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ADVANCEMENTS IN EEG TECHNOLOGY AND AI INTEGRATION IN NEUROLOGY

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Abstract: this article discusses the role of electroencephalography in the diagnosis of pathologies and diseases of the brain
Key words: Artificial intelligence, membrane potential, resting potential, EEG, Machine learning (ML).

The brain, a highly complex organ, acts as the control center of the body. It processes sensory information, regulates motor functions, and coordinates vital autonomic functions like heartbeat and respiration. Its intricate network of over 86 billion neurons enables rapid communication across the body.

Brain activity in terms of electricity is based on the electrical activity of neurons — the cells that make up the nervous system. Neurons communicate with each other through electrical impulses and chemical signals, which keeps the brain functioning.

Electrical activity of the brain is a fundamental process that ensures the functioning of the nervous system, communication between neurons and the implementation of cognitive functions. Let's expand on the main aspects of this topic:

The bioelectric activity of the brain is a process caused by the activity of a huge number of generators-neurons, and, in accordance with this, the field created by them appears to be very heterogeneous throughout the brain space and changing over time. In this regard, between two points of the brain, as well as between the brain and distant tissues of the body, there are variable potential differences, the registration of which is the task of electroencephalography.

The membrane of all living cells is polarized. The inner side of the membrane carries a negative charge compared to the intercellular space (Figure 1). The amount of charge that the membrane

carries is called the membrane potential (MP). In non-excitable tissues, MP is low, and is about -40 mV. In excitable tissues, it is high, about -60--100 mV and is called the resting potential (PP). The electric potential of the membrane is formed by positively and negatively charged surfaces. The positively charged surface of the membrane attracts negatively charged ions (anions) and repels positively charged ions (cations), and vice versa. Na+, K+, and Ca2+ions are examples of cations, and Cl– is an example of anions.
At rest, the inner surface of the membrane is negatively charged with respect to the outer surface. Thus, the membrane potential of neurons is defined as VMembr= VBnutp – VOutside, where VBnut(outside) is the potential in the intra - (extra -) cell surface of the membrane. In most neurons, the VMEbraveries between -65 and -75 mV.
Electrical impulses that occur in the brain can be detected by an electroencephalograph. It consists of electrodes attached to a computer. Electrodes attached to the patient's head pick up the pulses and transmit them to a computer for decoding and display. On paper, the pulses are displayed as waves. Waves differ in their characteristics (frequency and amplitude) and are divided into alpha, beta, delta, theta, and mu waves.
Delta waves (0.5–4 Hz):
Dominant during deep sleep and important for restorative functions.
Theta waves (4–8 Hz):
Seen in light sleep and relaxation.
Alpha waves (8–13 Hz):
Associated with calm wakefulness and reduced sensory input.
Beta waves (13–30 Hz):
Linked to active thinking, focus, and problem-solving.
Gamma waves (>30 Hz):
Involved in high-level cognitive processing, such as memory and perception.
The biopotential that reflects the electrical activity of the brainis called an electroencephalogram. A sufficient duration and length of small (microvolts) electrical fluxes of bioelectric activity in the brain is required so that the signal can be amplified and made available for interpretation.
An electroencephalogram allows a specialist to see signs of various brain disorders and assess their nature. For example, you can use the EEG to recognize:

- epileptic activity in various parts of the brain;
- possible causes of panic attacks and loss of consciousness.
- in what parts of the brain are the pathological foci located;
- how the electrical activity of the brain changes before seizures.

In addition, EEG can be used to determine whether the cause of neurological problems is functional disorders or organic damage, as well as to evaluate the effectiveness of therapy and rehabilitation (in this case, the EEG is removed before the start of treatment, and then – during or after a course of medication).
In order to decipher the EEG and provide accurate results, not to miss any minute manifestations on the record, neurophysiologists take into account all the important points that may affect the studied indicators, such as:

- patient's age.
- the presence of certain diseases;
- possible contraindications.

Diseases detected by EEG results

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The procedure can detect the following pathologies: epilepsy; dementia; vascular disorders; disorders of cerebral circulation; oacute tumors; inflammatory processes in the brain.
Indications for the procedure
Scheduled electroencephalography is performed to provide the patient with a certificate required for obtaining a driver's license. Also, athletes whose activities are associated with the risk of getting a head injury (for example, wrestlers) often undergo the study.
An unscheduled procedure is assigned if there are the following violations:
• frequent syncope; numbness of the extremities; migraines (EEG allows you to determine the cause of its development and determine the treatment strategy); violation of circadian rhythms; panic attacks; crises; regular headaches, dizziness; insomnia; convulsive attacks; nervous breakdowns; chronic fatigue syndrome; stuttering; memory disorders; delayed psychomotor or speech development in the child emotional disorders; sleep disorders (sleep apnea, sleepwalking, restless sleep, sleepwalking).
Also, EEG is prescribed for suspected epilepsy, schizophrenia, after traumatic brain injuries, concussions, poisoning, neurosurgical operations, strokes, as well as for the following diseases: vegetative-vascular dystonia; vascular disorders in the head and neck; encephalitis; meningitis; arterial hypertension; atherosclerosis; osteochondrosis of the cervical spine; endocrine disorders. diseases; consequences of birth injuries; cerebral palsy; Down syndrome; brain damage; autism.
Epilepsy is a pathology of the nervous system that causes periodic seizures with impaired motor and mental functions. This disease is a consequence of increased activity of neurons. Neural discharges spread throughout the brain and cause a seizure.

About 1% of the world's adult population suffers from epilepsy. Usually, this pathology manifests itself before the age of majority.

Epileptic seizures usually occur unexpectedly and are difficult to predict. There are no specific provoking factors. And the interval between them can reach several months, or it can be only one day.

Artificial intelligence is transforming how EEG data is processed and interpreted.

Machine learning (ML) algorithms are trained to identify patterns and correlations in large datasets

Deep learning (DL)

Deep learning (DL) models, such as convolutional neural networks (CNNs), excel at analyzing complex, high-dimensional EEG data.

AI enhances the speed, accuracy, and consistency of EEG analysis, offering real-time insights that were previously unattainable.

The integration of AI into EEG analysis has led to breakthroughs in several areas:

- Epilepsy: AI systems can detect and classify seizures with high accuracy, and some algorithms predict seizures before they occur.
- Sleep Studies: Automated scoring of sleep stages reduces the workload for clinicians and improves diagnostic precision.

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- Neurodegenerative Disorders: AI can identify subtle EEG changes associated with diseases like Alzheimer’s, enabling earlier intervention.
- Brain-Computer Interfaces (BCIs): AI interprets EEG signals to control external devices, offering life-changing solutions for individuals with paralysis.

Case Studies and Innovations

Seizure Prediction:

Researchers have developed AI models capable of predicting seizures up to several minutes in advance. These systems analyze patterns in EEG data, providing patients with a critical window to take preventive measures.

Wearable EEG Devices:

Compact, AI-powered devices are making continuous monitoring possible outside clinical settings, improving accessibility and convenience for patients.

Ethical and Practical Considerations

While AI offers immense potential, it also raises important ethical and practical concerns:

- Data Privacy: EEG data is highly sensitive, necessitating robust encryption and compliance with regulations like GDPR and HIPAA.
- Bias: AI models trained on limited datasets may produce biased results, highlighting the need for diversity in training data.
- Human Oversight: Despite automation, clinicians play a crucial role in contextualizing AI outputs and ensuring safe decision-making.

Addressing these challenges is essential for the responsible implementation of AI in EEG analysis.

Future Directions:

Multimodal Imaging:

Combining EEG with modalities like fMRI or PET can provide comprehensive insights into brain function.

Personalized AI:

Algorithms tailored to individual patients can enhance diagnostic accuracy and treatment efficacy.

Real-Time Monitoring:

AI-powered wearable devices could enable continuous assessment, particularly in resource-limited settings.

EEG Limitations

Despite its importance, EEG has limitations:

- It does not always detect epileptiform activity (especially during the inter-approach period).

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- Some patterns may be non-specific and can be observed in other diseases (for example, tumors or encephalitis).
- For a complete diagnosis of epilepsy, EEG should be used in conjunction with clinical analysis and neuroimaging methods (MRI, PET).

Conclusion

The EEG is an essential tool in the diagnosis, monitoring, and classification of epilepsy. It allows not only detecting epileptic activity, but also evaluating the effectiveness of treatment and predicting the further course of the disease. Modern technologies make EEG an even more valuable method in clinical practice, allowing us to significantly improve the accuracy of diagnosis and the quality of life of patients with epilepsy.

Electroencephalography (EEG) is more informative in the diagnosis and monitoring of Alzheimer's disease than in Parkinson's disease, as this disease leads to noticeable changes in the electrical activity of the cerebral cortex. The following are the main aspects of using EEG in the context of Alzheimer's disease:

The EEG can serve as a useful tool for diagnosing Alzheimer's disease, especially in the context of cognitive impairment and disease progression research. However, it must be used in combination with other methods such as MRI, PET, and biomarkers (such as amyloid and tau protein analysis in the cerebrospinal fluid) to ensure accurate diagnosis.

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