Part I Introduction

Chapter 1 EEG Basics

- How EEGs are recorded
- Three rules of polarity
- Parts of an EEG machine
- Electrodes
- Montages and localization
- Display
- Frequency
- Rhythm
- Normal adult EEG
- Strengths and limitations of EEG

This chapter introduces the basic concepts of electroencephalography (EEG) recording, with which readers need to be familiar before advancing. Specifically tailored to acute care providers, it assumes that most readers do not have prior EEG reading experience. Therefore, the neurophysiology has been simplified to the "bare basics." This chapter is intended as a foundation to understand further concepts described in this book; it cannot serve as a detailed reference, for which many excellent textbooks are available.

How EEGs Are Recorded

Electroencephalographs (EEGs) are graphical representations of continuous synaptic activity of the *pyramidal neurons* in the superficial cortex. These neurons are arranged radially, like spokes of a wheel, with their superficial ends towards the cortical surface. Each neuron also functions as a dipole, with each of its two ends carrying a small but opposing charge. Summations of tiny superficial charges form cortical potentials. Electrodes placed on the scalp can measure the potential of the underlying cortical region.

When electrodes are paired, the potential difference between two electrodes (V) causes a small current (I) to move across the resistance of the circuit (R) governed by *Ohm's law* ($V = I \times R$). The strength and direction of the current are computed by the EEG machine and displayed as a waveform over time. Inputs from deeper structures, such as the thalamus, synchronize cortical neuronal activity to generate patterns of electrographic activity called rhythms.

Since synaptic transmission occurs constantly, the normal EEG is always continuous. Disruptions to neuronal function and synaptic transmission will lead to breaks in the recording (discontinuity). Therefore, discontinuity indicates cortical neuronal dysfunction.

Three Rules of Polarity

The EEG screen shows an arrangement of channels, each showing a line with waveforms. Each *channel* consists of two electrodes that record the electrical potential from their underlying region of cortex. The EEG machine then computes the potential difference between those two electrodes and displays it as a waveform.

Three simple rules of polarity govern the appearance of each waveform.

Consider, for example, a single EEG channel, say D1-D2. This is composed of scalp electrodes D1 and D2, each sampling an area of underlying cortex. Depending on their arrangement, they may lie adjacent to or distant from another. The appearance of a waveform in channel D1-D2 will depend on the relative difference in electrical potentials at electrode D1 and electrode D2 (i.e., D1 − D2). The greater the difference, the higher the amplitude (voltage). Further, the direction (polarity) of the wave is determined as follows:

- Rule 1: If potential at D1 is less than D2 (i.e., D1 < D2 or D1 is relatively negative), their difference is negative – reflecting as an upward deflection.
- Rule 2: If potential at D1 is greater than D2 (i.e., D1 > D2 or D2 is relatively negative), their difference is positive – reflecting as a downward deflection.
- Rule 3: If both D1 and D2 are equipotential or inactive, then their difference is neutral – there is no deflection.

As you can see, the pointer simply deflects to the relatively smaller (i.e., more negative, or less positive) electrode potential as shown in Figure 1.1.

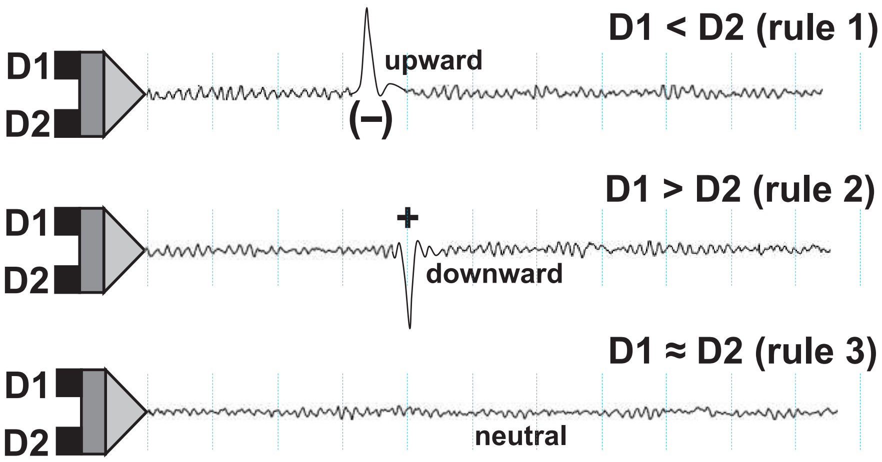

Figure 1.1 Three rules of polarity.

Parts of an EEG Machine

A typical EEG recording consists of electrodes (fixed to the patient's scalp), each of which is connected by wire to a head box. The head box is plugged into a portable computer with a display screen. It can be easily unplugged to temporarily disconnect the recording for transport.

Electrodes

These are small, circular, dome-shaped metallic discs perforated by a small hole on their top. They are applied to the scalp using glue or collodion. Collodion is extremely flammable and emits a noxious odor, but forms strong, sweat resistant, and durable connections, useful for continuous EEG.

Electrodes are made of paramagnetic materials such as stainless steel or tin and coated with silver or silver chloride. MRI conditional electrodes are also available.

Single use electrodes should be used in patients with suspected prion disease (e.g., Jakob–Creutzfeldt Disease) [1].

Application of Electrodes

First, the electrode is dipped in an adhesive paste and then placed on prepared skin. Next, a gauze soaked in collodion is placed over the electrode and air dried to form durable connections. Finally, each electrode is filled with electroconductive gel through the small hole on the top of its dome using a blunt needle and syringe. This ensures an adhesive electrical connection.

Placement of Electrodes

Electrodes are placed using the *standardized international 10–20 system*. This system uses three bony anatomical landmarks of the scalp to form a flexible map. These include the nasion (center of the nose bridge), inion (center of the occipital prominence), and preauricular point (just in front of the tragus). Points for electrode placement are selected at approximations of either 10% or 20% of the distance between the landmarks as shown below.

Each electrode is referenced by a letter representing the underlying region of cortex (e.g., frontopolar (Fp), frontal (F), temporal (T), parietal (P), occipital (O), or central (C)), and a number – even (2, 4, 6, 8) for right, odd (1, 3, 5, 7) for left, and Z for the midline (Fz, Cz, and Pz). For example, Fp1 is for the left frontopolar electrode, etc.

A common adaptation called the modified combinatorial nomenclature uses T7 for T3, T8 for T4, P7 for T5, and P8 for T6 [2]. This brings the names of these electrodes in line with the more extensive 10–10 system, which uses far more electrodes. Figures 1.2(a) and 1.2(b) show the placement of electrodes using the international 10–20 system.

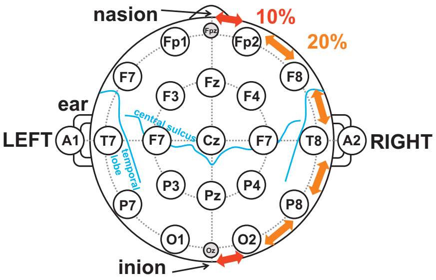

Figure 1.2(a) International 10–20 system; top view.

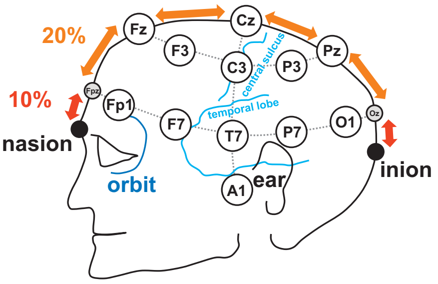

Figure 1.2(b) International 10–20 system; side view.

Montages and Localization

Montages

Channels (electrode pairs) are displayed on the EEG screen using specific arrangements. These specific arrangements are called *montages*.

There are many different types of montages, detailed descriptions of which are beyond the scope of this book. However, acute care providers should be familiar with using a longitudinal bipolar (double banana) montage, as this is a common default montage and easy to use at the bedside. All EEG examples in this book use this montage.

Each channel of a longitudinal bipolar montage shows the potential difference between two adjacent electrodes on the scalp, and is connected to other channels in longitudinal (front to back) chains as shown below [3].

Figure 1.3(a) shows an example of the longitudinal bipolar montage, while Figure 1.3(b) shows a schematic representation of its electrode chains.

Localization

This is the art of approximating the location (origin) of a waveform on the cortical surface.

Ideally, different types of montages should be used together during localization, but this can be challenging at the bedside. Therefore, we limit ourselves here to using the longitudinal bipolar montage.

The key to localization is an electrographic principle called a *phase reversal*. This is a simultaneous but opposite deflection in two adjacent EEG channels containing a common electrode. A phase reversal implies that the cortical potential is maximal at the location of the common electrode.

Most phase reversals are negative (><), though rarely positive phase reversals (<>) may occur. Figure 1.4 shows an example of localizing a focal sharp wave.

Cambridge University Press & Assessment
978-1-009-26116-6 — Critical Care EEG Basics
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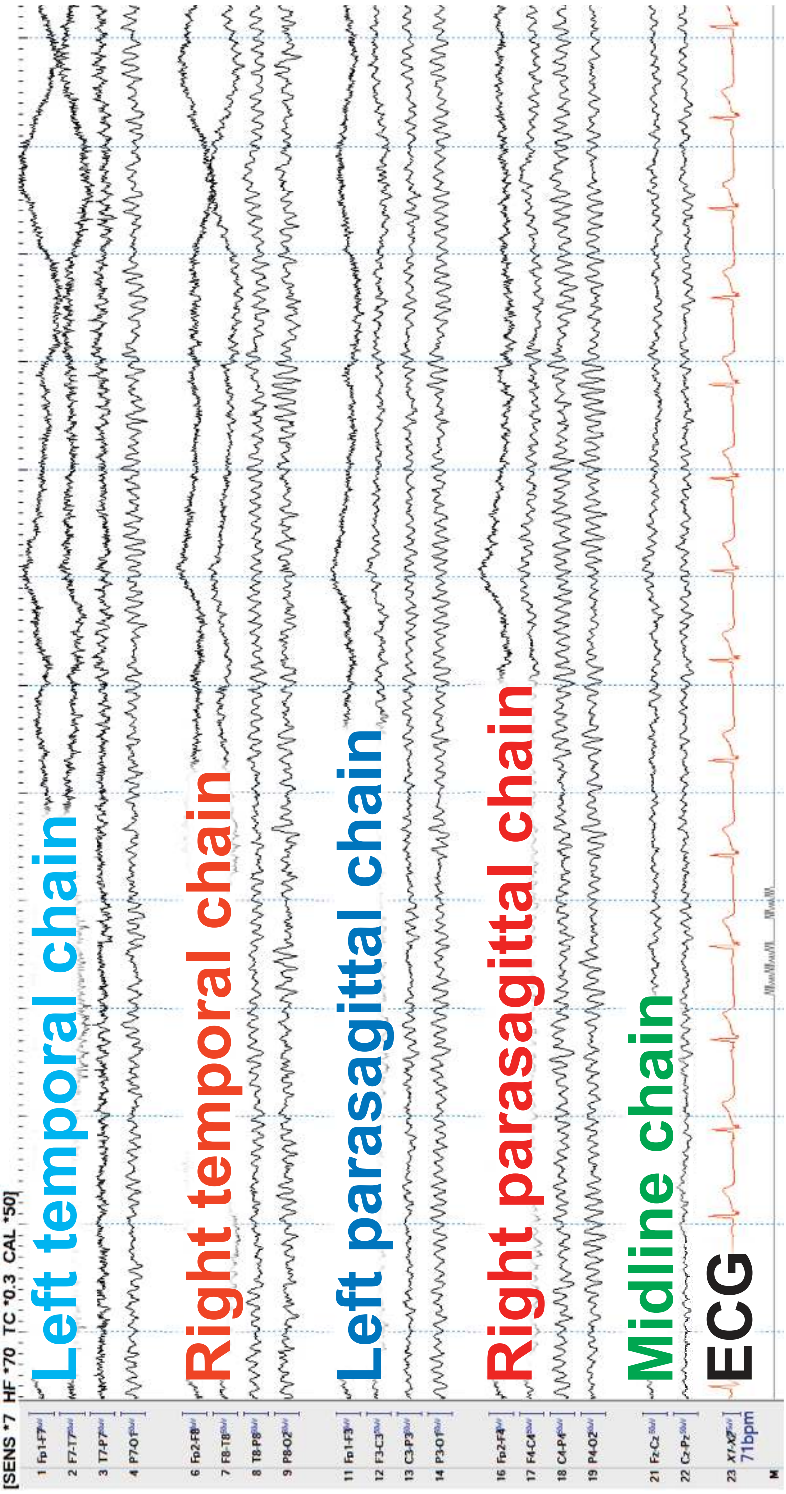

Figure 1.3(a) EEG in longitudinal bipolar montage.

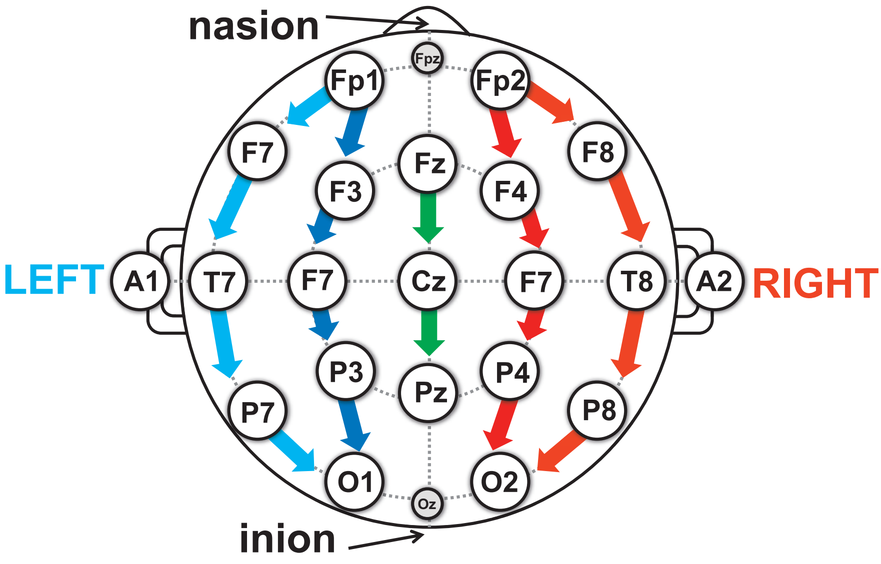

Figure 1.3(b) Longitudinal bipolar montage electrode chains.

Display (Parameters)

A typical bedside display using a longitudinal bipolar montage is shown in Figure 1.3(a). Variations to this format exist. Commonly, the left and the right temporal chains are stacked together followed by the left and right parasagittal chains. This makes it easy to compare the temporal and parasagittal regions of both hemispheres for asymmetry. Readers should know that the temporal regions are also the most epileptogenic so focusing on these channels yields results! The top bar of a recording shows the sensitivity, filter settings, and time base.

Sensitivity (μV/mm) is the magnification of EEG activity. The lower the value, the higher the amplitude of the waveform on the screen. Most EEGs are displayed at a sensitivity of 7 μV/mm as a default setting.

Frequency filters aim to reduce artifact or noise. The three common types of filters are high frequency filter (HFF), low frequency filter (LFF), and notch filter (60 Hz).

- High frequency filters (HFF) screen out frequencies greater than their setting and allow lower frequencies to pass (low pass). They are particularly useful to filter out myogenic (muscle) artifact but may alter the underlying activity to look falsely sharper. The HFF is usually set at 70 Hz.
- Low frequency filters (LFF) screen out frequencies lower than their setting and allow higher frequencies to pass (high pass).
- Notch filters are specific to screen out 60 Hz artifact.

Most displays show 10 or 15 seconds per page of EEG. Figure 1.5 shows a typical display using the longitudinal bipolar montage with excessive muscle artifact before (a) and after (b) application of 30 Hz high frequency filter.

Frequency

This refers to the number of waves occurring per second. It is measured in hertz (Hz). For example, if a rhythmic wave pattern occurs every second, its frequency is 1 Hz.

Activity can be easily described based on increasing order of frequency as follows:

- Delta range (1–4 Hz)
- Theta range (5–7 Hz)
- Alpha range (8–13 Hz)
- Beta range (>13 Hz).

Rhythm

This refers to an electrographic pattern that not only has a regular frequency, but also a specific shape and location. While frequency is merely a descriptive term, rhythms indicate normal or pathological significance – i.e., is it a normal or abnormal pattern?

For example, the "alpha rhythm" (a.k.a. posterior dominant rhythm) is an electrographic hallmark of normal wakefulness.

Normal Adult EEG

The normal background depends on the physiological state: awake, drowsy, or asleep.

Awake

Look for the *alpha rhythm (posterior dominant rhythm, PDR)*. This is the 8.5–13 Hz (alpha range) rhythm, maximal in the posterior head regions, that attenuates with eye opening (an indication of reactivity). The alpha rhythm is an obvious feature of normal wakefulness and is best observed after eye closure in the occipital channels (O). Lower amplitude *beta* activity occurs anteriorly. Any intrusion of theta or delta activity during full wakefulness is usually indicative of an abnormality. Furthermore, the amplitude of the background activity should normally decrease from posterior (O) to anterior (Fp). This is called the normal *anterior–posterior (AP) gradient*. Additionally, there will be artifact from *eye blinks* and *muscle* activity in the frontalis and temporalis muscles. Figure 1.6 shows an EEG during normal wakefulness.

Cambridge University Press & Assessment
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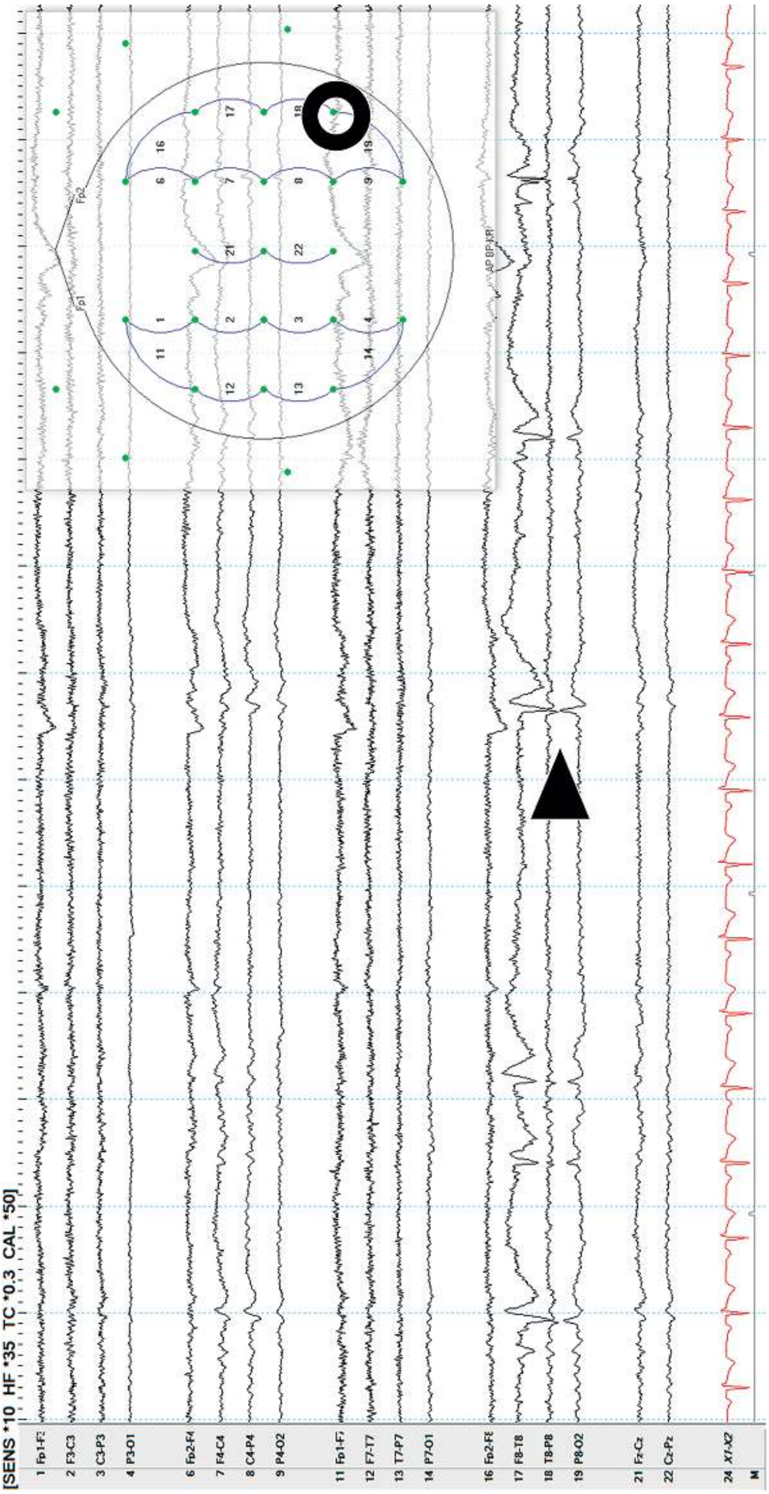

Figure 1.4 Localizing a sharp wave (black arrow) through phase reversal to electrode P8 (black circle).

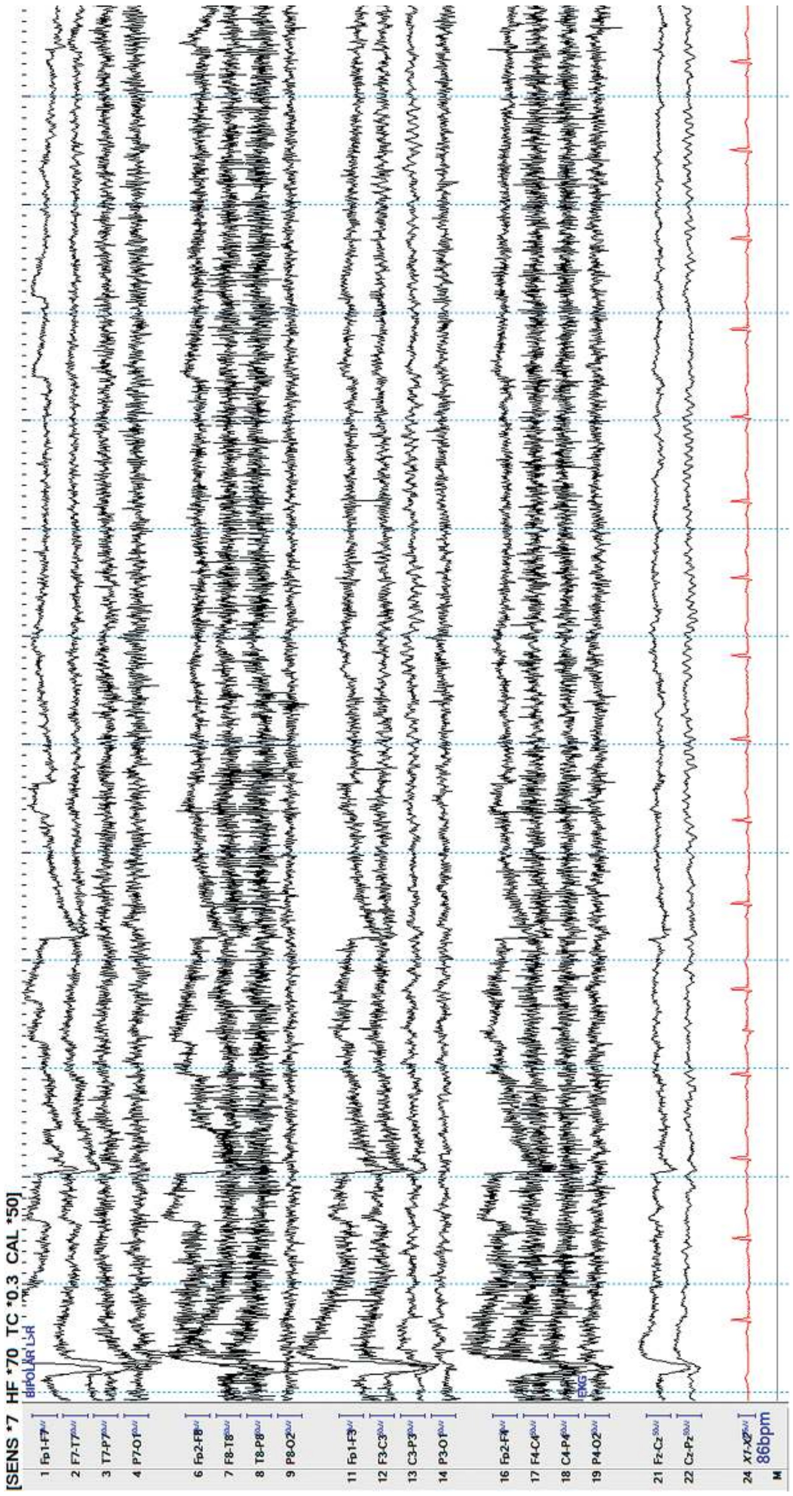

Figure 1.5(a) EEG with HFF set to 70 Hz.

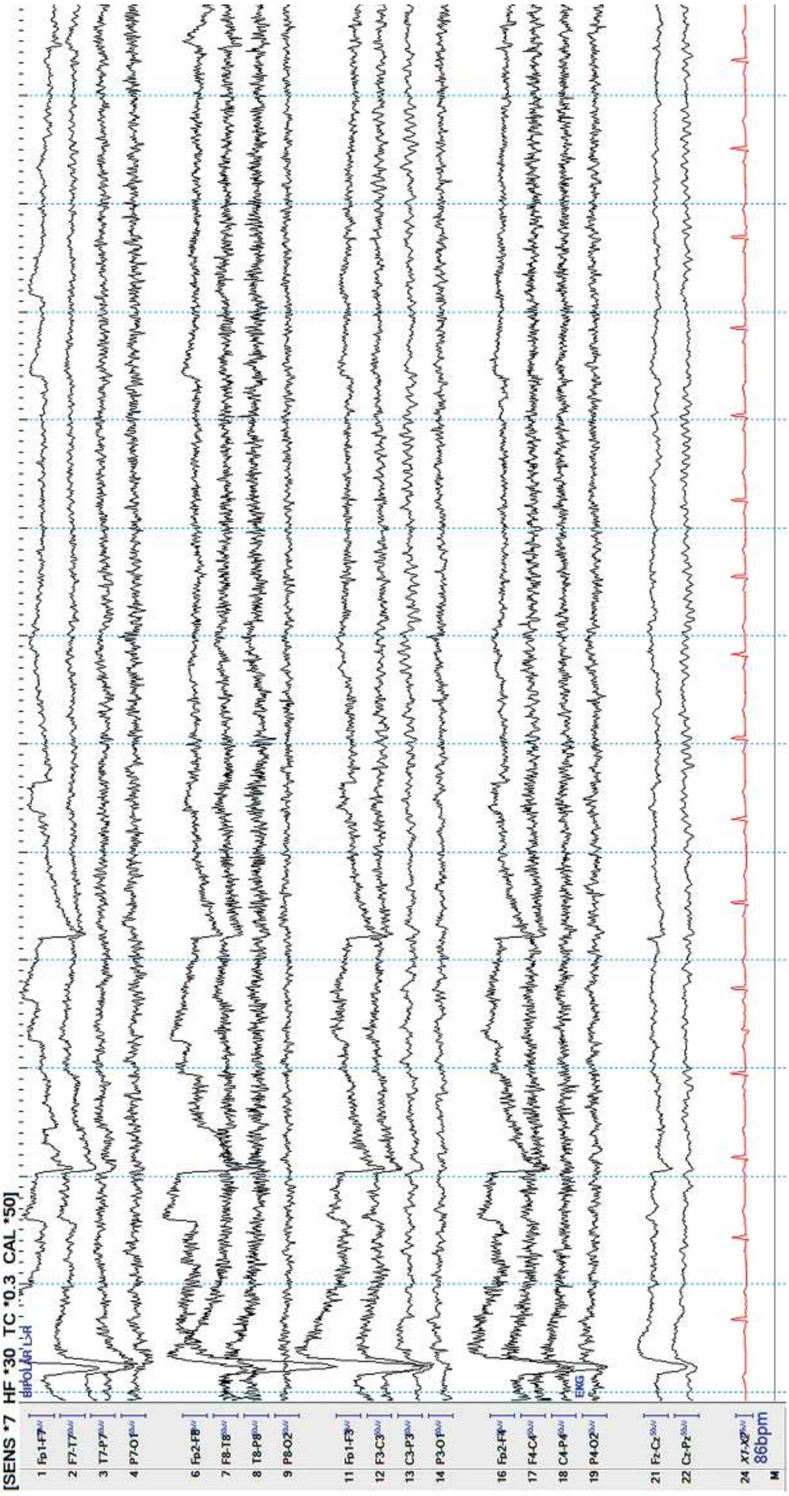

Figure 1.5(b) The same EEG with HFF set to 30 Hz.