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Imaging Brain Function With EEG

Advanced Temporal and Spatial Analysis of Electroencephalographic Signals

Springer

Chapter 1
Electroencephalography

1.1 Introduction

Our knowledge about brain function increased dramatically in the last decades due to the development and refinement of several recording techniques. Such advances flourished at different levels, ranging from the study of synaptic activity at the microscopic level to the refinement of brain imaging techniques at a macroscopic level. Modern data acquisition systems and new electrode designs enabled the simultaneous recording from dozens of neurons at a larger scale, and powerful computers allowed more complex simulations and data analysis, thus giving rise to the field of computational neuroscience. A somewhat less spectacular but also remarkable and steady progress has been made at an intermediate mesoscopic level (Freeman 1975, 1999) in the analysis of electroencephalograms (EEGs).

The EEG measures the electrical activity of the brain at different sites of the head, typically using electrodes placed on the scalp. Its main advantages over other recording techniques are its high temporal resolution and the fact that it can be recorded noninvasively (i.e., without the need of a surgery). Due to their relatively low cost, EEG recordings are widely used both in clinical settings and research laboratories. This makes the EEG a very accessible and useful tool, which is particularly interesting for the analysis of high-level brain processes that arise from the group activity of large cell populations. Such processes can be well localized in time or they can be correlated to time varying patterns, like brain oscillations, which are beyond the time resolution of imaging techniques as functional magnetic resonance imaging (fMRI). The caveat of noninvasive EEGs is the fact that they reflect the average activity of a large number of sources far from the recording sites and, therefore, they do not have an optimal spatial resolution.

Although the way of recording EEG signals did not change as much as in the case of microscopic and macroscopic recordings (though in later chapters, we will describe basic guidelines for electrode designs that improve the spatial analysis of the EEGs), there have been significant advances in the methodology for analyzing

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EEG data. In fact, EEG recordings have been an ultimate challenge for most methods of signal processing due to their high complexity, low signal to noise ratio, nonlinearity, and nonstationarity. As we will describe in this book, the development and implementation of new algorithms that are specifically designed for complex signals such as the EEGs will allow us to get much more information than has been accessible with previous methods and the conventional visual inspection of the recordings, as done by trained electroencephalographers. These methods open a new window to the study of high-level cognitive processes in humans with noninvasive techniques and at no great expense.

1.2 Brief History of EEG

The history of human EEG recordings goes back to Hans Berger (1873–1941), a professor of psychiatry at the University of Jena, Germany. Following the work of Richard Caton (1842–1926), a surgeon from Liverpool who successfully recorded the electrical activity of exposed cerebral hemispheres from monkeys and rabbits in 1875, Hans Berger was the first one able to record electrical activity from the human scalp in 1924. After 5 years collecting data and reexamining his results, he finally published in 1929 "Über das Elektroenkephalogramm des Menschen." In this seminal work, Berger already reported the presence of brain oscillations of about 10 cycles per second, what he called alpha waves, seen with the subject in a relaxed state with eyes closed. When opening the eyes, these waves disappeared (alpha blocking) and oscillations of higher frequencies (beta waves) were observed (Fig. 1.1). A similar type of beta oscillations was also observed with eyes closed when the subjects performed mental arithmetic tasks.

The importance of Berger's work was not recognized until 1934 when Lord Edgar Adrian (1889–1977), at Cambridge, confirmed his results. From then on, the EEG technique triggered a revolution in the way to study normal and pathological brain processes (Fig. 1.2). Just to mention some of the major achievements, in the 30s Grey Walter, first in London and then at the Burden Neurological Institute in Bristol, reported slow oscillations (delta waves) over hemispheric brain tumors and introduced the concept of EEG topography to localize brain lesions. Immediately after, EEG research spread to the USA. At Harvard, Hallowell Davis, Frederic Gibbs, Erna Gibbs, and William Lennox started to study paroxysmal EEG patterns related to epilepsy. These abnormal patterns, such as spikes or spike-waves, are still used to help the diagnosis of epilepsy. The 1940s saw the beginning of sleep studies. At the end of this decade, the first human intracranial recordings were performed. In our days, these types of recordings are mainly used in patients that are candidates to epilepsy surgery in order to determine the origin of the seizures. In the 1950s, Wilder Penfield and Herbert Jasper, at McGill University in Montreal, used electrical stimulation, with open brain surgeries under local anesthesia, to localize areas involved in different brain processes. In the same decade, a major advance in the field was

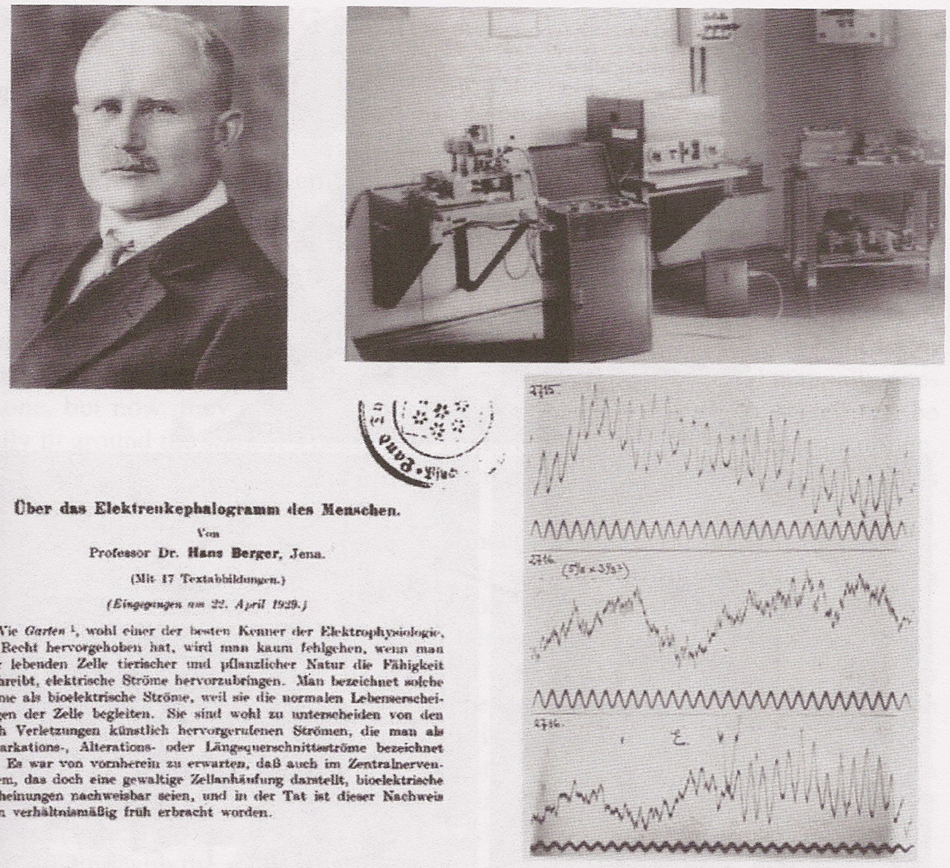

Fig. 1.1 Hans Berger and his laboratory at the University of Jena (*top*). Berger's seminal paper describing the EEG for the first time, and one of his recordings of alpha and beta oscillations (*upper traces*) and the appearance of alpha oscillations when closing the eyes (*lower trace*)

introduced by George Dawson, in London, who developed a summation technique to visualize average EEG responses to stimuli. Later on, a major breakthrough was the introduction of computers in the analysis of EEG signals, especially with the use of the fast Fourier transform developed by Cooley and Tukey (1965).

A significant slowdown in EEG research resulted as a consequence of the introduction of other methodologies for measuring brain activity, such as single neuron recordings in the 1950s and especially the emergence of imaging techniques and magnetoencephalography in the 1980s. In our days, EEG recordings are generally used for clinical diagnoses, like head injuries, brain tumors, and epilepsy. Neuroscientists also study different types of EEG activity during controlled behavior in human subjects and animals.