Tidsskriftet Tidsskrift for Den norske legeforening

A hundred years of EEG

IN BYGONE DAYS

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The year 2024 marked the centennial of the first registration of human cerebral activity by the German psychiatrist Hans Berger. He called the method 'electroencephalography', abbreviated as EEG. Today, EEG plays a key role in the assessment of epilepsy, including assessment for epilepsy surgery, sleep diagnostics, and the monitoring of cerebral activity in neurointensive and neonatal care units.

Hans Berger (1873–1941). Photo: Universitäts Klinikum Jena / In public ownership, Wikimedia Commons.

In earlier times, knowledge of the brain's structure and function was very limited. For example, the Greek physician and philosopher Hippocrates (approx. 460–370 BCE) believed that the brain was a phlegm-producing gland, while the influential Greco-Roman physician Galen (approx. 129–210) thought the cerebral ventricles were responsible for the brain's functions, and a blockage of the ventricles by phlegm or black bile could result in an epileptic seizure (1).

The Italian physician Luigi Galvani (1737–98) from Bologna was the first to impart actual knowledge about our nervous system. Through experiments on frogs in the 1780s, he succeeded in demonstrating that muscle contractions were a result of electrical activity in the peripheral nerves (2).

> ***«Caton demonstrated that by using a highly sensitive galvanometer, it was possible to register electrical activity directly from the cerebral cortex of dogs and monkeys»***

However, it was not known whether cerebral functions were also linked to electrical activity until the British physiologist Richard Caton (1842–1926) from Liverpool demonstrated at a meeting of the British Medical Association in 1875 that by using a highly sensitive galvanometer, it was possible to register electrical activity directly from the cerebral cortex of dogs and monkeys, and that this activity ceased when the animal died (3). Thus Caton laid the foundation for the discovery of electroencephalography 50 years later.

Who was Hans Berger?

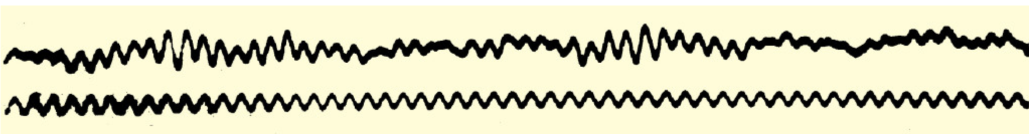
Hans Berger (1873–1941) was a German physician who was employed in 1897 at the psychiatric and neurological clinic in Jena, a clinic headed by Professor Otto Binswanger (1852–1929). In 1919, Berger took over the post from his boss at the same time as he was appointed professor of psychiatry. He was appointed as Rector of the University of Jena in 1927. His ambition was to find the physiological basis for psychological phenomena, particularly psychiatric disorders and telepathy (4). When he suffered a serious accident in 1893, his sister had a strong foreboding that he had been injured, and his family sent him a telegram asking if everything was all right. Berger was convinced that his brain had transmitted some kind of 'mental energy' that his sister had received (5).

Berger was familiar with Caton's studies, and from 1902 onwards, he attempted to capture electrical activity from the cerebral cortex of dogs' brains using a string galvanometer. He experimented with different types of electrodes, and despite experiencing many disappointments, he did not give up. It was said of him that his perseverance as a researcher confirmed Thomas Edison's claim that 'genius is one percent inspiration and 99 percent perspiration' (6).

He conducted the experiments late in the day, between 5pm and 8pm, because there was least electrical interference at the hospital then. His research was interrupted by World War I (1914–18). As a result of the war, he had access to many patients with cranial defects. In 1920, he unsuccessfully tried to capture electrical activity from electrodes placed on the scalp of a bald-headed medical student. Finally, in 1924, he succeeded in registering continuous oscillations by means of two skin electrodes placed four centimetres apart in a 17-year-old, tumour-operated patient with a large cranial defect.

Was it electrical activity that he measured?

He himself doubted whether it was actually electrical activity from the cerebral cortex he was measuring, or whether it was merely artefacts. He ruled out pulse, muscle and respiratory artefacts, and after carrying out a total of 38 measurements on other patients, hospital staff and his own 15-year-old son Klaus, he took the bold step of publishing his findings in 1929. He called the measurement method 'electroencephalography', abbreviated as EEG (7), and the article was entitled *Über das Elektrenkephalogramm des Menschen* (8). The article was published in a German psychiatric journal and attracted little attention. He was partly ridiculed by his colleagues, particularly by neurophysiologists who regarded him as an amateur in the specialist field, dismissing his findings as artefacts (9).



The first EEG-measurement. Illustration: In public ownership.

To his great disappointment, he found that patients with bipolar disorder, schizophrenia or 'mental retardation' generally exhibited normal curves (6). Different types of cerebral lesions appeared as focal slow wave activity in the EEG curve.

Berger used Greek letters to describe different rhythms: alpha, beta, theta and delta rhythms, a categorisation that we continue to use. He found that the alpha rhythm was most prominent when the person was lying down with their eyes closed, and it disappeared when the eyes were opened or when there was some kind of stimulation, for example touch, a loud sound or intellectual effort (a finding in his son Klaus). He registered 3/second *spike-wave* activity in children with absence seizures, but he was annoyed that he did not get the opportunity to register someone in the throes of a tonic-clonic seizure.

During his career, he published 102 articles and monographs, 28 of which dealt with EEG. The majority of these were written in German.

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Berger was an introvert. He found social interactions difficult, and he often felt lonely and isolated. The Canadian epileptologist Herbert H. Jasper (1906–99) paid him a visit in the 1930s, and described him as friendly, shy, honest, inspiring and courageous (6).

During the period of national socialism, Berger participated from 1936–38 as an expert in the Court for Genetic Health (*Erbgesundheitsgericht*), rejecting several appeals in court against forced sterilisation. In 1941, three years after retiring, he suffered severe depression and took his own life.

His findings were confirmed in Cambridge in 1934

Berger's findings were almost ignored until the English neurophysiologists Edgar D. Adrian (1889–1977) and Bryan H.C. Matthews (1906–86) in Cambridge confirmed and supplemented his findings in a well-known article from 1934 (10).

In 1935, the American scientists Gibbs, Gibbs and Lennox in Boston described characteristic EEG patterns in epilepsy patients between and during seizures, including during tonic-clonic seizures, and in 1936, they established the first EEG-laboratory at Massachusetts General Hospital (11).

A high point of Berger's career came during the international psychology conference in Paris in 1938. To his great surprise, he was received here as a celebrity and hailed as 'the father of electroencephalography'. The neurophysiologists Adrian and Matthews had proposed calling the alpha rhythms 'Berger rhythms', but he himself disliked the idea (10). In the course of a few years, EEG tests became widespread and were regarded as an important way of detecting functional brain disorders.

During a study tour to Copenhagen, Professor Sigvald Refsum (1907–91) paid for an EEG machine with his own money, and installed it in the neurological department of *Rikshospitalet* in 1943 (12). This marked the start of an active neurophysiological team, headed in the period from 1954–87 by Arne Lundervold (1915–2004). Early on, the Norwegian Centre for Epilepsy in Bærum acquired equipment for long-term video-EEG monitoring of patients. This equipment was put into operation in 1973.

EEG's role today

Epilepsy

EEG is a cornerstone of all epilepsy diagnostics. Most people with epilepsy have epileptiform discharges in the EEG-curve during a seizure, while only 30–40 % show such activity between seizures (13). The occurrence of epileptiform EEG activity considerably strengthens the suspicion of epilepsy. Nonetheless, such activity is not a requirement for an epilepsy diagnosis.

> ***«EEG is a cornerstone of all epilepsy diagnostics»***

Our sub-classification of epileptic seizures is based on the clinical features of the seizures (semiology) and EEG findings between and during seizures, as proposed by the French neurologist Henri Gastaut (1915–95) as early as 1970 (14).

Successful epilepsy surgery requires that the biological neural networks from which the seizure originates can be pinpointed in advance. Despite repeated ictal registrations (recording during a seizure) by electrodes placed on the scalp, there may be doubt about the exact localisation of the source of the seizure. Invasive EEG registration using intracerebral depth electrodes, so-called 'stereo EEG' (SEEG), is often used. This was introduced by the French scientists Jean Bancaud (1921–93) and Jean Talairach (1911–2007) in the 1950s (15).

Sleep-related disorders

Berger had earlier noted that the EEG-curve changed during sleep and was dominated by low-frequency theta (4–8 Hz) and delta waves (1–4 Hz) as well as brief bursts of high-frequency activity (sleep spindles).

Today, the EEG pattern during sleep together with simultaneous registration of eye movements and muscle tone form the basis for the current categorisation of sleep stages and polysomnography when assessing sleep disorders (16).

Monitoring of cerebral activity

EEG can provide clarification in the case of patients who are unconscious for no obvious reason. For example, it can detect convulsive or non-convulsive status epilepticus, special types of encephalitis and herpes simplex encephalitis (17).

For perinatal asphyxia and anoxic brain damage following cardiac arrest, EEG is of great value in assessing the prognosis (18).

Misuse of EEG

It has been asserted that EEG is one of the most misused tests in clinical medicine (11). There are both false positive and false negative findings, and there is considerable scope for misinterpretation (19). Misinterpretation of an EEG is one of the most important causes of an incorrect epilepsy diagnosis. EEG findings must always be collated with clinical data.

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When the classification of seizures in epilepsy patients is clear and the source established, a 'control EEG' is usually superfluous.

It is important to be aware that there is a poor association between the amount of epileptiform activity in the EEG and the patient's seizure risk. Using EEG to assess the effects of a treatment has not proved useful. The exceptions are the treatment of infantile epileptic spasms syndrome, childhood absence epilepsy and status epilepticus. Furthermore, EEG is of limited value when assessing neuropsychiatric functional disorders such as ADHD, autism or dementia (20). If an organic brain disorder is suspected to be the cause of a psychiatric disorder, the patient should be referred to a neurologist and brain MRI if appropriate.

EEG interpretation

Like all diagnostic tools, both the requisitioner and the person interpreting the findings must have fundamental knowledge of the method itself, the indications, strengths and limitations. The requisitioner must specify what they want an answer for, and if epilepsy is suspected, it is important to provide good descriptions of the seizures as well as information about any medications used (21).

In recent years, a standardised computer-based organised reporting of EEG (SCORE) has been developed (22). The use of common terms and less observer variability has improved the quality of the reporting.

EEG signals were digitalised in the 1990s. This has provided the basis for the use of software to assist in the interpretation and localisation of the source of the epileptic activity. Recently, artificial intelligence has also been used to further improve the diagnostics (SCORE-AI) (23).

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Publisert: 24 March 2025. Tidsskr Nor Legeforen. DOI: 10.4045/tidsskr.24.0657
Received 11.12.2024, first revision submitted 17.1.2025, accepted 27.1.2025.