Chapter

1 Introduction

Electroencephalography (EEG) remains one of the principle tools in the practice of clinical neurology. Notwithstanding the development of increasingly sophisticated imaging techniques over the years, including computed tomography (CT) scanning, magnetic resonance imaging (MRI), nuclear medicine imaging, and newer functional MRI techniques, the use of EEG in the assessment of neurological disorders continues to increase. The information learned from EEG testing differs in a number of ways from what is learned from radiological images such as MRI scans. Whereas MRI primarily furnishes anatomical information as a snapshot in time, EEG captures electrical information over time. Just as an X-ray image of the heart does not tell us whether a patient's heart is beating quickly or slowly, information easily learned from an electrocardiogram, likewise CT and MRI scans of the brain do not give direct information regarding electrical irritability in the brain or even indicate whether the patient is awake or asleep. Thus radiological imaging studies and electroencephalography are complementary techniques.

Electroencephalography is used in a variety of clinical situations, but the large majority of EEGs are obtained as a part of the evaluation of seizures or epilepsy. Estimates of the population prevalence of epilepsy range between 0.5% and 1%, suggesting that at least 2 million people in North America have epilepsy. EEG is also useful in the evaluation of confusional states and coma, and it can play an important role in separating psychiatric illness from organic disease.

Electroencephalography is a relatively young science. One hundred years ago, it was not yet a settled fact that there was electrical activity in the human brain. In 1875, Richard Caton was the first to report an observation of electrical activity from the brains of monkeys and rabbits, though techniques available at the time did not allow him to record these waveforms for posterity. Caton made his observations using a device called Thomson's mirror galvanometer (Caton, 1877). Oscillations in the mirror affixed to a galvanometer caused movements of a beam of light the mirror reflected on the wall of his laboratory. His report that "Feeble currents of varying direction pass through the multiplier when the electrodes are placed on two points of the external surface, or one electrode on the grey matter, and one on the surface of the skull" is considered the first description of an EEG wave (Caton, 1875). Thereafter, successful recordings were made by Caton and others from the brains of dogs, monkeys, rabbits, and cats, although some still claimed that the recorded waves were related to the pulsations of cerebral blood vessels rather than to brain electrical activity.

Hans Berger, considered the father of modern Electroencephalography, was the first to record EEG in humans (see Figure 1-1) while working as a professor of psychiatry at the University of Jena in Germany. His previous work included precise measurements of cerebral pulsations in both animals and humans and, later, the measurement of brain temperature variations in animals to determine whether temperature fluctuated in different behavioral states. His first attempts at recording brain waves in 1924 were carried out using a string galvanometer designed to record electrocardiograms (see Figure 1-2). The initial recordings were made in subjects with areas of missing cranial bone, either from palliative trepanations (creation of a window in the skull bone) for relief of increased intracranial pressure from brain tumors or from skull defects related to injuries sustained during the First World War. Because of these patients' skull defects, the needle electrodes he used could be placed only a few millimeters away from the brain surface.

In his first report, titled "On the Electroencephalogram of Man" and published in 1929, Berger outlines the path toward his first successful observation of the EEG of man (which he did not, at the time, have the equipment to record). The observation was made in 1924 in a 17-year-old boy who had undergone palliative trepanation over the left cerebral hemisphere for a brain tumor. The first published recorded rhythm, shown in Figure 1-3, was obtained in a 40-year-old man who had had a large bone flap removed to relieve pressure from a brain tumor. The recording was made with needle electrodes placed subcutaneously which, in this patient, represented the epidural space. The patient died from his tumor a few weeks later.

Berger's initial work was met with considerable skepticism, in part because the action potential of single nerves was just then under study. It was difficult to reconcile the short duration of the action potential, approximately 1 millisecond, with the much longer duration of the waves that comprised the "Berger Rhythm," the wavelengths of which were closer to 100 milliseconds.

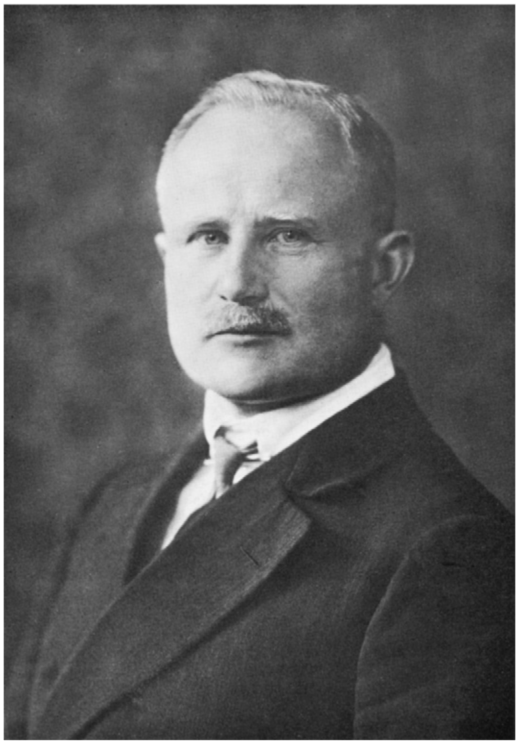

Figure 1-1 Hans Berger at age 52 (1925), one year after he began his work on the human electroencephalogram. *(Courtesy Mrs. Ursula Berger. With permission, from Berger H, Gloor P.* On the electroencephalogram of man; the fourteen original reports on the human electroencephalogram *[Gloor P, translator and editor], Amsterdam and New York, Elsevier, 1969.)*

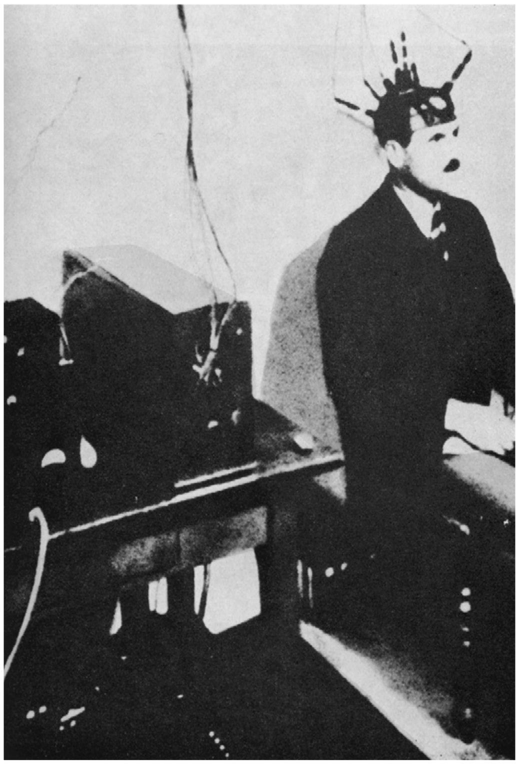

Figure 1-2 This photograph shows one of the first attempts at recording the electroencephalogram in humans. The patient had undergone a left-sided trepanation. The recording attempt was made with silver electrodes secured to the scalp with adhesive tape but was unsuccessful. This patient was recorded sitting up; later patients were studied lying on a couch with glass legs for electrical isolation. *(With permission, from Berger H, Gloor P.* On the electroencephalogram of man; the fourteen original reports on the human electroencephalogram *[Gloor P, translator and editor], Amsterdam and New York, Elsevier, 1969.)*

Berger also attempted recordings in subjects with intact skulls, starting as early as 1920 with unsuccessful attempts in a bald medical student "who put himself most obligingly" at Berger's disposal. The first series of successful recordings made in a subject with an intact skull were obtained from Berger's son, Klaus, when he was aged between 15 and 17 years (see Figure 1-4).

PLAN OF THE TEXT

The chapters in this text are ordered so that they can be read sequentially, although individual chapters may be referenced out of turn as necessary. Chapter 2, "Visual Analysis of the Electroencephalogram," begins with a brief overview of the appearance of the normal EEG during wakefulness, drowsiness, and sleep. After the basic visual features of the normal EEG are described, a discussion of EEG terminology follows. The vocabulary of EEG is intertwined with certain EEG concepts; a review of EEG terminology and several associated EEG concepts are discussed together in Chapter 3, "Introduction to Commonly Used Terms in Electroencephalography."

Chapter 4, "Electroencephalographic Localization," is the most important chapter in this text. Without excellent localization skills, it is impossible to become an excellent electroencephalographer. EEG localization techniques tell us much more than the location from which a wave originates. Localization techniques allow us to translate a group of waves on an EEG page into a three-dimensional map of charge on the scalp surface and to understand how the shapes on that map vary over time.

The ordering of the display of EEG channels generated from a specific electrode set is called the EEG montage. Montages are discussed in detail in Chapter 5,

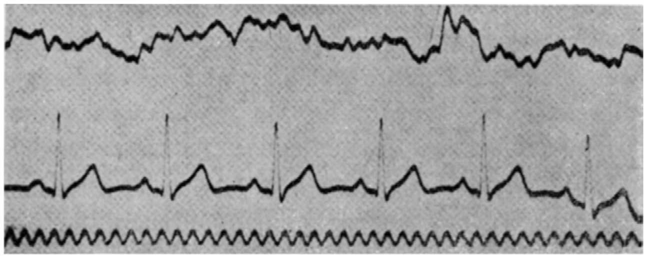

Figure 1-3 The first published recording of an electroencephalogram in a human. The top trace shows an electroencephalographic signal recorded from two needle electrodes in the area of a large bone defect. The middle trace shows the electrocardiogram and the bottom trace shows a 10-Hz calibration signal. *(With permission, from Berger H, Gloor P.* On the electroencephalogram of man; the fourteen original reports on the human electroencephalogram *[Gloor P, translator and editor], Amsterdam and New York, Elsevier, 1969.)*

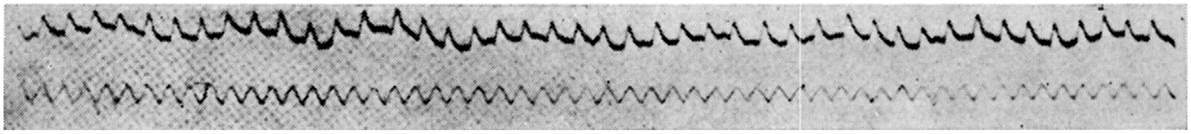

Figure 1-4 The first successful recordings of the EEG in man recorded from a patient with an intact skull were made in Hans Berger's son, Klaus, using needle electrodes. This particular example was obtained when Klaus was 16 years old. The top trace of this figure shows an EEG signal derived from a pair of electrodes "in the midline of the skull anteriorly within the hair line of the forehead and posteriorly two finger breadths above the external occipital protuberance." The bottom channel shows a 10 Hz calibration signal. *(With permission, from Berger H, Gloor P.* On the electroencephalogram of man; the fourteen original reports on the human electroencephalogram *[Gloor P, translator and editor], Amsterdam and New York, Elsevier, 1969.)*

"EEG Electrodes, Channels, and Montages and How They Are Chosen." Different montage strategies help the electroencephalographer to understand the distribution and polarity of different types of discharges. Visualizing these three-dimensional maps is not simply an academic exercise. The ability to classify specific EEG events as to whether they are normal or associated with disease depends significantly on the topography suggested by their polarities and localizations. The topography of an EEG event indicates whether it was generated in a specific part of the brain—or whether it originated from the brain at all. This latter possibility, that a wave on the EEG page has not come from the brain at all, brings us to a major topic in electroencephalography: the identification of EEG artifacts.

One of the main attractions of learning EEG interpretation is the prospect of understanding more about the phenomenology of the wave patterns that the brain generates. It may come as a surprise to the new student of electroencephalography how much time is spent analyzing and identifying waves in the EEG that are caused by the patient tossing and turning or blinking the eyes: so-called EEG artifacts, which is the topic of Chapter 6, "Artifacts." The considerable problem of identifying artifacts in the EEG stems from the high amplifier gains necessary to record the microvolt-level EEG signals that are the object of our interest. A byproduct of the high levels of amplification necessary to produce the beautiful EEG traces to which we have become accustomed is that everything gets amplified, including noncerebral electrical events. Experienced electroencephalographers will often be heard to say that "half of EEG is correctly identifying the artifacts." Although many artifactual waves are obviously not of cerebral origin, some may closely mimic true brain wave activity. Artifact recognition involves both pattern recognition and careful localization and topographic description of the wave in question, a skill that is absolutely essential in EEG interpretation.

All EEG signals are passed through a set of filters before being displayed. As discussed in Chapter 7, "Filters in the Electroencephalogram," filters may have a significant impact on the appearance of EEG waves, with the potential to enhance, suppress, or distort EEG information. Although knowledge of filter circuit design is not required for fundamental EEG interpretation, the electrical and digital strategies used to create simple high and low filters are also reviewed. Those not inclined to technical discussions may decide to postpone review of this portion of Chapter 7 until they are more comfortable with general EEG interpretation.

Often the only representation to the outside world of the time and thought that the electroencephalographer has put into the interpretation of the EEG is the written EEG report. The EEG report must include a distillation of the technique used to record the EEG, what the EEG tracing looked like and, most importantly, the EEG findings and their clinical implications. Strategies for producing useful EEG reports are discussed in Chapter 8, "The Structure and Philosophy of the EEG Report."

Before the advent of modern neuroimaging, EEG was an important tool for localizing anatomical lesions such as brain tumors and strokes in addition to its role in diagnosing seizure disorders. Although EEG abnormalities can still be divided into epilepsy- and nonepilepsy-related groups, the evaluation of possible seizure disorders has become the most common reason for EEG testing. Chapter 9, "The Abnormal Electroencephalogram," discusses both epileptic and nonepileptic EEG abnormalities in the EEG and describes the types of clinical disorders associated with each. Chapter 10, "The Electroencephalogram in Epilepsy," examines these associations from the opposite point of view, reviewing selected epilepsy syndromes and describing the EEG findings associated with each.

Over the past 70 years, a variety of EEG findings that were initially felt to be abnormal because of their resemblance to epileptiform abnormalities have been discovered to occur with significant frequency in the normal population and are, therefore, classified as "normal variants." The clinical significance of some of these variants is still under debate. This interesting group of EEG findings is discussed in Chapter 11, "Normal Variants in the Electroencephalogram."

EEG is an important tool for assessing neurological prognosis in coma. Although EEG is not used as a sole criterion for the determination of brain death, it is sometimes used as a confirmatory study in patients in whom brain death is suspected. Chapter 12, "Electroencephalogram Patterns in Stupor and Coma," discusses how the EEG can be used to evaluate patients in coma as well as the technical requirements for performing recordings in the setting of suspected brain death.

The EEG begins to attain adult patterns in patients as young as 2 months of age. Before that point, however, the form of the EEG in babies is remarkably unlike that of older patients. EEG patterns evolve with surprising rapidity from the earliest clinical recordings obtained at 23 to 24 weeks postconceptional age, to recordings performed in newborns at term (40 weeks postconceptional age), and finally when adult patterns appear. Chapter 13, "The Electroencephalogram of the Newborn," provides an introduction to the unique EEG patterns seen in newborns.

Much like driving a car, electroencephalography cannot be learned just by reading a textbook. While reading this text, the reader is encouraged to interpret as many EEG records as possible. Many students start to learn EEG record review by reading "over the shoulder" of a more experienced EEG reader. The real work of learning electroencephalography is done by "getting behind the wheel" and reading records alone, generating an opinion of the EEG's findings uninfluenced by the opinion of others, and then comparing the results to those of a more experienced reader.

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