Asmae Izlane El Khalfaouy

Assessing Variations in Clinical Interpretation of Visual and Somatosensory Evoked Potentials Due to Different Electrode Positioning Methods

Final Degree Project
directed by Dr. Albert Fabregat Sanjuan
directed by Dr. Vicenç Pascual Rubio

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Abbreviations and acronyms

VEP: Visual Evoked Potentials
SEP: Somatosensory Evoked Potentials
MS: Multiple Sclerosis
HC: Head Circumference
PC: Cranial Perimeter
Ns-In: Nasion-Inion
LPA: Left pre-auricular
RPA: Right pre-auricular
OD: Right Eye
OI: Left Eye
EP: EPlacement Device
Approx.: Approximative Method
1S-EP: EPlacement of one strip
2S-EP: EPlacement of two strips

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1 Introduction

In clinical neurophysiology, evoked potentials (EPs) are used to investigate the electrical activity of the nervous system in response to particular sensory stimuli. These tests require the placement of electrodes on the scalp and, depending on the type of evoked potential, the electrodes are placed in the affected cortical area.

The placement of electrodes is determined by the International 10:20 System (SI 10:20) of the International Federation of Clinical Neurophysiology (IFCN), which allows the proportional segmentation of the scalp based on established anatomical references. The 10:20 system is based on the relationship between the location of an electrode and the underlying area of the cerebral cortex[1], [2], [3] . The numbers "10" and "20" refer to the distances between adjacent electrodes, which are 10% or 20% of the total anteroposterior or right-left distance of the skull. Each location is labelled with a letter to identify the lobe and a number to identify the hemisphere. The main areas are frontopolar (Fp), frontal (F), central (C), temporal (T), parietal (P), and occipital (O), corresponding to the brain lobes. The "z" (zero) refers to an electrode placed on the midline. Even numbers refer to electrode positions in the right hemisphere, and odd numbers refer to positions in the left hemisphere.

For precise electrode placement according to the 10:20 system, four anatomical reference points are used: first, the nasion, which is the point between the forehead and the base of the nose; second, the inion, which is a posterior point of the skull located at the most prominent projection of the occipital bone; and the tragus, the preauricular points anterior to each ear [4]. It is important to note that each person has a specific head size that varies significantly depending on the age and shape of the skull, requiring individualized calculation and proportion-based determination of each cranial point.

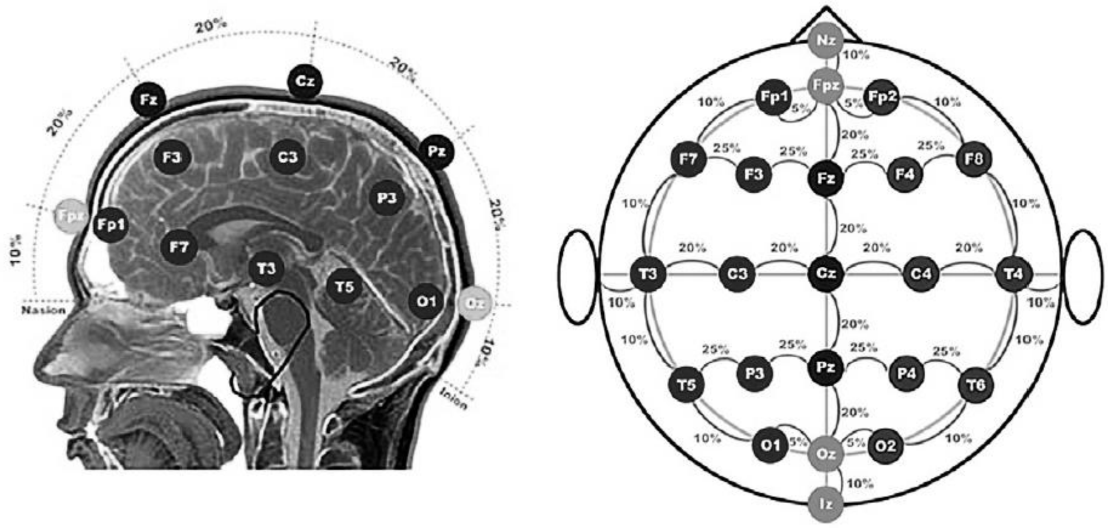

Figure 1: Representation of the International 10:20 System for electrode placement in clinical neurophysiology studies. It shows the proportional locations of the electrodes in relation to anatomical reference points such as the nasion and the inion [23].

But to save time, approximation techniques are frequently used in clinical practice, skipping the use of percentages and possibly ignoring individual differences in head morphology.

The main objective of this study is to compare the results obtained using the SI 10:20 system and the approximate method in visual and somatosensory evoked potentials. The goal is to assess differences in electrode placement, focusing on key variables such as latency and amplitude. Furthermore, the goal is to investigate whether these variations affect the findings of neurophysiological reports, which could aid in comprehension of possible medical implications.

1.1 Evoked Potentials

The term evoked potentials (EPs) refer to those electrical responses of the nervous system that are generated by internal or external stimuli. To record evoked potentials for diagnostic purposes, it is recommended to follow these considerations [5]:

- Generate a controlled and brief sensory stimulus.
- Record the electrical responses in the appropriate parts of the nervous system.
- Remove interferences that may hinder the interpretation of the response.

In clinical practice, evoked potentials are considered useful as they provide certain data that could detect abnormalities in sensory system conduction, reveal subclinical involvement of a sensory system, define the anatomical distribution, provide information about the pathophysiology of a pathological process, and monitor changes in the patient’s neurological status [6].

In the clinical neurophysiology service, various types of evoked potential studies are conducted, but for our study, we have decided to focus on investigating Visual Evoked Potentials (VEPs) and Somatosensory Evoked Potentials (SEPs).

1.1.1 Visual Evoked Potentials

In the fields of neurology and ophthalmology, Visual Evoked Potentials (VEPs) are excellent tools for diagnosing and monitoring diseases that affect the visual pathways. These potentials provide valuable information on the electrical activity that occurs in the visual system from the optic nerve to the calcarine cortex, evaluating visual function non-invasively, regardless of the patient’s attention or awareness [7].

The pattern-VEP (PVEP), which uses structured visual stimuli such as pattern reversal or onset-offset patterns, is the most employed type of VEP in neurophysiological studies. VEP responses are influenced by the spatial frequency and contrast of these stimuli.

When abnormalities are found in VEP studies, they could indicate a variety of conditions, from lesions in the cornea, lens, or optical media to disorders affecting the optic nerve and chiasm. In cases diagnosed with multiple sclerosis (MS), VEPs generally show delays in latencies. Another condition that can also be detected through VEPs, even before clinical signs are fully evident, is optic neuritis, which is often a common early symptom of multiple sclerosis. Optic neuritis is usually detected by the presence of prolonged latencies while preserving the overall configuration of the response [5], [7].

When a decrease in amplitude and an alteration in the configuration of VEPs, with or without latency prolongation, are detected in tests, it could indicate compressive, destructive, or degenerative lesions that interrupt axons [5], [7].

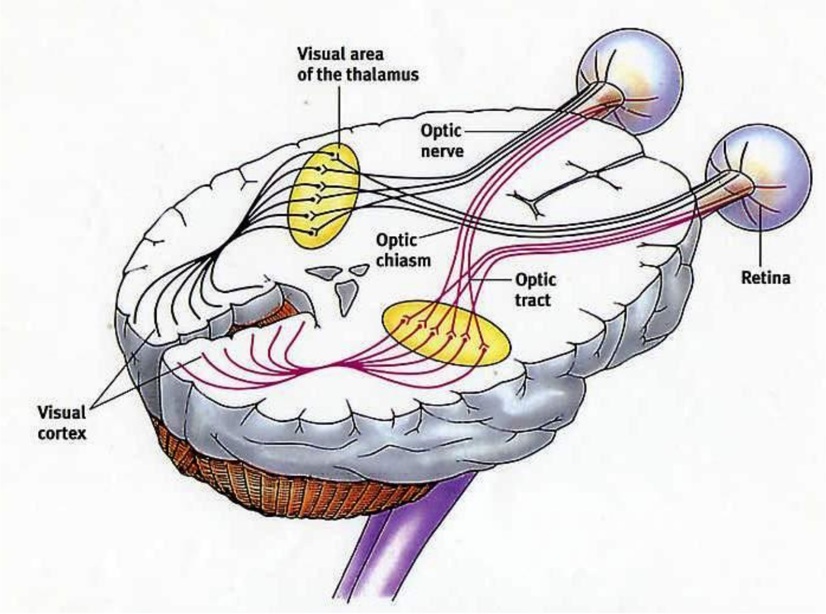

Figure 2: Visual Pathways: From Retina to Visual Cortex in VEPs Studies.

1.1.1.1 Techniques for recording Visual Evoked Potentials:

Regarding the method used to record VEPs, nowadays the standard clinical test involves the use of a high-contrast black and white checkerboard pattern displayed on a screen.

This checkerboard is periodically reversed while the subject undergoing the test must keep his gaze fixed on a point represented in red, thus stimulating the retina[6].

Typically, a period ranging from 200 to 500 ms after the onset of each visual stimulus is examined. However, when evaluating young infants, this analysis period should be extended to 300 ms or more, because the components of Visual Evoked Potentials may have longer peak latencies during early maturation of the visual nerve system. On the other hand, most children and adults can be assessed with an analysis period of 250 ms or less. Regarding amplifiers, the most common frequency pass limits are between 1 Hz and 100 Hz. Additionally, amplifier sensitivity varies, typically being +/- 10 μV for older children and adults, and +/- 20 to 50 μV for babies and younger children (Creel, 2019).

During the visual evoked potentials (VEP) procedure, the scalp is marked to determine the positions where recording electrodes will be placed. In a simple and practical set, three electrodes are used: active electrode, reference electrode, and ground electrode. The active electrode is placed near the primary visual cortex area, specifically in Brodmann area 17, at the location Oz according to the SI 10:20. The reference electrode is placed at Fpz, and the ground electrode can be positioned at the vertex (Cz or Fz).

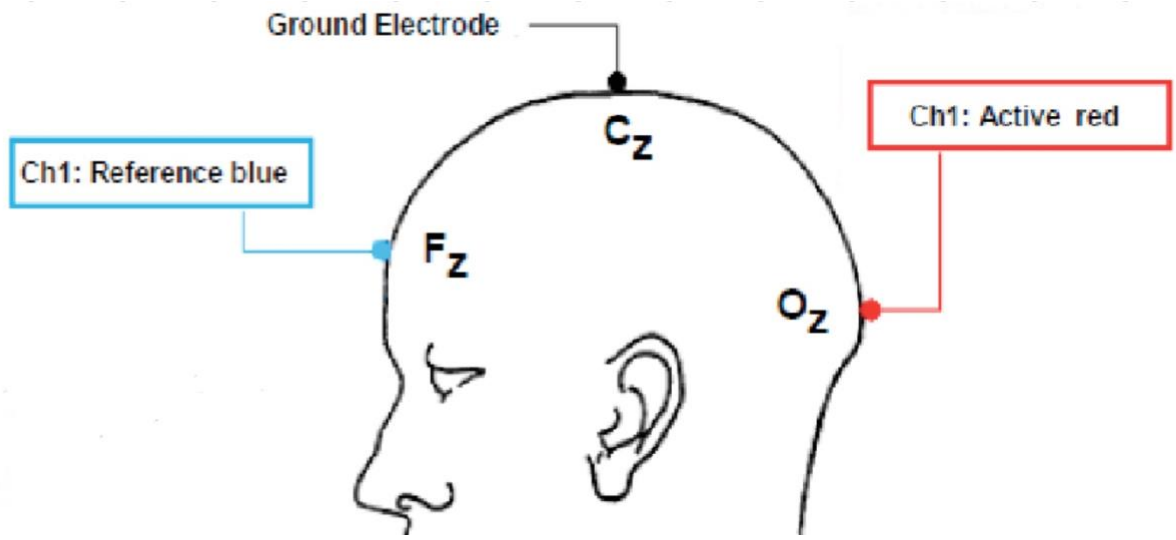

Figure 3: Electrode placement for Visual Evoked Potentials (VEPs).

1.1.1.2 Factors affecting Visual Evoked Potentials

Visual Evoked Potentials can be affected by a variety of factors, including:

1.1.1.2.1 Gender

In a study conducted in 2015, it was observed that the brain's electrical responses, represented by the N70, P100 and N145 waves, took longer in males than in females, and this difference was notably significant from a statistical perspective. It was also found that the maximum intensity of the P100 wave was higher in females in both eyes compared to males.

This difference in intensity was statistically highly significant for both the left and right eyes [9].

1.1.1.2.2 VEP recording under anaesthesia

When patients present certain conditions that could affect VEP results, examinations under anaesthesia are performed. These conditions could include the patient's age, inability to cooperate, or discomfort during standard examination procedures. The effect of anaesthesia on VEPs varies depending on its type and depth; traditional surgical anaesthetics frequently supress the cerebral activity required for VEP generation [8].

1.1.1.2.3 Age

Age is another factor that can change VEPs electrical responses. According to a 2020 study, aging affects initial visual processing capacity since the first negative component (N75) decreases with age. However, it was also shown that the P100 wave increases with aging, indicating increased neural activity in the visual processing-related posterior visual areas.

1.1.1.2.4 Level of alertness and attention

The patient’s level of alertness and focus during the examinations may also have an impact on the VEPs results. It has been shown that during the tests, patients who are more focused tend to provide more consistent and reliably responses. On the other hand, patients who show passivity and distraction throughout the examination produce neural responses that are less accurate and consistent. So, patients should work cooperatively and behave well during these tests, as this may have an impact on the interpretation of the findings as well as the identification of brain signals associated with visual stimuli.

1.1.2 Somatosensory Evoked Potentials

The Somatosensory Evoked Potentials (SEPs) are another test we sought to investigate in this study. The neurological system produces this type of evoked potential in reaction to inputs from sensory receptors that pick up on pressure, vibration, touch, and other physiological sensations [10]. Because of their utility in medical research and their capacity to identify anomalies in the somatosensory pathway, SEPs are useful instruments for the evaluation of the peripheral and central nervous systems [11].

Signals from electrical stimulation of peripheral nerves are sent to the brain via nerve pathways. To assess neuronal conduction velocity, the integrity of sensory pathways, and the performance of different peripheral system segments, these signals are collected and subsequently analysed.

Somatosensory Evoked Potentials can be classified based on the anatomical location of stimulation and recording. In this case, we can divide them into two categories: Upper and Lower Somatosensory Evoked Potentials [10].

Upper Somatosensory Evoked Potentials are generated from the stimulation of peripheral nerves in the upper limbs, such as the median and ulnar nerves in the wrists. We can assess the integrity and functionality of the sensory pathways that transmit sensations from the arms and hands to the brain by measuring the activity in the cerebral cortex or scalp that results from this stimulation. It is important to note that Upper SEPs can be utilized to identify cervical spinal cord injuries and peripheral neuropathies [10].

Lower Somatosensory Evoked Potentials are elicited through the stimulation of peripheral nerves in the lower limbs, such as the tibial nerve in the ankles or the peroneal nerve in the popliteal fossa. The resulting activity is recorded in the scalp of spinal cord, providing insights into the function of sensory pathways transmitting sensations from the legs and feet to the brain. Lower Somatosensory Evoked Potentials are used in diagnostic disorders affecting these nerve pathways such as peripheral neuropathies and injuries to the lumbar spinal cord [10].

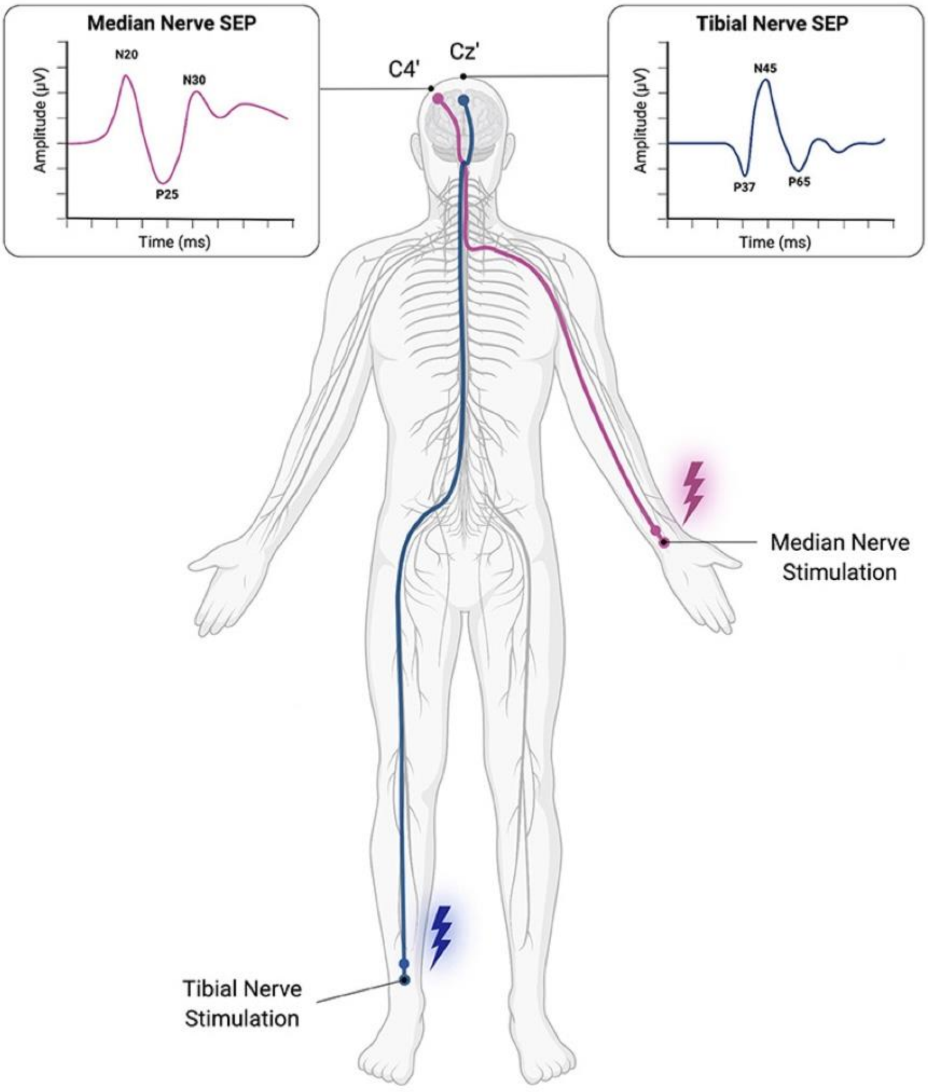

Figure 4: Median and Tibial Nerve Stimulation in Somatosensory Evoked Potentials [24] *.*

1.1.2.1 Techniques for recording Somatosensory Evoked Potentials:

In the recording of somatosensory evoked potentials, either surface electrodes or subdermal needles can be used. In our case, subdermal needles are used for these tests. It is important to note that one of the requirements for these electrodes is that the impedance must be below 5000Ω. This impedance must be adhered in order to prevent degradation of the amplifier’s ability to average low-amplitude signals.

Most hospitals use a system passband width of approximately 30 to 3000Hz, although there may be minor variations. Widening the passband width may be beneficial for recording prolonged signals but can introduce additional low-frequency noise, requiring averaging of a greater number of responses and extending the recording time. It is essential for patient tests to be conducted with the same system passband width used to acquire normative data to avoid distortions in the morphology and peak latency of SEPs. At least four channels are required to record SEPs [11].

The applied stimulus needs to be strong enough to generate a small muscle contraction, induced by transcutaneous bipolar electrical stimulation applied to the skin over the selected nerve. Constant monophasic square electrical pulses of 0.2 ms (0.1-0.3 ms) are frequently used, with stimulation frequencies of 2.5 Hz for upper limbs and 1-2 Hz for lower limbs[11].

The intensity typically ranges between 20 and 30 mA for constant current or between 80 and 120 V for constant voltage stimulation. While latencies change little with varying stimulus intensity, a study showed a slight shortening of peak latency for short-latency SEPs components with increased stimulus intensity. On the other hand, an increase in stimulus intensity will not enhance SEP amplitudes but will be uncomfortable for the patient [10], [11].

1.1.2.2 Factors affecting somatosensory evoked potentials

The factors that could affect the latency, amplitude, and morphology of somatosensory evoked potentials are the age, body size, body temperature and the patient's level of alertness. Below, we will explain in more detail how these factors can affect SEPs.

1.1.2.2.1 Age

Latency depends on peripheral-central conduction velocities and arm heights or length.

Peripheral and spinal conduction velocities reach adult level by 3 and 5 years of age, but after this age latency changes depend on arm height or length. Generally, latency remains stable from late teens to age 50 with a slight increase (0.3 ms) after age 50[10], [12].

In infants and young children, latency changes result from the combined effects of the maturation of peripheral and central somatosensory neural pathways and the increase in these pathways alongside body growth. Peripheral nerve conduction velocity is approximately half the adult value in the new-born and creases rapidly during the first year of life, reaching the adult value at 3 or 4 years old. With the combined effects of maturation and body size increase, latencies and cervical response remain relatively unchanged from birth to age 2 or 3, then increase to the adult level between 14 and 19 years old [10].

1.1.2.2.2 Body size

Once myelination is complete and the sensory pathway's conduction speed is established around 3 or 4 years of age, the absolute latency values show a direct relationship with arm length or height. When interpreting absolute latencies, it is vital to match them with arm length for upper limb studies and height for lower limb studies. However, if interpeak latencies are utilized, the impact of body size differences becomes negligible in adults and can be disregarded [10].

1.1.2.2.3 Body Temperature

Temperature is also a factor that can affect the interpretation of somatosensory evoked potentials. This can be observed with a significant decrease in peripheral nerve conduction velocity when limb temperature is reduced, while on the other hand, an increase in temperature does not affect latencies as much [10]. "*However, central conduction velocity is affected only if hypothermia is profound" (*Jonathan L. Carter and Clarke Stevens, n.d.).

1.1.2.2.4 Alertness level (Sleep)

The medium and long latency recorded electrical potentials are influenced by sleep, which causes a delay in their onset time and a decrease in their strength. The total elimination of long latency potentials is another phenomenon that occurs during sleep. Furthermore, it has been noted that when a person is in a deep sleep, the N20 wave's reaction time may be somewhat delayed. But in the early phases of sleep, this alteration is negligible, and it usually has no bearing on standard clinical examinations.

Additionally, during wakefulness, several rapid electrical peaks can be observed in the N20 waveform. These peaks disappear during certain sleep stages and reappear during REM sleep [10].

1.1.2.2.5 Sedative medications and muscle artifact

Muscle artifact is addressed by ensuring that the patient is relaxed, typically in a reclined position during the performance of the test. Evoked responses with high amplitude recorded at the elbow, Erb's point, or knee is usually unaffected by muscle activity. However, recording over the lumbar or cervical spine can be challenging due to motor unit activity in the paraspinal muscles and the distance from the signal sources. Muscle artifact in scalp leads is generally not a major concern. Sedating tense or spastic patients, often with diazepam, can be beneficial unless it is not recommended [12].

1.1.2.2.6 Electric artifact

Stimulus artefacts and 50 Hz alternating current are the main sources of electrical artefacts in somatosensory evoked potentials. To avoid these stimulus artefacts, a stimulus-isolation device, a fast-recovery amplifier, proper electrode orientation and contact, and non-excessive stimulus intensities are used.

Maintaining recording electrode impedance below 5000Ω through skin cleaning and proper grounding helps eliminate most 50-Hz noise. However, using different electrode types, like surface and subdermal needle electrodes, at recording and reference sites can create impedance mismatches, amplifying 50-Hz interference [12].

1.1.2.2.7 Filter settings

The best filter settings in SEPs aim to reduce noise while maintaining the waves of interest. Usually, a low-frequency filter setting of 30 Hz and a high-frequency setting of 3kHz are found to be effective. In certain situations, limiting low frequencies to 150 Hz can help decrease 50-cycle artifact and improve the visibility of some specific peaks. However, this adjustment might lead to a decrease in the amplitude of most peaks and a slight shortening of peak latencies. It's recommended to avoid using 50 Hz "notch" filter, as it could remove important physiological information present in SEPs within this frequency range [12].

1.1.3 Nomenclature

Evoked Potentials responses are named based on two main factors: the direction of the peak deflection (positive or negative) and the timing of the peak response. Conventionally, when the electrical signal goes up, it is labelled as negative (N), and when it goes down, it is labelled as positive (P).

The number following N or P indicates the average time it takes for the peak to appear after the stimulus, as observed in normal subject.

It is worth noting that there is not a strict standardization in naming these peaks. Different researchers and studies might use slightly different numbering systems to identify the same evoked potential. This lack of standardization can sometimes lead to a confusion, so for somatosensory evoked potentials peaks I will rely on article [12] and for visual evoked potentials peaks I will use articles [6], [13] to provide a detailed explanation of each peak.

1.1.3.1 Peaks of Visual Evoked Potentials

The responses generated by evoked potentials typically exhibit characteristic peaks that are studied (their latency, amplitude, and morphology) to determine whether the visual pathways are affected. The most important peaks in VEPs are:

- N75: The N75 component is a negative neural response that happens about 75 milliseconds after the start of visual stimulus. It originates in the primary visual cortex.
- P100: It is proposed that P100 is produced in the striate cortex or extrastriate visual regions. About 100 milliseconds after the start of visual stimulation, the positive wave achieves its maximum amplitude. It is considered as the most stable and reproducible VEP measurement.
- N145: The extrastriative visual cortex or striate and extrastriate sections are the source of this peak. It is a negative wave that starts to happen about 145 milliseconds after visual stimulus starts.

In the clinical practice, doctors rely more on delays in response time and interocular differences in P100 latency to detect issues in the visual pathway. Additionally, these warning signs can be identified even if there are no visible problems during a routine eye examination.

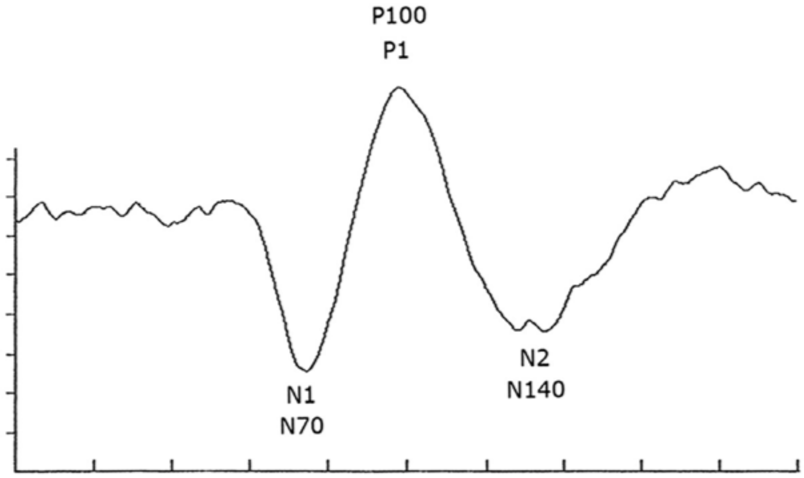

Figure 5: Normal VEP. N70 corresponds to N75 and N140 to N145 [5].

1.1.3.2 Peaks of Upper Somatosensory Evoked Potentials

For upper somatosensory evoked potentials, the median or ulnar nerves are stimulated at the wrist, allowing activity to be detected at the elbow, Erb's point, the cervical spine, and the scalp [12]. The most relevant peaks in this type of evoked potentials are peaks P25 and N20, which form the N20/P25 complex.

The N20 potential refers to electrical signals on the scalp that take at least 21.7 ms to appear [4]. These signals are generated by neurons in the primary somatosensory cortex, specifically in the area corresponding to the hand, in response to input from the thalamus. Although there is debate about the exact areas of the cortex that generate these signals, it is unclear whether they come from separate thalamus-cortical projections or sequential activity in a single pathway. It has also been suggested that these signals may be related to the perception of vibration and position, while later signals may be related to the perception of pain and temperature [12].

The N20/P25 complex, recorded with a specific bipolar montage, may represent a combination of independent generators in different areas of the brain or a single generator with electrodes placed at opposite ends of the signal source (Jonathan L. Carter and Clarke Stevens, n.d.).

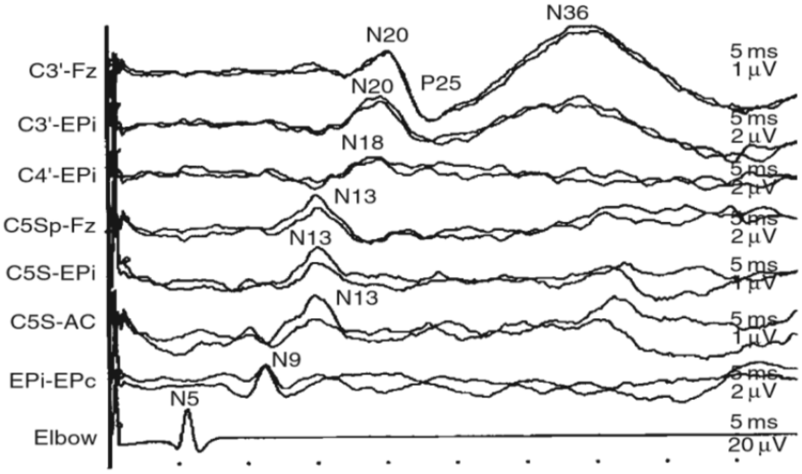

Figure 6: Normal Upper Somatosensory Evoked Potentials [9].

1.1.3.3 Peaks of Lower Somatosensory Evoked Potentials

For lower somatosensory evoked potentials, the tibial nerve at the ankle is stimulated, allowing the electrical signals to travel along the nerve pathways and to be recorded at various points along the nervous system, including the leg, lumbar and cervical spine, and scalp. The most relevant peaks in this type of evoked potentials are peaks N45 and P37. The activity observed in the part of the brain processing foot sensation is associated with a potential called P37 (also known as P38). Typically, this potential reaches its peak somewhere between the midline and the centroparietal scalp locations, contralateral to the stimulated leg [12].

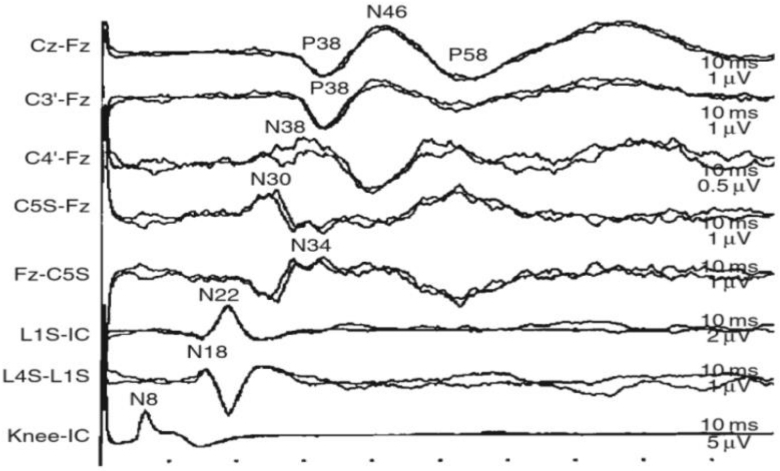

Figure 7: Normal Lower Somatosensory Evoked Potentials [12]

1.1.4 Methods of Electrode Localization

One of the essential elements of visual evoked potential research and therapeutic practice is the accurate placement of electrodes near the targeted cerebral cortex. Precise and correct placement of the electrodes on the scalp allows us to obtain meaningful and reliable data in this type of test.

In clinical practice, it is common to use approximate marking methods for electrode placements, measured with a measuring tape, during evoked potential testing to optimize both time and effectiveness. While the international 10:20 system is the standard for determining the exact positions of electrodes on the scalp, based on percentages that relate these positions to specific areas of the cerebral cortex, more rapid and simplified approximations are often employed.

In this study, we have used two methods of electrode placement: the system based on approximations calculated with a measuring tape and a device designed at Universitat Rovira i Virgili. This device, called EPlacement, is based on the internation 10:20 system of electrode placement. Below, we will explain both methods in more detail.

1.1.4.1 Approximate methods for electrode placement in evoked potentials for this study

For the Visual Evoked Potentials (VEP), instead of placing the active electrode precisely at the Oz position, as per the 10:20 system, it is approximately placed 5 cm vertically above the inion. The inion is a visible anatomical landmark on the back of the skull, which serves as a reference to approximate the location near the primary visual cortex. This approximate method facilitates quick localization and placement of the electrode without the need for precise measurements, still allowing for representative results of visual activity.

- Active electrode: 5 cm above the inion
- Reference electrode: Fpz
- Ground electrode Cz

In the case of Upper Somatosensory Evoked Potentials (SEPs), the active electrode is generally placed at Cz, a midpoint on the scalp's medial line. From this reference point, an approximation is made by placing the active electrode 5 cm backward and 7 cm laterally, resulting in the positions CP3 for the left side and CP4 for the right. These positions are associated with the cortical areas that register somatosensory sensitivity of the upper extremities.

- Active electrode: 5 cm back and 7 cm lateral from Cz
- Reference electrode: Fpz
- Ground electrode: Cz

For Lower Somatosensory Evoked Potentials (SEPs), rather than using CPz as the exact mark, a 2 cm backward approximation from Cz is made. The resultant point, termed Cz', is used to assess the somatosensory sensitivity of the lower extremities.

- Active electrode: 2 cm posterior to Cz
- Reference electrode: Fpz
- Ground electrode: Cz

These approximate methods not only speed up the electrode placement process but also maintain adequate precision for most clinical studies. However, it is crucial to recognize that techniques may vary between different institutions and according to specific protocols. Therefore, adherence to guidelines and standards provided by specialists in clinical neurophysiology and neurology is recommended to ensure correct electrode placement and reliable results.

1.1.4.2 EPlacement

EPlacement device cleverly utilizes the standard landmarks (nasion, inion, LPA and RPA) to automate and refine the electrode placement process. With its advanced technology, the device employs a specialized band equipped with a soft linear membrane potentiometer. This sensor is capable of detecting and measuring the pressure applied by medical staff at critical points designated by the 10:20 system (nasion, inion, and tragus). When the band is correctly positioned and sufficient pressure is applied, the device automatically performs the necessary calculations based on the 10-20 system's guidelines without the need for manual measurements by the clinician.

The EPlacement device’s components include the electronic unit’s display, the microcontroller, the battery, the pressure sensor, and the high-density LED lighting system. The professional healthcare can use this electronic device’s navigation menu to choose the tests they want to run. The instrument is designed to perform conventional intraoperative neuromuscular spinal monitoring as well as studies of somatosensory and visual evoked potentials. The tool also offers detailed instructions on the points required for every exam. The pressure sensor and the lighting system are connected by a band that is easily adjustable to fit the contour of the head [14].

To begin with, the medical staff places a special band around the patient’s head. This band has important points marked on it, which the medical staff locates following the 10:20 system. Once they find these points, they don’t’ need to make complicated calculations. Instead, they simply press the band onto those points (nasion, inion, tragus), and a special sensor inside the band automatically detects how much pressure they are applying. If this pressure is maintained for at least 3 seconds, the system, automatically takes the necessary measurements. This is possible thanks to a special sensor in the band called a soft linear membrane potentiometer, which, when pressed, changes its resistance in a predictable way, allowing the system to accurately calculate where the pressure is on the band. The, the system directly measures the length of the patient’s head and performs some internal calculations to determine exactly which point on the patient’s scalp should be marked. This is indicated by a small LED on the band that lights up [14].

What it is most interesting of this system is that the touch sensor is designed to adapt the different head sizes, which means it can work for most people, regardless of their head size.

The EPlacement device has two versions: the first is a single strip (1S-EP), and the second consists of two strips that can move relative to each other (2S-EP). The menu on the device adjusts the procedure based on which version is being used.

Determining the electrode positions in relation to the midline of the head is usually the first step in marking electrode positions. The tragus reference points are covered by one strip in the two-strip configuration (2S-EP), while the Inion and Nasion reference points are covered by the other. The midpoint where the strips should join is illuminated and distances are calculated by a microprocessor. The intended test can start after it is properly positioned.

Compared to the two-strip form, a step more is required to establish the midline in the single strip arrangement (1S-EP). Measuring the distance between the LPA (left preauricular) and RPA (right preauricular) points is the first step in professional treatment. The device indicates a place along the midline that needs to be marked after this measurement is made. Next, by pushing through both the Nasion and the previously designated point, the user calculates the Ns-In (Nasion-Inion) distance. After that, the apparatus shows the precise Cz position, and the midline is established using the Ns-In and Cz point. [14].

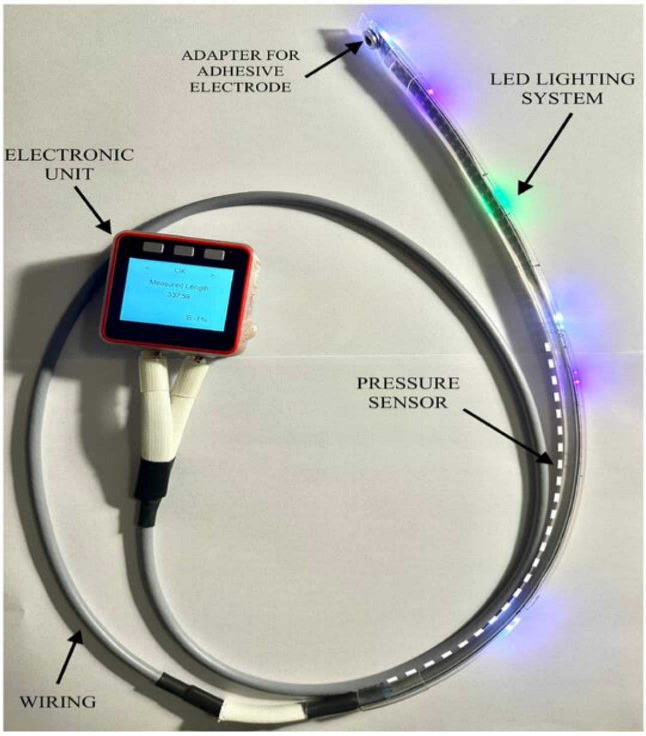

Figure 8: EPlacement Device and its component [14]

2 Methodology

2.1 Clinical research plan

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A cross-sectional study was conducted with the participation of patients referred to the Clinical Neurophysiology Service at Hospital Universitari Sant Joan de Reus. The goal was to determine if there are clinically significant differences in Visual Evoked Potentials (VEP), Lower Extremity Somatosensory Evoked Potentials (SEPs), and Upper Extremity Somatosensory Evoked Potentials (SEPs) depending on whether the international 10:20 system (EPlacement) or approximation methods are used. For this purpose, the test was performed on two occasions, changing only the active electrode between the approximation method and the rigorous 10:20 method.

This study was conducted on patients who voluntarily agreed to participate in the project and were referred to the clinical neurophysiology service at the "Hospital Universitari San Joan de Reus". In all cases patients came to obtain a diagnosis, meaning to identify potential issues in the related nerve pathways. Paediatric patients, those with scalp conditions, and those receiving anticoagulant treatment were excluded from the study. Patients who do not produce a detectable signal response following visual stimulation have been also excluded. The absence of a response in VEPs can be attributed to various factors, including technical issues during recording, improper electrode placement, or clinical conditions that hinder the generation of an adequate response. In the case of Visual Evoked Potentials, 59 cases were analysed, of which only three were excluded due to the absence of a response.

Visual Evoked Potentials and Somatosensory Evoked Potentials studies were conducted according to each patient's clinical need. In both types of studies, the procedure began with the marking and initial placement of electrodes using the approximate method by the clinical professional. Subsequently, the EPlacement device was used for more precise placement, following the International 10:20 system. First, the position of the active electrode will be determined using the approximate technique. Then, the 10:20 system technique will be applied to ensure it does not influence the initial marking.

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Participation in the study involved repositioning the active electrode on the patient to record the evoked potential again. This procedure is common in clinical practice when there are uncertainties in the interpretation of the evoked potential and a more precise localization is sought. No risks associated with participation in the study were identified, and it only extended the duration of the study by approximately 5 to 7 minutes. Additionally, conducting a re-test could indirectly benefit the patient by facilitating the interpretation of the evoked potential by the clinical neurophysiologist.

It is crucial to make sure that the impedance of each electrode in all three types of evoked potentials (VEP, upper SSEP, and lower SSEP) is less than 5 kΩ, with a variation between them of less than 2 kΩ. Subdermal electrodes will be used to accomplish this.

This comparison between the two methods is particularly insightful, as it can clearly demonstrate the potential errors that could arise when using the conventional method, which does not consider individual characteristics such a cranial perimeter and other patient-specific features.

With the approximate method, errors in percentage calculations are often encountered, especially when healthcare staff are under stressful conditions. These errors may stem from mental fatigue or distractions, resulting in inaccuracies in marking cranial points [14].

On the other hand, since both hands are occupied handling the measuring tape, the required calculations must be done mentally, and if the electrodes are not placed properly in relation to the cranial perimeter or reference planes, associated errors increase. This arises due to the interdependence of positions, which can increase the likelihood of inaccuracies [14].

2.2 Visual Evoked Potentials

In this type of test, the first step involves carrying out the marking, where each point on the skull is highlighted with a marker pen. This allows healthcare staff to place the electrodes more precisely and easily. It is essential to carry out this process accurately to avoid obtaining incorrect results, this ensuring that the neurophysiological technique is applied optimally.

During the marking procedure, the points where the electrodes should go are first located using the approximate method (using the red marker). Once identified, the EPlacement device is used (using the blue marker), the use of which we have previously explained.

In this type of Visual Evoked Potentials test, three electrodes are required: active electrode (Oz), reference electrode (Fpz), and ground electrode (Cz). For more information see Figure 3.

The reference and ground electrodes are placed following the international 10:20 system strictly. Therefore, the only point that varies depending on the method used is where the active electrode is placed. Using the international 10:20 system, this corresponds to the Oz point; using the approximate method, it corresponds to the point located 5 cm above the Inion (these points are clearly represented in Figure 1).

- Active electrode: Oz (or 5 cm above the inion)
- Reference electrode: Fpz
- Ground electrode: Cz

After this marking phase is over, the medical practitioner can begin the test to collect data. The doctor will then examine the data to determine whether the patient's visual pathways are damaged throughout the test.

To record electrical responses through electrodes, a visual pattern is presented to the patient using a monitor alternating high-contrast checkerboard-like patterns of black and white squares, like a chessboard. The dimensions of the squares are specified taking into account the patient's visual angle and the stimulus' distance from them, which is usually approximately one metre, in order to ensure accurate stimulus presentation. A fixation point is used to keep the patient's gaze steady during stimulation, and the refractive defects should be corrected with corrective lenses because poor focusing can alter response latency and amplitude. [4].

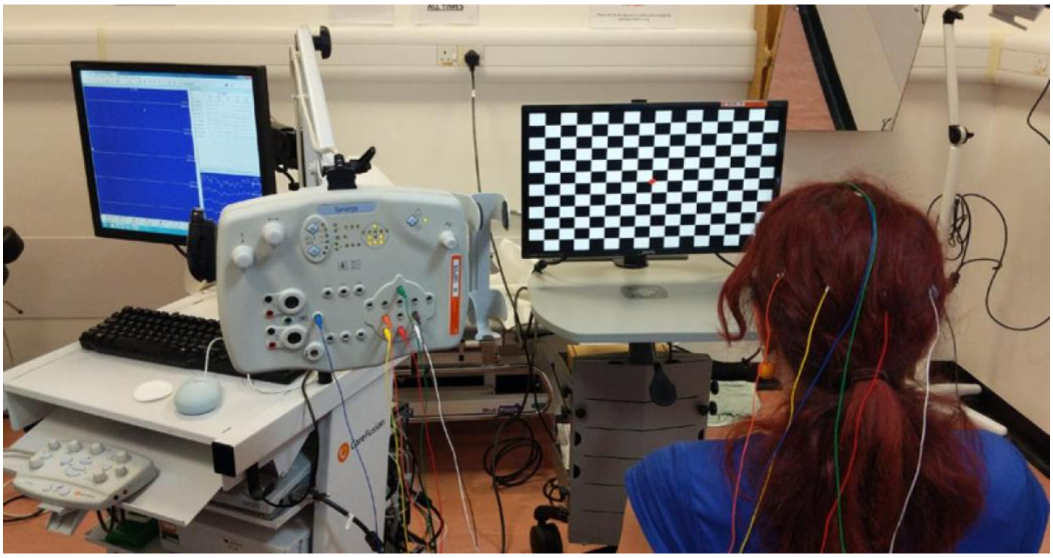

Figure 9: Recording of the Visual Evoked Potentials through electrodes with a visual pattern presented to the patient [25].

Three wave patterns are identified in standard electrical recordings; these are referred to as N75, P100, and N145. These forms can change based on a variety of parameters, including the type of stimulus presented, awake state, and electrode placement. The medical healthcare evaluates the appearance, absence or aberrant morphology of these forms, including their latency and amplitude. The measurements for every form are expressed in milliseconds and microvolts. [4].

Numerous factors may impact an individual's reaction to VEPs, which in turn may impact how the results are interpreted. These include the pupil's diameter, refractive errors linked to myopia or hyperopia, the stimulus type, the age and sex of the subject, the electrode placement, and anatomical variances. Therefore, it is important to take them into account to draw more precise conclusions [15].

2.2.1 Data collection and analysis

In this study, various aspects of evoked potential waves were examined to compare the two methods. Variables such as latency, amplitude, and waveform asymmetry at various points of interest were evaluated. By comparing the results of both methods, a more detailed understanding of sensory function in each case can be obtained, aiding in the identification of potential differences or benefits between the two approaches.

To conduct this comparison, measurements of cranial perimeter, the distance between the nasion and inion, and between both preauricular points were collected. Additionally, the distance between the active electrode point established by the 10:20 system and the point determined by the approximate method was also collected. This measurement included both vertical and horizontal axes, and differences exceeding 1 cm on either axis were considered significant.

Once the marking and measurements are done, the healthcare professional starts the test and collects the data, which will later be analysed to define the condition of the visual pathways of the patient's eyes.

To process the VEP records, a Python code was developed. This code handles the data using the Pandas library and generates graphical visualisations using Matplotlib.

First, a DataFrame was built, with columns denoting the many variables related to the VEP. The experimental data was then read from *.csv* files that corresponded to EPlacement and approximative methods. After that, the relevant values were extracted and added to the DataFrame.

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Finally, the results were visualised by creating graphs using Matplotlib. These graphs depict the responses to visual stimuli. Additionally, the N75, P100, and N145 inflection point were identified and recorded in the waves of both electrode placement methods and for both eyes. This information was subsequently used to compare and analyse the responses obtained for both methods.

The following plot (Figure 13) is an example of the electrical response obtained from the DataFrame that we have created. The values obtained using the approximate method are represented in yellow, while the data obtained with the EPlacement device are represented in blue. Additionally, the P100, N75, and N145 waves have been labelled with different markers to distinguish them.

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The data gathered from the VEP testing was easier to organise, process and, visualise thanks to this Python generated code. Additionally, it was used to compare the various electrode placement techniques.

In this phase, all the information collected from the study's participating patients, as well as the parameters derived from the analysis of VEP data, was consolidated into a *.csv* file.

This file includes demographic data of the patients such as age as well as the parameters extracted from the VEP, such as the amplitudes and latencies of the N75, P100, and N145 waves.

The purpose of creating this file is to provide an easily accessible and manageable tool for conducting subsequent statistical analysis, identifying trends, and facilitating the interpretation of results.

Analysing the answers' amplitude and latency is the next step. According to [16], amplitude is the magnitude of the recorded electrical response, whereas latency is the amount of time that passes after the stimulation until a neuron responds. Understanding the efficiency and speed of visual signal transmission depends on these two factors. The analysis concentrates on particular waves, such as the negative N75 phase (beginning of visual processing), the positive P100 phase, which represents the maximal response to the stimulus, and the negative N145 phase, which represents the beginning of visual processing.

Another parameter analysed in this study is latency difference. This parameter refers to variations in the responses recorded between the eyes. Measuring these differences is important for evaluating the symmetry and functional integrity of the visual systems of both eyes. Significant variations between eye responses may indicate possible asymmetries in visual function or specific problems in one eye. This assessment contributes to the understanding of overall visual function and may be helpful in diagnosing and addressing potential ophthalmological or neurological problems that unevenly affect both eyes. Latency difference has been calculated for each patient, using both the approximate and SI 10:20 system electrode placement methods. This difference is obtained by subtracting the latency time of the P100 wave recorded in the left eye from the latency time recorded in the right eye.

As we have discussed earlier, the latency difference can help us detect anomalies in the visual pathways of patients; therefore, it can provide very relevant information. That is why it is important for the calculation to be precise, and for it to be so, the exact placement of the electrodes plays a crucial role.

Understanding the latency difference is crucial for healthcare professionals when assessing the integrity of visual pathways. In our study, we employed two threshold values: 5 and 7. If the latency difference exceeds 5, it triggers an alert indicating a potential issue in the patient's visual pathways. However, in some hospitals, a threshold of 7 is more commonly used.

Taking these thresholds into account, we compare the value of the latency difference obtained with the P100 latencies of the responses generated both with the approximate electrode placement method and those generated with the EPlacement device. This allows us to evaluate the effectiveness and accuracy of both methods in detecting possible anomalies in patient's visual pathways.

To categorise patients according to the magnitude of the interocular difference, we have developed two scatter plots, one using the 5 ms threshold and the other using the 7 ms threshold. These scatter plots allow us to divide patients into three distinct groups:

- Pathological Group: This group includes patients whose latency difference in both methods (approximate and EPlacement) exceeds 5 ms or 7 ms, indicating potential anomalies in the integrity of visual pathways.
- Diagnostic Change Group: In this category, we find patients whose latency difference exceeds 5 ms or 7 ms in only one of the methods (either approximate or EPlacement). This finding suggests the need for a review and possible adjustment in the previously established diagnosis.
- Non-Pathological Group: This group comprises patients whose latency difference in neither of the methods exceeds 5 ms or 7 ms, suggesting visual function without detectable anomalies.

The most relevant category among these three, and the one we are most interested in for this study, is the "Diagnostic Change Group". This category indicates the percentage of cases, out of all those we have, that exceed the threshold of interocular difference with one method but not with the other. This is particularly interesting because it reveals that the interpretation of the interocular difference in a patient can vary depending on the electrode placement method used in the Visual Evoked Potentials study. In other words, one method may suggest a possible impairment of the visual pathway, while the other may indicate the opposite.

In addition to this classification, we have also categorized patients into different groups based on the possible pathologies they may be experiencing, considering the results of Visual Evoked Potentials. This allows us to have a more comprehensive and specific understanding of patient's health conditions. The content of this section has been removed due to the inclusion of confidential information.

2.3 Somatosensory Evoked Potentials

To conduct the study of somatosensory evoked potentials (SEP), the same steps as in visual evoked potentials are followed, adapting the placement of the electrodes for this type of study.

Firstly, the marking is carried out following the international 10:20 system. In the case of upper somatosensory evoked potentials, in the parietal channel the active electrode is placed at points CP3 and CP4, which are located near the parieto-occipital area.

After completing this initial marking, the points are marked following the rules of the approximate method. This method establishes that the active electrode should be placed 5 cm posterior and 7 cm lateral to the Cz point, which is the central point of the scalp according to the 10:20 system. This placement is called C3' on the left and C4' on the right.

In addition to the active electrode, a reference electrode is placed at Fpz, following the international 10:20 system. Fpz is a position in the frontal area, just above the nasal bridge. Finally, a ground electrode is placed at Cz, the central point of the scalp.

In upper somatosensory evoked potentials, in addition to the parietal channel, the peripheral channel, the cervical channel, and the frontal channel are also used.

In the peripheral channel (Erb's point), the electrodes are placed at the angle formed by the posterior border of the clavicular head of the sternocleidomastoid muscle and the clavicle, approximately 2-3 cm above the clavicle. The recording electrode is placed on the same side as the stimulation (ipsilateral) and the reference electrode can be the contralateral EP electrode (EPc) or an electrode placed on the scalp (Fz) [17].

In the cervical channel, the active electrode is placed on the spinous process of the sixth (Cv6) or seventh (Cv7) cervical vertebra, and the reference electrode is positioned on the front of the neck, aligned with the glottis [17].

In the frontal channel, the active electrode is placed at the Fz point according to the international 10:20 system and the reference electrode is generally placed on the earlobe on the same side as the stimulation [17].

In summary, the peripheral channel records activity in the brachial plexus, the cervical channel captures activity in the spinal cord, the parietal channel records activity in the contralateral somatosensory cortex, and finally, the frontal channel helps to identify frontal components and differentiate between cortical and subcortical activity [17].

For the study of lower somatosensory evoked potentials (SEPs), four channels are also used to record the electrical responses. In the cortical channel, three electrodes are used: the active electrode, the reference electrode, and the ground electrode.

As with other studies mentioned previously, what differentiates the two methods of electrode positioning is the location of the active electrode. Following the international 10:20 system, the active electrode is placed at the CPz point. According to the approximate method, it is placed 2 cm posterior to Cz and is referred to as Cz'. This electrode will record the somatosensory activity evoked in response to the stimulation.

The reference electrode and the ground electrode, in both positioning methods, are placed according to the rules of the international 10:20 system. The reference electrode is placed at Fpz, which is located on the midline of the scalp, just above the forehead, and the ground electrode is placed at Cz, which is the central point of the scalp.

In the peripheral channel, the recording electrode is placed in the popliteal fossa (back of the knee) and the reference electrode is placed on the medial surfaced of the knee (inner part of the knee) [17].

In the lumbar channel, the recording electrode is placed over the spinous processes of a lumbar vertebra, usually the first lumbar vertebra (L1), and the reference electrode is placed on the spinous process of the third lumbar vertebra (L3) [17].

Finally, in the supraspinal-subcortical channel, the recording electrode is placed on the scalps at the Fz position, according to the international 10:20 system, and the reference electrode is positioned on the back of the neck over the sixth cervical vertebra (Cv6) [17].

2.3.1 Data collection and analysis

In this study, procedures like those applied in the analysis of visual evoked potentials were used to collect and analyse the lower and upper somatosensory evoked potentials.

The comparison of both electrode placement methods focused on evaluating the latency, amplitude, and morphology of the waveform responses to the stimuli used for each type of somatosensory evoked potentials.

To perform this comparison, cranial perimeter measurements, the distance between the nasion and inion, and the distance between both preauricular points were also taken. Additionally, the distance between the electrode point defined by the 10:20 system and the point established by the approximate method on the vertical and horizontal axis was determined, considering differences greater than 1 cm on any axis as significant.

After making the marks and measurements, the healthcare professional conducted the tests and collected the data, which were then analysed to assess the condition of the patient's somatosensory pathways.

The processing of the Somatosensory Evoked Potentials data was carried out using Python code that employs the Pandas and Matplotlib libraries to handle the data and create graphical visualisations, as was done with the visual evoked potentials.

First, a DataFrame was created with columns representing the various variables associated with the somatosensory evoked potentials. Then, the experimental data were read from .txt files corresponding to the approximate and rigorous methods, extracting and adding the values of interest to the DataFrame.

The results were visualised using graphs created with Matplotlib, which depicted the responses to somatosensory stimuli. The relevant inflection points in the waveforms for both electrode placement methods and for both lower and upper somatosensory evoked potentials were identified and recorded. This information enabled the comparison and analysis of the responses obtained with each method.

The Python code facilitated the organisation, processing, and visualisation of the data obtained from the somatosensory evoked potentials tests, allowing the comparison between the electrode placement methods.

Finally, all the information collected from the study's participating patients, as well as the parameters derived from the analysis of the somatosensory evoked potentials data, were consolidated into a *.csv* file. This file includes demographic data of the patients, such as age, as well as the parameters extracted from the evoked potentials, such as the amplitudes and latencies of the relevant waves.

Once the data is organised in a *.csv* file, the next step is to analyse the latency and amplitude of the responses. For the upper somatosensory evoked potentials, the latencies of interest are those corresponding to the N20 and P25 waves.

In the analysis of Upper Somatosensory Evoked Potentials, the N20 wave represents the first cortical response to stimulation of the median nerve at the wrist, while the P25 wave follows the N20 and is another important indicator of cortical activity. It is important to note that the characteristics of these waves can vary depending on factors such as the patient's age, level of alertness, and the integrity of the central nervous system [17], [18].

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In the case of Lower Somatosensory Evoked Potentials, the latencies of interest are the P37 and N45 waved.

The P37 wave is the first major positive peak observed in the cortical response following the stimulation of peripheral nerves, such as the tibial nerve at the ankle. This wave reflects the initial processing of sensory input in the somatosensory cortex. The N45 wave, which follows the P37, represents a subsequent stage of cortical processing and is critical for assessing the integrity of the somatosensory pathways.

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A crucial parameter in the study of Somatosensory Evoked Potentials is the asymmetry in the latency of the N20 and P37 waves. For upper limb somatosensory evoked potentials, the N20 wave is analysed, while for lower limb somatosensory evoked potentials, the P37 wave is examined. The asymmetry in the latency of the N20 and P37 waves refers to differences in the magnitude of the response between the left and right hemispheres of the brain.

Under normal conditions, a relative symmetry in the latency of the N20 wave between both hemispheres is expected. Significant asymmetries may indicate specific neurological dysfunctions [19], [20].

3 Results and discussion

3.1 Introduction to the results

In this study, Visual Evoked Potentials (VEP) and Somatosensory Evoked Potentials (SEP) were analysed using two electrode placement methods: the approximate system and the International 10:20 system (EPlacement device). The results were evaluated in terms of latency, amplitude, and differences between the methods.

3.2 Results of the Visual Evoked Potentials (VEP)

3.2.1 Latency

The first parameter we studied is the latency of the P100 wave. The main objective was to analyse cases of Diagnostic Change Group, as these cases demonstrate that, depending on the electrode placement method used, different conclusions may be reached. To this end, two scatter plots were generated to classify patients based on the interocular latency difference, using thresholds of 5 ms and 7 ms.

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In conclusion, setting a threshold that is too low can heighten sensitivity to minor discrepancies, leading to an increase in cases categorized as "Diagnostic Change Group". Conversely, a threshold that is too high may overlook significant differences, potentially masking important diagnoses. For this reason, in this study, we have chosen to consider both thresholds to strike a balance that maximizes diagnostic accuracy, mirroring real-world clinical practice.

Additionally, this methodical approach mirrors the complex nature of clinical decision-making, which needs clinicians to carefully evaluate the trade-offs between potential errors in diagnosis. Our use of diverse criteria aims to bolster the reliability of our conclusions and provide a deeper understanding of the diagnostic process. Essentially, this approach underscores the critical importance of being adaptable and pragmatic when applying research findings in clinical practice.

3.2.1.1 Clinical History Follow-up: Diagnostic change Group

In this research, our goal was to follow up the medical background of the patients grouped as "Diagnostic Change Group" by considering both the 5 ms and 7 ms benchmarks. The aim of this subsequent investigation is to establish if additional studies on these cases can reveal which of the two methods used provided a more accurate indication of the extent of nerve pathway impairment in the patients.

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3.2.2 Classification according to pathologies

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3.2.3 Study of the correlation between different parameters

With the data collected on distances, latencies, and amplitude, we conducted a study to analyse the possible correlation between these parameters. The objective was to determine if there is a significant relationship between them. To this end, we used the Pearson correlation coefficient and the coefficient of determination (R^2), which allow us to assess the strength and direction of the relationships between the studied parameters.

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3.3 Results of the somatosensory evoked potentials

As mentioned earlier, we have also studied the lower and upper somatosensory evoked potentials.

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3.3.1 Upper somatosensory evoked potentials

For the upper somatosensory evoked potentials, the most studied component, and the one we have emphasised in this study, is the initial negative wave N20, which is detected approximately 20 ms after stimulation.

To analyse the values obtained from the Upper Somatosensory Evoked Potentials, it is important to consider that the N20 wave must exhibit specific characteristics regarding its latency. Specifically, the latency of this wave should be less than 21.7 ms, and the difference in latency between the left and right sides should be less than 1.1 ms. Cases that do not meet these criteria are considered to potentially exhibit an abnormal response.

For our study, we aimed to categorise patients into three distinct groups as we did in VEPs: "Pathological", "Non-pathological", and "Diagnostic Change Group". The primary criterion for classification was the latency difference between the right and left sides, which should not exceed 1.1 ms. Any latency difference greater than this threshold suggests a possible abnormality in the patient's response.

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3.3.1.1 Clinical History Follow-up

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3.3.1.2 Study of the correlation between different parameters

In the case of somatosensory evoked potentials, a detailed study of the correlation between different parameters recorded in the *.csv* file has also been conducted. This analysis is essential for better understanding the relationship between various variables and how they may influence the results of somatosensory evoked potentials. To study this correlation, the R^2 values and the Pearson correlation coefficient have been calculated. For a good correlation between parameters, the R^2 value and the Pearson correlation coefficient must be greater or equal to 0,7.

For the study of correlations between the parameters of upper somatosensory evoked potentials, in addition to the data we have in our *csv.* file, we have also used data from a fellow student's final degree project. This project is titled "Analysis of Different Heuristic Methods for Cranial Point Localization: Assessing Accuracy Against the International 10/20 System" and the author is Laia Mallol.

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3.3.2 Lower somatosensory evoked potentials

In the case of lower somatosensory evoked potentials, the wave of interest is P37, which represents the main positive component and manifests with a latency of around 37 ms. For the response to be considered within normal limits, the latency should be less than 44 ms, and the latency difference between the left and right sides should be less than 4.1 ms.

In the lower somatosensory evoked potentials, we have also classified patients into three groups: "Pathological", "Non-Pathological", and "Diagnostic Change Group" based on whether the P37 latency difference values between the right and left sides exceed 4.1 ms. Any latency difference lower than this threshold suggests a possible abnormality in the patient's response.

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3.3.2.1 Study of the correlation between different parameters

In lower somatosensory evoked potentials, the most significant correlation we have observed is illustrated in the following graph:

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4 Conclusions

The findings of this study underscore the crucial importance of electrode placement methods in the accuracy and reliability of visual evoked potential tests. Through detailed clinical analysis and comparison, it has been demonstrated that the EPlacement method exhibits greater accuracy compared to the approximate method. Specifically, the EPlacement method showed a significantly higher accuracy rate (54.55%) in detecting anomalies in visual pathways, in contrast to the 9.09% of the approximate method. This higher accuracy suggests that the EPlacement method is more effective in detecting anomalies in visual pathways, which is essential for accurate diagnosis and treatment in clinical settings.

In the case of upper somatosensory evoked potentials, the analysis of the N20 latency revealed that 28.57% of the cases belong to the "Diagnostic Change Group". Given that this is a considerable percentage, we decided to review the medical histories of these patients. Unfortunately, we do not yet have conclusive information to determine which of the two methods better assessed the state of the nerve pathways in these cases.

Regarding the correlation analysis between parameters, thanks to the theoretical data from Laia Mallol's final project degree, we observed a strong correlation between the placement of CP3 and CP4 electrodes and, the horizontal circumference and Nasion-Inion distance in the various head models she analysed.

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In the theoretical distance analysis, it was observed that the error in the approximate placement of the CP3 electrode varies between 4.82 and 14.67 units, and for the CP4, the error varies between 6.63 and 16.35 units. This analysis shows that placing electrodes using approximate methods can result in significant errors due to variations in individual head morphology.

Conversely, in the case of lower somatosensory evoked potentials, we have not found any cases where the two electrode placement methods contradict each other. This suggests greater consistency between the placement methods in this type of study.

In relation to the correlation study, we found that the correlation between the horizontal distance and the LPA-RPA distance has an R^2 value of 0.72, indicating a strong and significant correlation. However, this correlation needs to be verified with a larger sample size.

In clinical implications, the results suggest that the EPlacement method should be more widely used in clinical practice due to its higher accuracy and reliability. This approach could significantly reduce diagnostic errors, resulting in better patient outcomes. Additionally, understanding the differences between various electrode placement methods can help improve diagnostic criteria and standardise procedures in neurophysiological studies.

On the other hand, the generalisation of the findings is affected by the limitations imposed by the relatively small sample size of this study. In future research, increasing the sample size will improve the validity and reliability of the results, allowing for a more accurate identification of underlying trends and relationships. This will help to better understand the differences between electrode placement methods, which will allow us to comprehend how electrode placement affects the responses of neural pathways in both visual and somatosensory evoked potentials.

In conclusion, this study emphasises the fundamental importance of precise electrode placement in neurophysiological diagnostics. Given its higher level of accuracy, the EPlacement method emerges as a preferable technique. Future research with larger sample sizes will be essential to further validate these findings and potentially identify additional factors that may influence evoked potential measurements. This knowledge will drive the continuous improvement of diagnostic practices, ultimately benefiting patient care by providing more accurate diagnoses and more effective treatments.

5 References

[1] A. Morley, L. Hill, and A. G. Kaditis, "10-20 System EEG Placement," *European Respiratory Society*, 2016.

[2] M. Seeck *et al.*, "The standardized EEG electrode array of the IFCN," *Clinical Neurophysiology*, vol. 128, no. 10. 2017. doi: 10.1016/j.clinph.2017.06.254.

[3] M. R. Nuwer, "Recording electrode site nomenclature," *Journal of Clinical Neurophysiology*, vol. 4, no. 2, 1987, doi: 10.1097/00004691-198704000-00002.

[4] A. Fabregat Sanjuan, A. Rigo Vidal, M. Roselló Foguet, R. Pàmies Vilà, G. Montoya Aguirre, and V. Pascual Rubio, "Análisis de la exactitud de posicionado de los electrodos en potenciales evocados visuales y somatosensoriales," 2023.

[5] L. J. Dorfman, "SENSORY EVOKED POTENTIALS: Clinical Applications in Medicine," 1983. [Online]. Available: www.annualreviews.org

[6] P. Walsh, N. Kane, and S. Butler, "The clinical role of evoked potentials," *Neurology in Practice*, vol. 76, no. 2. Jun. 2005. doi: 10.1136/jnnp.2005.068130.

[7] C. Baiano and M. Zeppieri, "Visual Evoked Potential," *StatPearls*, 2023.

[8] D. J. Creel, "Visually evoked potentials," in *Handbook of Clinical Neurology*, vol. 160, Elsevier B.V., 2019, pp. 501–522. doi: 10.1016/B978-0-444-64032-1.00034-5.

[9] R. Sharma, S. Joshi, K. D. Singh, and A. Kumar, "Visual evoked potentials: Normative values and gender differences," *Journal of Clinical and Diagnostic Research*, vol. 9, no. 7, pp. 12–15, Jul. 2015, doi: 10.7860/JCDR/2015/12764.6181.

[10] T. Yamada, M. Yeh, and J. Kimura, "Fundamental principles of somatosensory evoked potentials," *Physical Medicine and Rehabilitation Clinics of North America*, vol. 15, no. 1. W.B. Saunders, pp. 19–42, 2004. doi: 10.1016/S1047-9651(03)00100-1.

[11] I. M. Muzyka and B. Estephan, "Somatosensory evoked potentials," in *Handbook of Clinical Neurology*, vol. 160, Elsevier B.V., 2019, pp. 523–540. doi: 10.1016/B978-0-444-64032-1.00035-7.

[12] Jonathan L. Carter and Clarke Stevens, "Somatosensory Evoked Potentials".

[13] P. Lesiakowski, W. Lubiński, and T. Zwierko, "Electrophysiological findings of the visual system in amateur boxers," *tandfonline*, 2018.

[14] A. Fabregat-Sanjuan, R. Pàmies-Vilà, A. Rigo-Vidal, and V. Pascual-Rubio, "Comparison of electrode position marking procedures on the cranial surface," *Brain Behav*, vol. 13, no. 10, 2023, doi: 10.1002/brb3.3187.

[15] A. Agrawal, A. S. Puthalath, S. K. Mittal, S. Mittal, Y. Singh, and A. Singh, "Alteration in pattern reversal visual evoked potential in pediatric population with amblyopia and spherical refractive errors," *Indian J Ophthalmol*, vol. 70, no. 5, 2022, doi: 10.4103/ijo.IJO_2692_21.

[16] T. Y. T. Tai, "Visual evoked potentials and glaucoma," *Asia-Pacific Journal of Ophthalmology*, vol. 7, no. 5. 2018. doi: 10.22608/APO.2017532.

[17] G. Cruccu *et al.*, "Recommendations for the clinical use of somatosensory-evoked potentials," *Clinical Neurophysiology*, vol. 119, no. 8. 2008. doi: 10.1016/j.clinph.2008.03.016.

[18] M. J. Aminoff, "Evoked Potentials in Clinical Medicine," 1986.

[19] S. Benghanem *et al.*, "SSEP N20 and P25 amplitudes predict poor and good neurologic outcomes after cardiac arrest," *Ann Intensive Care*, vol. 12, no. 1, 2022, doi: 10.1186/s13613-022-00999-6.

[20] A. B. Glimmerveen, H. M. Keijzer, B. J. Ruijter, M. C. Tjepkema-Cloostermans, M. J. A. M. van Putten, and J. Hofmeijer, "Relevance of Somatosensory Evoked Potential Amplitude After Cardiac Arrest," *Front Neurol*, vol. 11, 2020, doi: 10.3389/fneur.2020.00335.

[21] J. Jančić *et al.*, "Visual evoked potentials – Current concepts and future perspectives," *Vojnosanitetski Pregled*, vol. 75, no. 5. 2018. doi: 10.2298/VSP160613342J.

[22] Franklin W. Lusby, Lusby Vision Institute, and David C. Dugdale, "Degeneración macular asociada con la edad."

[23] "Electroencefalograma y potenciales evocados: el lenguaje eléctrico del cerebro."

[24] T. Maudrich, S. Hähner, R. Kenville, and P. Ragert, "Somatosensory-Evoked Potentials as a Marker of Functional Neuroplasticity in Athletes: A Systematic Review," *Frontiers in Physiology*, vol. 12. 2022. doi: 10.3389/fphys.2021.821605.

[25] "MS Trust. (2022, March 1). Evoked potentials. MS Trust. Retrieved July 4, 2024".

Annex

Annex 1. Python Code of data Processing. VEPs

```
import pandas as pd
import  matplotlib.pyplot
as plt import numpy as np

     #Firstly, I define the columns that my DataFrame
will have data = {
         "Temps": [],
         "D_Aprox": [],
         "I_Aprox": [],
         "D_Riguros":[],
         "I_Riguros": []
     }
valor_i
=0

     # We generate the values for the "Temps" column until reaching a total
of 512 columns

     while   len(data["Temps"])   <=
511:
data["Temps"].append(valor_i)
data["D_Aprox"].append(None)
data["I_Aprox"].append(None)
data["D_Riguros"].append(None)
data["I_Riguros"].append(None)
valor_i += (282.5/512)

     df = pd.DataFrame(data)

     # We read the Excel file where we have the data for the approximate
method of the said patient
     data_file                                            =
"/Users/asmaeizlane/Desktop/TFG//1_aprox_visuals.xlsx" df_excel
= pd.read_excel(data_file)

     # We read the Excel file where we have the data for the EPlacement method
of         the         said         patient         data_file_r         =
"/Users/asmaeizlane/Desktop/TFG/1_riguros_visuals.xlsx"
```

```
    df_excel_r = pd.read_excel(data_file_r)
    # We select the columns that contain the values of OD P-VEP Right from
the approximate method
    selected_columns_aprox_D = [0, 2, 4, 6]


    # We create an empty list where we will store the values of "OD P-VEP
Right" from the approximate method
    Aprox_D_values = []


    # We select the columns that contain the values of OI P-VEP Left from
the approximate method selected_columns_aprox_I = [1, 3, 5, 7]
    # We create an empty list where we will store the values of "OI P-VEP
Left" from the approximate method
    Aprox_I_values = []


    # We select the columns that contain the values of OD P-VEP Right from
the rigorous method selected_columns_riguros_D = [0, 2, 4, 6]
    # We create an empty list where we will store the values of "OD P-VEP
Right" from the rigorous method
    Rig_D_values = []


    # We select the columns that contain the values of OI P-VEP Left from
the rigorous method selected_columns_riguros_I = [1, 3, 5, 7]
    # We create an empty list where we will store the values of "OI P-VEP
Left" from the rigorous method
    Rig_I_values = []


    # We iterate over the selected columns for the approximate values of the
right eye and store them in the list Aprox_D_values for column_index in
selected_columns_aprox_D:
        # We get the values of the current column and we add
them to the list     Aprox_D_values.extend(df_excel.iloc[:,
column_index].tolist())      for      column_index      in
selected_columns_aprox_I:
        Aprox_I_values.extend(df_excel.iloc[:,
column_index].tolist())     for     column_index     in
selected_columns_riguros_D:
        Rig_D_values.extend(df_excel_r.iloc[:,
column_index].tolist())     for     column_index     in
selected_columns_riguros_I:

        Rig_I_values.extend(df_excel_r.iloc[:, column_index].tolist())
    #  We  add  the  values  stored  in  the  lists  to  the
corresponding  columns  df["D_Aprox"]  =  Aprox_D_values
```

```
df["I_Aprox"] = Aprox_I_values df["D_Riguros"] =
Rig_D_values df["I_Riguros"] = Rig_I_values

    # We create a figure with two
subplots fig, axs = plt.subplots(1,
2, figsize=(24, 8))

    # We create the graph of the left eye which includes I_Aprox
and I_Rigorous axs[0].plot(df["Temps"], df["I_Aprox"],
color='orange', label='I_Aprox') axs[0].plot(df["Temps"],
df["I_Riguros"], color='blue', label='I_Riguros')
axs[0].set_xlabel("Temps(ms)") axs[0].set_ylabel("Voltaje(V)")
axs[0].set_title("Ojo Izquierdo (ID)")

    # We create the graph of the right eye which includes D_Aprox
and D_Rigorous axs[1].plot(df["Temps"], df["D_Aprox"],
color='orange', label='D_Aprox') axs[1].plot(df["Temps"],
df["D_Riguros"], color='blue', label='D_Riguros')
axs[1].set_xlabel("Temps(ms)") axs[1].set_ylabel("Voltaje (V)")
axs[1].set_title("Ojo derecho (OD)")

    # We define approximate ranges for the inflection points N75, P100, and
N145 that we will indicate on the graphs range_start_N75 = 55 range_end_N75
= 80 range_start_P100 = 80 range_end_P100 = 125 range_start_N145 = 130
range_end_N145 = 162

    # We find the indices of the minimum and maximum values for the right
eye, taking into account the specified ranges
    n75_aprox_index_d = (df["D_Aprox"].loc[(df["Temps"] >= range_start_N75)
& (df["Temps"]
    <= range_end_N75)]).idxmin()
n75_10_20_index_d = (df["D_Riguros"].loc[(df["Temps"] >=
          range_start_N75) &
    (df["Temps"] <= range_end_N75)]).idxmin()
p100_aprox_index_d = (df["D_Aprox"].loc[(df["Temps"] >=
          range_start_P100) &
    (df["Temps"] <= range_end_P100)]).idxmax()
    p100_10_20_index_d = (df["D_Riguros"].loc[(df["Temps"] >=
range_start_P100) &
    (df["Temps"] <= range_end_P100)]).idxmax()
n145_aprox_index_d = (df["D_Aprox"].loc[(df["Temps"] >=
          range_start_N145) &
    (df["Temps"] <= range_end_N145)]).idxmin()
    n145_10_20_index_d = (df["D_Riguros"].loc[(df["Temps"] >=
range_start_N145) & (df["Temps"] <= range_end_N145)]).idxmin()
```

```
     # We obtain the values of the inflection points for
the      right      eye            n75_aprox_d      =
df["Temps"].loc[n75_aprox_index_d]     n75_10_20_d    =
df["Temps"].loc[n75_10_20_index_d]    p100_aprox_d    =
df["Temps"].loc[p100_aprox_index_d]    p100_10_20_d   =
df["Temps"].loc[p100_10_20_index_d]    n145_aprox_d   =
df["Temps"].loc[n145_aprox_index_d]    n145_10_20_d   =
df["Temps"].loc[n145_10_20_index_d]

     print('Right                                  eye
EPlacement:',round(p100_10_20_d,2))  print('Right  eye
approx:', round(p100_aprox_d,2))

     # We find the indices of the minimum and maximum values for the left
eye, taking into account the specified ranges
     n75_aprox_index_i = (df["I_Aprox"].loc[(df["Temps"] >= range_start_N75)
& (df["Temps"]
     <= range_end_N75)]).idxmin()
     n75_10_20_index_i      =      (df["I_Riguros"].loc[(df["Temps"]      >=
range_start_N75) & (df["Temps"]
     <= range_end_N75)]).idxmin()
     p100_aprox_index_i      =      (df["I_Aprox"].loc[(df["Temps"]      >=
range_start_P100) & (df["Temps"]
     <= range_end_P100)]).idxmax()
p100_10_20_index_i  = (df["I_Riguros"].loc[(df["Temps"]
                    >=      range_start_P100) &
     (df["Temps"] <= range_end_P100)]).idxmax()
     n145_aprox_index_i      =      (df["I_Aprox"].loc[(df["Temps"]      >=
range_start_N145) & (df["Temps"]
     <= range_end_N145)]).idxmin()
     n145_10_20_index_i      =      (df["I_Riguros"].loc[(df["Temps"]      >=
range_start_N145) & (df["Temps"] <= range_end_N145)]).idxmin()

     # We obtain the values of the inflection points
for      the      left      eye      n75_aprox_i      =
df["Temps"].loc[n75_aprox_index_i]    n75_10_20_i    =
df["Temps"].loc[n75_10_20_index_i]   p100_aprox_i   =
df["Temps"].loc[p100_aprox_index_i]   p100_10_20_i   =
df["Temps"].loc[p100_10_20_index_i]   n145_aprox_i   =
df["Temps"].loc[n145_aprox_index_i]   n145_10_20_i   =
df["Temps"].loc[n145_10_20_index_i]

     print('Left                                 eye
EPlacement:',round(p100_10_20_i,2)) print('Left eye
approx:', round(p100_aprox_i,2))
```

```
     # We plot the inflection points with markers and labels in the legend
on the graph of the left eye

     axs[0].scatter(n75_aprox_i,    df["I_Aprox"][n75_aprox_index_i],
marker='^',       s=60, color='orange', label='N75_Aprox')

     axs[0].scatter(n75_10_20_i,    df["I_Riguros"][n75_10_20_index_i],
marker='^',       s=60, color='blue', label='N75_10/20')

     axs[0].scatter(p100_aprox_i,   df["I_Aprox"][p100_aprox_index_i],
marker='o',       s=50, color='orange', label='P100_Aprox')

     axs[0].scatter(p100_10_20_i,       df["I_Riguros"][p100_10_20_index_i],
marker='o', s=50, color='blue', label='P100_10/20')

     axs[0].scatter(n145_aprox_i,   df["I_Aprox"][n145_aprox_index_i],
marker='s',       s=50, color='orange', label='N145_Aprox')

     axs[0].scatter(n145_10_20_i,   df["I_Riguros"][n145_10_20_index_i],
marker='s',       s=50, color='blue', label='N145_10/20')


     # We plot the inflection points with markers and labels in the legend
on the graph of the right eye

     axs[1].scatter(n75_aprox_d,    df["D_Aprox"][n75_aprox_index_d],
marker='^',       s=60, color='orange', label='N75_Aprox')

     axs[1].scatter(n75_10_20_d,         df["D_Riguros"][n75_10_20_index_d],
marker='^', s=60, color='blue', label='N75_10/20')

     axs[1].scatter(p100_aprox_d,   df["D_Aprox"][p100_aprox_index_d],
marker='o',       s=50, color='orange', label='P100_Aprox')

     axs[1].scatter(p100_10_20_d,       df["D_Riguros"][p100_10_20_index_d],
marker='o', s=50, color='blue', label='P100_10/20')

     axs[1].scatter(n145_aprox_d,   df["D_Aprox"][n145_aprox_index_d],
marker='s',       s=50, color='orange', label='N145_Aprox')

     axs[1].scatter(n145_10_20_d,       df["D_Riguros"][n145_10_20_index_d],
marker='s', s=50, color='blue', label='N145_10/20')


     plt.tight_layout
()    axs[0].legend()
axs[1].legend()
plt.show()


     # We extract the values of the P100 wave and the N75 wave


     p100_aprox_amplitude_D      =      df["D_Aprox"].loc[p100_aprox_index_d]
p100_10_20_amplitude_D       =       df["D_Riguros"].loc[p100_10_20_index_d]
p100_aprox_amplitude_I        =        df["I_Aprox"].loc[p100_aprox_index_i]
p100_10_20_amplitude_I = df["I_Riguros"].loc[p100_10_20_index_i]
     n75_aprox_amplitude_D     =     df["D_Aprox"].loc[n75_aprox_index_d]
n75_10_20_amplitude_D      =      df["D_Riguros"].loc[n75_10_20_index_d]
n75_aprox_amplitude_I       =       df["I_Aprox"].loc[n75_aprox_index_i]
n75_10_20_amplitude_I = df["I_Riguros"].loc[n75_10_20_index_i]
```

```
    # To calculate the amplitude, we will find the difference between the
P100 point and the N75 point for each case
    Amplitud_Aprox_D = p100_aprox_amplitude_D - n75_aprox_amplitude_D
    Amplitud_Riguros_D = p100_10_20_amplitude_D - n75_10_20_amplitude_D
    Amplitud_Aprox_I = p100_aprox_amplitude_I - n75_aprox_amplitude_I
    Amplitud_Riguros_I = p100_10_20_amplitude_I -  n75_10_20_amplitude_I

    print("\nAMPLITUDES")
    print("OD_EP:  ",  Amplitud_Riguros_D,'V')
print("OD_Aprox:    ",    Amplitud_Aprox_D,'V')
print("OI_EP:    ",    Amplitud_Riguros_I,'V')
print("OI_Aprox: ", Amplitud_Aprox_I,'V')
```

Annex 2. Python Code of data processing. SEPs

For somatosensory evoked potentials, the code is the same for both upper and lower limbs. The example code provided below corresponds to an example of lower somatosensory evoked potentials.

```
import pandas as pd
import matplotlib.pyplot
as plt

     #Firstly, I define the columns that my
DataFrame will have data = {
          "Temps”: [],
          "D_Aprox”: [],
          "D_Riguros”:[],
          "I_Aprox”: [],
          "I_Riguros”: []
     }
valor_i =
0
     # We generate the values for the "Temps" column until reaching a
total    of    960    columns    while    len(data["Temps"])    <=    959:
data["Temps"].append(valor_i)              data["D_Aprox"].append(None)
data["I_Aprox"].append(None)             data["D_Riguros"].append(None)
data["I_Riguros"].append(None)     valor_i += (1/12000)

     df = pd.DataFrame(data)

     # We read the .txt file where we have the values for the right eye using
the approximate method with open("1_EI_D_Aprox.txt", "r") as file:
          primera_linea                                        =
float(file.readline().strip().replace(",",               "."))
valores_linea = file.readline().strip().split(",")
     # We read the .txt file where we have the values for the right eye using
the approximate method
     valores_multiplicados = [float(valor.replace("/", "")) * primera_linea
for valor in valores_linea] # Assign the multiplied values to the "D_Aprox"
column df["D_Aprox"] = valores_multiplicados

     # We read the .txt file where we have the values for the right eye using
the rigorous method with open("1_EI_D_10_20.txt", "r") as file:
```

```
        primera_linea_a = float(file.readline().strip().replace(",", "."))
# Read and convert the value from the first line to a float
        valores_linea_a = file.readline().strip().split(",")  # Read and
split the values from the second line


    # Multiply the values from the second line by the value from the first
line
    valores_multiplicados_a = [float(valor.replace("/", "")) *
primera_linea_a for valor in valores_linea_a]


    df["D_Riguros"] = valores_multiplicados_a


    with open("1_EI_I_Aprox.txt", "r") as file:
        primera_linea_b =
float(file.readline().strip().replace(",", "."))
valores_linea_b = file.readline().strip().split(",")


    valores_multiplicados_b = [float(valor.replace("/", "")) *
primera_linea_b for valor in valores_linea_b]
    df["I_Aprox"] = valores_multiplicados_b


    with open("1_EI_I_10_20.txt", "r") as file:
        primera_linea_c =
float(file.readline().strip().replace(",", "."))
valores_linea_c = file.readline().strip().split(",")


    valores_multiplicados_c = [float(valor.replace("/", "")) *
primera_linea_c for valor in valores_linea_c]
    df["I_Riguros"] = valores_multiplicados_c


    fig, axs = plt.subplots(1, 2, figsize=(24, 8))
fig.suptitle(‘Somatosensory Evoked Potential’, fontsize=16)


    axs[0].plot(df["Temps"], df["I_Aprox"], color='orange',
label='I_Aprox') axs[0].plot(df["Temps"], df["I_Riguros"], color='blue',
label='I_Riguros') axs[0].set_xlabel("Temps")
    axs[0].set_ylabel("Voltaje (V)")
axs[0].set_title("Ojo Izquierdo (ID)")
axs[0].set_ylim(4,-4)


    axs[1].plot(df["Temps"], df["D_Aprox"], color='orange',
label='D_Aprox') axs[1].plot(df["Temps"], df["D_Riguros"],
color='blue', label='D_Riguros') axs[1].set_xlabel("Temps")
```

```
axs[1].set_ylabel("Voltaje    (V)")    axs[1].set_title("Ojo
derecho (OD)") axs[1].set_ylim(4,-4)

     # We define the approximate ranges for the inflection points
     #For lower somatosensory evoked potentials, the approximate ranges are:
     range_start_P37    =    0.034
range_end_P37       =       0.049
range_start_N45_D     =     0.049
range_end_N45_D      =      0.063
range_start_N45_I     =     0.049
range_end_N45_I = 0.051

     #For upper somatosensory evoked potentials, the approximate ranges are:
     range_start_N20    =    0.018
range_end_N20       =       0.035
range_start_P25      =      0.025
range_end_P25 = 0.042

     p37_aprox_index_d = (df["D_Aprox"].loc[(df["Temps"] >= range_start_P37)
& (df["Temps"]
     <= range_end_P37)]).idxmax()
p37_10_20_index_d  = (df["D_Riguros"].loc[(df["Temps"]          >=
            range_start_P37)         &
     (df["Temps"] <= range_end_P37)]).idxmax()
n45_aprox_index_d  = (df["D_Aprox"].loc[(df["Temps"]            >=
          range_start_N45_D)       &
     (df["Temps"] <= range_end_N45_D)]).idxmin()
     n45_10_20_index_d      =      (df["D_Riguros"].loc[(df["Temps"]      >=
range_start_N45_D) &
     (df["Temps"] <= range_end_N45_D)]).idxmin()
     n45_aprox_index_d_      =      (df["D_Aprox"].loc[(df["Temps"]      >=
range_start_N45_I) &
     (df["Temps"] <= range_end_N45_I)]).idxmin()
     n45_10_20_index_d_      =      (df["D_Riguros"].loc[(df["Temps"]      >=
range_start_N45_I) & (df["Temps"] <= range_end_N45_I)]).idxmin()
     p37_aprox_d  =  df["Temps"].loc[p37_aprox_index_d]
p37_10_20_d    =    df["Temps"].loc[p37_10_20_index_d]
n45_aprox_d    =    df["Temps"].loc[n45_aprox_index_d]
n45_10_20_d = df["Temps"].loc[n45_10_20_index_d]

     p37_aprox_index_i = (df["I_Aprox"].loc[(df["Temps"] >= range_start_P37)
& (df["Temps"]
     <= range_end_P37)]).idxmax()
     p37_10_20_index_i      =      (df["I_Riguros"].loc[(df["Temps"]      >=
range_start_P37) & (df["Temps"]
     <= range_end_P37)]).idxmax()
```

```
n45_aprox_index_i = (df["D_Aprox"].loc[(df["Temps"]            >=
          range_start_N45_I)       &
     (df["Temps"] <= range_end_N45_I)]).idxmin()

     n45_10_20_index_i      =      (df["D_Riguros"].loc[(df["Temps"]      >=
range_start_N45_I) & (df["Temps"] <= range_end_N45_I)]).idxmin()


     p37_aprox_i = df["Temps"].loc[p37_aprox_index_i]
p37_10_20_i    =    df["Temps"].loc[p37_10_20_index_i]
n45_aprox_i    =    df["Temps"].loc[n45_aprox_index_i]
n45_10_20_i = df["Temps"].loc[n45_10_20_index_i]


     rango_especificado   =   df.loc[(df["Temps"]   >=   range_start_P37)   &
(df["Temps"] <= range_end_P37)]
     p37_aprox_max_d    =    rango_especificado["D_Aprox"].max()
p37_10_20_max_d     =     rango_especificado["D_Riguros"].max()
p37_aprox_max_i      =      rango_especificado["I_Aprox"].max()
p37_10_20_max_i = rango_especificado["I_Riguros"].max()


     print("VALUE OF P37 POSITIVITY")
     print("OD_P37_EP:    ",    p37_10_20_max_d,    "microV")
print("OD_P37_Aprox:    ",    p37_aprox_max_d,    "microV")
print("OI_P37_EP:     ",     p37_10_20_max_i,     "microV")
print("OI_P37_Aprox: ", p37_aprox_max_i, "microV")



     rango_especificadoB   =   df.loc[(df["Temps"]   >=   range_start_N45)   &
(df["Temps"] <= range_end_N45)]
     n45_aprox_min_d    =    rango_especificadoB["D_Aprox"].min()
n45_10_20_min_d     =     rango_especificadoB["D_Riguros"].min()
n45_aprox_min_i      =      rango_especificadoB["I_Aprox"].min()
n45_10_20_min_i = rango_especificadoB["I_Riguros"].min()


     print("\nVALUE    OF    N45    NEGATIVITY")
print("OD_N45_EP: ", n45_10_20_min_d, "microV")
print("OD_N45_Aprox:     ",     n45_aprox_min_d,
"microV") print("OI_N45_EP: ", n45_10_20_min_i,
"microV")        print("OI_N45_Aprox:        ",
n45_aprox_min_i, "microV")

axs[0].scatter(p37_aprox_i,                               marker='^',  s=60,
df["I_Aprox"][p37_aprox_index_i],          color='orange',
label='P37_Aprox')
axs[0].scatter(p37_10_20_i,                                marker='^', s=60,
      df["I_Riguros"][p37_10_20_index_i],    color='blue',
label='P37_10/20')
```

```
axs[0].scatter(n45_aprox_i,                              marker='o',  s=60,
      df["I_Aprox"][n45_aprox_index_i],    color='orange',
label='N45_Aprox')
axs[0].scatter(n45_10_20_i,                              marker='o', s=60,
df["I_Riguros"][n45_10_20_index_i],          color='blue',
label='N45_10/20')

axs[1].scatter(p37_aprox_d,                              marker='^',  s=60,
df["D_Aprox"][p37_aprox_index_d],          color='orange',
label='P37_Aprox')
     axs[1].scatter(p37_10_20_d,         df["D_Riguros"][p37_10_20_index_d],
marker='^', s=60, color='blue', label='P37_10/20')
     axs[1].scatter(n45_aprox_d,    df["D_Aprox"][n45_aprox_index_d],
marker='o',       s=60, color='orange', label='N45_Aprox')
     axs[1].scatter(n45_10_20_d,    df["D_Riguros"][n45_10_20_index_d],
marker='o',       s=60, color='blue', label='N45_10/20')


     plt.tight_layout
()    axs[0].legend()
axs[1].legend()
plt.show()

     # In this section, we will extract the time at which the P37 wave occurs,
for both eyes and both methods
     print("OD_P37_EP:",          p37_10_20_d,"s")
print("OD_P37_Aprox:",           p37_aprox_d,"s")
print("OI_P37_EP:",              p37_10_20_i,"s")
print("OI_P37_Aprox:", p37_aprox_i,"s") # In this
section, we will extract the time at which the N45
wave occurs, for both eyes and both methods
     print("OD_N45_EP:",
n45_10_20_d,"s")
print("OD_N45_Aprox:",
n45_aprox_d,"s")
print("OI_N45_EP:",
n45_10_20_i,"s")
print("OI_N45_Aprox:",
n45_aprox_i,"s")
```

Annex 3 Table with the data on head measurements and latency differences for each patient. VEPs

The content of this section has been removed due to the inclusion of confidential information.

Annex 4 Table with the data on head measurements. Upper Somatosensory Evoked Potentials.

The content of this section has been removed due to the inclusion of confidential information.

Annex 5 Table with the data on head measurements. Lower Somatosensory Evoked Potentials.

The content of this section has been removed due to the inclusion of confidential information.