

Part I

Basics

Chapter

1

Introduction

Electroencephalograms (EEGs) are commonly used to evaluate transient neurological symptoms (e.g., impaired awareness, abnormal movements, or sensory phenomena) and form a part of the workup for neurological conditions such as epilepsy, stroke, tumors, dementia, and encephalitis. The role of EEG in caring for critically ill patients is also recognized. Neurological trainees can be sure to encounter EEGs in the office, at the bedside, and during various certification exams. However, the level of comfort among trainees to confidently interpret EEGs is variable. At first, most trainees will be intimidated and instinctively limit themselves to reading reports. Misinterpretation of EEG waveforms is also common, resulting in misdiagnosis and unnecessary medications use. The best way to avoid these situations is to be able to interpret the EEG yourself and understand its implications [1].

Simply put, this book allows you to do just that!

Basics

History

In 1875, a British physiologist, Richard Caton first recorded “feeble currents of varying direction” through electrodes placed on the cortical surfaces. In 1929, Hans Berger, a German psychiatrist, recorded the first alpha rhythm (Berger waves), inventing modern EEG. Gibbs, Davis, and Lennox were the first to demonstrate generalized spike and wave discharges in a patient with generalized epilepsy. Gibbs and Jasper also reported interictal discharges in focal epilepsy. In 1936, the first EEG laboratory opened at the Massachusetts General Hospital in Boston [2–5].

Biology

EEG activity is generated by summation of excitatory and inhibitory post synaptic potentials of pyramidal cells in the superficial cerebral cortex. Synaptic activity, unlike action potentials, occurs constantly – not an all or none response. Therefore, *the normal EEG is continuous*. Because pyramidal neurons are arranged radially (like spokes of a wheel), they generate radially oriented dipoles (opposite polar charges). The superficial ends of these dipoles lead to tiny voltage fields (potentials) on the scalp. The EEG record displays the spatial distribution of these potentials and their variation with time. Additionally, input from subcortical structures such as the thalamus and reticular activating system synchronize neuronal activity and generate EEG rhythms. Reportedly, at least 6–10 square centimeters of cortex are required to generate EEG waveforms over the scalp [6–8].

Physics

Scalp potentials (generated by cortical neuronal activity) can be imagined to resemble mountain peaks. They are maximum at their focus and lose strength as distance from the source increases. Voltage (microvolts) is the difference between the strength of two potentials and current is the flow of charge (electrons) between them (milliamperes). Like the flow of water in a river, current flows from a region of higher potential (higher altitude) to lower potential (lower altitude). Resistance (ohms) is the impediment encountered by current during its flow. The relationship between voltage (V), current (I) and resistance (R), $V = I \times R$ (Ohm’s law), is the basic principle of EEG recording.

The EEG machine measures and amplifies the strength and direction of current flow between two electrodes and displays this as a waveform. The reader then interprets these to determine their origin (location) and significance. Pairs of electrodes (channels) are displayed in standardized arrangements (montages) enabling proper interpretation [9].

Indications

The EEG is cost effective, easily available, painless, and noninvasive. Further, it has incredible *temporal resolution* that is, it changes almost instantly with changes in neuronal activity (milliseconds), far superior to most neuroimaging scans, which take at least a few minutes to show physiological changes. A few common indications are listed here.

Clinic

- Evaluate transient neurological spells or symptoms for potential seizures.
- Identify the risk of recurrence (epilepsy) after a first-time seizure.
- Define the type of epilepsy or syndrome.
- Investigate cognitive decline.

Wards (or Epilepsy Monitoring Unit)

- Capture and characterize neurological events.
- Potentially rule in or rule out epilepsy.
- Quantify and localize seizures.
- Guide epilepsy treatments including medication adjustments and surgery.
- Characterize sleep-wake states (sleep studies).

Emergency Room and Intensive Care Unit

- Diagnose and manage status epilepticus.
- Diagnose and differentiate encephalopathic states.
- Guide the titration of anesthesia and sedation.

Operating Room

- Intraoperative guidance in several neurosurgical and vascular procedures (e.g., carotid endarterectomy).

Limitations

There are important technical and practical limitations.

Technical

- Despite the best techniques (and intentions), recording cerebral activity from the scalp has limited *spatial resolution*. As an electrode samples a sizable area of cortex, the precise origin of waveforms is difficult to pinpoint.
- The dampening effect of thick skull bones makes scalp potentials very small (microvolts) and they must be amplified many times to be displayed. Large amplifications also result in contamination from ambient electrical noise (60 Hz) and other artifacts.
- The EEG in principle assumes the cortical surface as a smooth sphere but the cortex is deeply folded with only a third of the cortex (superficial gyri) accessible for scalp recordings. Deep (sulcal), inferior (basal), or hidden (insular/mesial) potentials have poor scalp signals [10].

Practical

- The EEG is a snapshot in time. Like a photograph of the ocean, it reflects the surf only at that point in time. It cannot predict future storms or calm seas.
- When observed, epileptiform abnormalities are associated with (but not diagnostic of) epilepsy. They are indeed more specific (95%) than sensitive (30%) for epilepsy. For this reason, a small percentage of normal healthy adults (<1%) and healthy children (<4%) may have epileptiform abnormalities.
- Less than a third of those with focal brain lesions also have epileptiform abnormalities in the absence of clinical seizures.
- Conversely, less than half of those with epilepsy have epileptiform abnormalities on a single scalp EEG. This yield is maximum immediately after a seizure and decreases thereafter. Repeat EEGs improve the yield. Sleep – whether natural or after sleep deprivation – also increases an EEGs yield and every effort should be made to include it. So do photic stimulation and hyperventilation. Longer duration of monitoring (e.g., ambulatory EEG) improves the sensitivity and specificity. Capture and characterization of seizures on EEG confirm a diagnosis of epilepsy.
- The quantity of discharges seen does not always correlate with severity of the epilepsy [11–15].

Finally, there is the experience and skill of the EEG reader for which there is no substitute.

Electrodes

Scalp electrodes are small silver coated cups or discs. They have a flat rim with a 1 cm diameter and small hole in the central dome for electroconductive gel. This allows the electrodes to fix on the scalp and effortlessly conduct electrical signals onward into the system. The electrode impedance (resistance to the flow of alternating current) should be <5 ohms (higher impedances = bad recordings). After carefully cleaning the scalp, electrodes are affixed with the help of small strips of gauze soaked in collodion or using electroconductive paste. If used, collodion is airdried to form secure connections.

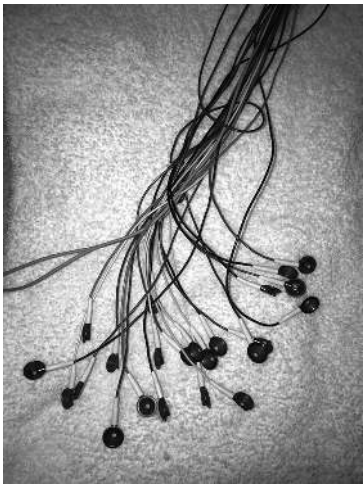


Figure 1.1 Scalp electrodes.

Unprepared oily scalps result in higher impedance that distort the cerebral waveforms while sweat or gel bridges between electrodes result in lower impedances (short circuits) and artifact [16]. MRI compatible electrodes are also available. Figure 1.1 shows scalp electrodes.

Placing Electrodes (10–20 System)

Scalp electrodes are placed in a standardized fashion so that EEG recordings do not differ between laboratories. To achieve this, the International 10–20 System of Electrode Placement was developed in the 1950s and is now widely used with modifications.

- Electrodes are placed based on 10% or 20% increments of circumference measurements using easily identifiable skull landmarks. These are the nasion (top of the nose), inion (occiput), tragus, pinna, and mastoids. Each position has letter and a number.
- The letter indicates the underlying region the electrode records from (not exactly the lobe) such as prefrontal (Fp), frontal (F), temporal (T), posterior temporal (P), occipital (O) and central (C).
- The number assigns its distance and side (right or left) of the midline (Z). Odd numbers over the left hemisphere and even numbers over the right hemisphere. A1 and A2 indicate the left and right ear lobes (or mastoids).

Modified Combinatorial Nomenclature and Other Systems

Most examples here use an adaptation of the original 10–20 system called the modified combinatorial nomenclature as it renames four electrodes (T3 is T7, T4 is T8, T5 is P7, and T6 is P8) conforming with American Clinical Neurophysiology Society guidelines [18–20]. Figure 1.2 shows a schematic of electrode positions on the scalp according to this system.

1. The technician first measures the longitudinal circumference of the head in the sagittal plane from nasion through the vertex (uppermost point of the head) to inion;

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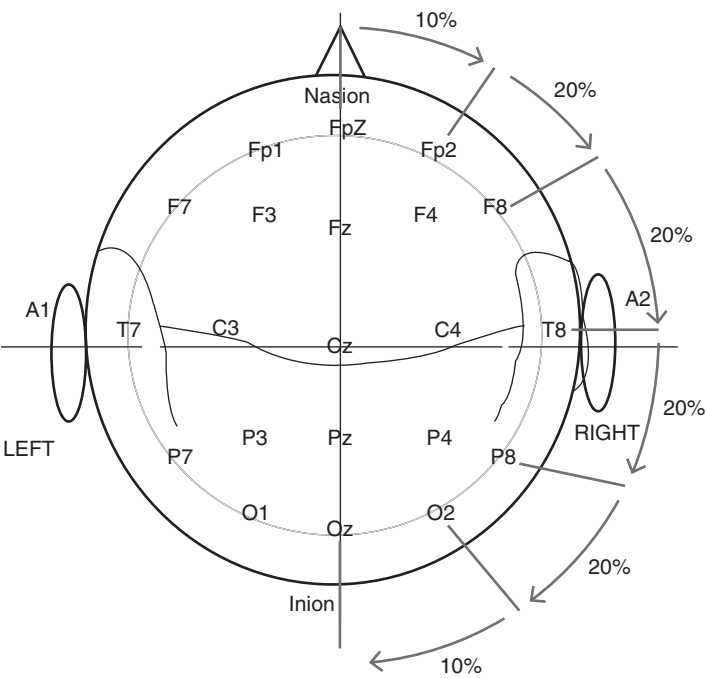


Figure 1.2 Electrode positions (modified 10–20 system); viewed from the top (not to scale).

- this distance is considered 100%. Five points are marked along this line as follows: **Fpz** (10% from nasion), **Fz** (20% from Fp), **Cz** (20% from Fz), **Pz** (20% from Cz), and **Oz** (20% from Pz and 10% from inion).
- Next, the transverse circumference is measured in the coronal plane from left to right preauricular points (root of the zygoma) through the vertex – this distance is considered a 100%. Seven points are marked along this line as follows: **A1** (left preauricular point), **T7** (10% from left preauricular point), **C3** (20% from T7), **Cz** (20% from C3), **C4** (20% from Cz), **T8** (20% from C4), and **A2** (10% from T8 and at right preauricular point).
 - Then, then a lateral circumference is measured from Fpz (anteriorly) to Oz (posteriorly), this passes through T7 on the left and T8 on the right. Points are marked (left/right) as follows: **Fp1/2** (10% from Fpz), **F7/8** (20% from Fp1/2), **T7/8** (20% from F7/8), **P7/8** (20% from T7/8), and **O1/2** (20% from P7/8 and 10% from Oz).
 - Finally, another parasagittal circumference is marked from Fp1 to O1 (through C3, left) and Fp2 to O2 (through C4, right) and considered 80% of the distance from Fpz to Oz. Three points are marked at 25% along this line as follows: **F3/4**, **C3/4** and **P3/4**. See Figure 1.3. Similarly, 10–10 (10% divisions) or 10–5 (5% divisions) system may also be used for higher electrode resolution [17–19].

Sometimes nasopharyngeal or sphenoidal electrodes may be used. Nasopharyngeal electrodes are placed through the nares into the posterior pharynx while sphenoidal

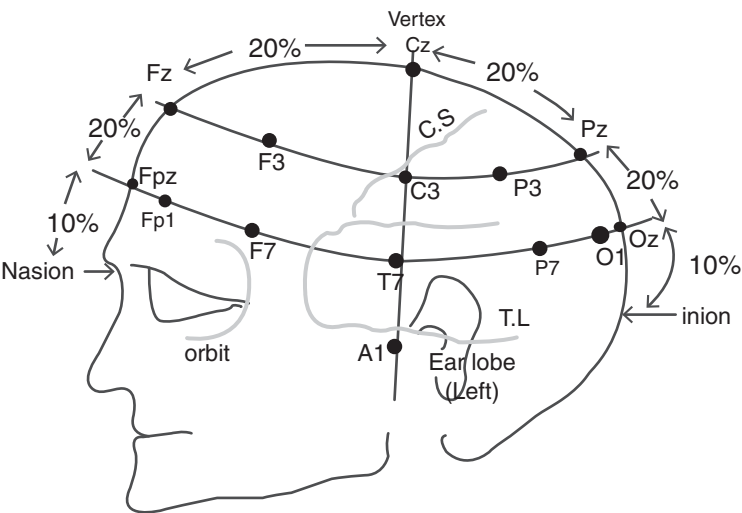


Figure 1.3 Electrode positions (modified 10–20 system); viewed from the left (not to scale).

electrodes are thin wires inserted through a needle placed between the zygoma and mandibular notch. They penetrate to a depth of 3 cm and may provide better resolution of anterior and mesial temporal regions. These are not routinely used as they are invasive and uncomfortable with debatable benefits. Intracranial electrodes are used during evaluation of refractory epilepsies where epilepsy surgery or implantable neurostimulation devices may be a consideration. Most commonly, stereotactically placed depth electrodes are used. Sometimes grid or strip electrodes may be placed over the cortical surface [20,21].

Instrument

The EEG amplifies and processes electrical signals recorded by pairs of scalp electrodes and displays these as waveforms on a digital screen. At its core are combinations of differential amplifiers. These reduce noise artifact between electrode pairs by *common mode rejection* (same artifact potential at both electrodes in each pair cancels out). However, both electrodes in a pair must be equally matched for this to work. If one of them is poorly fixed (high impedance) there will be artifact in the channel. Scalp electrode impedances should be low for onward flow of current into the EEG system (<5 ohms). Impedance checks should be performed before each recording. Gain refers to the factor by which the signal is amplified and is measured in decibels (dB). Typically, a scalp signal needs to be amplified 1,000–100,000 times over (60–100 dB). Digital systems sample the amplified signal for storage and display. The sampling frequency refers to the number and density of data points sampled in time. Cerebral waveforms typically occur within 0.5–30 Hz range so most systems will use a sampling frequency of 100–500 Hz to display representative waveforms. A typical EEG setup consists of electrodes (affixed to the patient’s scalp) with a wire connection to a headbox. This is attached to a computer with a display screen using a thick cable. Figure 1.4 shows the parts of a typical EEG setup [22].

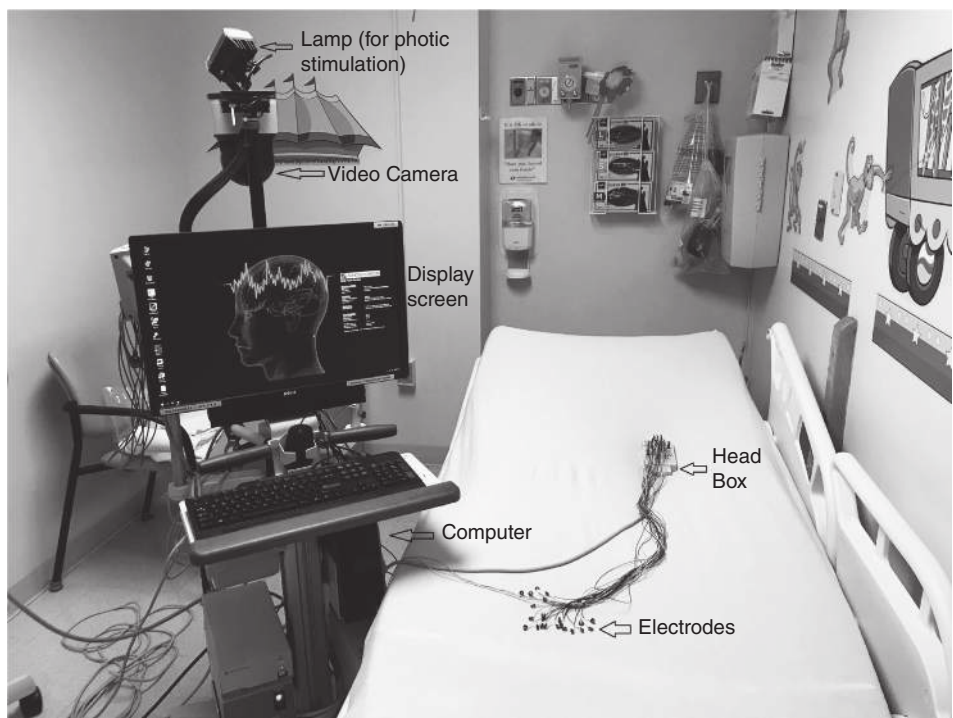


Figure 1.4 Typical EEG setup.

Display

Many different EEG systems are available. Readers should familiarize themselves with the nuances of the system used in their laboratory. Most have a top bar containing recording parameters, montages, and other settings that can be adjusted. A technologist’s log may be pulled up to the right. Commonly, 10–15 s per page are displayed. Each major division (thick lines) is 1 s within which there are five subdivisions (thin lines) of 200 milliseconds each.

The appearance of an EEG screen depends on the *montage*. Most default to the longitudinal bipolar montage (“double banana”) to begin reviewing. Figure 1.5 shows an example of an EEG in the longitudinal bipolar montage.

- The top four channels (each pair of electrodes) are Fp1-F7, F7-T7, T7-P7, P7-O1. These record the patient’s *left temporal* region in anterior to posterior direction (i.e., Fp1 anterior most and O1 posterior most in the chain).
- The next four channels are Fp2-F8, F8-T8, T8-P8, P8-O2. These record the *right temporal* region in anterior to posterior direction. (Placing these two sets in staggered fashion allows easy comparison of both temporal regions.)
- Similarly, the following two sets compare the left (Fp1-F3, F3-C3, C3-P3, P3-O1) and right *paracentral* regions (Fp2-F4, F4-C4, C4-P4, P4-O2).
- The bottom two channels Fz-Cz and Cz-Pz record over the *midline*.
- The final channel represents the electrocardiogram.

Other montages are described in Chapter 2.

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Neville M. Jadeja
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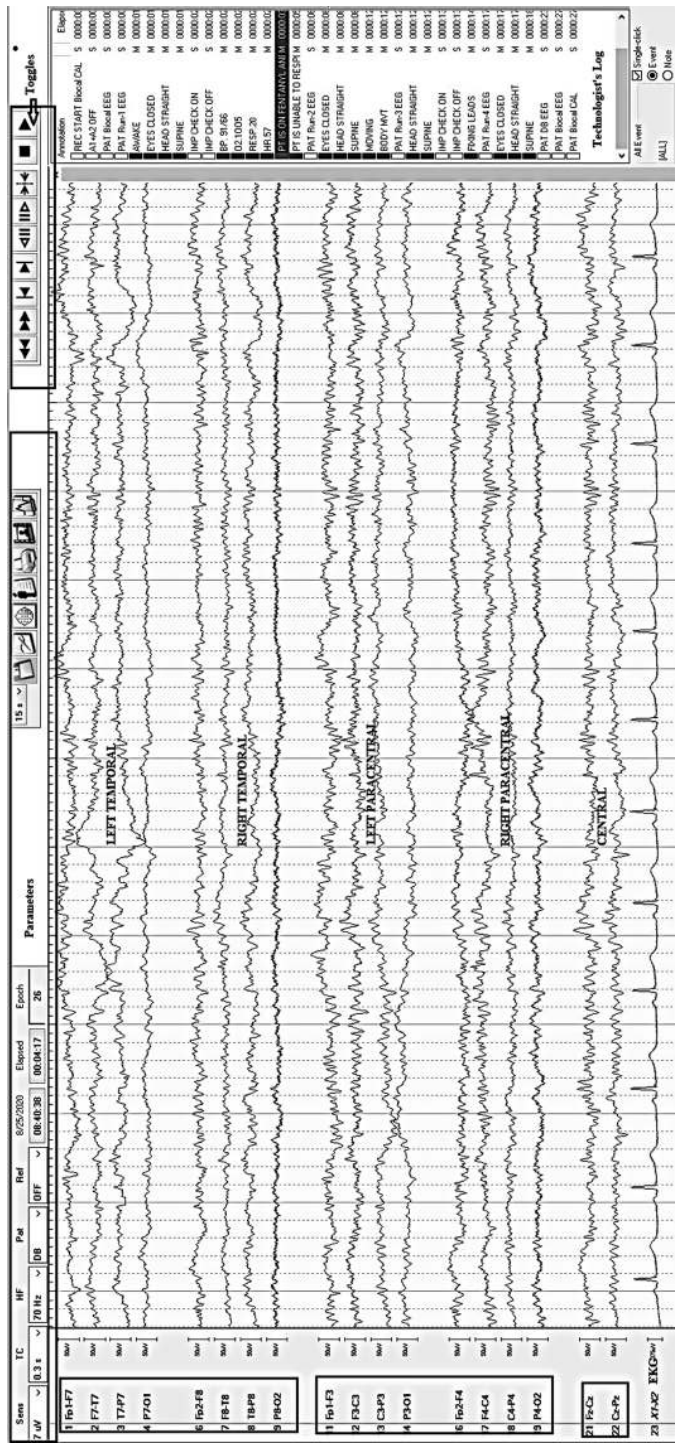


Figure 1.5 Typical EEG display in longitudinal bipolar montage (double banana). Our lab uses a version of the Nihon Kohden Workbench ©. Displays vary depending on software.

Parameters

Sensitivity (Unit: uV/mm)

Sensitivity determines magnification (size) of the waveform. Strength of the potential (uV) is product of its height (mm) and sensitivity (uV/mm). A sensitivity of 7 uV/mm is preferred. Low-voltage records require high sensitivity. Maximum sensitivity of 2 uV/mm may be used to detect very low-voltage cerebral activity (e.g., postcardiac arrest). Low sensitivity (e.g., 15 uV/mm) is useful when reviewing high-amplitude waveforms to appreciate their morphology (e.g., spike waves).

Filters

Clinically relevant cerebral activity lies between 0.5–50 Hz. Activities outside of this range are potentially noise and need to be filtered out to appreciate underlying waveforms. At the filter cutoff frequency, at least 30% of activity occurring at that frequency is attenuated and this amount increases exponentially above or below that frequency depending on the filter type. Time constant is reciprocally related to the filter cutoff frequency. There are three common filters:

- *Low-frequency filter (LFF; high pass):* This filters out frequencies lower than the cutoff frequency allowing higher frequencies to pass. Standard LFF setting is 1 Hz. LFF reduces contaminants (e.g., pulsations, movements, and temperature related artifacts) while preserving low-frequency details (e.g., slowing).
- *High-frequency filter (HFF; low pass):* This filters out frequencies higher than the cutoff frequency allowing lower frequencies to pass. Standard HFF setting is 70 Hz. HFFs reduce high-frequency contaminants (e.g., myogenic artifact) while preserving high-frequency detail (e.g., sharpness).
- *Notch filter* specifically reduces 60 Hz electrical noise.

Paper Speed

The paper speed is commonly set at 30 mm per second. Faster speeds (e.g., 60 mm/second) are used to review high-frequency waveforms as they space out the closely packed activity. Slower speeds (e.g., 15 mm/s) can be used to review slower waveforms.

Calibration Signal

Technologists calibrate the EEG at the start and end of each recording to confirm the sensitivity scale and system integrity.

- Initially, bio calibration is performed (the patients themselves serve as signal source) and all channels use the same electrode pair (usually Fp1-O2 given the long interelectrode distance). In an awake patient, the posterior dominant rhythm and blink artifact will be displayed in all channels confirming the ability of the EEG to record scalp signals. Technologists should check responses for uniformity.
- Next, standard square wave calibration should be performed. At a sensitivity of 7 uV/mm, a calibration signal of 50 uV results in a deflection 7.1 mm in amplitude [23].

Figure 1.6 shows bio calibration; Figure 1.7 shows square wave calibration.

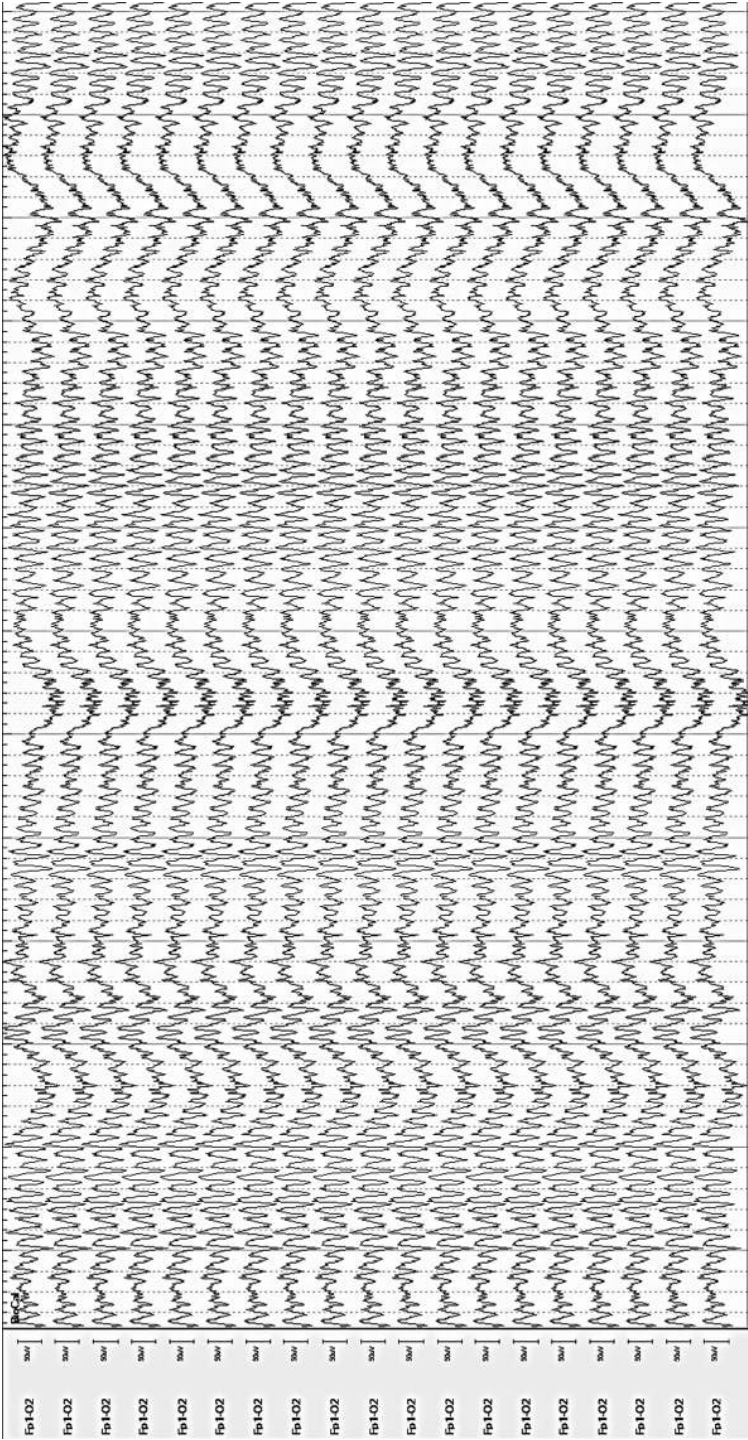


Figure 1.6 Bio calibration using Fp1-O2 channel.