



# International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Operating Publisher  
SciFormat Publishing Inc.  
ISNI: 0000 0005 1449 8214

2734 17 Avenue SW,  
Calgary, Alberta, T3E0A7,  
Canada  
+15878858911  
editorial-office@sciformat.ca

---

**ARTICLE TITLE** BROAD APPLICATIONS OF CONSUMER-GRADE EEG DEVICES:  
FROM CLINICAL DIAGNOSTICS TO BRAIN-COMPUTER  
INTERFACES AND SOCIAL SCIENCES – LITERATURE REVIEW

---

**DOI** [https://doi.org/10.31435/ijitss.2\(50\).2026.5446](https://doi.org/10.31435/ijitss.2(50).2026.5446)

---

**RECEIVED** 19 February 2026

---

**ACCEPTED** 05 June 2026

---

**PUBLISHED** 11 June 2026

---

**LICENSE**



The article is licensed under a **Creative Commons Attribution 4.0 International License**.

---

© The author(s) 2026.

This article is published as open access under the Creative Commons Attribution 4.0 International License (CC BY 4.0), allowing the author to retain copyright. The CC BY 4.0 License permits the content to be copied, adapted, displayed, distributed, republished, or reused for any purpose, including adaptation and commercial use, as long as proper attribution is provided.

# **BROAD APPLICATIONS OF CONSUMER-GRADE EEG DEVICES: FROM CLINICAL DIAGNOSTICS TO BRAIN-COMPUTER INTERFACES AND SOCIAL SCIENCES – LITERATURE REVIEW**

**Katarzyna Anna Borzęcka** (Corresponding Author, Email: [kasiaborz13@gmail.com](mailto:kasiaborz13@gmail.com))

Medical Center in Łańcut Sp. z o.o., Łańcut, Poland

ORCID ID: 0009-0007-4084-4370

**Agnieszka Szwed**

MSWiA Hospital, Rzeszów, Poland

ORCID ID: 0009-0003-6395-5365

**Aleksandra Soltys**

University of Rzeszow, Rzeszów, Poland

ORCID ID: 0009-0007-2557-2696

**Daria Aleksandra Warzocha-Żurek**

Clinical Provincial Hospital in Rzeszow, Rzeszów, Poland

ORCID ID: 0009-0005-5756-2404

**Ewa Maria Polewczak-Karp**

Medical Center in Łańcut Sp. z o.o., Łańcut, Poland

ORCID ID: 0009-0006-6411-4826

**Katarzyna Wawrzonek**

Clinical Provincial Hospital in Rzeszow, Rzeszów, Poland

ORCID ID: 0009-0007-6883-422X

**Krzysztof Andryszko**

Clinical Regional Hospital of Saint Jadwiga The Queen in Rzeszów, Rzeszów, Poland

ORCID ID: 0009-0006-6170-5663

**Marcelina Dymon**

University of Rzeszow, Rzeszów, Poland

ORCID ID: 0009-0000-8008-7932

**Natalia Matylda Ziemia-Furgala**

MSWiA Hospital, Rzeszów, Poland

ORCID ID: 0009-0009-5031-3930

**Paulina Krysa**

City Hospital of John Paul II in Rzeszów, Rzeszów, Poland

ORCID ID: 0009-0000-6633-3586

## ABSTRACT

**Research Objective:** This review article aims to assess the rapidly growing market for commercial electroencephalography (EEG) devices and analyze their transition from sterile laboratory conditions to a variety of real-world applications. The paper examines the technological evolution of wireless systems and their effectiveness in clinical, social, and engineering fields.

**Methods:** This article synthesizes the current scientific literature on mobile EEG platforms, such as the Emotiv and Muse systems, and Ear-EEG technologies. Applications are classified by clinical specialties, behavioral monitoring, and novel brain-computer interface (BCI) technologies, while also assessing validation studies against the "gold standard" of medical equipment.

**Results:** The analysis demonstrates that modern consumer-grade EEG devices, supported by machine learning algorithms and artificial intelligence, provide high diagnostic accuracy in detecting sleep disorders, neurodegenerative markers (Alzheimer's and Parkinson's disease), and psychiatric conditions (anxiety, depression, ADHD). Furthermore, the review identifies key advances in emergency neurology, addiction monitoring, and intraoperative safety. Emerging fields such as ethical neuromarketing and BCI-guided assistive robotics demonstrate the technology's potential to improve human-machine interaction and social inclusion for people with disabilities.

**Conclusions:** Commercial EEG devices represent a paradigm shift in personalized healthcare and social science research. Despite persistent challenges related to signal artifacts and data privacy, the democratization of neurotechnology enables continuous monitoring with high ecological validity. Integrating these devices into everyday life offers unprecedented opportunities for early diagnosis, non-pharmacological interventions, and the development of "digital biomarkers" ultimately transforming brain health management and decision-making in the digital age.

---

## KEYWORDS

Consumer-Grade EEG, Wireless EEG Devices, Digital Biomarkers, Mobile Health

---

## CITATION

Katarzyna Anna Borzęcka, Agnieszka Szwed, Aleksandra Soltys, Daria Aleksandra Warzocha-Żurek, Ewa Maria Polewczak-Karp, Katarzyna Wawrzonek, Krystian Andryszko, Marcelina Dymon, Natalia Matylda Ziemia-Furgała, Paulina Krysa. (2026) Broad Applications of Consumer-Grade EEG Devices: From Clinical Diagnostics to Brain-Computer Interfaces and Social Sciences – Literature Review. *International Journal of Innovative Technologies in Social Science*. 2(50). doi: 10.31435/ijitss.2(50).2026.5446

---

## COPYRIGHT

© The author(s) 2026. This article is published as open access under the **Creative Commons Attribution 4.0 International License (CC BY 4.0)**, allowing the author to retain copyright. The CC BY 4.0 License permits the content to be copied, adapted, displayed, distributed, republished, or reused for any purpose, including adaptation and commercial use, as long as proper attribution is provided.

---

## Introduction

Electroencephalography (EEG) is currently one of the most crucial non-invasive methods for monitoring electrophysiological brain function. In recent years, this technique has experienced a renaissance, a direct result of the rapid growth in the technology sector's interest in wearable systems. EEG recording, reflecting bioelectrical processes occurring in the cerebral cortex—specifically, the collective synaptic activity of neurons—allows for the identification of specific patterns of neuronal activity. This is widely used not only in traditional clinical diagnostics and advanced scientific research, but also in modern brain-computer interface (BCI) technologies. [32]

According to a systematic review by Niso et al. (2023), the miniaturization of equipment has led to the emergence of a diverse landscape of wireless devices (Wireless EEG), which effectively overcome the barriers associated with traditional laboratory use. While standard clinical sets typically utilize 19 to 32 channels (and sometimes even 256) and require the use of wet electrodes with conductive gel, modern consumer-grade EEG devices prioritize practicality and ecological validity. Typically offering 2 to 8 channels and utilizing dry electrodes, these systems eliminate the problem of gel drying and the need for cumbersome patient preparation. This enables long-term monitoring in natural conditions—during walking, work, or social interactions. [38]

The growing trust of the scientific community in these mobile solutions is confirmed by the analysis by Sabio et al. (2024), which shows that devices from brands such as Emotiv, Muse, and NeuroSky have evolved from technological gadgets to fully-fledged research tools. Their use in scientific publications spans a broad

spectrum: from the study of emotions and affect, through the analysis of cognitive processes (memory, attention), to the diagnosis of pathological conditions. Although these systems often have lower sampling rates and are more susceptible to motion artifacts than their medical counterparts, their ability to provide reliable data at a low entry threshold (financial and technical) makes them uniquely valuable in the process of the so-called democratization of neuroscience. [41]

Contemporary commercial devices are increasingly adopting discrete forms (form factors), as analyzed in detail by Markov et al. (2024). They classify wearable devices based on electrode placement into: forehead-based systems, in-ear and around-the-ear systems, and the less common neck-based sensors. This diversification of forms allows for long-term studies, impossible with traditional polysomnography (PSG). However, the authors emphasize that despite promising applications, this technology faces challenges such as rigorous validation against PSG, regulatory barriers, privacy of neurophysiological data, and electrode stability during user activity. [31]

Many modern devices now offer data fusion, enabling the integration of EEG with sensors for electromyography (EMG), heart rate (ECG/PPG), electrodermal activity (EDA), and respiratory parameters. This multimodal approach allows for a holistic view of the human physiological state in its natural environment. The aim of this article is to review and systematize the current and future applications of mobile EEG systems in medicine, rehabilitation engineering, and the social sciences, with particular emphasis on their diagnostic and therapeutic potential.

### **Methodology**

Data collection was conducted through a structured review of peer-reviewed scientific literature from 2013 to 2026 and publicly available technical specifications from devices provided by manufacturers such as Emotiv, Interaxon, NeuroSky, and OpenBCI. Scientific sources included studies evaluating wireless EEG performance, signal quality, and clinical or experimental applications (e.g., electroencephalographic monitoring of sleep, cognitive function, and neurological disorders).

The selection criteria for included studies focused on: (1) the use of portable or wireless EEG systems, (2) validation against clinical equipment, and (3) application in real-world or outpatient settings. Both experimental studies and systematic reviews were included to ensure methodological robustness. Furthermore, data analysis included qualitative synthesis and comparative assessment of device characteristics, including the number of channels, signal acquisition quality, usability, and application areas. Additionally, reported performance metrics such as accuracy, reliability, and feasibility across studies were analyzed to assess the strengths and weaknesses of consumer-grade EEG technology.

This approach allowed for a comprehensive assessment of the current state of commercial EEG devices and their potential integration into clinical, research, and everyday monitoring settings.

### **Results**

Modern commercial devices take a variety of forms, from headbands to discreet in-ear sensors. Key technical parameters of the most popular systems are summarized in Table 1.

The availability of diverse sensor formats and the integration of EEG recording with additional physiological parameters (such as heart rate and accelerometry) allows for moving beyond traditional brain activity analysis toward comprehensive monitoring of biological cycles in the home environment. The parameters presented in Table 1, such as high bit resolution and precision in low-frequency bands, constitute the technological foundation for the most crucial and best-documented area of mobile EEG applications: the objectification of sleep architecture and the diagnosis of sleep-related pathologies.

**Table 1.** Technical parameters and applications of selected commercial EEG systems. Own elaboration. [21] [13] [35] [18] [20] [14] [39]

Device name	Electrode location	Number of channels	Sample Rate / Resolution	Key Features and Sensors
<b>Muse 2 / Muse S</b>	Forehead / Behind the ears (dry)	4	256 Hz / 12-bit	Accelerometer, gyroscope, PPG (heart rate), and respiration sensor. Most popular for meditation and sleep.
<b>Emotiv EPOC X</b>	Whole head (felt/salted)	14	128-256 Hz / 14-bit	High spatial resolution (14 electrodes). Often used in emotion and affect research.
<b>NeuroSky MindWave</b>	Forehead (FP1)	1	512 Hz / 12-bit	Single frontal electrode. Focus analysis of attention (Attention) and relaxation (Meditation).
<b>Zmachine Insight+</b>	Behind the ears/neck	1	256 Hz / 16-bit	High precision in the Delta/Theta bands. Designed for clinical sleep assessment at home.
<b>Open-cEEGrid</b>	Peri-auricular (C-shape)	10	Depends on the amplifier	Flexible printed electrode. Minimal motion artifacts, ideal for Mobile Brain Imaging (MoBI) studies.
<b>Emotiv MN8</b>	Earbuds	2	128 Hz / 14-bit	Extremely discreet design. Sensors allow for monitoring cognitive load and stress.
<b>OpenBCI (Cyton)</b>	Any (caps/dry)	8-16	250 Hz / 24-bit	Open-source system. High bit resolution, preferred by programmers and hobbyist scientists.

### 1. The Use of Wireless EEG Devices to Objectify Sleep Disorders and Actively Modulate Nighttime Rest Architecture.

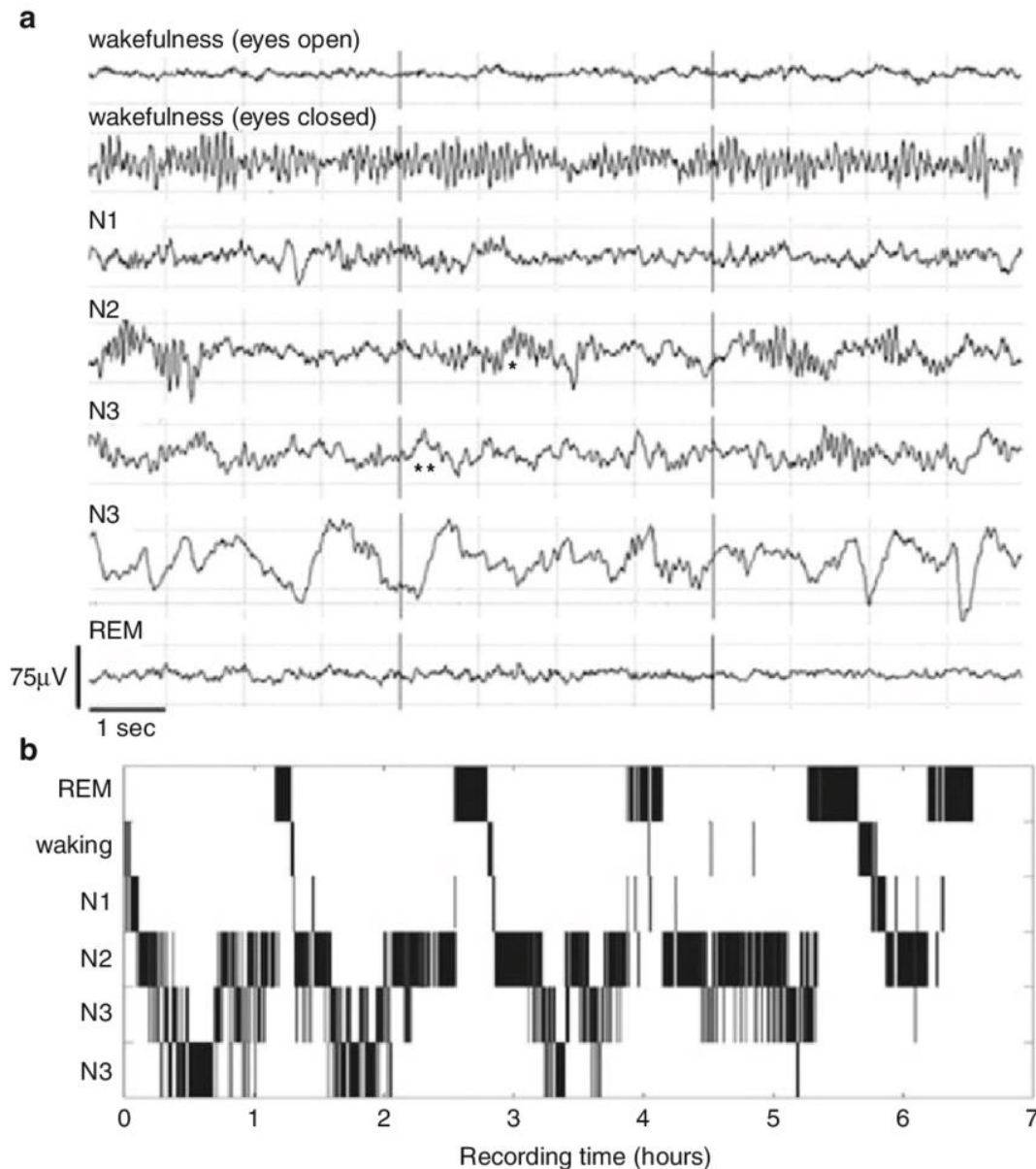
Sleep is an extremely important and dynamic physiological state, performing key adaptive functions necessary for maintaining body homeostasis. Functional theories suggest that it is during nighttime rest that memory consolidation, activation of the glymphatic system (responsible for detoxification of the central nervous system), growth hormone secretion, and precise metabolic regulation of hormones such as cortisol, leptin, and ghrelin occur. Epidemiological studies clearly demonstrate that sleep deprivation below recommended levels is associated with a higher risk of cardiovascular disease and metabolic disorders. Furthermore, these deficits are strongly associated with psychiatric conditions, including depression, anxiety disorders, and an increased risk of burnout. The appropriate sleep duration, adjusted for patient age, according to the American Academy of Sleep Medicine (AASM) guidelines, is presented in Table 2. [2][40]

**Table 2.** Recommended sleep duration by age (AASM).

Age	Optimal sleep time
4-12 months	12-16 h (including naps)
1 - 2 years	11-14 h (including naps)
3-5 years	10-13 h (including naps)
6-12 years	9-12 h
13-18 years	8-10 h
18+ years	7 h

Despite the crucial role of sleep in health, its diagnosis faces technical and logistical barriers. The primary method for recording sleep patterns remains polysomnography, however, it is fraught with high costs and requires hospitalization, which often disrupts the patient's natural rest profile. Advances in bioengineering have led to the development of modern wearable devices equipped with dry forehead or in-ear electrodes (Ear-EEG).

The effectiveness of these mobile solutions is based on their ability to precisely record key neural oscillations that define individual sleep stages. Modern algorithms can recognize unique EEG characteristics, such as sleep spindles and slow waves, in real time, allowing for the generation of a hypnogram without the involvement of a laboratory technician. The characteristics of these signals and their correlation with sleep stages are presented in Figure 1.



**Fig. 1.** "Sleep stages and cycles. (a) EEG waveform during wakefulness with eyes open and closed and during the different stages of sleep. (b) Average times and sequences of sleep cycles during the night". [37]

The use of mobile EEG allows for the identification of a wide spectrum of sleep disorders, which, according to the International Classification of Sleep Disorders (ICSD), are divided into six main categories: insomnia (difficulty falling asleep or staying asleep), sleep-related breathing disorders (e.g., sleep apnea), central hypersomnia (e.g., narcolepsy), circadian rhythm disorders (e.g., jet lag), parasomnias (e.g., somnambulism), and sleep-related movement disorders (e.g., restless legs syndrome – RLS). The use of EEG allows for the objectification of these disorders by analyzing changes in sleep architecture and the power of individual frequency bands, as summarized in Table 3. [15][16]

**Table 3.** Selected sleep disorders and their corresponding EEG changes.

Disorder category	Clinical example	Typical EEG changes
Insomnia	Psychophysiological insomnia	Increased power of Beta and Gamma waves (hyperarousal) during the sleep onset phase; shortening of the deep sleep phase (N3).
Respiratory disorders	Obstructive Sleep Apnea (OSA)	Frequent micro-arousals visible as sudden shifts to higher frequencies; fragmentation of sleep architecture.
Hypersomnia	Narcolepsy type 1	Premature occurrence of REM sleep (SOREMPs) immediately after falling asleep (skipping NREM sleep).
Circadian rhythm disorders	Delayed sleep phase syndrome	Correct waveform, but shifted in time relative to social norms; difficulty initiating N1 phase at desired time.
Parasomnias	Night terrors / Somnambulism	Sudden awakenings from deep sleep (N3) with overlap of wakefulness rhythms (Alpha) with slow wave rhythms (Delta).
Movement disorders	Restless legs syndrome (RLS)	Sleep fragmentation induced by periodic limb movements; increased number of micro-arousals in stages N1 and N2.

Wireless EEG devices enable long-term, objective measurements at home. An example of advanced use of this technology is the study by Hestermann et al. (2024), which tested whether a wireless in-ear EEG device could effectively induce and deepen deep sleep using auditory stimuli.

This study used a proprietary in-ear device equipped with conductive fabric electrodes to monitor the sleep of 15 volunteers. The system analyzed sleep stages in real time and, upon detecting NREM stage 2, triggered stimulation to facilitate the brain's transition to NREM stage 3 (deep sleep). The experimental group received a combination of ASMR sounds and binaural beats at a frequency of 3 Hz, corresponding to Delta waves. [19]

Results of the study by Hestermann et al. confirmed that electrodes placed in the ear canal are capable of reliably recording microvoltage ( $\mu\text{V}$ ) signals and correctly identifying sleep stages according to AASM standards. Importantly, the experimental group observed a significant increase in Delta wave power and an increase in the duration of NREM sleep stage 3 compared to the baseline night, while simultaneously shortening sleep latency (time to fall asleep).

This demonstrates that commercial EEG platforms, integrating machine learning algorithms with sensory stimulation loops, are becoming comprehensive therapeutic tools. They not only allow for monitoring pathologies but also actively support the body's regeneration through conscious "programming" and deepening of slow-wave sleep during daily life.

## **2. Sleep Architecture and Neurodegeneration: The Use of In-Ear and Frontal Systems in Long-Term Population Screening, Including the Detection of Early Markers of Alzheimer's and Parkinson's Diseases.**

As early as 2016, Braley et al. pointed out that the key to understanding neurodegenerative diseases lies not in the high electrode density in the laboratory, but in the continuous measurement provided by discrete commercial devices. The article emphasizes that commercial devices can detect subtle changes in brain rhythms (e.g., changes in alpha and theta wave power) that precede cognitive decline in Alzheimer's and Parkinson's disease. [5]

The article by Kent et al. used the Zmachine Insight+ system, which utilizes three sensors placed behind the ears (mastoid process) and on the neck. The researchers compared sleep recordings in individuals with mild to moderate Alzheimer's disease (AD) and a healthy control group. The measurements were taken in the patients' natural environment (in their own beds) over several nights, a feat nearly impossible with standard clinical equipment. The commercial device was shown to effectively detect that AD patients had significantly less deep sleep (delta waves) than their healthy peers. Furthermore, reduced spectral power in the low-frequency range was observed, which correlates with memory impairment and the progression of neurodegeneration. The study demonstrated that simplified, home EEG is sensitive enough to detect differences in sleep architecture, which can serve as an early biomarker of AD. It is worth noting that this study also revealed discrepancies between what patients reported in their sleep diaries and what was recorded on the EEG. This strongly supports the argument that subjective assessments by patients with NDD are unreliable and require objective monitoring with a wearable device. [25]

An article by Yo-El S. Ju and colleagues examined how specific sleep stages affected the levels of Alzheimer's-related proteins in the cerebrospinal fluid (CSF). They found that just one night of disrupted deep sleep (detected by EEG) caused a measurable increase in CSF amyloid- $\beta$  levels. Furthermore, poorer sleep quality, measured at home with wearable devices in the days preceding the study, correlated with higher Tau protein levels. The study demonstrated that it is not overall sleep duration, but specifically the lack of Delta waves recorded by EEG, that is responsible for the accumulation of toxic proteins in the brain. [23]

Another study demonstrated that a dry electrode inside the ear canal can provide a signal of sufficient quality for advanced biomarker analysis over a long period of time. Thanks to the precision of in-ear EEG, the authors identified specific changes in the microstructure of sleep – patients with Parkinson's and Alzheimer's disease were shown to experience changes in the density and amplitude of sleep spindles. The study suggests that such in-ear devices could become "digital biomarkers," allowing doctors to check monthly whether the disease is progressing, without requiring a hospital visit. The authors emphasize that, thanks to wearable devices, they discovered significant sleep variability in patients with neurodegenerative diseases, which cannot be detected during a single night in the hospital (polysomnography). Furthermore, the study used machine learning algorithms that, based on the raw EEG signal from the ear, were able to distinguish healthy individuals from patients with Parkinson's disease with high accuracy. This suggests that such devices could become a tool for mass, low-cost population screening for the early detection of brain diseases. [24]

## **3. Application of Wireless EEG in Drowsiness Prevention and Public Safety.**

Modern commercial-grade EEG devices are used to monitor conditions critical to public safety, such as drowsiness in vehicle operators.

The development of commercial EEG systems has allowed for the transition from early prototypes to highly integrated platforms monitoring user alertness in real time. Pioneering work by Lin et al. (2014) demonstrated that mobile headsets equipped with dry electrodes can effectively identify driver alertness declines by analyzing spectral power in the alpha and theta bands. These studies demonstrated a strong correlation between changes in EEG and driving performance, laying the foundation for the use of commercial devices in active safety systems. [29]

A decade later, Kaveh et al. (2024) presented the next stage of this evolution, moving measurement points from the traditional cap directly to the ear canal (Ear-EEG). Their wireless platform, utilizing miniature headphones with 3D-printed dry electrodes, allows for the detection of drowsiness with an accuracy exceeding 93%. The use of advanced machine learning (SVM) algorithms enabled diagnostic accuracy comparable to clinical systems, while eliminating the discomfort and stigma associated with wearing visible electrodes on the forehead or back of the head. The study demonstrates that in-ear EEG with dry electrodes is a reliable tool for monitoring behavioral states in real time. This device has enormous potential in safety systems (e.g., for drivers or pilots), offering diagnostic parameters comparable to clinical systems while maintaining complete

discretion and comfort of use. This demonstrates that modern electroencephalography is undergoing a transformation from a purely laboratory technique toward mobile platforms supporting personalized healthcare, and that commercial Ear-EEG is evolving into life-saving systems and finding applications in various sectors of everyday life. [24]

#### **4. Modern EEG Interfaces in Epilepsy Diagnostics and Treatment: From Personalization to Closed-Loop Systems.**

The evolution of commercial EEG devices is opening up entirely new possibilities in the care of epilepsy patients, offering a discreet and effective alternative to cumbersome hospital monitoring. A key development direction is the creation of multimodal systems that combine electrophysiological data from various sources, increasing detection precision. Nielsen et al. (2022) evaluated the effectiveness of a prototype system consisting of an Ear-EEG device (placed behind the ear), a wireless ECG, and an accelerometer. Using machine learning algorithms (SVM), the researchers demonstrated that this sensor synergy allows for the effective identification of correlates of seizure activity, including difficult-to-detect focal seizures without a motor component. Personalization of algorithms based on multimodal data provides the foundation for safe, long-term monitoring of patients in their natural home environment. [36]

The reliability of these simplified systems has been confirmed in rigorous comparative studies with the diagnostic gold standard. Joyner et al. (2024) validated the in-ear EEG system by directly comparing it with intracranial EEG (iEEG). Analysis of over 1,200 hours of recordings showed that despite the limited number of channels, the in-ear device exhibited extremely high sensitivity, allowing for the identification of 100% of seizures visible on iEEG in some patients. The ability to precisely record spike-and-wave discharges with such a small device suggests that commercial in-ear interfaces may soon revolutionize the diagnosis of drug-resistant epilepsy. Zeydabazinezhad et al. (2024) proposed further optimization in this area by introducing personalized in-ear headphones (earbuds) tailored to the individual anatomy of the patient's ear. This solution not only improves wearing comfort but, above all, stabilizes the quality of electrode-skin contact. This, combined with dedicated data pipelines, allows for stable monitoring of brain activity over many days, effectively eliminating artifacts typical of out-of-hospital conditions. [22][49]

The most innovative aspect of mobile EEG, however, is the transition from passive diagnostics to active, closed-loop seizure control. Zou et al. (2024) developed a non-invasive, acoustic brain-computer interface that analyzes the EEG signal in real time and, upon detecting epileptic discharges, immediately triggers specific sound stimulation. This system utilizes the mechanism of neuromodulation of inhibitory pathways in the brainstem, which in tests effectively shortened the duration and intensity of seizures. This solution transforms commercial EEG kits into intelligent "digital medicines" that not only monitor the patient's condition but also independently undertake non-pharmacological interventions in times of danger, thus establishing a new paradigm in the treatment of epilepsy using wearable technologies. [51]

#### **5. Simplified Wireless EEG (swEEG) in Emergency Care: Effective Bedside Diagnostics in the Emergency Department.**

Commercial and simplified EEG systems are finding real, critical applications in emergency medicine, shortening the time to diagnosis.

The article by T.M. Welte et al. presents the results of a study on the use of simplified wireless EEG (swEEG) in the neurological emergency department (nER).

It assesses the usefulness and feasibility of using the CerebAir® 8-channel EEG system by non-EEG technicians (medical students) in patients with impaired consciousness or post-seizure seizures. The analysis included 100 patients (mean age 57.6 years). The swEEG results were compared to a standard, 21-channel routine EEG (rEEG) performed using a 10/20 mode. The authors demonstrated that simplified wireless EEG is a practical and valuable technique that can be quickly implemented by emergency medical personnel in situations where routine EEG is unavailable (e.g., at night or on weekends). swEEG helps avoid underdiagnosis and can expedite the implementation of appropriate treatment. In 94.5% of cases, swEEG detected the same or additional pathological patterns as routine EEG. In 9.3% of patients who did not receive rEEG or received it much later, swEEG revealed significant abnormalities (e.g., status epilepticus, interictal discharges) that could influence immediate treatment decisions. [46]

### **6. Wireless EEG as an Objective Biomarker of Prognosis.**

Modern medical wireless EEG systems are critically important in the diagnosis of acute stroke, where the portability of the equipment allows for bedside assessment before initiating reperfusion therapy. As demonstrated by Ajčević et al. (2021) found that measurements taken directly at the patient's bedside, prior to the implementation of thrombolytic treatment, predict the degree of disability and the final volume of brain damage after 7 days and 12 months. The researchers demonstrated that spectral parameters obtained using wireless technology, such as the delta-to-alpha ratio (DAR), are objective biomarkers that allow for highly accurate prediction of both the volume of the final infarct focus and the patient's long-term functional status 12 months after the incident. Implementation of such solutions in Stroke Units allows for a transition from static neuroimaging to dynamic neurophysiological monitoring. While computed tomography (CT) provides a "static image" of the structure, wireless EEG allows for real-time "functional monitoring" of neuronal viability, which is crucial for personalizing therapeutic strategies in emergency medicine. The conclusion is that mobile EEG is an objective tool supporting the personalization of therapeutic and rehabilitation strategies in emergency situations. [1]

### **7. Digital Psychiatry and Neuroeducation: Objectifying Mental Disorders and Supporting Cognitive Development in Natural Settings.**

The use of commercial EEG systems is establishing a new paradigm in digital psychiatry, offering advanced tools for objectifying mental states, which have traditionally been diagnosed primarily through subjective questionnaire methods. The shift from medicine based on patient self-reports to medicine based on measurable physiological data allows for avoiding errors resulting from defense mechanisms, difficulties with introspection, and self-presentation bias. As demonstrated by Baghdadi et al. (2019), wireless headsets such as the Emotiv EPOC provide a reliable platform for detecting anxiety states in natural social interaction. By using deep autoencoders (AI), researchers achieved over 83% accuracy in anxiety classification, proving that reliable affect assessment is possible from even short, 1-second recording fragments. This means that modern technology allows the creation of early warning systems that can monitor a patient's well-being in real time, alerting them to an impending panic attack or severe stress before they are fully aware of it. [3]

This potential is particularly supported by research on the mental health of young adults, a group particularly vulnerable to mood disorders in the age of intense digitalization. Sakib et al. (2023) demonstrated that the use of the Emotiv EPOC+ kit combined with advanced machine learning algorithms (KNN) allows for the identification of depression with an impressive accuracy exceeding 98%. This study highlights the importance of spectral analysis in the alpha and beta bands, performed using lightweight and aesthetically pleasing equipment that does not stigmatize the user. Such high classification precision suggests that consumer-grade devices may soon become standard screening tools, enabling mass population screening for depression without the need for highly specialized technical staff in the initial diagnostic phase. [42]

The potential of mobile EEG is also expanding into the realm of neuroaesthetics and the study of anhedonia – a key yet difficult-to-objectively measure symptom of depression, characterized by the inability to experience pleasure. Chabin et al. (2020) confirmed that mobile headsets can precisely record markers of reward system activation (e.g., so-called musical chills), manifested by increased power in theta bands and specific activity in the prefrontal cortex. The ability to study the "brain in action" outside of a sterile laboratory allows for a much deeper understanding of the affective mechanisms underlying mood disorders. However, a key element of success in psychiatry is advanced signal processing, which overcomes hardware limitations. Bashivan et al. (2016) demonstrated that deep belief networks (DBNs) can effectively distinguish states of cognitive engagement from emotional responses, even with the lower signal resolution typical of wearable devices. This allows for the personalization of psychological care by tailoring therapy to the patient's individual neural reactivity. [4][7]

In the field of neurodevelopmental and emotional disorders in children, mobile EEG is becoming a "bridge" connecting neural theory with school practice. As Lenartowicz and Loo (2014) point out, electrophysiological indicators such as theta-to-beta wave power ratio (TBR) are becoming increasingly reliable markers of attention in ADHD. This is confirmed by recent validation studies by Khng and Mane (2020), which demonstrated that devices such as the Emotiv EPOC+ can effectively monitor the effects of psychological interventions, such as breathing training to reduce test anxiety, directly in the classroom. The ability to detect changes in attention control at the neural level before they become measurable in behavior makes commercial EEG a powerful tool for assessing the effectiveness of early therapies. Integrating these systems into everyday life – from a child building self-confidence at school to an adult struggling with social anxiety – offers objective, non-pharmacological support that has the potential to revolutionize contemporary approaches to mental health prevention and care across society. [27][26]

### **8. Objectifying the Treatment of Alcohol and Opioid Addictions Using Wearable Technology and Deep Learning Algorithms.**

The use of wireless, commercial EEG systems opens groundbreaking perspectives in the monitoring of patients with substance use disorders (SUDs), offering tools for objectifying conditions that have previously been based almost exclusively on subjective clinical assessment. As Dey (2022) points out, implementing advanced algorithms on wearable devices (OMAD system) allows for the real-time detection of mental and behavioral anomalies directly on the mobile device, enabling early identification of crisis moments that signal the risk of relapse. [9]

This is particularly important for diagnostic purposes in the case of chronic substance abuse, such as alcohol, which leaves lasting and measurable neurophysiological "imprints" in the brain. Research by Li and Wu (2022) demonstrates that hybrid deep learning models can almost accurately distinguish addicts from controls based solely on EEG signal analysis. These changes in bioelectrical activity have a profound basis in brain structure. As Zhang et al. (2021) demonstrated, sleep architecture disturbances visible on EEG—such as shortened deep sleep (N3) and REM sleep—are directly linked to gray matter atrophy in the cerebral cortex in alcohol-dependent individuals. This phenomenon makes EEG parameters not only a diagnostic tool but also an objective indicator of the degree of alcohol-induced neurodegeneration. [28][50]

This diagnostic tool is complemented by solutions dedicated to the most challenging phases of treatment, namely opioid withdrawal. Dunn et al. (2022) demonstrated that wireless EEG monitors are well-tolerated by patients during detoxification and provide data on sleep efficiency that closely correlates with the severity of physical withdrawal symptoms. This allows physicians to precisely monitor the course of treatment in real time, allowing for a faster response to disturbances that could lead to treatment discontinuation and relapse. [12]

### **9. Patient Monitoring Under Anesthesia and Intraoperative Safety.**

Another key area for the implementation of mobile EEG solutions (commercial EEG devices) is perioperative medicine, with particular attention to the specific needs of pediatric patients. As Yuan et al. (2024) point out, intraoperative monitoring of electrophysiological brain activity in children enables precise titration of anesthetic doses, which directly minimizes the risk of burst suppression and postoperative delirium. However, the integration of simplified, wireless EEG systems into anesthesia protocols emphasizes the need to consider neurodevelopmental differences in signal analysis algorithms, as the characteristics of alpha and beta bands evolve with the patient's age. According to Manohar et al. (2024), such an individualized approach allows for early detection of ischemic events and silent epileptic activity, which might otherwise remain undetected in a critically ill patient. Moreover, analysis of the relationship between EEG recordings and the occurrence of emergence delirium suggests that portable EEG systems could also be used during the recovery phase, allowing for the prediction and prevention of acute postoperative arousal reactions. Implementing these solutions, similar to home neuropathic pain therapy, represents a significant step towards personalized and safer neurological care (brain health), delivered using modern brain-machine interfaces that combine clinical precision with the portability of commercial-grade devices. [47][30]

### **10. An Innovative Approach to the Diagnosis and Treatment of Chronic Pain Using Wearable Systems.**

The contemporary evolution of consumer-grade EEG devices extends far beyond simple diagnostics to encompass increasingly broader and more promising applications in non-pharmacological pain management. The scientific foundation for this form of intervention is the precise identification of objective electrophysiological biomarkers, which, as it turns out, transcend traditional fields of neurology and affect a wide spectrum of inflammatory conditions.

In their systematic literature review, Mussigmann et al. (2022) demonstrated that neuropathic pain is not merely a subjective experience but has a measurable representation in the brain; it is characterized by reproducible changes in the resting EEG recording, such as a marked increase in the power of theta waves and a slowing of the peak frequency of the alpha rhythm. These phenomena, closely linked to the mechanism of so-called thalamocortical dysrhythmia, provide a starting point for designing targeted interventions. De Blasio et al. (2024) identified similar, unique "neural signatures" in patients with endometriosis. Their study revealed pathologically enhanced delta-beta coupling, which correlated directly with the severity of subjective pelvic pain, suggesting that mobile EEG systems could serve as a precise tool for monitoring inflammation and pain conditions previously unrelated to neurobiology. [33][8]

Understanding these patterns allows for the implementation of interactive neurofeedback interventions delivered using affordable commercial devices. The effectiveness of this approach in the home setting was confirmed by Mussigmann et al. (2025), who demonstrated that wireless EEG headsets enabled patients to effectively and independently reduce pain through conscious modulation of their own alpha and theta rhythms. The clinically significant reductions in pain reported by participants provide definitive evidence that even in chronic conditions, the brain retains a plastic capacity to reorganize and permanently change its activity patterns with regular training. In light of this data, consumer-grade devices are no longer considered mere gadgets, but are becoming sufficiently precise mobile therapeutic systems that can truly support and complement traditional neurological treatment regimens.[34]

### **11. Multi-parameter glucose monitoring and sleep safety.**

The use of commercial EEG devices in the field of metabolic diseases creates new opportunities for personalized medicine, where sleep monitoring becomes a key element of patient management outside the clinic. A study conducted by Brandt R. et al. (2021) aimed to objectively verify the relationship between the quality of nighttime rest and glycemic stability. For this purpose, a mobile EEG system (Zmachine Insight+) was used, which patients with type 1 diabetes self-administered in their homes for up to 15 nights. Glucose levels were simultaneously recorded using continuous glucose monitoring (CGM) systems. Analysis of the data obtained showed that objective sleep parameters – such as the duration of the deep sleep phase and the number of awakenings – are directly correlated with next-day glucose variability. Integrating wireless neurological sensors with CGM systems therefore allows for the creation of multi-parameter wearable diagnostics, which allows patients to better understand the impact of the circadian cycle on their metabolic indicators. A key aspect of the use of these devices is their role in preventing life-threatening conditions, particularly dangerous nocturnal hypoglycemia. As indicated by a systematic review by Diouri et al. (2021), a drop in blood glucose levels triggers a cascade of electrophysiological changes in the brain, known as neuroglycopenia. The studies included in the review focused on identifying specific shifts in the EEG power spectrum: as glycemia decreases, there is a pathological increase in the power of low-frequency bands (delta and theta) while the alpha rhythm is suppressed. The authors emphasize that modern, commercial EEG sets, despite their simplified design, are able to record these changes faster than traditional biochemical measurements. By using machine learning algorithms in mobile devices, these discrete sensors can act as a "smart alarm" that detects impending hypoglycemia at the neuronal level. This synergy of mobile technologies provides patients with a level of safety unattainable with standard methods, transforming commercial EEG sets into professional tools supporting daily life with chronic disease. [6][11]

### **12. The Impact of Gestational Diabetes on Early Neurological Development in Newborns.**

The use of mobile EEG technologies is also justified in the very early stages of human life, allowing for the non-invasive identification of neurodevelopmental markers in newborns exposed to an abnormal metabolic environment in the womb. A study by Shuffrey et al. (2025) analyzed the impact of gestational diabetes mellitus (GDM) on the electrophysiological activity of the brain in healthy, full-term newborns. Using EEG recordings recorded during natural sleep (so-called natural sleep) in the third week of life, the researchers demonstrated that GDM significantly moderates the relationship between birth weight and brainwave spectral power.

Particular differences were noted in the theta band, where the interaction between maternal diabetes and newborn weight was most pronounced in the parietal and occipital regions of the cerebral cortex. These changes, observed during active sleep, may constitute an early biomarker of altered neural network development in children at metabolic risk. The ability to conduct such studies in a home environment, without subjecting infants to stressful clinical procedures, highlights the advantage of mobile EEG systems over traditional stationary equipment. Integrating knowledge from gestational diabetes and developmental neurobiology using wearable technology paves the way for early prevention and monitoring of children at risk for long-term neurodevelopmental effects. [43]

### 13. Studying complex sensory-motor interactions.

Another important argument for implementing commercial and mobile EEG systems in scientific research is their ability to operate in conditions requiring the user to engage in natural, often intense, motor activity. Groundbreaking evidence for this thesis is provided by the study by Zamm et al. (2017), who successfully validated a wireless EEG system (the study used the Smarting mBrainTrain system) during dynamic piano performances. They demonstrated that modern wearable devices, despite their lack of shielding and the presence of movement artifacts, enable the extraction of precise electrophysiological parameters, such as evoked potentials (ERPs) and neuronal oscillations correlated with the individual performer's tempo. The ability to maintain high temporal resolution while eliminating physical constraints (e.g., cables) makes these devices useful not only in neuroaesthetics but, above all, in the study of complex sensory-motor interactions. This success opens new perspectives for patients with motor and neurodegenerative disorders, enabling the monitoring of their brain activity during unrestricted daily activities, a feat previously unattainable with stationary clinical equipment. [48]

### 14. Studying Emotions and Pleasure in Natural Environments.

The use of commercial EEG headsets also opens new doors to understanding the neurobiological basis of human emotions and aesthetic experiences. An example is the study conducted by Chabin et al. (2020), which tested the reliability of mobile headsets (Emotiv EPOC) in assessing the pleasure of listening to music. The researchers demonstrated that inexpensive, wireless devices are capable of recording specific marker changes in brain activity—such as so-called musical chills—that correlate with dopamine release in the reward system. The ability of these devices to identify increases in theta-band power and changes in the prefrontal cortex during the experience of strong emotions demonstrates that mobile EEG allows for the study of the "brain in action" outside of the sterile clinical environment. This allows scientists to better understand how complex affective processes shape our everyday behaviors, a process previously limited by the necessity of sitting still in a laboratory. [7]

### Discussion

The presented literature review demonstrates that contemporary EEG technology has undergone a fundamental transformation – from exclusively stationary equipment towards mobile platforms with high ecological validity. Analysis of results in areas such as sleep diagnostics (Hestermann et al., 2024), early detection of neurodegenerative diseases (Kent et al., 2024), and monitoring critical conditions in vehicle operators (Kaveh et al., 2024) clearly indicates that consumer-grade devices offer diagnostic accuracy that often exceeds 90% of the clinical gold standard. [19][25][24]

The key conclusion from the analysis is that it is not the density of electrodes, but the continuity of measurement in the patient's natural environment that constitutes the breakthrough value of wearable systems. As demonstrated in the context of Alzheimer's disease, subjective patient diaries often differ from objective bioelectrical recordings, making mobile EEG an indispensable tool in objectifying disease processes (Ju et al., 2021). Furthermore, integrating machine learning algorithms (e.g., SVM, KNN) with simplified electrode arrays allows for the identification of digital biomarkers that are invisible to traditional visual analysis by a technician. [23]

However, the limitations of this technology must be duly addressed. Despite advanced noise filtering methods (Bashivan et al., 2016), commercial devices are still more susceptible to muscle and movement artifacts than medical systems with conductive gel. The stability of dry electrode contact with the skin during intense physical activity remains an engineering challenge, which may limit their use in certain sports medicine or emergency medical scenarios. [4]

Another important aspect addressed in publications (Markov et al., 2024) is the regulatory barriers and ethical issues related to the privacy of neurophysiological data. As EEG becomes a component of everyday brain health monitoring, it is necessary to develop standards for protecting "neuroprivacy" to prevent unauthorized interpretation of users' affective states or intentions by third parties. [31]

In summary, despite technical and ethical challenges, wireless EEG systems are defining a new paradigm in personalized medicine. The transition from passive monitoring to closed-loop systems capable of non-pharmacological interventions (e.g., in epilepsy or pain management) represents a milestone in the development of digital therapeutics.

A natural consequence of this transformation is the expansion of applications of mobile EEG systems beyond traditional medical areas. Progress in device miniaturization, multimodal sensor integration, and the

development of artificial intelligence algorithms indicate that in the coming years, this technology will play an increasingly important role not only in diagnostics and therapy, but also in human-machine interactions, social behavior analysis, and cognitive optimization.

The following are the most important development directions and future applications of wireless EEG systems, which go beyond current clinical and research standards.

### **1. Thought-Assisted Mobility: Controlling Robots and Assistive Devices**

A key application area for wireless EEG systems is rehabilitation engineering, which seeks to bypass physical communication barriers by directly connecting the brain to external devices (Brain-Computer Interface – BCI). As demonstrated in the Shyaa project (2018), the use of portable EEG sensors enables the creation of adaptive brain-robot interfaces that convert bioelectrical activity patterns into specific control commands. This process relies on multi-stage signal translation: from recording brainwaves generated during movement intention (e.g., imagining moving a hand), through advanced computer analysis, to command execution via external hardware. These systems use Bluetooth technology to transmit data from an off-the-shelf sensor to a computing platform, which, in this study, enabled remote control of a robotic arm and a mobile robot.

The foundation of these solutions' effectiveness is the ability of algorithms to recognize specific neural signatures corresponding to specific intentions, such as "I want to move my left hand" or "I want to move forward." Using phenomena such as motor imagery, the computer learns to detect patterns of motor cortex activity and translate them into digital control instructions. In clinical practice, this allows the creation of bionic prosthetic limbs in which the thought of closing a hand almost instantly translates into the physical closing of the fingers of a mechanical gripper. A similar mechanism is used in smart wheelchairs, where a paralyzed person can independently control the direction and turns of the device by focusing on specific symbols or visualizing movement.

The use of commercial-grade devices in these scenarios is particularly important due to their low weight and ease of configuration, which allows for the integration of control systems in the patient's home environment. Modern BCI systems are currently evolving towards intelligent assistants that, by fusion of EEG data and environmental sensors, can increase the safety and precision of movement in public spaces. This approach not only makes it easier for operators to control robots in difficult conditions but, above all, supports people with profound motor disabilities in regaining independence, which is a significant step towards full social inclusion. [44]

### **2. Neuromarketing and Neuroeconomics: Beyond Declarative Consumer Attitudes**

The evolution of commercial EEG devices is opening new horizons in the study of business ethics and market behavior, providing insight into decision-making processes occurring beyond consumer awareness. Traditional market research methods based on declarations are often subject to self-presentation bias; however, as demonstrated by Di Gruttola et al. (2021), frontal alpha asymmetry (FAA) is an objective biomarker of trust and investment attitudes. Left-sided frontal activation reflects approach motivation and brand acceptance, while right-hemisphere dominance suggests withdrawal and distrust. [10]

The use of wireless EEG systems allows for an objective assessment of brain responses to honest vs. manipulative advertising. When consumers encounter offers inconsistent with social values (e.g., greenwashing), the brain generates specific signals in the delta and theta bands, while increased activity in the beta band signals high cognitive load resulting from analyzing the manipulative message. This, as suggested by Fronza and Angioletti (2020), allows for the study of purchasing decisions related to social values, allowing for the development of a genuine ethical brand strategy based on consumers' real emotional engagement, not just their declarations. [17]

### **3. Psychological Research in the Natural Environment: VR and Economic Games**

Wireless EEG removes the barriers of traditional laboratories, enabling the study of group dynamics and moral decisions in real time. The use of mobile systems combined with virtual reality (VR) simulations creates unique conditions for observing brain responses in crisis or socially complex situations, while maintaining the user's full freedom of movement. In the context of economic games and moral dilemmas, wireless EEG allows for the monitoring of deliberative (deliberative) and affective (emotional) processes as they occur. Increased activity in parietal regions observed during altruistic behavior suggests that mobile technologies can serve as a tool for mapping "empathy in action." The stability of neurometrics under such conditions, confirmed by Vincenzo et al. (2026), allows for reliable inferences about social processes occurring during complex interpersonal interactions. [45]

#### 4. Decision-Making Training and Neurofeedback: Engineering Mental Resilience

A recent, highly promising application of commercial EEG systems is their use in neurofeedback protocols aimed at optimizing cognitive processes. Real-time data can be used to train emotion control when making difficult decisions. By learning to consciously modulate their own brain rhythms (e.g., increasing the power of alpha waves to achieve a state of relaxation), users can develop the ability to remain calm in situations of high moral or professional stress.

These systems also support improved concentration when analyzing complex problems. Users receive immediate feedback on their attention levels, allowing them to train their brains to process information more effectively. This non-pharmacological support, delivered via discreet wearable devices, transforms EEG from a passive monitor into an active tool for developing "cognitive muscles." This is particularly important in professions requiring high mental resilience and decision-making precision, offering a method for building lasting competencies in neurophysiological self-regulation.

#### Conclusion

**Summary and Development Prospects:** This review demonstrates that commercial-grade EEG devices have ceased to be the domain of enthusiasts and have become fully-fledged tools supporting modern medicine, psychology, and engineering. From detecting early biomarkers of neurodegenerative diseases in the comfort of the home, to saving lives in emergency departments, to controlling advanced prosthetics – mobile electroencephalography democratizes access to knowledge about the human brain. Further validation of artificial intelligence algorithms and ensuring the privacy of neurophysiological data remain key challenges. Nevertheless, integrating EEG with everyday wearable devices paves the way for a future in which personalized mental and physical health care is accessible to everyone, regardless of laboratory barriers.

**Conflict of interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

#### REFERENCES

1. Ajčević, M., Furlanis, G., Naccarato, M., Polverino, P., Marsich, A., Sulligoi, G., & Manganotti, P. (2021). Hyperacute EEG alterations predict functional and morphological outcomes in thrombolysis-treated ischemic stroke: A wireless EEG study. *Medical & Biological Engineering & Computing*, 59(1), 121–129. <https://doi.org/10.1007/s11517-020-02280-z>
2. American Academy of Sleep Medicine. (2015, June 1). *Seven or more hours of sleep per night: A health necessity for adults*. <https://aasm.org/seven-or-more-hours-of-sleep-per-night-a-health-necessity-for-adults/>
3. Baghdadi, A., Aribi, Y., Fourati, R., Halouani, N., Siarry, P., & Alimi, A. M. (2019). DASPS: A database for anxious states based on a psychological stimulation. *arXiv*. <https://doi.org/10.48550/arXiv.1901.02942>
4. Bashivan, P., Rish, I., & Heisig, S. (2016). Mental state recognition via wearable EEG. *arXiv*. <https://doi.org/10.48550/arXiv.1602.00985>
5. Braley, T. J., & Boudreau, E. A. (2016). Sleep disorders in multiple sclerosis. *Current Neurology and Neuroscience Reports*, 16(5), Article 50. <https://doi.org/10.1007/s11910-016-0649-2>
6. Brandt, R., Park, M., Wroblewski, K., Arana, A. C., Isola, M. S., & Tansey, M. (2021). Sleep quality and glycaemic variability in a real-life setting in adults with type 1 diabetes. *Diabetologia*, 64(10), 2159–2169. <https://doi.org/10.1007/s00125-021-05500-9>
7. Chabin, T., Gabriel, D., Haffen, E., Moulin, T., & Pazart, L. (2020). Are the new mobile wireless EEG headsets reliable for the evaluation of musical pleasure? *PLOS ONE*, 15(12), Article e0244820. <https://doi.org/10.1371/journal.pone.0244820>
8. De Blasio, F. M., Love, S., Barry, R. J., Wassink, K., Cave, A. E., Armour, M., & Steiner-Lim, G. Z. (2023). Frontocentral delta-beta amplitude coupling in endometriosis-related chronic pelvic pain. *Clinical Neurophysiology*, 149, 146–156. <https://doi.org/10.1016/j.clinph.2023.02.173>
9. Dey, E., & Roy, N. (2022). OMAD: On-device mental anomaly detection for substance and non-substance users. *arXiv*. <https://doi.org/10.48550/arXiv.2204.07038>
10. Di Gruttola, F., Malizia, A. P., D'Arcangelo, S., Lattanzi, N., Ricciardi, E., & Orfei, M. D. (2021). The relation between consumers' frontal alpha asymmetry, attitude, and investment decision. *Frontiers in Neuroscience*, 14, Article 577978. <https://doi.org/10.3389/fnins.2020.577978>
11. Diouri, O., Cigler, M., Vettoretti, M., Mader, J. K., Choudhary, P., & Renard, E. (2021). Hypoglycaemia detection and prediction techniques: A systematic review on the latest developments. *Diabetes/Metabolism Research and Reviews*, 37(7), Article e3449. <https://doi.org/10.1002/dmrr.3449>

12. Dunn, K. E., Finan, P. H., Huhn, A. S., Gamaldo, C., Bergeria, C. L., & Strain, E. C. (2022). Wireless electroencephalography (EEG) to monitor sleep among patients being withdrawn from opioids: Evidence of feasibility and utility. *Experimental and Clinical Psychopharmacology*, 30(6), 1016–1023. <https://doi.org/10.1037/pha0000483>
13. Emotiv Inc. (n.d.-a). *EPOC X: 14-channel wireless EEG headset*. Retrieved March 19, 2026, from <https://www.emotiv.com/pl/epoc-x>
14. Emotiv Inc. (n.d.-b). *MN8: Enterprise brain-sensing earbuds*. Retrieved March 19, 2026, from <https://www.emotiv.com/pl/mn8>
15. Encyclopaedia Britannica. (n.d.-a). *Sleep*. Retrieved March 19, 2026, from <https://www.britannica.com/science/sleep>
16. Encyclopaedia Britannica. (n.d.-b). *Sleep: Pathological aspects*. Retrieved March 19, 2026, from <https://www.britannica.com/science/sleep/Pathological-aspects>
17. Fronda, G., Angioletti, L., & Balconi, M. (2024). EEG correlates of moral decision-making: Effect of choices and offers types. *AJOB Neuroscience*, 15(3), 191–205. <https://doi.org/10.1080/21507740.2024.2306270>
18. General Sleep Corp. (n.d.). *Zmachine Insight+: Clinical-grade sleep EEG monitor*. Retrieved March 19, 2026, from <https://www.generalsleep.com/zmachine-insight.html>
19. Hestermann, E., Schreve, K., & Vandenheever, D. (2024). Enhancing deep sleep induction through a wireless in-ear EEG device delivering binaural beats and ASMR: A proof-of-concept study. *Sensors*, 24(23), Article 7471. <https://doi.org/10.3390/s24237471>
20. Holtze, B., Rosenkranz, M., Jaeger, M., Debener, S., & Mirkovic, B. (2022). Ear-EEG measures of auditory attention to continuous speech. *Frontiers in Neuroscience*, 16, Article 869424. <https://doi.org/10.3389/fnins.2022.869426>
21. Interaxon Inc. (n.d.). *Muse 2: Brain sensing headband*. Retrieved March 19, 2026, from <https://choosemuse.com/products/muse-2>
22. Joyner, M., Hsu, S. H., Martin, S., & Shafi, M. M. (2024). Using a standalone ear-EEG device for focal-onset seizure detection. *Bioelectronic Medicine*, 10, Article 4. <https://doi.org/10.1186/s42234-023-00135-0>
23. Ju, Y. S., Ooms, S. J., Sutphen, C., Macauley, S. L., Zangrilli, M. A., Jerome, G., & Holtzman, D. M. (2017). Slow wave sleep disruption increases cerebrospinal fluid amyloid- $\beta$  levels. *Brain*, 140(8), 2104–2111. <https://doi.org/10.1093/brain/awx148>
24. Kaveh, R., Schwendeman, C., Pu, L., Ogbeide, O., Al-Aswad, L., & Arias, M. (2024). Wireless ear EEG to monitor drowsiness. *Nature Communications*, 15, Article 6520. <https://doi.org/10.1038/s41467-024-48682-7>
25. Kent, B. A., Casciola, A. A., Carlucci, S. K., Chen, M., Stager, S., Mirian, M. S., & Nygaard, H. B. (2022). Home EEG sleep assessment shows reduced slow-wave sleep in mild–moderate Alzheimer’s disease. *Alzheimer’s & Dementia: Translational Research & Clinical Interventions*, 8(1), Article e12347. <https://doi.org/10.1002/trc2.12347>
26. Khng, K. H., & Mane, R. (2020). Beyond BCI—Validating a wireless, consumer-grade EEG headset against a medical-grade system for evaluating EEG effects of a test anxiety intervention in school. *Advanced Engineering Informatics*, 45, Article 101106. <https://doi.org/10.1016/j.aei.2020.101106>
27. Lenartowicz, A., & Loo, S. K. (2014). Use of EEG to diagnose ADHD. *Current Psychiatry Reports*, 16(11), Article 498. <https://doi.org/10.1007/s11920-014-0498-0>
28. Li, H., & Wu, L. (2022). EEG classification of normal and alcoholic by deep learning. *Brain Sciences*, 12(6), Article 778. <https://doi.org/10.3390/brainsci12060778>
29. Lin, C. T., Chuang, C. H., Huang, C. S., Tsai, S. F., Lu, S. W., & Chen, Y. H. (2014). Wireless and wearable EEG system for evaluating driver vigilance. *IEEE Transactions on Biomedical Circuits and Systems*, 8(2), 165–176. <https://doi.org/10.1109/TBCAS.2014.2316224>
30. Manohara, N., Ferrari, A., Greenblatt, A., Berardino, A., Peixoto, C., Duarte, F., & Lobo, F. A. (2025). Electroencephalogram monitoring during anesthesia and critical care: A guide for the clinician. *Journal of Clinical Monitoring and Computing*, 39(2), 315–348. <https://doi.org/10.1007/s10877-024-01250-2>
31. Markov, K., Elgendy, M., & Menon, C. (2024). EEG-based headset sleep wearable devices. *Communications Medicine*, 4, Article 13. <https://doi.org/10.1038/s44328-024-00013-y>
32. Mihajlović, V., Grundlehner, B., Vullers, R., & Penders, J. (2015). Wearable, wireless EEG solutions in daily life applications: What are we missing? *IEEE Journal of Biomedical and Health Informatics*, 19(1), 6–21. <https://doi.org/10.1109/JBHI.2014.2328317>
33. Mussigmann, T., Bardel, B., Créange, A., Senova, S., Goujon, C., Gendre, T., & Lefaucheur, J. P. (2025). Relieving chronic neuropathic pain with EEG-neurofeedback. *European Journal of Neurology*, 32(9), Article e70363. <https://doi.org/10.1111/ene.70363>
34. Mussigmann, T., Bardel, B., & Lefaucheur, J. P. (2022). Resting-state electroencephalography (EEG) biomarkers of chronic neuropathic pain: A systematic review. *NeuroImage*, 258, Article 119351. <https://doi.org/10.1016/j.neuroimage.2022.119351>
35. NeuroSky Inc. (n.d.). *MindWave: Mobile brainwave starter kit*. Retrieved March 19, 2026, from <https://neurosky.com/neurosky-products/mindwave-headset/>

36. Nielsen, J. M., Zibrandtsen, I. C., Masulli, P., Sørensen, T. L., Andersen, T. S., & Kjær, T. W. (2022). Towards a wearable multi-modal seizure detection system in epilepsy: A pilot study. *Clinical Neurophysiology*, *136*, 40–48. <https://doi.org/10.1016/j.clinph.2022.01.005>
37. Nir, Y., Massimini, M., Boly, M., & Tononi, G. (2013). Sleep and consciousness. In G. Tononi (Ed.), *Neuroimaging of consciousness* (pp. 133–182). Springer. [https://doi.org/10.1007/978-3-642-37580-4\\_9](https://doi.org/10.1007/978-3-642-37580-4_9)
38. Niso, G., Romero, E., Moreau, J. T., Araujo, A., & Krol, L. R. (2023). Sleep stages and cycles [Figure]. In *Wireless EEG: A survey of systems and studies*. *NeuroImage*, *269*, Article 119895. <https://doi.org/10.1016/j.neuroimage.2022.119895>
39. OpenBCI Inc. (n.d.). *Cyton Board: 8-channel neural interface*. Retrieved March 19, 2026, from <https://docs.openbci.com/GettingStarted/Boards/CytonGS/>
40. Paruthi, S., Brooks, L. J., D'Ambrosio, C., Hall, W. A., Kotagal, S., Lloyd, R. M., & Wise, M. S. (2016). Consensus statement of the American Academy of Sleep Medicine on the recommended amount of sleep for healthy children: Methodology and discussion. *Journal of Clinical Sleep Medicine*, *12*(11), 1549–1561. <https://doi.org/10.5664/jcsm.6288>
41. Sabio, J., Williams, N. S., McArthur, G. M., & Badcock, N. A. (2023). A scoping review on the use of consumer-grade EEG devices for research. *PLOS ONE*, *18*(9), Article e0291186. <https://doi.org/10.1371/journal.pone.0291186>
42. Sakib, N., Islam, M. K., & Faruk, T. (2023). Machine learning model for computer-aided depression screening among young adults using wireless EEG headset. *Computational Intelligence and Neuroscience*, *2023*, Article 1701429. <https://doi.org/10.1155/2023/1701429>
43. Shuffrey, L. C., Pini, N., Mei, H., Rodriguez, C., Gimenez, L. A., Barbosa, J. R., & Fifer, W. P. (2022). Maternal gestational diabetes mellitus (GDM) moderates the association between birth weight and (EEG) power in healthy term-age newborns. *Developmental Psychobiology*, *64*(4), Article e22267. <https://doi.org/10.1002/dev.70014>
44. Shyaa, N. S. (2018). Electroencephalography (EEG) based mobile robot control through an adaptive brain robot interface. *American Scientific Research Journal for Engineering, Technology, and Sciences*, *42*(1), 139–147.
45. Vincenzo, R., Marianna, C., Rossella, C., & Giulia, C. (2026). Beyond the lab: Real-world benchmarking of wearable EEGs for passive brain-computer interfaces. *Brain Informatics*, *13*, Article 3. <https://doi.org/10.1186/s40708-025-00290-x>
46. Welte, T. M., Janner, F., Lindner, S., Gollwitzer, S., Stritzelberger, J., Lang, J. D., & Hamer, H. M. (2024). Evaluation of simplified wireless EEG recordings in the neurological emergency room. *PLOS ONE*, *19*(10), Article e0310223. <https://doi.org/10.1371/journal.pone.0310223>
47. Yuan, I., Bong, C. L., & Chao, J. Y. (2024). Intraoperative pediatric electroencephalography monitoring: An updated review. *Korean Journal of Anesthesiology*, *77*(3), 289–305. <https://doi.org/10.4097/kja.23843>
48. Zamm, A., Palmer, C., Bauer, A. K. R., Bleichner, M. G., Demos, A. P., & Debener, S. (2019). Synchronizing MIDI and wireless EEG measurements during natural piano performance. *Brain Research*, *1716*, 27–38. <https://doi.org/10.1016/j.brainres.2017.07.001>
49. Zeydabadezhad, M., Jowers, J., Buhl, D., Cabaniss, B., & Mahmoudi, B. (2024). A personalized earbud for noninvasive long-term EEG monitoring. *Journal of Neural Engineering*, *21*(2), Article 026017. <https://doi.org/10.1088/1741-2552/ad33af>
50. Zhang, R., Tomasi, D., Manza, P., & Volkow, N. D. (2021). Sleep disturbances are associated with cortical and subcortical atrophy in alcohol use disorder. *Translational Psychiatry*, *11*, Article 428. <https://doi.org/10.1038/s41398-021-01534-0>
51. Zou, J., Chen, H., Chen, X., Lin, Z., Yang, Q., Tie, C., & Zheng, H. (2024). Noninvasive closed-loop acoustic brain-computer interface for seizure control. *Theranostics*, *14*(15), 5965–5981. <https://doi.org/10.7150/thno.99820>