EXPLORING ELECTROENCEPHALOGRAPHY (EEG): HANDS-ON ACTIVITIES IN THE LABORATORY

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ABSTRACT

Electroencephalography (EEG) is a non-invasive neurophysiological technique that measures the electrical activity of the brain through electrodes on the scalp, and is widely used in scientific research and clinical diagnosis. This article describes the methodology for the use of EEG, addressing its main components, such as electrodes, amplifiers and analysis software, as well as the protocols of good practice for data collection and processing. The technique offers high temporal resolution, crucial for studies on cognitive functions and responses to stimuli. Despite its limitations, such as low spatial resolution and sensitivity to artifacts, EEG stands out for its accessibility and applicability in clinical and experimental studies. Examples of its application include the analysis of event-related potentials (ERPs) and the investigation of functional connectivity between cortical areas, contributing to the understanding of neural networks and their relationship with cognitive and emotional processes. The advantages and challenges associated with EEG are discussed, highlighting its relevance as an essential tool in neurosciences.

Keywords: Electroencephalography, Event-related potentials.

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BRIEF LITERATURE REVIEW

Electroencephalography (EEG) is a non-invasive neurophysiological technique that records brain electrical activity through electrodes on the scalp. Widely used in research and clinical diagnosis, EEG allows the analysis of brain functions and responses to stimuli, providing essential data for the study of complex processes in neurosciences (Luck, 2014; Schomer & Lopes da Silva, 2017; Santos & Coutinho, 2024).

Due to its sensitive nature and the involvement of human beings, the use of EEG should be guided by **strict protocols of good practice**, which ensure the quality of the data and safeguard the well-being of the participants (Sanei & Chambers, 2007). According to Thakor & Sherman (2013), Siuly & Zhang (2016), Im (2018) and Sazgar & Young (2019) EEG equipment is composed **of electrodes** in specific points of the scalp, according to standard positioning systems (e.g., 10-20 system), allowing the consistent and accurate capture of brain activity, They are available in different sizes and configurations to better adapt to the needs of the participants and the experimental protocol.

Electrodes are small devices that interface directly with the scalp, picking up electrical activity in the brain. These can be disposable and reusable, and it is essential that they are positioned according to the protocols to ensure the validity of the data. **Conductive Paste or Gel** is a conductive material that improves the quality of the bond between the electrode and the scalp, ensuring a more accurate reading of electrical signals. Since the brain's electrical activity is of low amplitude, the **amplifier** is essential to increase the power of the signals, allowing a reliable and detailed reading. To make reading easier, researchers use **Data Collection and Analysis Software** that monitors, records and processes signals in real time. It allows the application of filters and data segmentation for analysis according to the needs of the study. Obviously, the software is run through a **computer** where the data is analyzed. In controlled experiments, the computer can also present stimuli and record responses synchronized with EEG activity. Last but not least, an **Artifact Monitoring System** (cameras or motion sensors) is also used, capable of monitoring the environment and minimizing sources of noise or interference, such as participants' movements (Santos & Coutinho, 2024).

To ensure the validity of the data and the safety of conducting EEG experiments, it is critical to **implement rigorous good practices at all stages of the process** (Chatrian et al., 1985; Delorme & Makeig, 2004; Luck, 2014; APA, 2017). One of the first steps is the **Preparation of the Participants** by making an **Informed Consent** before the start of the process.

Skin Preparation, used to reduce the resistance between the electrodes and the scalp, may include gently cleansing the area with an appropriate solution, such as alcohol, to ensure good conductivity. Also **Proper Electrode Positioning** should be performed according to system 10-20 standards, ensuring that the data collected are consistent and comparable across different studies. A second moment goes through **the Equipment Configuration** in the form of **Calibration and Pre-Experiment Tests** in order to ensure the accurate capture of the signals. Checking the resistance of the electrodes and their suitability is routine procedure. All **Artifacts must be properly controlled** as a way to minimize interference with the EEG signal, eliminating sources of electrical noise and mobile devices (Ferreira et al, 2022). It is important to ensure that the participant is comfortable and instructed to avoid sudden movements that could interfere with data **collection**. This should be done through Real-Time **Monitoring** in order to avoid technical problems, such as dislodged electrodes or interference, and correct it immediately, avoiding data loss. The use of **event markers** is crucial to synchronize the presentation of stimuli with the EEG recording, facilitating the analysis of specific brain responses. Minimizing **Physiological Artifacts** such as blinking or head wiggle can introduce noise into the EEG data. The participant should be instructed to minimize these movements (Santos & Coutinho, 2024). In terms of **Completion Procedures**, it is important to perform a **Safe Removal** in order not to cause discomfort to the participant. After each use, the electrodes and helmet must be properly sanitized. **Data Storage and Analysis** leads the researcher to respect data protection and confidentiality regulations. Before final analysis, the **data should be carefully inspected** to identify and remove undesirable artifacts, such as low-frequency noise, muscle interference, or movement. To finish, raw EEG files and subsequent analyses must be properly organized and subject to regular backups, preventing data loss and facilitating future access (Chatrian et al., 1985; Delorme & Makeig, 2004; Luck, 2014).

CHARACTERIZATION OF THE EEG TECHNIQUE AS A TOOL FOR NEUROPHYSIOLOGICAL DATA COLLECTION

Electroencephalography (EEG) allows the monitoring and recording, in real time, of the electrical activity generated by neurons, especially in the cortical layers, providing essential information for the study of brain functions and for the diagnosis of neurological conditions (Ferreira et al, 2022; Montenegro et al, 2022).

EQUIPMENT AND FUNCTION OF COMPONENTS

To carry out monitoring and recording, several pieces of equipment are required, as can be seen in table nr 1.

Table nr. 1 Components versus Functions of EEG Components

Component	Function
Electrodes	They capture the electrical activity generated by neurons in the cerebral cortex.
Helmet or Electrode Attachment System	It keeps the electrodes positioned at specific points on the scalp, ensuring consistency and accuracy in data collection.
Conductive Paste or Gel	Reduces the impedance between the electrodes and the scalp, improving electrical conductivity.
Amplifier	It amplifies the electrical signal picked up by the electrodes so that it can be processed and analyzed.
Analog-to-Digital Converter (A/D Converter)	It converts the captured analog signals into digital data for processing in the computer.
Reference System and Earth Electrode	They establish a stable baseline for signal recording and help reduce interference and noise in the data.
Data Acquisition System	It records and stores EEG signals in real time, so that they can be analyzed later.
Analysis Software	It processes and analyzes EEG data, applying filters, extracting patterns, and identifying specific events.
Computer	It controls the EEG system and stores the data.
Event and Motion Monitoring Devices	They assist in the detection and elimination of artifacts caused by participant movements or external interference.

Source: Delorme & Makeig (2004); Luck (2014); Schomer & Lopes da Silva (2017); Ferreira et al. (2022)

ASSEMBLY

To begin the procedure, careful configuration such as placement of the equipment is essential to ensure the quality and validity of the data. The assembly of the electrodes is based on the 10-20 positioning system, a standardized system that ensures uniform placement of the electrodes in specific areas of the scalp, allowing comparability of data between different individuals and studies (Delorme & Makeig, 2004). This system uses anatomical landmarks such as the nasion (point between the eyes) and the inion (at the back of the skull) to determine the position of the electrodes, ensuring that all major cortical regions are monitored. The electrodes can be dry or wet (using conductive gel). Wet electrodes, while they may require more detailed preparation, offer better signal quality due to lower resistance. The brain signal is of low amplitude (microvolts), and an amplifier is needed to increase the power of the signals captured. This amplifier should have high resolution and an adequate sampling rate (at least 250 Hz, but preferably above 500 Hz), to ensure that brain signals are recorded faithfully. In addition, it is necessary to define a reference electrode and a ground electrode to reduce interference and stabilize the circuit, crucial elements to ensure accurate data capture (Thakor & Sherman, 2013).

DATA PLACEMENT AND COLLECTION

With the equipment configured, the data collection process begins. Procedure that follows a strict protocol in order to ensure the quality of the data and the safety of the participant. During collection, the researcher must continuously monitor the EEG signal in real-time to identify possible technical problems, such as dislodged electrodes or high-resistance signals. It is common to check the resistance of the electrodes before starting recording and, if necessary, adjust it to maintain acceptable levels (< 10 kΩ), which helps to reduce noise and improve signal quality.

The participant should be instructed to avoid sudden movements, excessive blinking or contracting facial muscles, as these movements can interfere with data analysis. In EEG studies that involve response to stimuli (such as images, sounds, or cognitive tasks), stimuli are presented to the participant in a synchronized manner with the EEG system, allowing the identification of event-related potentials (ERPs), which are specific responses of the brain to stimuli, and provides a direct measure of how the nervous system responds to different sensory inputs. EEG data collection is susceptible to various types of events, which can compromise data quality. These can have a physiological origin (such as eye, heart and muscle movements) or environmental (such as electromagnetic interference). Physiological electrodes are often identified and controlled by placing additional electrodes such as eye electrodes to monitor blinks and eye movements. Analysis techniques, such as independent component decomposition (ICA), are used to isolate and remove these events in data processing (Luck, 2014). In order to minimize external interference, the collection environment should be prepared to reduce the presence of electromagnetic noise sources, such as electronic devices and fluorescent lighting. In addition, it is recommended that the EEG system include a low-pass filter to attenuate frequencies above the range of interest and minimize high-frequency interference. After collection, EEG data must be carefully processed and analysed to extract relevant information about brain activity (Chatrian et al., 1985; APA, 2017; Santos & Coutinho, 2024).

Pre-processing is essential to prepare the data for analysis. This process includes filtering the data to remove low- or high-frequency noise (typically using high-pass and low-pass filters between 0.1 Hz and 50 Hz) and removing artifacts identified during collection. Analysis software, such as EEGLAB or Brainstorm, offers advanced tools for this pre-processing step, such as identifying noisy channels and interpolating problematic electrodes (Delorme & Makeig, 2004). Frequency analysis allows the identification of specific patterns of neuronal activity, such as alpha, beta, delta and gamma waves, which reflect different cognitive and emotional states. Event-related potential (ERP) analysis allows you to measure specific responses to stimuli, providing detailed information about sensory and cognitive processing.

Connectivity analysis techniques, such as coherence and phase analysis, are used to assess how different brain regions interact with each other. This analysis is essential for understanding brain networks and how specific areas of the brain collaborate in complex processes, such as attention and memory. To ensure data reproducibility and security, it is essential to follow good storage and documentation practices. Raw EEG data should be stored in secure and organized systems to prevent data loss and facilitate future access. It is recommended to perform regular backups to ensure data integrity. Detailed documentation of all study parameters (such as electrode position, experimental conditions, and equipment configurations) is essential to ensure that the data can be reproduced and analyzed by other researchers (Delorme & Makeig, 2004; Luck, 2014; Schomer & Lopes da Silva 2017; Ferreira et al. 2022)

CHARACTERISTICS OF THE MEASURE OF FUNCTIONING OF THE NERVOUS SYSTEM OBTAINED USING THE TECHNIQUE

Electroencephalography (EEG) is a non-invasive neurophysiological technique that directly measures the electrical activity of the brain, offering a temporal resolution in milliseconds, which allows real-time monitoring of fast neuronal processes. This temporal precision makes EEG fundamental for the investigation of cognitive and sensory functions, capturing neuronal events synchronized with external stimuli. In addition, EEG enables the analysis of brain frequency bands, such as delta, theta, alpha, beta, and gamma, each associated with specific states of cortical activation and emotional or cognitive processes (Schomer & Lopes da Silva 2017; Ferreira et al. 2022).

The technique also allows the extraction of event-related potentials (ERPs), indicators of the central nervous system's response to sensory and cognitive stimuli. Additionally, EEG facilitates the assessment of functional connectivity between different cortical regions, essential for studying neural networks and their interactions in complex functions, such as memory and executive control. Because it is a relatively accessible and portable technique, EEG is widely applicable in both clinical studies and experimental investigations, including contexts with samples from specific populations (Santos & Coutinho, 2024).

The sensitivity of EEG to pathological changes allows for the early identification of neurological dysfunctions, being especially useful for the diagnosis of conditions such as epilepsy, where abnormal patterns of rhythmic activity are detectable. Finally, EEG can be integrated with other neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), allowing for a multimodal analysis that combines the high temporal resolution of EEG with the spatial resolution of fMRI, offering a comprehensive and accurate view of brain dynamics (Santos & Coutinho, 2024)

CONCLUSION

The electroencephalography (EEG) technique offers a high temporal resolution, capturing brain electrical activity in milliseconds, which allows a detailed analysis of fast and dynamic processes, such as attention and response to stimuli. This feature, coupled with its accessibility and portability, makes EEG valuable both in research contexts and in clinical applications, such as the diagnosis of neurological conditions (epilepsy, sleep disorders, and psychiatric disorders). EEG allows direct measurement of cortical activity and analysis of functional connectivity between brain regions (Nunez & Srinivasan, 2006; Schomer & Lopes da Silva, 2017; Ferreira et al. 2022).

However, EEG has limitations, such as low spatial resolution and sensitivity to artifacts (eye movements and muscle interference), which requires rigorous pre-processing techniques and experience in data interpretation. The technique is effective in capturing superficial cortical activity, but limited to deep areas, and is therefore ideally complemented by other neuroimaging techniques for an integrated analysis of brain functioning (Nunez & Srinivasan, 2006; Schomer & Lopes da Silva, 2017; Ferreira et al. 2022).

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