmitted to the recording equipment. While effective, the use of gels can add an extra step to the preparation process, which may be time-consuming and require careful application to ensure optimal contact.
- A more recent innovation in EEG technology involves the development of dry electrodes. These electrodes capitalize on advancements in materials science and electronics, allowing for a significant reduction in the preparation needed for patients’ scalps prior to the recording session (Biasiucci et al., 2019). The introduction of dry electrodes not only enhances the efficiency of EEG recordings but also improves patient comfort. However, studies and reports provide evidence

that further research and development are necessary before dry electrodes can serve as a viable alternative to the standard electrodes used for recording EEG signals (Lopez-Gordo et al., 2014).

- Electrodes are used to measure potential changes over time through an electric circuit that is formed between an active electrode and a reference electrode. An additional ground electrode is used to obtain a differential voltage by subtracting common voltages at the active and reference points (Teplan, 2002).

Amplifiers

- The EEG signal is inherently small and often difficult to detect accurately due to its low amplitude. The waves are typically measured from peak to peak, with amplitudes usually between 0.5 to 100 μV (Teplan, 2002). As a result, specialized amplifiers are required to enhance the signal before it can be processed. These amplifiers need to have a high gain and be able to effectively filter out external noise and interference (Li et al., 2021). Without such features, the weak EEG signals can easily be overshadowed by noise, making it challenging to obtain a clear and reliable reading for further analysis and processing.
- Recent advancements in amplifier design have significantly enhanced the capabilities of EEG technology, allowing for faster sampling rates and a larger number of simultaneously recorded channels. These innovations are crucial for capturing the dynamic and complex electrical activity of the brain with greater precision and detail (Biasiucci et al., 2019).
- The amplifiers used for EEG signal acquisition must meet specific requirements: they should not influence the physiological processes being monitored, should not distort the signal, should provide optimal separation of the signal and interference, must protect the patient from any risk of electric shock, and need to be safeguarded against damage that may occur due to high input voltages (Teplan, 2002).

Standard commercial EEG systems can acquire data up to 128 channels. The systems operate at sampling rates that exceed 10 kHz for all channels, ensuring that even rapid neuronal events can be accurately captured and analysed. Furthermore, these systems possess amplifiers that provide a 24-bit resolution, allowing for a high degree of sensitivity in detecting subtle variations in electrical signals (Biasiucci et al., 2019).

The EEG signal can be decomposed into a series of sine waves to generate a frequency spectrum of the data, and these waves can be characterized at each point in time by their amplitude, power and phase. Previous studies have categorized EEG brain waves into different bands, each frequency band is associated with specific cognitive and physiological processes: delta (0.5 – 4 Hz), theta (4 - 8 Hz), alpha (8 – 13 Hz), beta (13 – 30 Hz), gamma (30 – 90 Hz) and high frequencies (> 90 Hz) (Biasiucci et al., 2019)(Teplan, 2002).

The cerebral cortex (Figure 2.3), which forms the outer layer of the cerebrum, is the largest part of the human brain and is responsible for higher brain functions such as such as perception, attention, and decision-making. The cerebral cortex is divided into four sections called lobes: the frontal lobe, parietal lobe, occipital lobe, and temporal lobe. The frontal lobe is associated with reasoning, planning, speech, motor control, emotions, and problem-solving. The parietal lobe is responsible for sensory perception and spatial orientation, orientation, recognition, and perception of stimuli. The occipital lobe is primarily involved in visual processing, while the temporal lobe is associated with the perception and recognition of auditory stimuli, memory, and language comprehension (Upadhaya, 2018). Based on this, the frontal, parietal, and occipital lobes will be crucial for this dissertation, as they play a key role in concentration, vision, perception of visual stimuli, visual interference caused by the dazzling light, and reaction times.

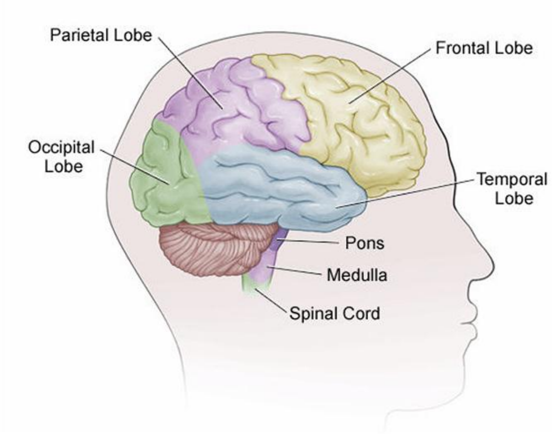


Figure 2.3 – Cerebral cortex (Upadhaya, 2018)

2.2.1. Event-related Potentials

Event-related potentials (ERPs) are a class of evoked potentials and consist of voltage fluctuations that are time-locked to neural activity in response to external or internal stimuli. ERPs provide a valuable method for studying cognitive processes in both normal and abnormal conditions (Teplan, 2002). However, like any technique, ERPs are susceptible to misuse and misinterpretation (Biasiucci et al., 2019). ERP component amplitudes are often much smaller than EEG signals, making them difficult to detect. ERPs are derived from individual EEG recordings. Instead of examining the entire EEG, researchers focus on specific segments of the data that are tied to repeated occurrences of sensory, cognitive, or motor events. Then, to improve the signal-to-noise ratio and make ERPs more distinguishable, they are digitally averaged. This process averages out the spontaneous background EEG fluctuations, which are random in relation to the timing of the stimulus, leaving only the event-related brain potentials, thus providing a high temporal resolution of the neuronal activity patterns evoked by a stimulus (Teplan, 2002).

As shown in Figure 2.4, the EEG segment following each stimulus is extracted for averaging. Brain activity that is unrelated to the stimulus will average out to zero, while brain activity that is consistently synchronized to the stimulus will remain in the averaged result. The resulting averaged ERP waveform consists of several positive and negative oscillations, known as peaks, and these peaks are typically labelled with a “P” or “N” to denote positive or negative deflections, respectively (Luck et al., 2000).

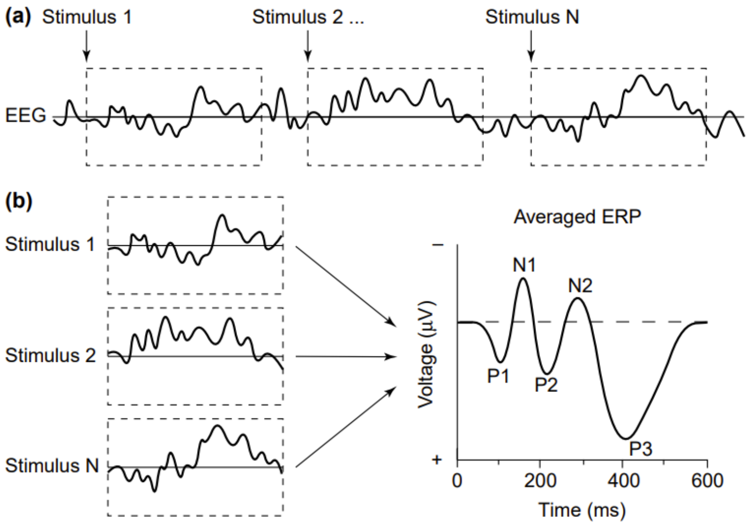


Figure 2.4 – Extraction of the ERP waveform: (a) During the EEG recording, stimuli (1, 2… N) are presented; however, the specific response to each stimulus is too small to be seen in the larger EEG signal. (b) To isolate the ERP, the EEG segments that follow each stimulus are extracted and averaged together, resulting in the creation of the averaged ERP waveform (Luck et al., 2000)

2.2.2. EEG Signal Acquisition

There are several and crucial decisions to make before recording data to ensure the experiment's success. The surrounding environment where the EEG recording is taking place is also an extremely important factor that shouldn't be overlooked. Studies suggest conducting data collection in sound- and light-attenuated rooms with controlled temperature and humidity. Participants should be provided with a comfortable chair or bed, and any additional equipment in the room should be electrically quiet. To take it a step further, the use of a Faraday Cage can significantly benefit the recording session, as it shields the equipment and participant from external electromagnetic interference (Perera et al., 2018)(Kaya, 2021). However, a drawback of using a Faraday cage is that it may cause discomfort in participants due to the enclosed environment (Suwandi et al., 2022). Skin preparation can vary, but it generally involves cleaning the skin surface to remove oil and brushing off any dried skin from the scalp.

A cap system is a head-mounted setup used in EEG recordings, equipped with electrodes arranged according to standardized spatial configurations, to enable accurate and consistent measurement of the brain's electrical activity. In cap systems, a pointless needle is often used for skin scraping, but this method can lead to irritation, pain, and infection which can potentially cause discomfort and even bleeding. Therefore, it is essential to follow appropriate hygiene and safety protocols. A small hole is provided for injecting conductive gel, to function as a medium for reducing contact impedance at the electrode-skin interface (Teplan, 2002). With these conditions met, data acquisition can initiate. The most recommended method for the electrode placements is the 10-20 electrode placement system (Perera et al., 2018). The captured signals are then amplified to bring the µV level signals to a range that can be accurately digitized. For multichannel montages, electrode caps are preferred, with configurations that can include up to 128 or 256 electrodes (Teplan, 2002).

The 10-20 electrode placement system (Figure 2.5) standardized physical placement and designations of electrodes on the scalp, with the "10" and "20" indicating that the distances between adjacent electrodes are either 10% or 20% of the total front-to-back or right-to-left dimensions of the skull. This system ensures adequate coverage of all brain regions by dividing the head into proportional distances from key skull landmarks. Electrode locations are labelled according to the adjacent brain areas: F (frontal), C (central), T (temporal), P (parietal), and O (occipital). Odd numbers are assigned to the left side of the head, while even numbers are assigned to the right, with left and right defined from the participant's perspective (Teplan, 2002)(Perera et al., 2018). There are other possible setups that can be used depending on the studies objectives.

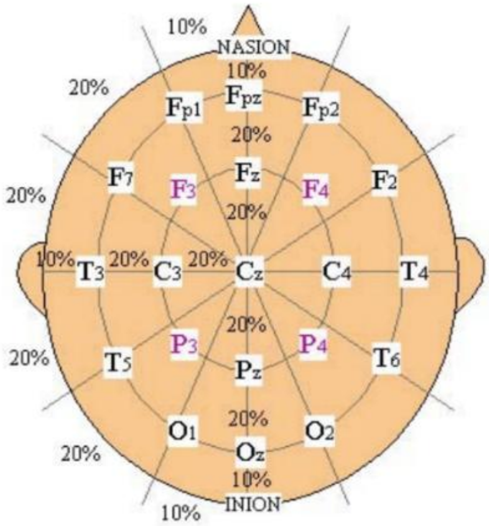


Figure 2.5 – The 10-20 electrode placement system (Teplan, 2002).

Each scalp electrode is positioned near specific brain centres: Fz is close to intentional and motivational centres, Cz is involved in sensory and motor functions and Pz contributes to perception and differentiation activities. However, pinpointing the exact location of active sources remains a challenge due to the non-homogeneous properties of the skull, the varying orientations of cortical sources and the coherence between these sources. The ground electrode's choice has minimal effect on measurements, with the forehead, electrode Fpz, or ear locations preferred, though wrist or leg locations may also be utilized (Teplan, 2002).

The amplifier gain is defined as the ratio of the output signal to the input signal. To ensure optimal signal quality and sufficient voltage levels for the subsequent signal processing, the amplifier must provide a gain between 100 to 100,000 while maintaining the best possible signal-to-noise ratio, having high common-mode rejection ratios, of at least 100 dB, and high input impedance, around 100 M Ohms. However, it is important to note that a higher gain does not necessarily mean it is the best option to use since more parameters are involved, such as noise, ADC range and sampling rate (Teplan, 2002).

2.2.3. EEG Signal Pre-Processing and Analysis

Pre-processing is an essential step following signal acquisition, as it aims to remove noise or artifacts captured during the recording of device signals. These include interference caused when an electronic device is being set up, muscular activity and ocular artifacts caused by eye movement or blinking. The presence of these unwanted artifacts in EEG recordings can complicate the analysis and classification process, leading to inaccurate conclusions and biased results. To mitigate this, during the pre-processing phase, filters are applied to remove the noise from the signal. For example, a crucial aspect to filter before analysis is the noise caused by electric power lines, typically observed at 50 Hz, which can be eliminated using a notch filter (Abdulwahab et al., 2020)(Perera et al., 2018).

Artifacts in EEG can be categorized as either patient-related or technical. Patient-related artifacts are unwanted physiological signals that can significantly interfere the EEG recordings; examples include eye blinks and movements (ocular artifacts), scalp contractions, swallowing (muscular artifacts), and other minor body movements. For better discrimination of different patient-related artifacts, the use of additional electrodes for monitoring eye movement, ECG, and muscle activity may be important. (Teplan, 2002). Technical artifacts can be reduced by positioning the electrode leads closer together, moving the electrodes and participant's away from noise sources, and by using a single isolated earth for the entire setup (Kaya, 2021). Furthermore, it is important to emphasize that, to ensure proper recordings, the EEG room conditions should meet the requirements mentioned in chapter 2.2.2. "EEG Signal Acquisition".

Handling EEG artifacts involves various methods, each with its limitations. Artifact avoidance, such as instructing participants to refrain from blinking or moving, can reduce artifacts. Manual rejection requires a individual to visually remove artifacts one by one, which is subjective, time-consuming, and unsuitable for real-time processing. Automatic rejection can optimize this process, but it may mistakenly remove non-artifact signals if the programmed parameters are inadequate. For an example of artifact handling methods, in blink artifact removal, since blinks have low frequency content compared to EEG, a low-pass filter can easily differentiate between the blink artifact and the EEG signal (Kaya, 2021). Independent Component Analysis (ICA) is also an option for artifact removal, and it can easily be done with software like Python or MATLAB.

For EEG signal analysis, the Fast Fourier Transform (FFT) is applied to break down the signal into a sum of sinusoids at different frequencies, revealing spikes in the frequency domain that are otherwise hidden. Alternatively, wavelet analysis decomposes the signal into wavelet basis functions, enabling analysis in both the frequency and time domains. The choice between these methods depends on the desired outcome; while wavelet analysis provides additional detail, it may not be necessary if the goal is simply to identify voltage at each frequency, without the need to determine specific timing (Kaya, 2021).

3. LITERATURE REVIEW

The objective of this chapter was to conduct a systematic review of studies utilizing EEG to detect and evaluate changes in concentration caused by dazzling. However, the literature on this topic is very limited, as most experiments in this area are conducted in military settings, making them inaccessible to the public. But even if limited, there's still literature that tackled this theme available in public sources, which will serve as the baseline for the methodology used in this work.

3.1. Evaluation of dazzling effect

A study that was conducted by *Lee et al. (2017)* aimed to investigate the effects of glare from different types of vehicle headlamps: Halogen, HID, and LED, with surface areas of 50.24 cm², 56.25 cm², and 36.75 cm² respectively, and varying illumination levels: 0.7, 2 and 5 lux. The primary focus was on studying the effects of glare on drivers by measuring changes in pupil size, brain activity, and subjective discomfort using the Borg scale, incorporating pupil size measurements and EEG data to evaluate physiological and neurological responses to better understand the impact of glare on visual and cognitive performance.

The sample size was composed by 20 healthy male drivers who had no visual diseases, and all participants provided written informed consent for ethical approvement. A dark room simulated nighttime driving. The setup replicated an oncoming vehicle at 30 meters, with the headlamp positioned 0.66 meters above the ground and the participant's eye level at 1.15 meters at an angle of 5° from the source of light. Pupil size was tracked using the FaceLab-5 eye-tracking system at 60 Hz, while EEG data was recorded focusing on the Fz (frontal lobe) and O1 (occipital lobe) electrodes.

The findings revealed that the average pupil size decreased significantly when using LED headlamps compared to Halogen and HID headlamps. Additionally, as illumination levels increased, pupil size decreased. EEG results showed that increased illumination levels resulted in higher Theta wave activity in the frontal lobe, indicating increased cognitive load and reduced concentration. Subjective discomfort was also greater with LED headlamps and higher illumination levels, with these factors being associated with the highest discomfort ratings.

3.2. Concentration measurement

A study that was conducted by *Santos, Pinto Coelho, et al. (2019)* aimed to induce a concentration state in 6 participants, with a mean age of 23 years old, using an N-back task, to discover what EEG features were affected when dazzling them while performing the task. The N-back task is a well-known method to measure cognitive workload. It involves presenting participants with a sequence of letters on a screen, and then they must respond by pressing a keyboard key based on specific conditions tied to one of the three different difficulty levels: in the 0-back task, participants press the key when a specific pre-determined letter appears. In the 1-back task, they press the key when a letter is repeated consecutively (e.g. "X – X"). In the 2-back task, they press the key when a letter appears again after one intervening letter (e.g. "X – Y – X"). By analysing EEG data during these tasks, the study explored how dazzling can alter brain activity related to concentration.

In this experiment, EEG data was collected using a BITalino board, while a participant performed N-back tasks on a laptop running Unity software and responded with the "up" arrow key when a target stimulus appeared. The laptop controlled an Arduino board, which activated a 10 W white LED near the keyboard to create a dazzling effect that aimed to influence the participant's performance.

Before starting the experiment, participants were provided with instructions and underwent a training period to familiarize themselves with the task. The task was divided into conditions, dazzle and no-dazzle. Each condition consisted of three trials, corresponding to different difficulty levels and each trial was further divided into epochs, which included a fixation cross period (baseline for setting up concentration state), a stimulus period, and a response period. The Unity software recorded response times and scores. The scoring system assigned one point per wrong answer, which means higher scores meant worse performances. Letters for the N-back task were generated from the 21 consonants in the Portuguese alphabet. Each trial presented 48 letters, with 33% being targets. The tasks were presented in random order to minimize expectation bias.

The light source used was a 10W white LED with a brightness of 800 lumens and the LED was supplied with 12 V for maximum luminous power. The illuminance of the computer monitor used was also measured, using a digital lux meter. EEG data was acquired at a sampling rate of 1000 Hz. The system included a main BITalino board, a

Wi-Fi module, a power module, a battery, two EEG sensors, and one electrooculography (EOG) sensor. The EOG sensor provided eye movement data, which was used to remove eye-related artifacts from the EEG signal through Independent Component Analysis (ICA). The experiment used seven electrodes: four electrodes measured EEG signals in a dipolar configuration at positions *AF7* and *Fp1*, and *AF8* and *Fp2*, as these positions target frontal brain activity related to concentration and attention. Two electrodes were used for electrooculography (EOG) in a dipolar configuration, placed above and below the left eye. A common reference electrode was placed on the left earlobe, shared by both the EEG and EOG sensors. The key features analysed to assess task difficulty and concentration were the score, which is the number of incorrect answers; latency, time in seconds taken to respond to an N-back stimulus; absolute power, total power of the EEG signal, divided into frequency bands; and peak frequency of the highest absolute power within a specific band. The EEG signals were then pre-processed and analysed using python scripts.

The results showed that significant differences were observed between conditions for the Alpha frequency band at the 0-back and 1-back levels with the *AF7-Fp1* electrode pair. The *AF8-Fp2* pair also showed significant differences for the Alpha and Beta frequency bands at the 1-back level. The results supported literature evidence that indicated that Alpha and Beta waves are important indicators of concentration: the Alpha band power decreased, and the Beta band power increased with task difficulty. Alpha power increased in the dazzle condition, suggesting that participants became less concentrated when dazzled. In contrast, Beta power increased during the 1-back level under the dazzle condition, possibly due to compensatory efforts by participants to counteract the distraction of the dazzling effect.

4. METHODS

In this chapter, the methodology used in this work is presented, based upon the theoretical foundations and previous studies discussed in the preceding chapter. This section outlines the experimental design, data acquisition procedures, materials and equipment used, as well as the methods applied for data processing and analysis.

4.1. Test Information

This study was conducted in a laboratory setting at IBEB in Lisbon, Portugal, a centre specialised in brain connectivity and neurorehabilitation. The research plan builds on findings and resources from IBEB to advance understanding in this field. Participants had their brain activity recorded using the Black Unicorn Recorder, a dry electrode cap with 8 channels, which allows comfortable and efficient EEG data collection without the need for gel. The goal is to understand how the brain reacts when a person is briefly distracted by sudden, bright flashes of light during a mental task. Each participant completed a single experimental session lasting approximately 25 minutes and Figure 4.1 illustrates the experimental setup used. The method follows these steps:

1. **Participant Recruitment and Consent**: participants were recruited from the public. They received a detailed information sheet about the study, including the purpose, procedure, risks, and their rights. A trained member of the research team answered any questions. Participants must give written informed consent before taking part.
2. **Initial Screening and Questionnaire**: Upon arrival at the lab, participants were asked to complete a short questionnaire, written in Portuguese (check Appendix), to confirm that they meet the inclusion criteria. The inclusion criteria are as follows: participants must be between ages 18 and 30; all participants must be right-handed, as neural network interactions differ between right- and left-handed individuals, and standardization of the sample is essential for EEG analysis; participants must not wear glasses or contact lenses to avoid unpredictable light scattering; participants must have no history of epilepsy, photosensitivity, or other visual impairments. Additional information collected include average daily screen time, hours of sleep the previous night, coffee and alcohol consumption in the last 12 hours, and whether participants are currently taking any type of medication

(e.g., antidepressants, antipsychotics, sedatives, or stimulants), as these factors can severely influence task performance.

3. **EEG Setup**: Participants were fitted with the Black Unicorn dry electrode cap. Adjustments were made as needed to ensure good signal quality and participant comfort. For these recording sessions, reference electrodes were placed on both the left and right mastoid bones.
4. **Baseline Recording**: Participants were asked to sit quietly for two minutes while their brain activity is recorded. This serves as a baseline measurement.
5. **Task Performance Without Light Flashes**: Participants completed a N-back task that requires them to respond as quickly and accurately as possible to letters appearing on the screen. This part takes around two minutes and helps us understand their normal reaction times and brain activity during a focused task. Key metrics assessed include test accuracy and reaction time.
6. **Task Performance With Dazzling Stimuli**: Participants then repeat a similar task twice. However, during this phase, they were exposed to short, bright flashes of light at random times. These flashes are not harmful and are designed to simulate sudden distractions or sensory overload. We measured how these bursts affect their attention, reaction time, and brain activity.
7. **Post-Task Questionnaire**: After the experiment, participants completed a short questionnaire about how they felt during the task and whether they experienced any discomfort or confusion.
8. **EEG Cap Removal and Debriefing**: The EEG cap was gently removed. The participant were then fully debriefed about the study’s aims and can ask further questions.
9. **Data Collection and Storage**: All EEG recordings and questionnaire responses were coded so that individual participants cannot be identified. Data was stored securely on password-protected computers at IBEB. Only authorized members of the research team can have access. No data will be shared with third parties or stored in cloud-based systems. Participants were be identified only by a number, not by name, and no personal or sensitive economic/social data was be collected. Data will be kept for a maximum of 3 years for research purposes only and then deleted. This research does not involve any physical risk, and all procedures follow current safety and ethical standards.

Figure 4.1 – Experimental setup. The participant depicted in the figure has provided informed consent for the image to be included in this dissertation

4.2. Materials

Besides the already mentioned questionnaire, other materials that were used on this dissertation are the following: light source, the EEG equipment, the N-Back Task, an Arduino with a LDR and the software for signal preprocessing and analysis.

Light source: The experiment used a flashlight, model GLM-520-850-25560 Green Laser Dazzler, capable of producing an effective yet harmless dazzling effect, either using white light (LED) or a laser beam. This model, from Lasence, delivers 850mW of green light (520nm), which is sufficient to dazzle up to 30m at night. The dazzling distance is adjustable from 3m to 30m. There is a distance scale at the adjusting part to make sure that the power density is between 0.1mW/cm^2 and 2.6mW/cm^2 in daytime and between 0.06mW/cm^2 and 1.3mW/cm^2 at night. The dazzler is operated with a rechargeable battery of 5000mAh, which grants a long operation time. It fulfils the requirements for protection class IP65 and can be operated within a temperature range of -20°C to +50°C. With a length of 255mm, a diameter of 40mm (tube) / 60mm (head) and a weight of 800g, it is very compact and lightweight. More information regarding model specifications is available in the official Frankfurt Laser Company website.

The light stimulus was activated approximately every 15 seconds during each two-minute task, resulting in a total of 16 light-dazzle events per participant. This approach ensures that the recorded EEG activity will correspond to the participants' physiological responses to these light activations, as there were many occurrences of this event through the recording session. The lumens of the white light, as well as the computer screen, white and black background, were be measured using a luminance meter. In Figure 4.2 and Figure 4.3 are the flashlight and the lux meter used. The average illuminance of the light source was measured at 1408 lux, with values ranging from 950 to 1550 lux. For the computer screen backgrounds, the average illuminance of the black background was 15.4 lux (ranging from 13 to 21 lux), while the white background averaged 21.4 lux (ranging from 17 to 27 lux). All measurements were conducted in the same room at 14:00h; however, participants did their recording sessions in different days. Ambient lighting conditions could not be fully controlled, as weather variations may have contributed to the fluctuations in the recorded values.

Figure 4.2 – Flashlight

Figure 4.3 – Digital lux meter

EEG equipment: EEG recordings were used to measure cognitive and visual processing responses during the experimental tasks. Data acquisition was performed using the Unicorn Hybrid Black system (g.tec Medical Engineering GmbH, Austria). This device was selected for its versatility and user-friendly design, allowing data collection to take place in a spacious environment rather than within a Faraday cage, thereby reducing potential discomfort for participants and allowing the setup to have proper distances for light exposure safety. The system features eight channels equipped with hybrid electrodes suitable for both wet and dry configurations, positioned according to standard EEG electrode placements to ensure reliable brain wave recordings. As mentioned before, this dissertation used the dry electrodes as it provides more comfort to the participants and less time setting up. The Unicorn Hybrid Black also enables wireless data transmission via radio signal. Additional technical specifications can be found on the official g.tec website. Figure 4.4 shows the equipment used for this dissertation.

Figure 4.4 - Unicorn Hybrid Black

N-Back Task: participants will press the left mouse button when visual stimuli are displayed on the computer screen. The visual stimuli will consist of letters from the Portuguese alphabet, excluding vowels, to prevent the participants from creating "words" that can aid in memorization of the letters and reduce their mental effort. (Santos, Pinto Coelho, et al., 2019)

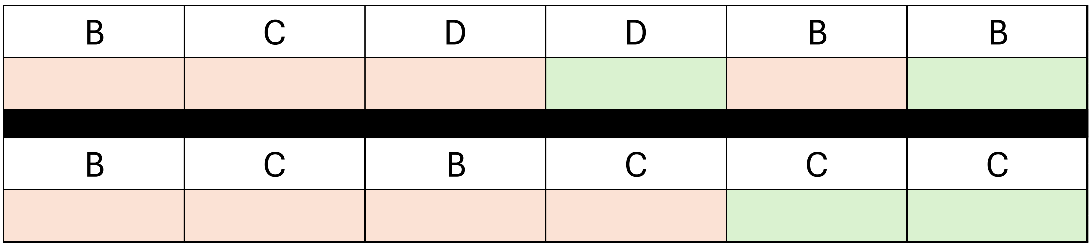
The N-Back Task was developed using Python (version 3.12.8), using the pygame module. The program generates a controlled experimental environment where each letter appears on the screen for a duration of 1 second, followed by a 500 ms interval between letters. The sequence of letters is randomized, as well as the positioning of the N-back letter stimuli, ensuring that the task is dynamic yet standardized across participants.

The program features a black background with white letters, meaning that this requires measuring the screen's luminance prior to starting the test, as mentioned earlier. Each task consists of 80 letters, with exactly 15 correct stimuli (N-back letter matches) included. This consistent ratio ensures that every participant is exposed to the same number of stimuli, enabling reliable comparisons of data across individuals.

At the conclusion of the task, the program outputs a summary of participant performance, including: the number of correct, incorrect and false alarms, and reaction times for each response. These precise timings and outputs help the process of labelling epochs for brain activity analysis, correlating neural responses with the appearance of stimuli.

All experimental data was recorded and stored in a excel file for subsequent analysis. This file contained the results of each participant, allowing for group-level comparisons and performance evaluation across them. From these data, variables such as individual and overall mean reaction times, as well as task accuracy (the proportion of correct responses in the N-back tasks), were extracted. Reaction times were then correlated with accuracy for each task to assess the relationship between response speed and performance consistency.

The N-back task used in this study was a 1-back version, in which participants were instructed to respond whenever the same letter appeared consecutively. Figure 4.5 presents the visual representation shown to participants to help them understand the rules of the 1-back task. Figure 4.6 represents the workflow of the 12-minute record session.



B	C	D	D	B	B
🟥	🟥	🟥	🟩	🟥	🟩

B	C	B	C	C	C
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Figure 4.5 – 1-back task: the green colour represents the stimuli the participants have to react to

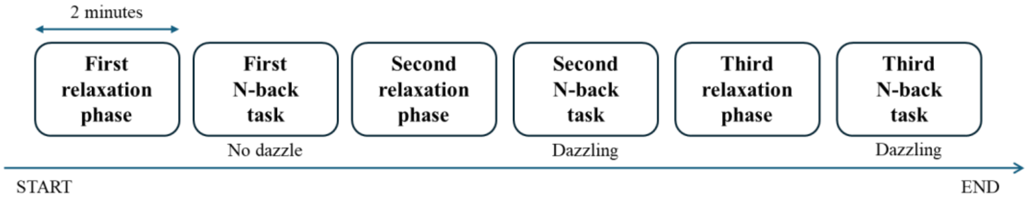

Figure 4.6 – workflow of the 12-minute record session

Arduino and LDR: To enhance the analysis of EEG data in the context of the N-Back Task, it is necessary to account for occurrences of light dazzling stimuli, which, due to the characteristics of the flashlight used, cannot be triggered automatically. To address this, a system integrating an Arduino, model R3 DIP (Arduino UNO – compatible), and a LDR comes into play (Figure 4.7). The setup involves placing the Arduino setup near the participant, where it detects light stimuli and generates a signal synchronized with the EEG recording. When the light source dazzles the participant, the LDR signal will generate a peak, corresponding to the moment of the dazzling event. This synchronization ensures that the exact timestamp of the LDR peak can be aligned with the EEG data, providing a clear reference point, to help easily identify and analyse the brain activity associated with the dazzling event in the EEG signal.

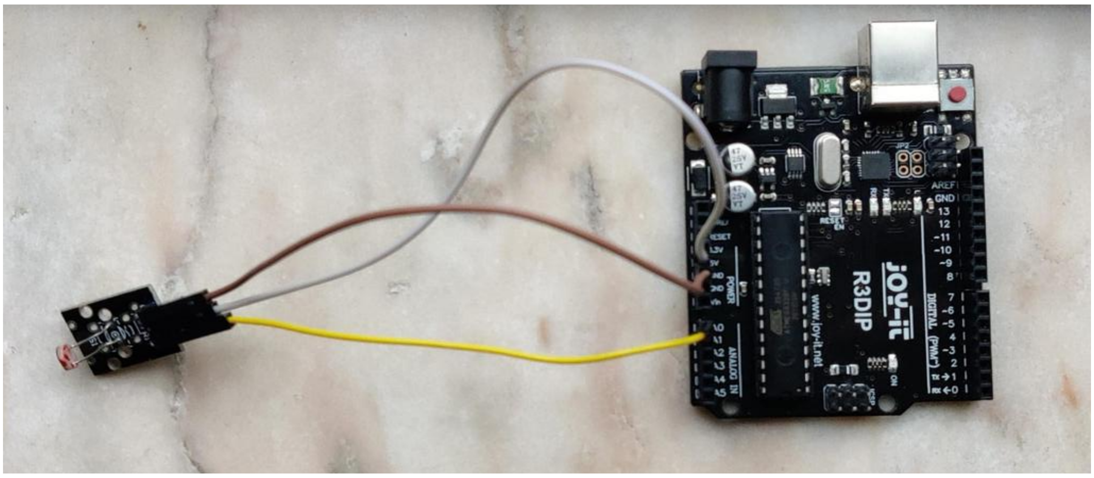

Figure 4.7 – Arduino with a LDR

4.3. Data Analysis

EEG data analysis began with the preprocessing stage, conducted using the EEGLAB toolbox in MATLAB (version R2025b), due to its flexibility and simple user interface. Upon loading the data into the software, electrode positions were first verified to ensure correct channel localization, after which the signals were re-referenced to the common average. The data was then filtered between 0.1 Hz to remove low frequencies and 49.5 Hz to remove electronic noise. ICA was subsequently performed on each participant's dataset, and components with a brain activity probability above 75% were included. This preprocess was done individually for every participant in the sample.

Following preprocessing, the cleaned EEG data was analysed using a custom Python (version 3.12.8) script developed for this study. The script utilized functions from the MNE and Matplotlib libraries for EEG data handling and graphics output and visualization, respectively. Since task times were measured manually during data collection, individual start times were entered manually into the script for each participant (e.g., participant 8 began the first N-back task at 126 seconds, whereas participant 3 began at 121 seconds). This variability, inherent to manual timing, is addressed further in Chapter 6. "Limitations and Future Perspectives".

Light source activations were monitored by an Arduino device together with a photodiode, which generated a CSV file containing the timestamps of each activation.

These timestamps were likewise manually entered into the analysis script for each participant. Once all relevant variables were defined, the script identified all light activation events and extracted epochs. Epochs are short, time-locked segments of the continuous EEG signal extracted around specific events, used to analyse the brain's response to the stimuli that occurs during the event. In this dissertation, epochs were defined as 250 milliseconds before and after each event. From these epochs, the alpha and beta frequency bands were computed for further analysis. The alpha band was selected due to its association with relaxed state, while the beta band was examined for its link to active concentration and cognitive processing. Additionally, an ERP analysis script was implemented to extract N200 and P300 biomarkers, to detect phase-locked responses. Due to the Unicorn Hybrid Black cap only having eight electrodes, four electrodes were selected for analysis, based on their relevance to visual and cognitive processing: one located on the frontal lobe (Fz), two on the parietal-occipital lobe (PO7 and PO8), and one on the occipital lobe (Oz).

To resume, Figure 4.8 illustrates a simplified version of the protocol described in this chapter, outlining the workflow followed for each participant individually.

Figure 4.8 – Protocol flowchart

5. RESULTS

In this chapter, the results obtained from the questionnaires, EEG recordings, and data processed through MATLAB and Python are presented and analysed.

5.1. Questionnaire and N-Back Task Data

The questionnaire that was administered to participants helped collecting some personal information to identify potential factors that could influence performance and to ensure that all individuals met the inclusion criteria for the sample. The average age of the sample was 23 years, with the oldest participant being 25 and the youngest 22 years old.

Among the eight participants, five reported not playing video games that require fast reaction times or include flashing visual stimuli, such as first-person shooters or rhythm games. Of the remaining three, Participant 4 reported playing approximately 17 hours per week. This pattern is reflected in the self-reported light sensitivity scores, where participants rated their sensitivity to light on a scale from 1 (least sensitive) to 5 (most sensitive). Participant 4 rated a 2, whereas the rest of the sample reported neutral (3) responses. These results are showed in the pie charts in Figures 5.1 and 5.2.

Figure 5.1 – Weekly gaming hours

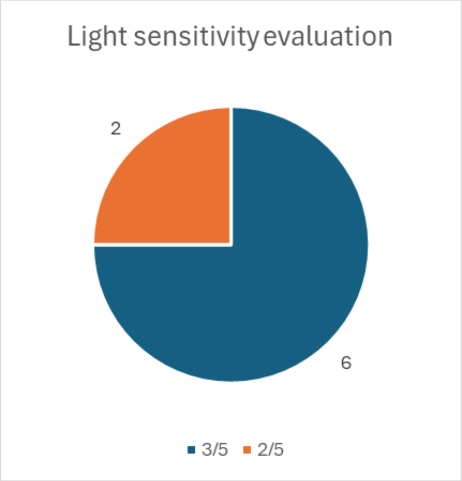

Figure 5.2 – Light sensitivity

The average number of hours slept before the experiment was 7.5 hours, indicating that no participant was sleep deprived during testing. Most participants did not consume coffee within 12 hours prior to the session, except for Participant 3, who reported drinking two coffees. All participants reported feeling comfortable during the test in terms of room space, temperature, and the EEG equipment, except for Participant 4, who noted that the EEG cap felt too tight, likely due to their thick hair. No participant found the N-back task difficult to understand, except for Participant 1. Additionally, no participant reported being distracted by external noise such as passing cars or airplanes.

Reactions to the dazzling light were mixed: Participants 1 and 5 reported that the light did not impair their performance. Participant 5 also noted that the contrast between the white letters and the black background created a visible "halo" effect around the stimuli when the light activated. This was the only participant to mention such an observation. It is worth noting that the light source may not have been perfectly aligned for Participant 5, as the same setup was used for all participants and this individual was the shortest in the sample, potentially resulting in a slightly different angle of light incidence compared with the others.

Additional observations were also recorded during the experiment. Participant 4 reported occasional confusion between visually similar letters, such as Q and G or B and D, particularly when they appeared consecutively. However, this factor was beyond the experimenter's control, as the sequence and selection of letters were randomized by the task software. Participant 8 exhibited a highly competitive attitude, stating upon entering the testing room that they intended to achieve the best and fastest performance among the sample. This competitiveness may have influenced both their task performance and light exposure, as they might have adjusted their posture or seating position during the test, thereby altering the angle of light incidence and reducing the dazzling effect compared to other participants.

As mentioned previously, the N-back task scores were recorded in an Excel file. The individual performance of each participant is presented in Figure 5.3 and Table 5.1. The collected data included the number of correct responses, missed responses (marked as wrong), and "false alarms," referring to instances where participants responded to a letter that was not a stimulus. These data can subsequently be converted into task accuracy using the following Equation 1.

$$Accuracy\ (\%) = \frac{Correct}{(Correct + Wrong + False\ Alarm)} \times 100 \qquad (1)$$

In addition to accuracy, the average reaction time was also calculated by the N-back task script. Moreover, detailed files containing all reaction times for each stimulus were generated, allowing for a deeper analysis, particularly in cases where participants produced “false alarms”, as if their reaction times are higher than the average, it may indicate hesitation or uncertainty before responding.

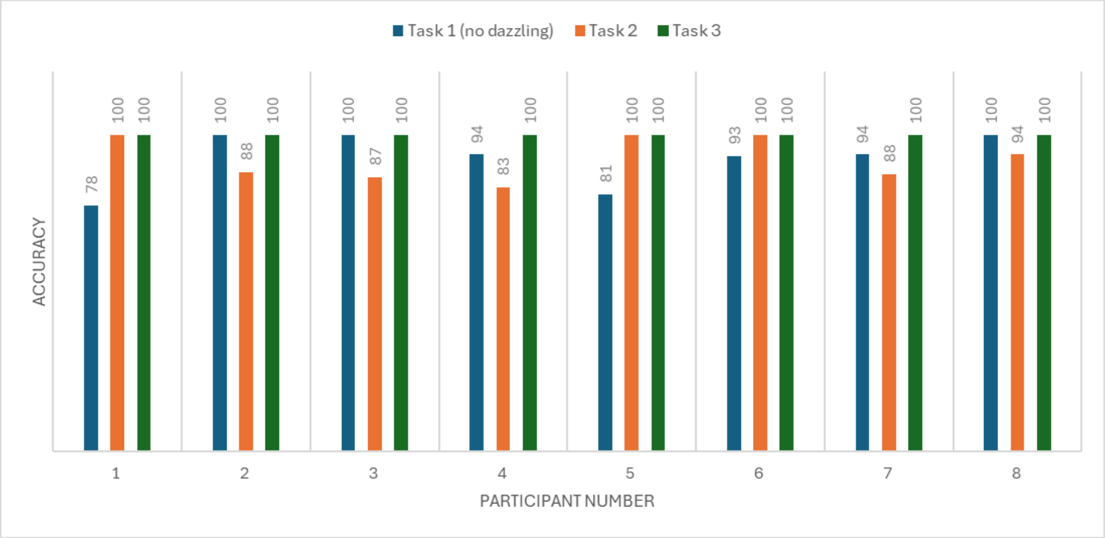

Figure 5.3 – Accuracy of each participant for each task

Table 5.1 – individual performance of each participant in the three N-back tasks

Participant	Task 1 - no dazzling				Task 2 - dazzling				Task 3 - dazzling			
	Correct	Wrong	False alarm	Reaction time	Correct	Wrong	False alarm	Reaction time	Correct	Wrong	False alarm	Reaction time
1	14	1	3	0.5	15	0	0	0.44	15	0	0	0.46
2	15	0	0	0.4	15	0	2	0.45	15	0	0	0.39
3	15	0	0	0.41	13	2	0	0.43	15	0	0	0.41
4	15	0	1	0.38	15	0	3	0.35	15	0	0	0.43
5	13	2	1	0.44	15	0	0	0.42	15	0	0	0.51
6	14	1	0	0.3	15	0	0	0.35	15	0	0	0.33
7	15	0	1	0.44	14	1	1	0.46	15	0	0	0.45
8	15	0	0	0.3	15	0	1	0.35	15	0	0	0.33

As illustrated in the results, the first task (performed without intermittent light exposure) served as a familiarization phase to ensure that participants understood the task requirements before introducing the light-dazzle conditions. Some participants exhibited slightly lower accuracies (Table 5.2) during this initial task, for example, Participant 1 achieved 78% accuracy and Participant 5 achieved 81%. This outcome likely reflects their process of adapting to the N-back task and understanding its rules. Consequently, Tasks 2 and 3, which incorporated dazzling light stimuli, were expected to capture participants’ performance under more stable and focused conditions. The primary objective of this work was to investigate whether intermittent light exposure could impair participants’ concentration during a cognitively demanding task, with the first task serving as a baseline and motivation for a better performance in the subsequent ones.

Table 5.2 – Accuracy of every participant in every task

Participant	Accuracy (%)		
	Task 1	Task 2	Task 3
1	78	100	100
2	100	88	100
3	100	87	100
4	94	83	100
5	81	100	100
6	93	100	100
7	94	88	100
8	100	94	100

Still in Figure 5.3, the results from Task 2 reveal several noteworthy patterns. The previously mentioned Participants 1 and 5, demonstrated improved performance even under light exposure, suggesting that they may have adapted to the demanding nature of the task and maintained concentration despite the visual disturbance. In contrast, Participants 2, 3, and 4 exhibited reduced performance. Participant 2 produced two false alarms and showed increased reaction times. These false alarms occurred 0.58 seconds and 0.50 seconds after stimulus presentation, indicating possible hesitation in determining whether the displayed letter was indeed a target. This impairment could possibly be attributed to the dazzling light present during this task, which may have momentarily disrupted the participant's attention. Participant 3 missed two stimuli entirely, which could, likewise, be explained by reduced concentration due to the light interference. Participant 4, on the other hand, committed three false alarms, most likely resulting from the previously mentioned issue of visually similar letters, in addition to the distracting effect of the light exposure. It is also important to note that participants were not informed of the total number of target stimuli. This prevented them from counting or anticipating how many stimuli remained throughout the task.

Lastly, there is very limited analysis to be drawn from Task 3 from these results, as all participants appeared to have adapted to the 1-back task, which is relatively simple by design; even the dazzling light interference did not seem sufficient to disrupt their performance. It is also possible that participants unconsciously adjusted their behaviour to mitigate the light's impact, such as by slightly lowering their gaze or partially closing their eyes to maintain focus on the computer screen. Another plausible explanation is that participants gradually adapted to the light intensity, leading to a reduced dazzling effect over time. Figure 5.4 presents a scatter plot of accuracy versus reaction time for each task, clearly illustrating the patterns discussed previously. Tasks 1 and 2 exhibit a wide range of accuracies, from 78% to 100%, whereas all Task 3 data are concentrated in the maximum accuracy. Reaction times across the sample ranged from 0.3 to 0.51 seconds.

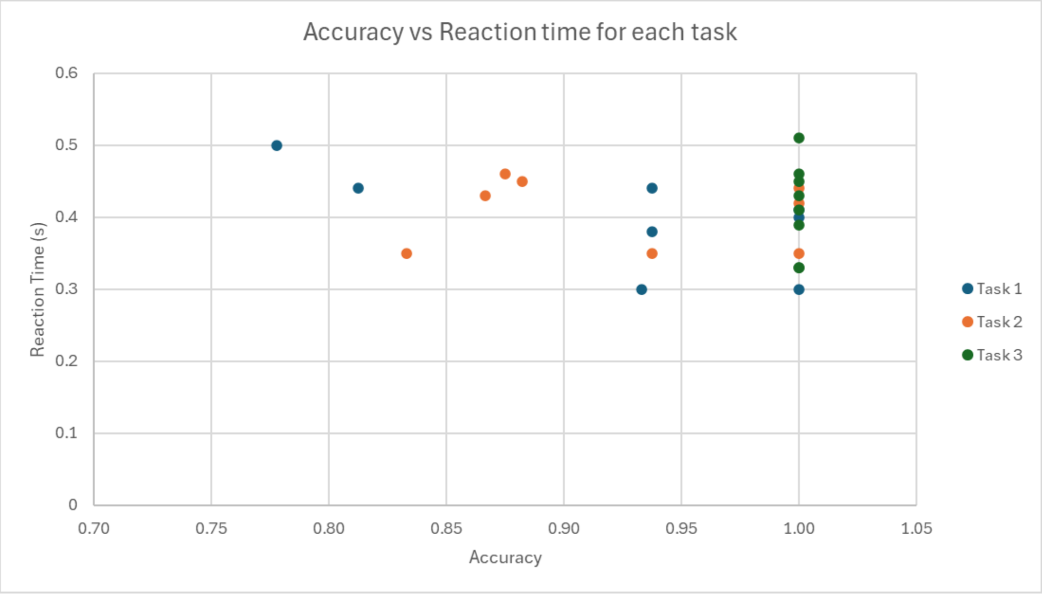

Figure 5.4 – Accuracy vs reaction time for each task

5.2. EEG Data

During preprocessing, a file containing the electrode names was created and imported into EEGLAB. Thanks to the software's versatility, providing the electrode labels along with the model specification of the Unicorn Hybrid Black system automatically assigned the corresponding three-dimensional coordinates to each channel. This process generated the electrode placement map illustrated in Figure 5.5.

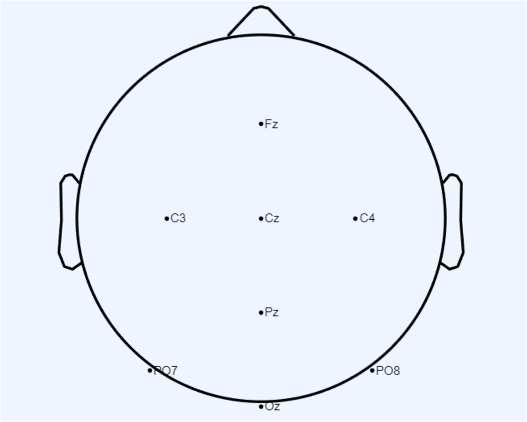

Figure 5.5 – Electrode locations

After filtering and performing ICA, the independent components were extracted for inspection. Figure 5.6 illustrates this stage of the preprocessing pipeline, showing the components obtained from the EEG data of Participant 2. It is clearly visible that at least one component should be rejected, as it exhibits little to no brain-related activity, likely representing artifacts caused by external noise or participant movement during the recording. Figure 5.7 presents an example of a component that needs to be rejected. This component contained only 26.1% brain activity, with the remaining 73.9% classified as muscle, eye and other artifacts. Lastly, Figure 5.8 displays an example of a retained component, characterized by 97.3% brain activity, and therefore considered suitable for further analysis. However, not all participants required component removal. For instance, Participant 3 exhibited an average of 95.9% brain activity across all components (Figure 5.9).

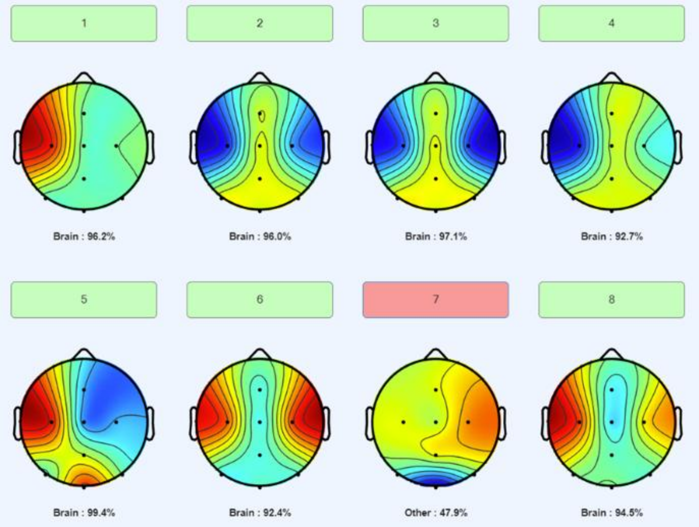

Figure 5.6 – components from participant 2

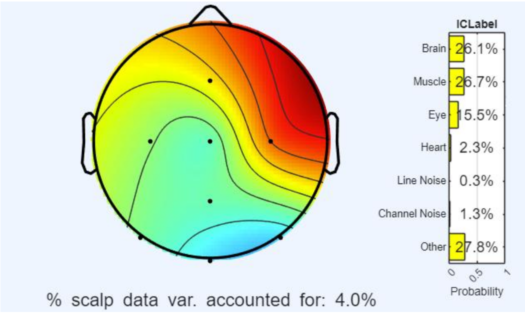

Figure 5.7 – Example of a rejected component (Participant 6)

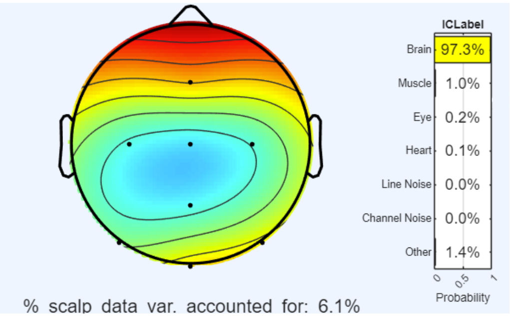

Figure 5.8 – Example of a good component (Participant 6)

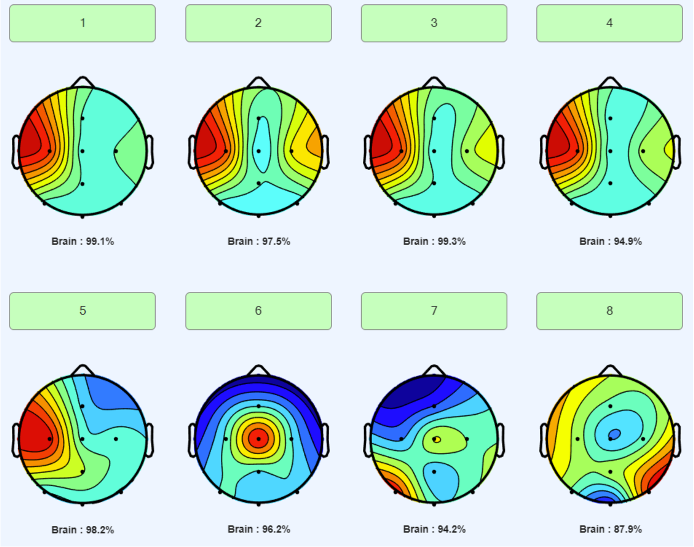

Figure 5.9 – Components from participant 3

After completing this process for each participant individually, the data was imported into Python. Using the MNE toolbox, the pre-processed MATLAB data files could be opened for further analysis. Following preprocessing, the cleaned EEG data was analysed using a custom Python (version 3.12.8) script developed for this study. The script utilized functions from the MNE and Matplotlib libraries for EEG data handling and graphics output and visualization, respectively. These timestamps were also manually entered by using the data from the CSV output from the Arduino. The resulting light activation events were subsequently plotted, as illustrated in Figure 5.10.

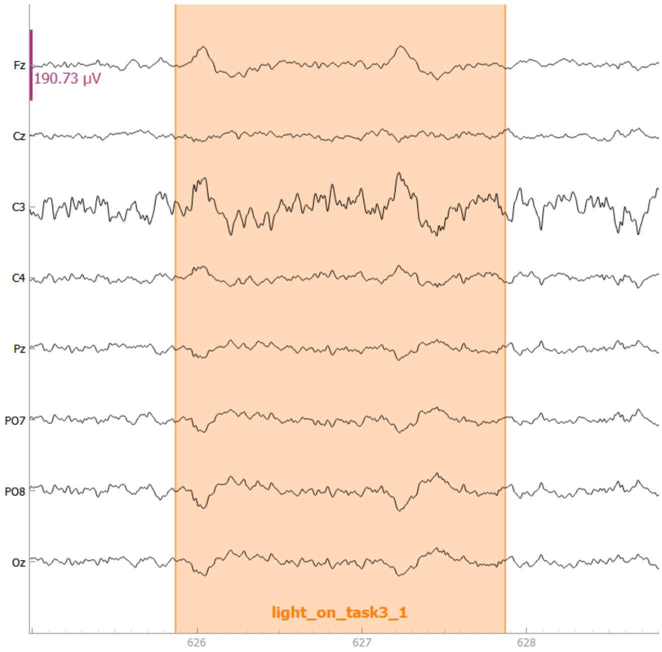

Figure 5.10 – Light activation event

Still in Figure 5.10, it is possible to observe two peaks in the Fz electrode during light activation. It is unclear whether this pattern results from the fact that this dissertation used intermittent light to cause the dazzle, causing participants to respond twice within a single event, or if it coincided with the presentation of an N-back stimulus, leading to responses to both the light and the letter in the same event. Addressing this issue would require more advanced signal filtering, which will be discussed further in Chapter 6, “Limitations and Future Perspectives.”

With the light activation events defined, the next step was to epoch the data 250 milliseconds before and after each event. This approach allowed the examination of ERPs, specifically the N200 and P300 biomarkers. However, as illustrated in Figure 5.11, this proved to be a challenging task, as, once again, the filtering required for this study was more complex than initially anticipated. Multiple stimuli occurred simultaneously, making it difficult to determine whether a given epoch reflects a participant’s response solely to the light activation. The figure provides an example of the outputs generated by the analysis script; however, noise is obviously apparent in this segment, preventing any accurate conclusions from being drawn. This type of graph was generated to every light activation event for both task 2 and task 3.

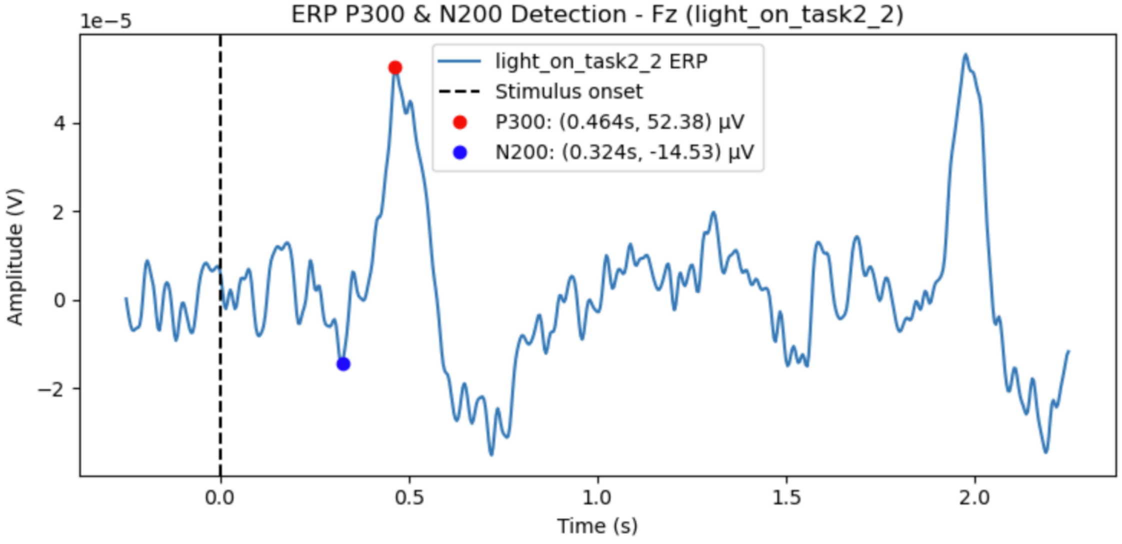

Figure 5.11 – P300 and N200 biomarkers

The next step in the analysis focused on frequency bands. A script was developed to examine alpha frequencies (8–13 Hz). Scripts for beta and gamma frequencies (up to 50 Hz) were also created for potential exploratory analysis; however, due to the same limitations encountered with the ERP analysis, the results from these bands are not reported, as no concise conclusions could be made.

For alpha frequencies however, some conclusions could be made. Figure 5.12 presents the alpha frequency analysis for Participant 8, measuring the peak of the FWHM window for each light activation event. Although it is not possible to confirm definitively that these peaks correspond solely to the light activations, it is highly likely that they represent moments when the participant was exposed to the dazzle, which explains the clear peak observed in the graph. Alpha power is relatively low during Task 2, suggesting that Participant 8 may have been distracted by the light, resulting in reduced alpha power as the task required greater concentration. This interpretation is further supported by Figure 5.13, which shows alpha activity during a light activation in Task 3 on the same electrode. The observed increase in alpha power suggests that Participant 8 was more relaxed during the second N-back task, despite the presence of the dazzling light. Given that all participants had adapted to the task by the third session, these results appear plausible.

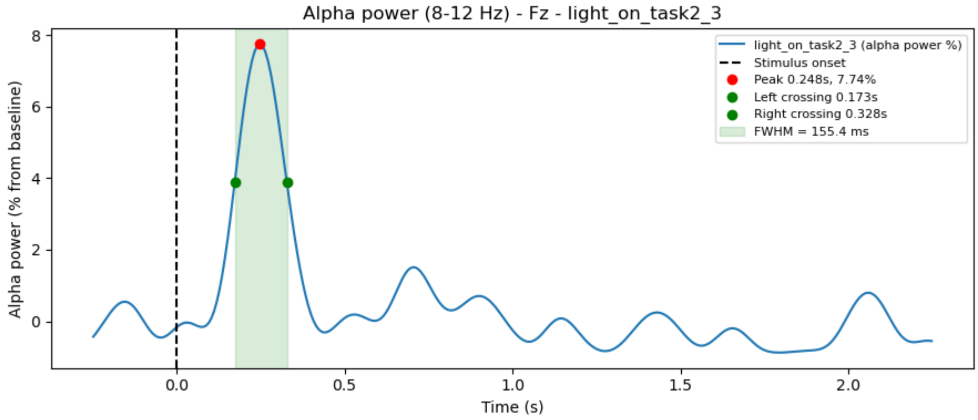

Figure 5.12 – Alpha power on task 2 (Participant 8)

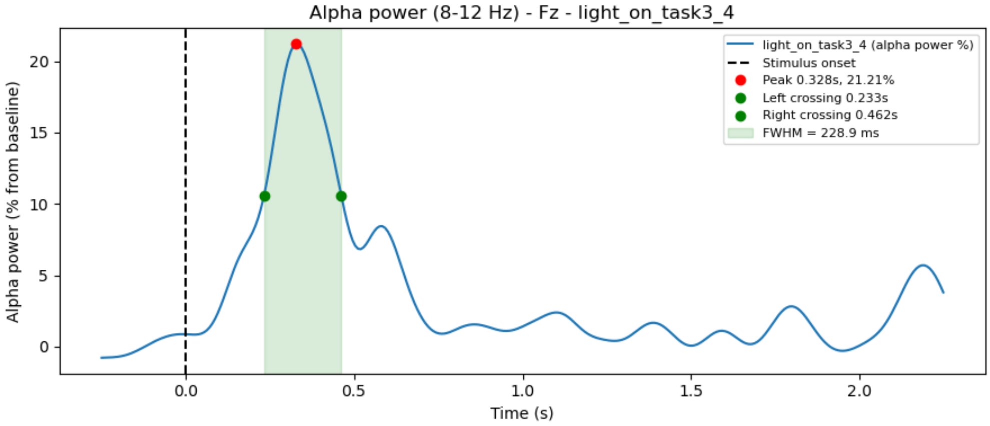

Figure 5.13 – Alpha power on task 3 (Participant 8)

6. LIMITATIONS AND FUTURE PERSPECTIVES

This project would have benefited from greater attention to the signal filtering process, as a key issue was only identified later in the analysis process, which couldn't be solved due to the lack of time. During the N-back task, multiple stimuli occurred simultaneously, making it difficult to ensure that the N200 and P300 biomarkers being studied were specifically related to the light activation events. The overlapping stimuli include: the light turning on and off, the appearance and disappearance of letters, participants' mouse clicks, and other minor events that could still influence the results. Given the current level of signal filtering, it is not possible to confidently determine whether the activity previously showed truly represents the ERP response to the light activation or reflects participants' reactions to other concurrent stimuli, such as the appearance of letters on the screen. However, it remains quite plausible that the observed activity is indeed related to the light activation.

Unfortunately, this project did not incorporate an EEG trigger, meaning that event timings were recorded manually rather than by the computer, which may introduce slight inaccuracies for each event. Implementing an EEG trigger would greatly improve timing precision throughout the task and eliminate the need for manually adjusting variables. Additionally, the current N-back task script is only two minutes long and must be manually initiated in the command window for each task. This manual activation introduces noise into the EEG signal in the beginning of each N-back task event. To address these issues, the script should be modified to run for the full recording session, automatically guiding participants through alternating two-minute relaxation and N-back task phases.

It is necessary to test the positioning of the light source with participants prior to the experiment. Variations in participant height may result in some individuals receiving insufficient light exposure, as may have occurred in this sample. Changes in posture during the task or participants unconsciously moving closer to the screen to maintain focus can also alter the effectiveness of the light stimulus.

As noted by Participant 5, the contrast between the letters and the background colour was excessively high. To address this, it's suggested that letters should be displayed in grey in future tests, rather than white on a black background. This would reduce contrast and may alleviate this issue.

Integration of a system capable of automatically activating the light would improve the precision of both the timing and duration of light exposures. In the current setup, light activation was performed manually, resulting in slight variations in exposure duration, ranging from approximately two to three seconds. For experiments of this nature, where precise control over stimulus timing is critical, implementing an automated light control system would be highly beneficial.

Although these issues constitute relatively minor adjustments, in the N-back task, responses currently labelled as “incorrect” should be reclassified as “misses,” as they correspond to instances in which participants fail to respond to a target stimulus, rather than responding incorrectly. Additionally, for ERPs and frequency band analyses, the current figures are not presented on a standardized scale. This limits direct visual comparison across conditions. Future analyses would benefit from the use of consistent scaling across all images, thereby facilitating clearer identification and comparison of peak amplitude differences.

Finally, although this project was initially intended to investigate laser dazzling, it was adapted to study white light dazzling instead. Laser-based experiments would have required considerably greater complexity, including strict safety protocols and additional variables to ensure participants’ ocular health and safety. A larger room would also have been necessary to maintain a safe distance between the laser and participants. To address these considerations, a meeting was held with a professional ophthalmologist to discuss the experimental protocol and verify appropriate safety measures. Although the laser dazzle was not ultimately used, a 3D-printed support was produced to hold the laser on a tripod and ensure the required safety distance. This support is shown in Figure 6.1, and the 3D model is available on the Thingiverse website.

Figure 6.1 – 3D-printed support for laser that can be attached to a tripod

7. CONCLUSION

In this dissertation, a complete experimental setup was designed to investigate the effects of dazzle on participants performing tasks that require sustained attention. A Python script was developed to standardize and customize the 1-back task, allowing precise control over the number and timing of stimuli presented. In addition, a second Python script was created to support EEG data analysis, enabling flexible preprocessing and the generation of graphical outputs to support the interpretation and discussion of results.

With the analysis of alpha frequency bands suggests that the light dazzle did influence concentration, as evidenced by a decrease in alpha power during Task 2, indicating that participants needed to focus more on the task. In Task 3, alpha power increased, which is interpreted as participants having adapted to the N-back task, such that the light seemed to no longer affect their concentration. This interpretation is further supported by task accuracy data, as all participants performed without errors in Task 3.

This work presented several limitations; however, most of these can be addressed in future sessions. Improvements such as a better-controlled room environment, better management of the Unicorn Hybrid Black system and stricter control of participant movement can significantly reduce noise in the EEG data. Additionally, this refining, will make the scripts for ERP analysis and frequency bands produce more precise and interpretable results.

Finally, future studies should focus on perfecting this protocol to later reintroduce laser dazzling. It is essential to first implement the safety measures discussed with the ophthalmologist to ensure participant safety throughout the experiment. This would include conducting pre- and post-experiment eye examinations to monitor and confirm the ocular health of all participants before and after data collection.

8. REFERENCES

Abdulwahab, S., Khleaf, H., & Jassim, M. (2020). A Systematic Review of Brain-Computer Interface Based EEG. *Iraqi Journal for Electrical and Electronic Engineering*, *16*(2), 1–10. https://doi.org/10.37917/ijeee.16.2.9

Biasiucci, A., Franceschiello, B., & Murray, M. M. (2019). Electroencephalography. In *Current Biology* (Vol. 29, Issue 3, pp. R80–R85). Cell Press. https://doi.org/10.1016/j.cub.2018.11.052

Coelho, J. M. P., Freitas, J., & Williamson, C. A. (2016). Optical eye simulator for laser dazzle events. *Applied Optics*, *55*(9), 2240. https://doi.org/10.1364/ao.55.002240

Kaya, I. (2021). *A Brief Summary of EEG Artifact Handling*.

Lee, H. S., Kim, J. Y., Subramaniyam, M., Park, S., & Min, S. N. (2017). Evaluation of quantitative glare technique based on the analysis of bio-signals. *Ergonomics*, *60*(10), 1376–1383. https://doi.org/10.1080/00140139.2016.1251620

Li, B., Cheng, T., & Guo, Z. (2021). A review of EEG acquisition, processing and application. *Journal of Physics: Conference Series*, *1907*(1). https://doi.org/10.1088/1742-6596/1907/1/012045

Lopez-Gordo, M. A., Sanchez Morillo, D., & Pelayo Valle, F. (2014). Dry EEG electrodes. In *Sensors (Switzerland)* (Vol. 14, Issue 7, pp. 12847–12870). MDPI AG. https://doi.org/10.3390/s140712847

Luck, S. J., Woodman, G. F., Vogel, E. K., Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). *Event-related potential studies of attention*.

Perera, H., Shiratuddin, M. F., & Wong, K. W. (2018). Review of EEG-based pattern classification frameworks for dyslexia. *Brain Informatics*, *5*(2). https://doi.org/10.1186/s40708-018-0079-9

Sammarco, J. J., Mayton, A., Lutz, T., & Gallagher, S. (2010). Discomfort glare comparison for various LED cap lamps. *Conference Record - IAS Annual Meeting (IEEE Industry Applications Society)*. https://doi.org/10.1109/IAS.2010.5615978

Santos, J., Coelho, J., Mendonça, P., & Ferreira, H. (2019). *Study of the light's dazzling effect on the eeg signal of subjects performing tasks that require concentration*. http://hdl.handle.net/10451/39948

Santos, J., Pinto Coelho, J. M., Mendonça, P., & Ferreira, H. A. (2019). *Assessment of light's dazzling effect on the EEG signal of subjects performing tasks that require concentration*. 197. https://doi.org/10.1117/12.2530543

Suwandi, G. R. F., Khotimah, S. N., & Suprijadi. (2022). Electroencephalography Signal Power Spectral Density from Measurements in Room with and Without Faraday Cage: A Comparative Study. *Journal of Physics: Conference Series*, *2243*(1). https://doi.org/10.1088/1742-6596/2243/1/012002

Teplan, M. (2002). Fundamentals of EEG measurement. In *MEASUREMENT SCIENCE REVIEW* (Vol. 2, Issue 2).

Upadhaya, T. (2018). *Multimodal radiomics in neuro-oncology*. https://www.researchgate.net/publication/325660673

Williamson, C. A., & McLin, L. N. (2015). Nominal ocular dazzle distance (NODD). *Applied Optics*, *54*(7), 1564. https://doi.org/10.1364/ao.54.001564

APPENDIX

QUESTIONARIO PARA PARTICIPANTES DO PROJETO “EVALUATION OF ELECTROPHYSIOLOGICAL PARAMETERS OF DAZZLING EFFECT”

OBJETIVO: O principal objetivo deste projeto é estudar o impacto do efeito de encadeamento causado por uma fonte de luz no nível de concentração de um participante, através da análise das ondas cerebrais registadas pelo EEG. O participante irá participar em um teste de 25 minutos, dividido em três fases, em que vai realizar uma N-Back Task, que é uma forma simples que permite induzir um estado de concentração ao participante: Um dos testes será sem encadeamento, enquanto os outros serão com encadeamento causado por uma fonte de luz branca.

QUESTIONARIO:

Nome: ____

Género:

☐ Masculino ☐ Feminino ☐ Outro

Idade: ________________

Qual é a sua mão dominante?

☐ Esquerda ☐ Direita ☐ Ambidestro

Usa lentes de contacto ou óculos?

☐ SIM ☐ NÃO

Tem algum problema de visão?

☐ SIM ☐ NÃO

Tem diagnostico de epilepsia?

☐ SIM ☐ NÃO

Joga jogos online que requerem concentração e tempo de reação? Se sim, escreva uma estimativa de quantas horas semanais joga este tipo de jogos. (Exemplo: Jogos first person shooter, jogos de ritmo)

____

Qual o seu tempo médio diário de exposição a ecrãs? (telemóvel, computador, televisão…) ___________________

Quantas horas dormiu na última noite? __________________

Quantos cafés bebeu hoje?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ou +

Bebeu álcool nas últimas 12 horas?

☐ SIM ☐ NÃO

Está atualmente a tomar alguma medicação que possa influenciar a sua performance? (Ex: anticonvulsivos, antidepressivos, antipsicóticos, sedativos e estimulantes)

☐ SIM ☐ NÃO

Já teve reações adversas a exposição forte de uma fonte de luz?

☐ SIM ☐ NÃO

Sente desconforto e dor de cabeça depois de se expor a fontes luminosas?

☐ SIM ☐ NÃO

Na sua opinião, o quão sensível é à luz? Avalie de 1 (pouco sensível) até 5 (muito sensível).

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Eu, _____________________________________, declaro que li e compreendi as informações prestadas acima. Estou ciente dos riscos e benefícios e concordo em participar voluntariamente neste estudo.

QUESTIONARIO PÓS TESTE

Sentiu-se confortável durante do teste?

☐ SIM ☐ NÃO

Achou a N-Back Task difícil de realizar/compreender?

☐ SIM ☐ NÃO

Classifique o nível de distração causado pela intensidade da luz numa escala de 1 (insuportável) a 9 (desprezível), sendo que 5 representa o meio termo, em que a intensidade da luz é considerada razoavelmente aceitável, ou seja, causa distração, mas não magoa a visão: ______

Sentiu-se distraído durante o teste devido ao impacto da luz?

☐ SIM ☐ NÃO

Sentiu-se distraído durante o teste devido a estímulos exteriores? (Ex: barulho vindo de fora da sala onde realizou o teste)

☐ SIM ☐ NÃO

ASSINATURA: ___________________________________