RCMOS – Multidisciplinary Scientific Journal of Knowledge.
ISSN: 2675-9128. São Paulo-SP.
Year IV, v.1, n.2, Aug./Dec. 2024. | submission: 2024-12-02 | accepted: 2024-12-04 | publication: 2024-12-06

Exploring Electroencephalography (EEG): Hands-On Lab Activities

Juliana Oliveira Paul
University of Aveiro, Aveiro, Portugal, DEP -
Department of Education and Psychology E-
mail: julianapaul.psi@gmail.com
Gabrielle Ultramar
Lusófona University, Porto, Portugal HEI-Lab Digital
Human-environment Interaction Lab E-mail:
gabrielle.ultramar@gmail.com **Maria Birth Cunha**

Lusophone University, Porto, Portugal
ISMT - Miguel Torga Higher Institute, Coimbra, Portugal
CIAC - Center for Research in Arts and Communication, University of Algarve, Faro, Portugal
Email:maria14276@gmail.com **Maria Virginia Araujo**

Fernando Pessoa University, Porto, Portugal,
Faculty of Humanities and Social Sciences E-mail:
virginiaa481@gmail.com **Silvia Costa Pinto**

https://orcid.org/0000-0002-0606-8255 Fernando
Pessoa University, Porto, Portugal, Faculty of
Humanities and Social Sciences E-mail:
silviamncosta@gmail.com

Summary

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 using EEG, addressing its main components, such as electrodes, amplifiers and analysis software, as well as good practice protocols for data collection and processing. The technique offers high temporal resolution, which is 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 neuroscience.

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 neuroscience (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 good practice protocols**, which ensure data quality and safeguard the well-being of participants (Sanei & Chambers, 2007). According to Thakor & Sherman (2013), Siuly & Zhang (2016), Im (2018) and Sazgar & Young (2019) EEG equipment consists of**Electrode Helmet**is a structure that contains electrodes at specific points on the scalp, according to standard positioning systems (eg, 10-20 system), allowing 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.

Electrodesare small devices that interface directly with the scalp, capturing the brain electrical activity. 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 connection between the electrode and the scalp, ensuring a more accurate reading of electrical signals. Since brain 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 monitor, record and process signals in real time. It allows the application of filters and the segmentation of data for analysis according to the needs of the study. Obviously the software is executed 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, a **Artifact Monitoring System**(cameras or motion sensors), capable of monitoring the environment and minimizing sources of noise or interference, such as participant movements (Santos & Coutinho, 2024).

To ensure data validity and safety when performing EEG experiments, it is essential **implement rigorous best practices at every stage of the process**(Chatrian et al., 1985; Delorme & Makeig, 2004; Luck, 2014; APA, 2017). One of the first steps is to**Participant Preparation**through the realization of a**Informed Consent**before the start of the process.

THE**Skin Preparation**used to reduce resistance between the electrodes and the scalp, may include gently cleaning the area with an appropriate solution, such as alcohol, to ensure good conductivity. Also**Proper Electrode Positioning**must be carried out according to the 10-20 system standards, ensuring that the data collected are consistent and comparable between different studies. A second step involves**Equipment Configuration**in the form of**Calibration and Pre-Experiment Testing**in order to ensure accurate signal capture. Checking electrode resistance and suitability are routine procedures. All**Artifacts must be properly controlled**as a way to minimize interference in 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 may interfere with the**data collection.**This must be prepared through a**Real-Time Monitoring**in order to avoid technical problems, such as dislodged electrodes or interference, and correct them 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 moving the head can introduce noise into the EEG data. The participant should be instructed to minimize these movements (Santos & Coutinho, 2024). In terms of**Finalization Procedures**it is important to carry out a**Safe Removal**so as 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 the final analysis, the**data must be carefully inspected**to identify and remove unwanted artifacts such as low-frequency noise, muscle or movement interference. To complete the analysis, raw EEG files and subsequent analyses must be organized appropriately and subject to regular backups, avoiding data loss and facilitating future access (Chatrian et al., 1985; Delorme & Makeig, 2004; Luck, 2014).

Characterization of the EEG Technique as a Tool for Collecting Neurophysiological Data:

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

Equipment and function of components

To carry out monitoring and recording, various pieces of equipment are required, as can be seen in table no. 1.

Table no. 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 Fixation System	Keeps electrodes positioned at specific points on the scalp, ensuring consistency and accuracy in data collection.
Conductive Paste or Gel	Reduces impedance between electrodes and scalp, improving electrical conductivity.
Amplifier	It amplifies the electrical signal captured by the electrodes so that it can be processed and analyzed.
Analog-to-Digital Converter (A/D Converter)	Converts the captured analog signals into digital data for processing on the computer.
Reference System and Ground Electrode	They establish a stable baseline for recording signals and help reduce interference and noise in the data.
Data Acquisition System	Records and stores EEG signals in real time so they can be analyzed later.
Analysis Software	Processes and analyzes EEG data, applying filters, extracting patterns, and identifying specific events.
Computer	Controls the EEG system and stores the data.
Event and Motion Monitoring Devices	They help detect and eliminate 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 setup and placement of the equipment is essential to ensure data quality and validity. Electrode assembly is based on the 10-20 positioning system, a standardized system that ensures uniform placement of electrodes in specific areas of the scalp, allowing data to be comparable across 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 electrode position, ensuring that all major cortical regions are monitored. Electrodes can be dry or moist (using conductive gel). Moist electrodes, although they may require more detailed preparation, offer better signal quality due to lower resistance. The brain signal is of low amplitude (microvolts), requiring a**amplifier**to increase the power of the captured signals. This amplifier must 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, elements that are crucial to ensuring accurate data capture (Thakor & Sherman, 2013).

Data collection and placement

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

The participant should be instructed to avoid sudden movements, excessive blinking or conbetray facial muscles, since these movements can generate interference in the data analysis. In EEG studies that involve the response to stimuli (such as images, sounds or cognitive tasks), the 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 several types of events, which can compromise data quality. These can be physiological in origin (such as eye, heart, and muscle movements) or environmental (such as electromagnetic interference). Physiological events are often identified and controlled by placing additional electrodes, such as ocular 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 sources of electromagnetic noise, 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 band of interest and minimize high-frequency interference. After collection, EEG data must be carefully processed and analyzed to extract relevant information about brain activity (Chatrian et al., 1985; APA, 2017; Santos & Coutinho, 2024).

Preprocessing is essential to prepare data for analysis. This process includes filtering the data to remove low- and high-frequency noise (typically using high- and low-pass filters between 0.1 Hz and 50 Hz) and removing artifacts identified during data collection. Analysis software such as EEGLAB or Brainstorm offers advanced tools for this preprocessing step, such as identifying noisy channels and interpolating problematic electrodes (Delorme & Makeig, 2004). Frequency analysis allows us to identify specific patterns of neuronal activity, such as alpha, beta, delta, and gamma waves, that reflect different cognitive and emotional states. Analysis of event-related potentials (ERPs) allows us 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 to understand brain networks and how specific brain areas 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. Regular backups are recommended to ensure data integrity. Detailed documentation of all study parameters (such as electrode positions, experimental conditions, and equipment settings) 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 measurement of nervous system functioning obtained using the technique

Electroencephalography (EEG) is a noninvasive neurophysiological technique that directly measures the electrical activity of the brain, offering 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 allows 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 research. experimental, including contexts with samples from specific populations (Santos & Coutinho, 2024).

The sensitivity of EEG to pathological changes allows the early identification of neurological dysfunctions, and is especially useful for the diagnosis of conditions such as epilepsy, where anomalous patterns of rhythmic activity are detectable. Finally, EEG can be integrated with other neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), allowing 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 high temporal resolution, capturing the activity of brain electrical activity in milliseconds, which allows detailed analysis of fast and dynamic processes, such as attention and response to stimuli. This characteristic, combined 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 for deep areas, and is therefore ideally complemented by other neuroimaging techniques for an integrated analysis of brain function (Nunez & Srinivasan, 2006; Schomer & Lopes da Silva, 2017; Ferreira et al. 2022).

Bibliographic References

American Psychological Association. (2017). Ethical principles of psychologists and code of conduct. APA.

Chatrian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten Percent Electrode System for Topographic Studies of Spontaneous and Evoked EEG Activities.*American Journal of Electroneurodiagnostic Technology, 25*, 83-92.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis.*Journal of Neuroscience Methods, 134*(1), 9–21.https://doi.org/10.1016/j.jneumeth.2003.10.009

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis.*Journal of Neuroscience Methods, 134*(1), 9-21.https://doi.org/10.1016/j.jneumeth.2003.10.009

Esperidião-Antonio, V., Majeski-Colombo, M., Toledo-Monteverde, D., Moraes-Martins, G., Fernandes, J. J., Bauchiglion de Assis, M., & Siqueira-Batista, R. (2008). Neurobiology of emotions.*Journal of Clinical Psychiatry, 35*(2), 55-65.

Ferreira, L. S., Caixeta, F. V., Ferreira, A. G., Cunha, P. E., & Schuch, H. C. (2022).*EEG Technician's Handbook*(2nd ed.). Thieme Revinter. Chapter 2: Basis of electrical activity in the brain.

Ferreira, L. S., Caixeta, F. V., & Schuch, H. C. (2022).*EEG Technician's Handbook*(2nd ed.). Thieme Retwenty.

Im, C. H. (2018). Basics of EEG: Generation, acquisition, and applications of EEG. In CH Im (Ed.), *Computational EEG analysis. Biological and medical physics, biomedical engineering*(pp. 1–28). Springer, Singapore.https://doi.org/10.1007/978-981-13-0908-3_1

Luck, S. J. (2014). An introduction to the event-related potential technique (2nd ed.). MIT Press.

Montenegro, MA, Cendes, F., Guerreiro, MM, & Guerreiro, CAM (2022).*EEG in clinical practice (4th ed.).* Thieme Revinter.

Niedermeyer, E., & da Silva, FL (2005).*Electroencephalography: Basic principles, clinical applications tions, and related fields*. Lippincott Williams & Wilkins.

Nunez, P. L., & Srinivasan, R. (2006).*Electric Fields of the Brain: The Neurophysics of EEG*(2nd ed.). OxfordUniversity Press.

Pereira, M., Bastos, J. H., Oliveira, L., Soares, J. M., Oliveira, J. F., & Freitas, J. C. (2003).*Emotional stimuli: sensory processing and motor responses. Brazilian Journal of Psychiatry, 25*(suppl 2).https://doi.org/10.1590/S1516-44462003000600007

Sanei, S., & Chambers, J. A. (2007).*EEG Signal Processing*. Wiley.

Santos, RS, & Coutinho, DJG (2024). Neuroscience, concepts and theories.*Ibero-American Journal of Humanities, Sciences and Education, 10*(5), 2611.https://doi.org/10.51891/rease.v10i5.14048

Sazgar, M., Young, M. G. (2019). Overview of EEG, Electrode Placement, and Montages. In:*Absofight Epilepsy and EEG Rotation Review*. Springer, Cham.https://doi.org/10.1007/978-3-030-03511-2_5

Schomer, DL, & Lopes da Silva, FH (Eds.). (2017). Niedermeyer's electroencephalography:*Basic principles, clinical applications, and related fields*(7th ed.). OxfordUniversity Press.https://doi.org/10.1093/med/9780190228484.001.0001

Siuly, S., Li, Y., & Zhang, Y. (2016). Electroencephalogram (EEG) and its background. In*EEG sig-*

nal analysis and classification. Health information science(pp. 1–22). Springer, Cham.https://doi. org/10.1007/978-3-319-47653-7_1

Sizino da Victoria, M., Soares, AB, & Moratori, PB (2005). The influence of positive and negative emotional states on cognitive processing.*Studies and Research in Psychology, 5*(2), State University of Rio de Janeiro (UERJ).

Thakor, N. V., Sherman, D. L. (2013). EEG Signal Processing: Theory and Applications. In: He, B. (eds) *Neural Engineering. Springer*, Boston, MA.https://doi.org/10.1007/978-1-4614-5227-0_5