Al-Kitab Journal for Pure Sciences (2023); 7(1):69-82.

https://doi.org/10.32441/kjps.07.01.p7

Al-Kitab Journal for Pure Sciences
ISSN: 2617-1260 (print), 2617-8141(online)
www.kjps.isnra.org

Designing a Wearable EEG Device and Its Benefits for Epilepsy Patients: A Review

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Citation: Assim OM, Mahmood AF. Designing a Wearable EEG Device and Its Benefits for Epilepsy Patients: A Review. Al-Kitab J. Pure Sci. [Internet]. 2023 Aug. 20 [cited 2023 Aug. 20];7(1):69-82. https://isnra.net/index.php/kjps/article/view/927
DOI: https://doi.org/10.32441/kjps.07.01.p7.

Keywords: Wearable EEG device, Epilepsy patients, Electroencephalography, Signal quality.

Article History

Received	02 Jun. 2023
Accepted	12 Aug. 2023
Available online	20 Aug. 2023

Abstract:

Epilepsy is a neurological disorder that causes repeated seizures in millions of people worldwide. Traditional Electroencephalography (EEG) systems can be cumbersome and limited to clinical settings, but they have helped diagnose and monitor epilepsy. Wearable EEG devices have transformed epilepsy management by providing real-time, non-invasive, and continuous monitoring capabilities. This review paper investigates the design considerations and technological advancements in wearable EEG devices, emphasizing their numerous benefits in treating epileptic patients and the limitation of designing wearable devices. In conclusion, the integration of multimodal data can offer a comprehensive overview of a patient's health, enabling the implementation of personalized and efficient treatment approaches.

Keywords: Wearable EEG device, Epilepsy patients, Electroencephalography, Signal quality.

تصميم جهاز مخطط كهربائية الدماغ قابل للارتداء وفوائده لمرضى الصرع: مراجعة

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الصرع هو اضطراب عصبي يسبب نوبات متكررة لملايين الأشخاص في جميع أنحاء العالم. يمكن أن تكون أنظمة مخطط كهربية الدماغ التقليدية مفيدة في تشخيص الصرع ومراقبته لكنها مرهقة ومقتصرة على الإعدادات السريرية. لقد حولت أجهزة التخطيط الكهربائي للدماغ القابلة للارتداء إدارة الصرع من خلال توفير إمكانيات المراقبة المستمرة في الوقت الفعلي. تبحث ورقة المراجعة هذه في اعتبارات التصميم والتقدم التكنولوجي في أجهزة مخطط كهربائية الدماغ القابلة للارتداء، مع التركيز على فوائدها في إدارة مرض الصرع والمحددات التي تواجهها عملية تصميم مخطط كهربائية الدماغ القابلة للارتداء. وكاستنتاج، يمكن أن توفر البيانات المأخوذة من وسائط متعددة نظرة عامة شاملة على صحة المريض، مما يتيح تنفيذ أساليب العلاج الشخصية والفعالة.

الكلمات المفتاحية: جهاز مخطط كهربائية الدماغ القابل للارتداء، مرضى الصرع، تخطيط كهربية الدماغ، جودة الإشارة.

1. Introduction:

Epilepsy is a neurological condition impacting about 1% of the global population and millions worldwide **[1-3]**. It is distinguished by recurrent seizures that vary in frequency and intensity, making managing it challenging. Electroencephalography (EEG) has long been used to diagnose and monitor epilepsy, providing valuable insights into the brain's electrical activity during seizures and interictal periods **[4,5]**.

Traditional EEG systems are frequently restricted to clinical settings, necessitating patient visits to healthcare facilities for intermittent monitoring. This limitation limits the continuous monitoring required to capture the full spectrum of seizure patterns and accurately identify potential triggers **[6,7]**. Furthermore, traditional EEG systems can be cumbersome and uncomfortable to use, reducing patient compliance and the overall effectiveness of epilepsy management **[8]**.

The development of wearable EEG devices has resulted in a new era in epilepsy care, allowing for real-time, non-invasive, and continuous monitoring **[9]**. These cutting-edge devices are lightweight, comfortable, and simple, allowing patients to actively participate in their healthcare journey **[10]**. Wearable EEG devices enable healthcare professionals to better understand each patient's unique seizure patterns and responses to treatment by capturing EEG signals over extended periods of time in real-life situations **[11]**. **Fig. 1** shows an example of a wearable EEG device.

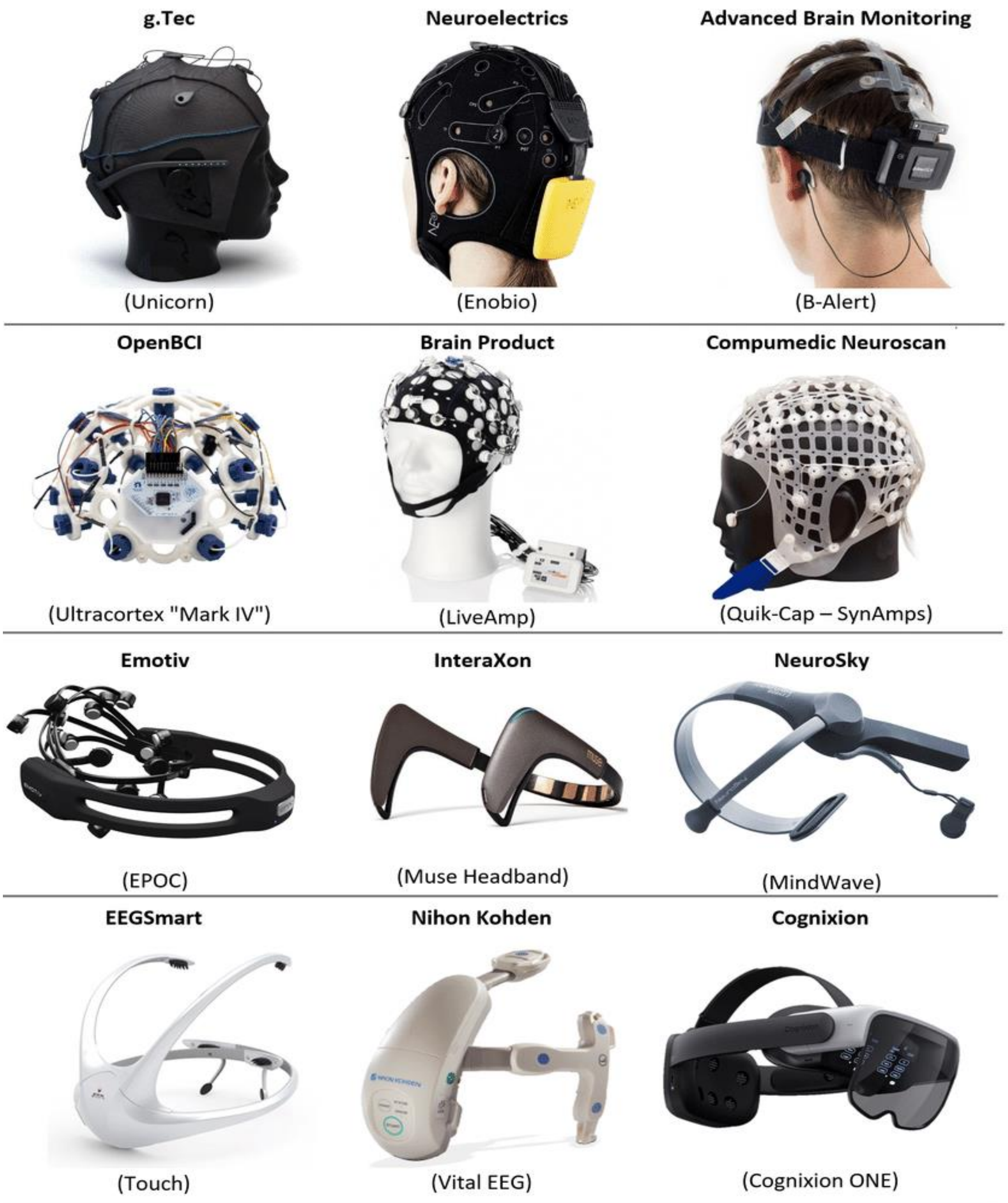


Fig. 1: Wearable EEG device.

The details of some of these devices (For example wearable EEG devices g.Tech, Open BCI, Emotive, and Muse headband.), how to use them for monitoring epilepsy patients, and their cost are explained in **Table 1**.

Table 1: Wearable EEG Devices Details

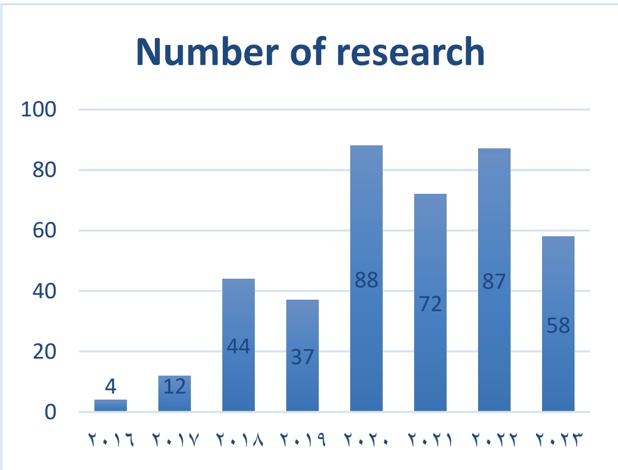
Device	Description	Number of channels	Monitor epilepsy patients	Cost
g.Tec [12]	High-performance medical products for invasive and non-invasive brain use in research and clinical settings.	8/16/32/64 EEG channels are available	• The g.tec EEG system can continuously monitor the patient's brain activity, allowing healthcare professionals to identify and characterize epileptic seizures. The EEG data can help determine the type, duration, and frequency of seizures. • aim to predict epileptic seizures before they occur. By analyzing the EEG patterns that precede seizures, the system may be able to provide an alert or warning to patients or caregivers, allowing them to take preventive measures.	(329-4.950 €)
Open BCI [13-16]	Open BCI provides hardware and software tools for recording brain signals (EEG, EMG, ECG, and more) and experimenting with brain-computer interfaces.	4/8/16 EEG channels are available	By combining the machine learning model with the 16-channel 10-20 system Ultra cortex Mark IV, the user, and their family will be notified if a seizure occurs. The electrode system will be linked to an Open BCI, which will filter raw EEG signals. These signals will be wirelessly transmitted to a Raspberry Pi, which will contain a machine-learning model. If the model detects preictal waveforms in sensor data, indicating the onset of a seizure, the Pi emits a loud, ambulance-like sound. This would alert nearby pedestrians that the user requires assistance.	(885-3450 $)
Emotive [17-19]	EMOTIV has maintained its leadership in wireless EEG innovation, developing solutions for a wide range of applications such as scientific and consumer research, product innovation, and workplace wellness.	2/5/14/32 EEG channels	• Analyze the EEG data collected during the study to observe patterns associated with epileptic seizures. While Emotive headsets are not typically used for medical diagnosis, researchers might observe trends or correlations that could inform further studies or clinical investigations. • explore seizure prediction algorithms using EEG data	(849-2099 $)

			collected from Emotive headsets. It's important to remember that seizure prediction is a complex and challenging task that requires rigorous validation before clinical applications.	
Muse headband [20- 22]	the brain-sensing device developed by Intera Xon. It is a consumer-grade EEG (electroencephalogram) headband designed to measure brainwave activity and provide real-time feedback for meditation and stress management.	multiple EEG sensors that contact the user's forehead (4 channels).	While consumer EEG devices like the Muse headband can measure brainwave activity, they lack the necessary validation and regulatory approvals required for medical applications. As such, they should not be used as a substitute for medical-grade EEG equipment in any medical context, including epilepsy monitoring or seizure prediction.	(295-445 $)

Numerous research studies have been published in scientific journals, conference proceedings, and dissertations that focus on different aspects of wearable EEG devices for example the number of research using open BCI was shown in Table 2.

Table 2: Number of research using open BCI device.

Year	Number of research
2016	4
2017	12
2018	44
2019	37
2020	88
2021	72
2022	87
2023	58



It's important to note that designing a wearable EEG device for medical purposes, especially epilepsy monitoring, requires expertise in medical device development, data processing, and compliance with relevant regulations. Working with a team of medical professionals, engineers, and researchers is crucial to ensure the device's safety, efficacy, and usability for epilepsy patients.

Overall, wearable EEG devices represent a promising paradigm shift in epilepsy management, presenting an opportunity to improve patient well-being, optimize treatment strategies, and advance our understanding of this complex neurological condition. Through this comprehensive review, we aim to shed light on the transformative impact of wearable EEG devices and stimulate further research and development in this crucial area of healthcare technology.

The following is how the rest of the paper is organized: Section II provides design considerations for wearable EEG devices. Section III presents the Benefits of Wearable EEG Devices for Epilepsy Patients. Section IV discusses Challenges and Future Directions. Section V shows the Limitations of Wearable EEG Devices. Finally, Section VI concludes the paper.

2. Design Considerations for Wearable EEG Devices:

2.1 Electrode Placement: Electrode placement is critical for capturing reliable EEG signals **[23]**. Wearable electrodes are dry, flexible, and comfortable, allowing long-term use without discomfort or skin irritation **[24,25]**. **Fig. 2** presents the international 10-20 electrode placement system.

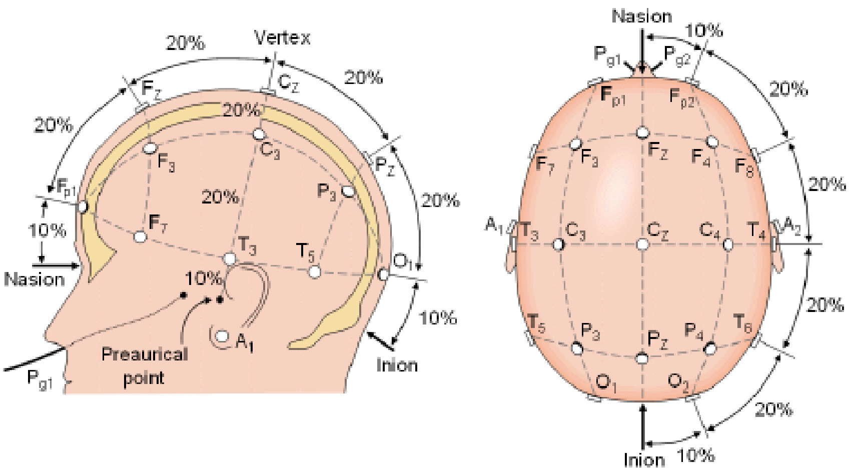


Fig. 2: international 10-20 system.

2.2 Signal Quality: Maintaining signal quality in wearable EEG devices presents challenges due to motion artifacts, ambient noise, and electrode-skin impedance **[26]**. Advances in signal processing and noise reduction techniques have improved signal fidelity **[27]**.

2.3 Power Efficiency: Because wearable EEG devices are designed for continuous monitoring, power efficiency is critical to extending battery life **[28-30]**. Some strategies to address this issue include low-power components, wireless data transmission, and energy-saving algorithms [31].

2.4 Data Storage and Transmission: Wearable EEG devices store and transmit data to a centralized system or cloud platform for analysis and monitoring. Maintaining patient privacy requires secure and efficient data transfer [32].

3. Benefits of Wearable EEG Devices for Epilepsy Patients:

1. Early Seizure Detection: Continuous monitoring with wearable EEG devices allows for the early detection of seizures, providing patients and caregivers with timely alerts. This feature enables proactive responses and lowers the risk of injury during a seizure [33].
2. Seizure Pattern Analysis: Long-term EEG data collected via wearable devices allows for in-depth analysis of seizure patterns, which can aid in identifying triggers and personalizing treatment plans [34].
3. Improved Treatment Compliance: By tracking brain activity and medication adherence, wearable EEG devices enable patients to participate in their treatment actively; increased compliance results in better seizure control and overall health outcomes [35].
4. Patients in faraway locations or with limited access to healthcare facilities can benefit from wearable EEG devices, which enable remote monitoring and telemedicine consultations with healthcare professionals [36].
5. Advances in Research and Treatment: The massive amount of EEG data collected by wearable devices contributes to research efforts to understand epilepsy better. This data-driven approach has the potential to yield novel treatment options and better management strategies [36].

4. Challenges and Future Directions:

- Standardization: Establishing standardized protocols for data acquisition, analysis, and interpretation of wearable EEG devices is essential for practical integration into clinical practice [37].
- Designing User-Friendly Interface: is crucial to encourage patient compliance and engagement with wearable EEG devices [38].
- Data Privacy and Security: Addressing data privacy and security concerns is vital in gaining patients' trust and ensuring the ethical use of EEG data [39].
- Multimodal Integration: Future wearable EEG devices may integrate other physiological sensors better to understand a patient's health status and potential seizure triggers.

Combining EEG data with metrics from heart rate monitors, accelerometers, or other physiological sensors may enable an improved comprehension of the relationship between physical and neurological health, as well as aid in the identification of additional seizure triggers **[40].**

- Furthermore, research and development efforts should focus on enhancing signal quality, reducing motion artifacts, and extending battery life to improve wearable EEG devices' overall performance and usability. Advancements in machine learning algorithms can aid in real-time data analysis, enabling faster and more accurate seizure detection and prediction **[41-42]**.

5. Limitations of Wearable EEG Devices:

Wearable EEG devices provide numerous benefits for epilepsy management **[43]**, but they do have some limitations that must be recognized and addressed:

A. Limited Channel Configurations: To maintain device portability and comfort, wearable EEG devices frequently have fewer electrodes than traditional clinical EEG systems. Because there are fewer channels, the spatial resolution and comprehensiveness of the recorded brain activity may be limited, potentially missing subtle abnormalities or localized epileptic activity **[44]**.

B. Battery Life and Power Efficiency: Continuous monitoring necessitates energy-efficient and long-lasting wearable EEG devices. However, balancing power consumption with the need for prolonged monitoring can be difficult, potentially resulting in limited recording duration and frequent recharging **[45]**.

C. Calibration and Individual Variability: Accurate data collection requires properly calibrating wearable EEG devices. Individual differences in head shape, skin conductivity, and electrode-skin contact can all impact signal quality and consistency. To account for these variations, careful calibration and user-specific adjustments may be required **[46]**.

D. External Device Interference: Wearable EEG devices, especially those that use wireless data transmission, Other electronic devices, or environmental factors may cause interference. To ensure data integrity and reliability, proper shielding and robust communication protocols are required **[47]**.

E. Data Security and Privacy: Continuous monitoring generates much sensitive neurological data. To comply with ethical and legal standards, it is essential to ensure the security of this data. To build patient trust and protect their information, strict data encryption, secure data storage, and clear data ownership policies are required **[48].**

F. Clinical Validation and Standardization: While wearable EEG devices show promise, rigorous clinical validation and standardization of their use are required to ensure their efficacy and reliability. Comparison studies against traditional clinical EEG systems and standardized protocols for data collection and analysis are critical steps in establishing the clinical utility of these devices **[49,50]**.

G. Cost and Accessibility: The high price of wearable EEG devices may prevent widespread adoption, particularly in resource-constrained healthcare settings. Making these devices affordable and accessible to a larger patient population will be critical to their general use **[51]**.

6. Discussion:

Wearable EEG devices represent a significant advancement in the management of epilepsy patients, allowing for a transformative approach to continuous monitoring and personalized care. This review has focused on the numerous advantages these devices bring to the field of epilepsy management.

Wearable EEG devices allow for early seizure detection, providing patients and caregivers with timely alerts that can lead to proactive responses and reduce the risk of injury during a seizure. These devices capture long-term EEG data, allowing for in-depth analysis of seizure patterns, assisting in identifying triggers, and tailoring treatment plans to each patient's specific needs. Furthermore, monitoring patients in real-time allows them to actively participate in their treatment actively, promoting better treatment compliance and, ultimately, better seizure control and overall health outcomes. Wearable EEG devices' remote monitoring and telemedicine capabilities expand the reach of healthcare services to patients in remote or underserved areas. This feature improves access to expert consultations, reduces travel burdens, and promotes ongoing care for those far from specialized epilepsy centers. The wealth of EEG data collected by wearable devices contributes to ongoing research, fueling a better understanding of the complexities of epilepsy. This data-driven approach can open up new treatment options while optimizing current therapeutic strategies, paving the way for better patient outcomes and quality of life.

While wearable EEG devices appear to have promising benefits, challenges remain. Standardizing data acquisition, analysis, and interpretation protocols will ensure consistent and reliable results across devices and clinical settings. To encourage patient acceptance and maintain trust in these technologies, user-friendly interfaces and data privacy and security concerns must be treated.

In the future, integrating wearable EEG devices with other physiological sensors could lead to a more comprehensive understanding of patients' health status and potential seizure triggers. Multimodal data integration can provide a complete picture of a patient's health, allowing for more tailored and effective treatment strategies.

7. Conclusion:

Wearable EEG devices are a potent tool in the modern epilepsy management landscape. Their real-time, continuous monitoring capabilities, combined with the possibility of personalized care and remote access, offer promising avenues for improving patient outcomes and revolutionizing epilepsy care. Wearable EEG devices will undoubtedly play a pivotal role in empowering epilepsy patients and healthcare professionals alike as research and technology advance, bringing us closer to a future of improved seizure management and a better quality of life for those living with epilepsy.

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