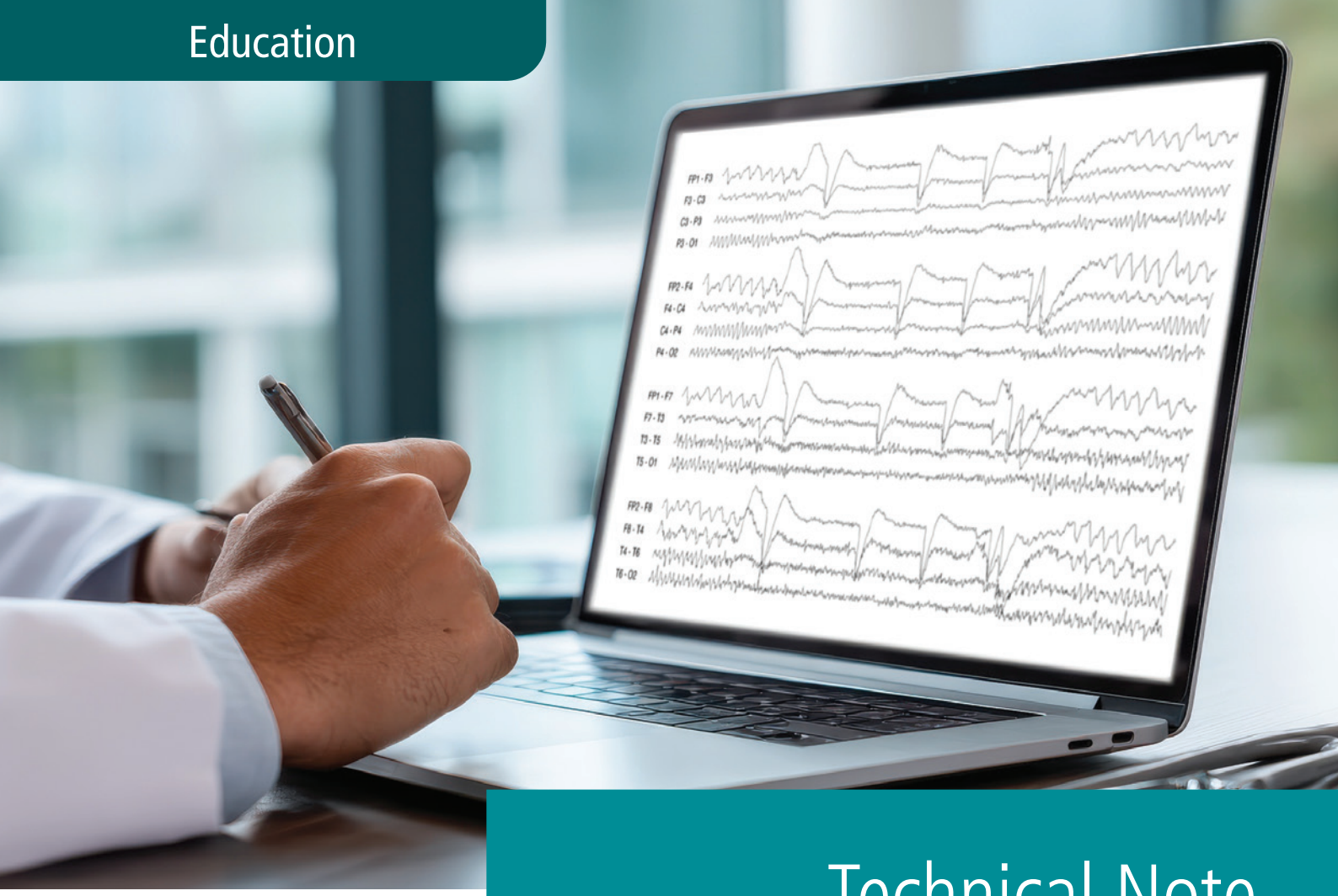
Education



Technical Note

Artifacts in EEG: How to Reduce and Reject

By Simon Yap
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natus®

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Abbreviations

ACNS	American Clinical Neurophysiology Society
CMRR	Common Mode Rejection Ratio
EMU	Epilepsy Monitoring Unit
HVAC	Heating, Ventilation, and Air Conditioning
ISO	Isolation transformer
LTM	Long-Term Monitoring
NCS	Non-convulsive seizure
SE	Status Epilepticus
VNS	Vagus nerve stimulator
DBS	Deep brain stimulators

Introduction

The American Clinical Neurophysiology Society (ACNS) recommends the use of digital EEG systems as the standard for clinical EEG recordings due to their superior sensitivity, reliability, and flexibility compared to paper-based systems. These systems allow post-recording adjustments of gain, montage, and filters, and should be capable of recording from multiple scalp regions simultaneously minimizing interpretation errors.

Proper electrode selection and impedance management are essential for high-quality recordings. Silver-silver chloride and gold cup electrodes are preferred due to their stability, low polarization, and excellent conductivity. Needle electrodes are generally discouraged for routine EEG because of patient discomfort, their invasive nature, increased risk of bleeding and infection, inability to maintain stable long-term recordings, greater susceptibility to movement-related impedance changes, and limited compatibility with prolonged monitoring or repeated examinations. In addition, needle electrodes sample a smaller contact area than surface cup electrodes, which may reduce signal consistency and make reproducible electrode placement more challenging. Their use should therefore be reserved for specific clinical situations where conventional surface electrodes cannot be applied, such as during intraoperative monitoring or when scalp access is severely limited.

Using the same electrode material throughout the EEG montage minimizes electrode-generated voltage differences, improves signal stability, reduces artifacts, and ensures that differences observed between channels are more likely to represent true cerebral activity rather than variations in electrode performance. This is why organizations such as the ACNS recommend using a uniform electrode type whenever possible.

Electrode impedance refers to the resistance to electrical current flow between the electrode and the patient's skin. In EEG recording, high or uneven electrode impedance can negatively affect signal quality because EEG signals are extremely small (typically 10–100 μV). Electrode impedances, including ground and reference electrodes (if applicable), should be checked before recording, ideally remaining balanced and below 10 kΩ, while values below 100 Ω should be avoided as they may indicate a short circuit.

Ground and reference electrodes are critical for recording stability and patient safety. An isolated ground electrode, commonly placed on the forehead, should be used according to manufacturer recommendations and must never be connected to the equipment chassis or earth ground. The ground electrode is mainly used to stabilize the signal and reduce noise levels. Most digital EEG systems also require an additional common reference electrode, typically placed between Fz–Cz or Cz–Pz, to minimize contamination from cerebral activity and improve signal quality. The reference electrode is typically required for EEG measurements according to the differential amplifier design, e.g., F3 (positive input) – Ref (negative input).

Artifacts are an unavoidable part of every EEG recording. They represent electrical signals that do not originate from cerebral activity but are captured by the EEG system. While some artifacts simply obscure

the underlying EEG, others can closely mimic epileptiform discharges, slowing, or even seizure activity, potentially leading to misinterpretation.

In general, a referential montage is commonly used during quality assessment and troubleshooting because it allows individual electrode activity to be evaluated independently. This makes it easier to identify noise, localize the electrode(s) responsible for introducing unwanted activity, and distinguish electrode-related artifacts from true cerebral signals.

Artifacts can be broadly divided into two categories:

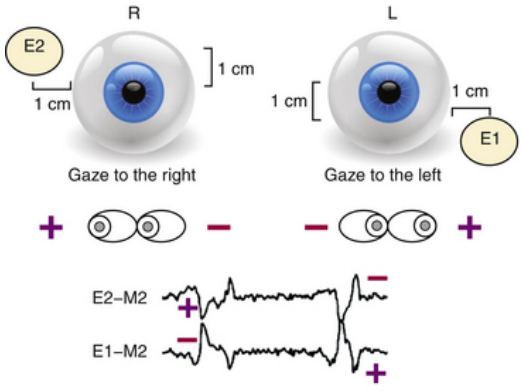
- Physiological artifacts, generated by the patient.
- Non-physiological artifacts, generated by electrodes, equipment, environmental sources, or implanted devices.

Recognizing these artifacts is an essential skill for both EEG technologists and EEG readers. Interestingly, artifacts are not always undesirable. For example, eye movements provide valuable information about vigilance state, muscle activity may indicate patient tension, and the appearance of power-line interference can alert the technologist to electrode impedance problems that require immediate attention.

Physiological artifacts

Eye Movement Artifacts

The eye behaves as an electrical dipole, with the cornea carrying a positive charge and the retina carrying a negative charge. Whenever the eyes move, this dipole generates electrical potentials that are detected by nearby frontal electrodes.



E1: Left outer canthus eye electrode (previously LOC)
E2: Right outer canthus eye electrode (previously ROC)
M2: Right mastoid electrode location

Eye blinks are among the most common EEG artifacts and typically appear as large slow waves in the frontal channels. Eye closure and eye opening generate characteristic deflections that can easily be mistaken for cerebral activity if their morphology is not recognized. Repetitive blinking or eyelid flutter may create rhythmic theta or alpha-frequency activity over the frontal regions, occasionally resembling epileptiform discharges.

Having said that, routine EEG protocols include both eyes-open (EO) and eyes-closed (EC) conditions to assess patient brain's reactivity. Switching between these states forces the visual cortex to adapt to

changing sensory inputs, which helps clinicians establish an arousal baseline, provoke specific brain waves, and highlight underlying neurological abnormalities.



Figure 1 Rapid Blinking. The eye is an electric dipole, with an anterior positive charge and posterior negative charge. During a normal eye blink, the eyes look upwards, creating a positive charge at the anterior frontal leads. This movement is known as Bell's phenomenon.

Horizontal eye movements produce opposite polarities over the left and right frontal electrodes. During REM sleep or nystagmus, activity from the lateral rectus muscles may generate sharp transients known as rectus lateralis spikes.

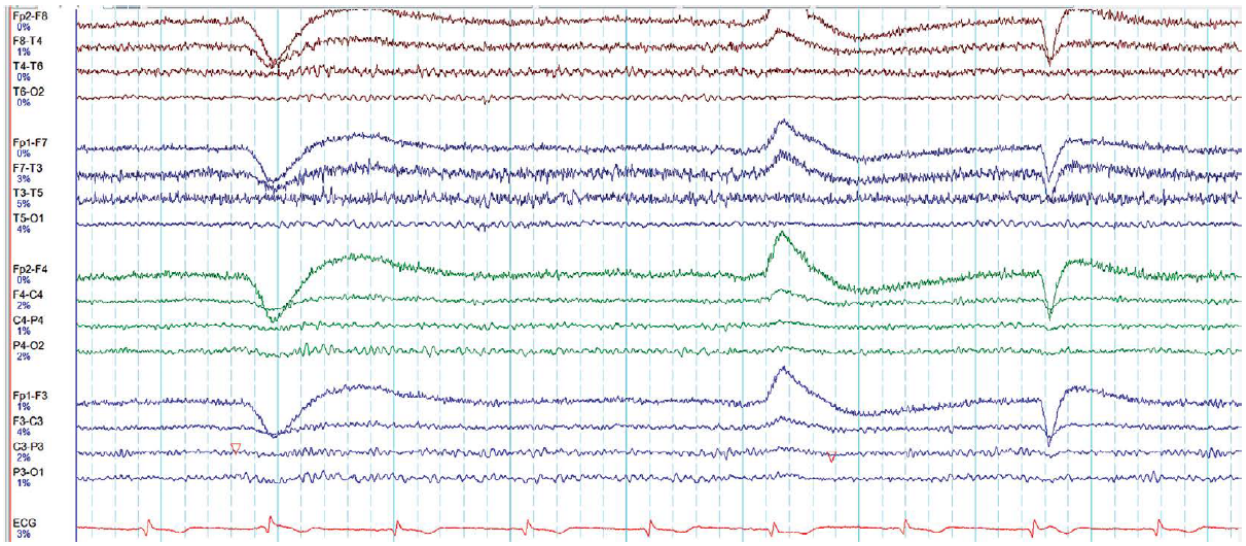


Figure 1.1 Eye-movement artifacts. The first downward deflection is consistent with eye closure, whereas the next upward deflection is caused by eye opening. The last downward deflection is due to an eye blink.

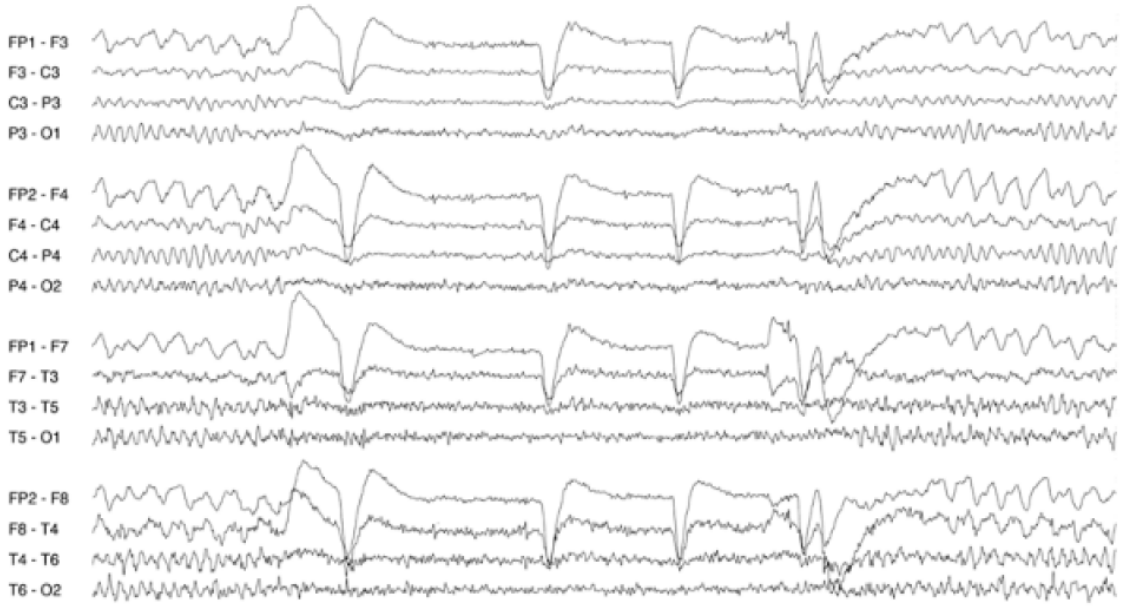


Figure 1.2 Eyelid flutter causing a rhythmic artifact involving the anterior channels in theta frequency.

To minimize eye movement artifacts, patients should be encouraged to relax and minimize excessive blinking. Eye patches may be useful in anxious individuals with persistent eyelid flutter. During data review, correlation with EOG channels and video recordings is invaluable for distinguishing ocular artifacts from genuine cerebral activity. Alternatively, software tool such as Persyst Artifact Reduction (AR) also works in near-real-time to reduce EMG, Electrode Artifact and Eye Movement

Muscle (Myogenic) Artifacts

Muscle activity is one of the most frequent challenges in EEG interpretation. Artifacts commonly arise from the frontalis, temporalis, masseter, and neck muscles.

Muscle artifacts may appear as isolated twitches, repetitive bursts, or continuous high-frequency activity. Single muscle twitches often resemble epileptiform spikes because of their sharp morphology. However, they typically have a narrow field, are polyphasic in appearance, and lack the after-coming slow wave commonly associated with epileptiform discharges.

Chewing produces repetitive burst-like artifacts that may mimic rhythmic seizure activity. Continuous muscle tension, particularly in anxious or uncomfortable patients, creates dense high-frequency activity over frontal and temporal regions. Excessive filtering may reduce the artifact but can leave residual activity resembling beta rhythms, leading to further confusion.

To facilitate identification of EMG artifacts, dedicated EMG channels should be recorded whenever appropriate (e.g., chin/submental EMG, masseter EMG, or other muscle leads depending on the study). Simultaneous EMG recording allows the technologist and interpreting physician to correlate periods of increased muscle activity with suspicious EEG patterns, helping differentiate true cerebral activity from

artifact. Proper placement and secure attachment of EMG electrodes are essential to ensure reliable muscle recordings.

If excessive EMG contamination is observed, patients may be instructed to relax facial and jaw muscles, avoid talking or chewing, and maintain a comfortable position to minimize muscle tension. Correlation with video recordings can further assist in confirming the source of the artifact.

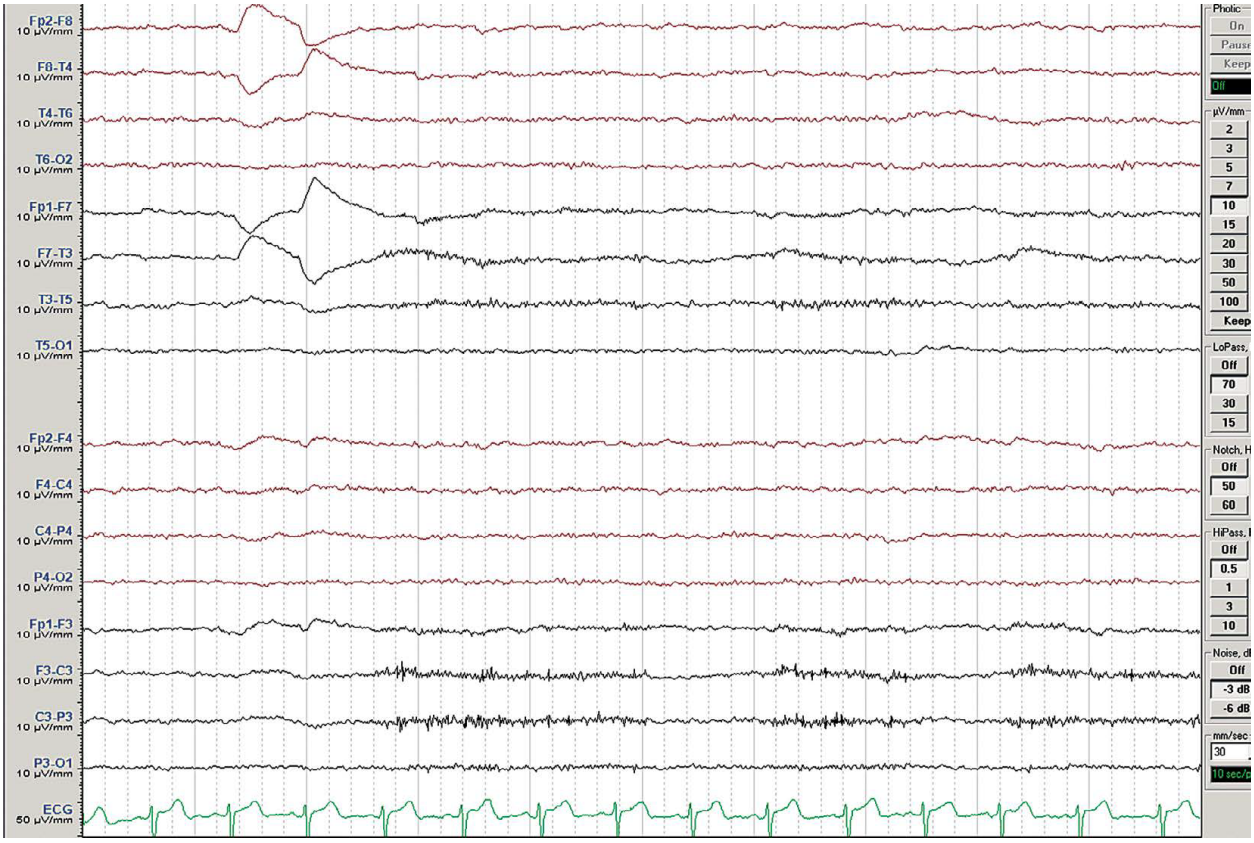


Figure 2 An eye-movement artifact generated by first looking to the right and then quickly looking to the left. Note the opposite polarities of the artifacts.

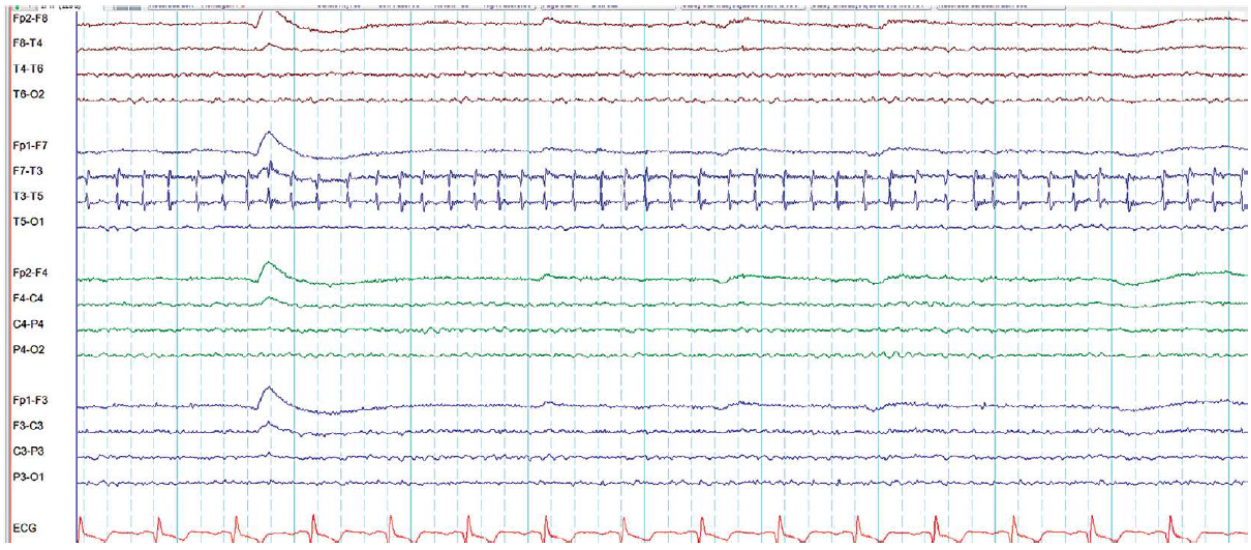


Figure 2.1 Artifact due to a single muscle twitch of the left temporalis muscle captured by the T3 electrode.

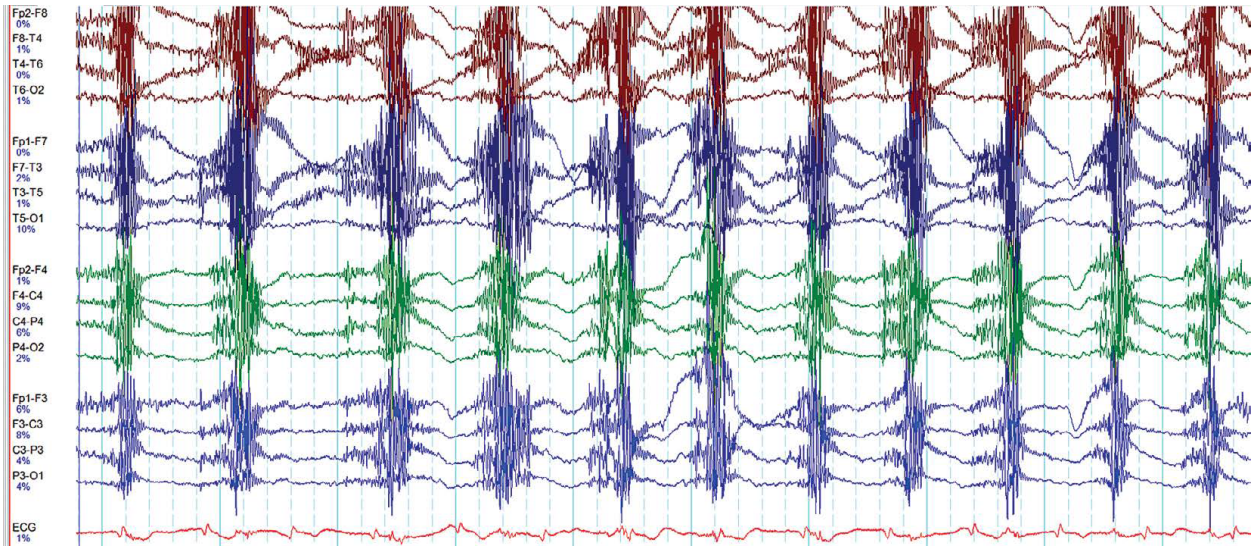


Figure 2.2 The burst pattern of muscle artifact generated by chewing.

Effective management begins with reassuring the patient and encouraging relaxation. If jaw muscle activity is suspected, asking the patient to slightly open their mouth and perform slow deep breathing often significantly reduce temporal muscle artifact. The occipitalis and neck muscles at the back of the head could affect posterior electrodes (O1, O2, P3, P4 and nearby sites). Head movements, neck tension, and even swallowing can inject EMG into these channels. Ensure that the patient is seated comfortably with adequate head and neck support. Make sure they are not craning or straining their neck to view a screen. The room should also be kept at a comfortable temperature to prevent the patient from tensing or hunching their shoulders. If necessary, consider placing the patient in a comfortable supine or reclined position to promote relaxation and further minimize muscle artifacts. During review, frequency filtering and spectral analysis may assist in differentiating EMG activity from cerebral signals. Advanced tools such as Persyst can also help classify and suppress muscle artifacts during interpretation.

Tongue Movement (Glossokinetic) Artifacts

The tongue also functions as a bioelectrical dipole. Movements of the tongue generate slow electrical potentials that can be recorded by scalp electrodes.

Up-and-down tongue movements, such as repeatedly saying "la-la-la," often produce rhythmic bifrontal delta activity. Side-to-side tongue movements tend to generate rhythmic slowing over the temporal

regions. During talking, chewing, or swallowing, these slow potentials are frequently mixed with muscle artifacts, creating complex waveforms that may resemble polyspike-wave activity.

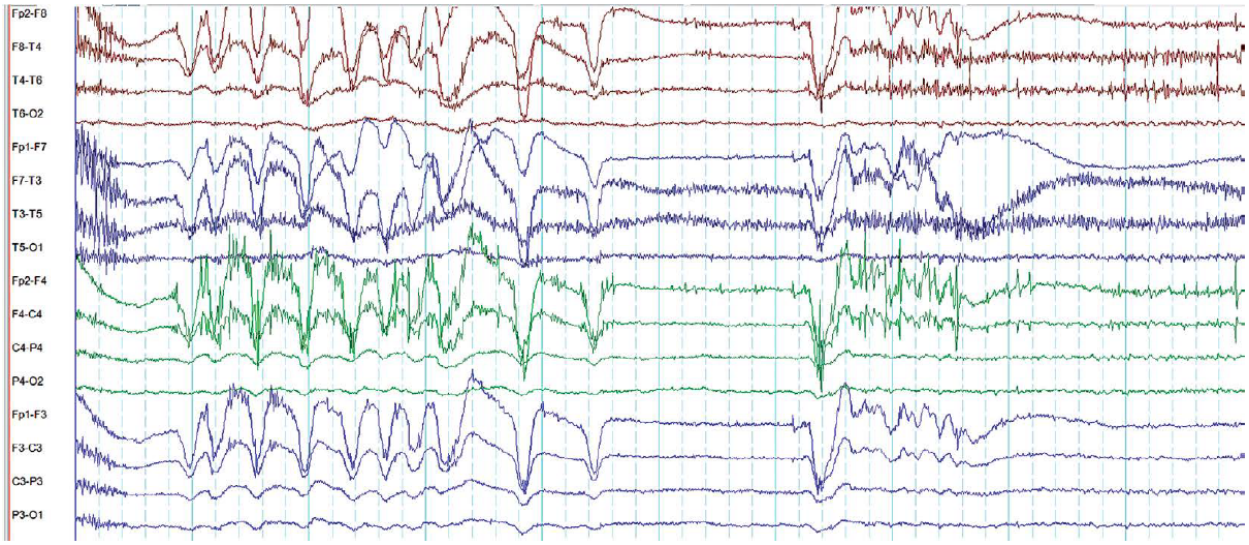


Figure 3 A glossokinetic artifact generated by up-down movements of the tongue.

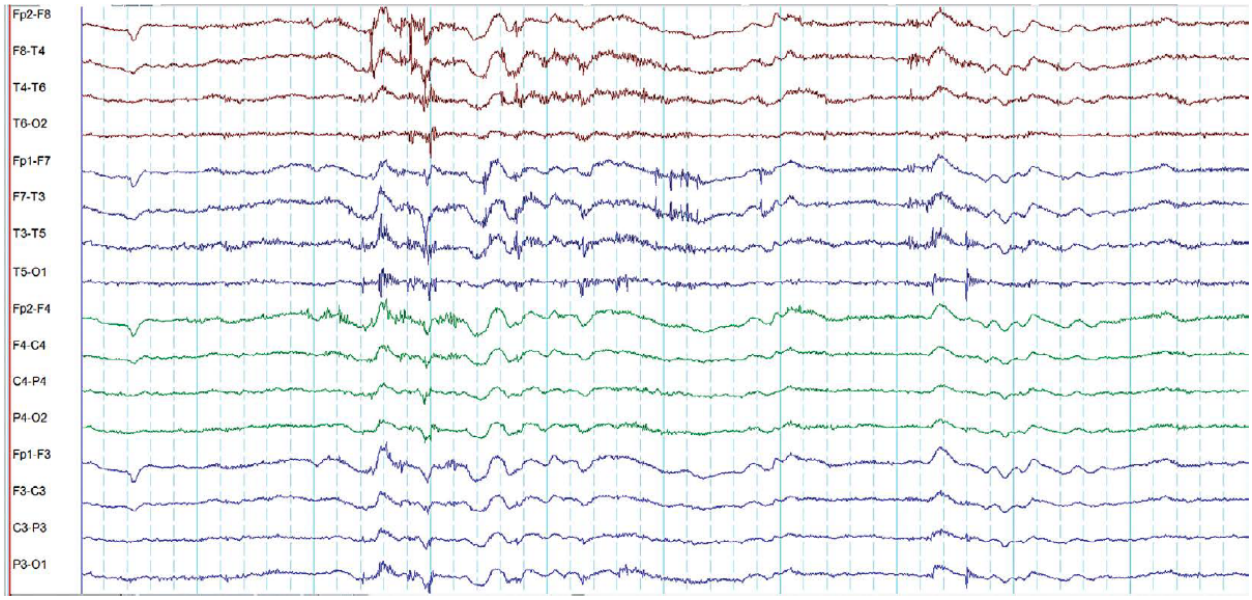


Figure 3.1 A glossokinetic artifact generated by lateral movements of the tongue.

When tongue artifacts are suspected, video correlation and additional facial electrodes can help confirm the source.

Movement Artifacts

Movement artifacts result from physical displacement of electrodes, lead wires, or the patient's head. They frequently occur during restlessness, tremor, or psychogenic non-epileptic events.

These artifacts can be rhythmic or irregular and may closely resemble ictal EEG patterns. Unlike true seizures, however, movement artifacts generally lack the evolution in frequency, amplitude, or spatial distribution that characterizes epileptic activity.

Secure electrode application, proper cable management, and video review are critical for identifying and minimizing movement-related artifacts.

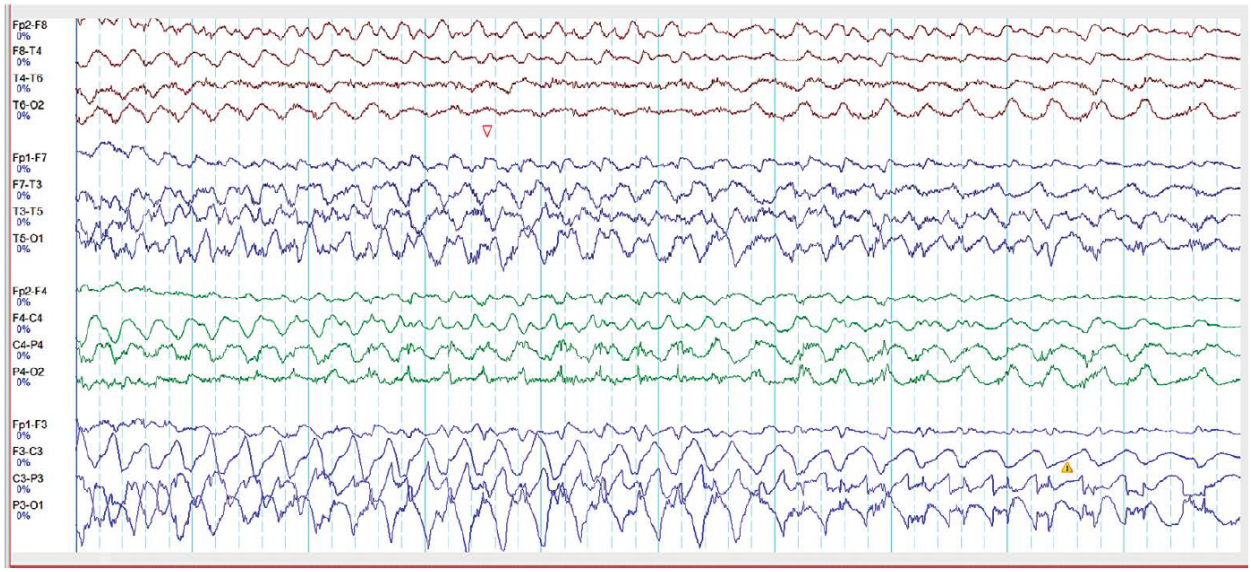


Figure 4 A rhythmic movement artifact caused by a psychogenic non-epileptic seizure. Note the multiple phase reversals, varying amplitudes, and the lack of evolution of rhythmic activity.

Cardiac Artifacts

Cardiac activity can appear on EEG recordings in several forms.

- **ECG Artifact**

The electrical activity generated by the heart may spread to scalp electrodes and produce periodic sharp transients that occur synchronously with the QRS complexes seen on the ECG channel. This artifact is particularly common in obese individuals or those with short necks.

Verification is straightforward by comparing the EEG waveform with the ECG channel and confirming a consistent one-to-one relationship.

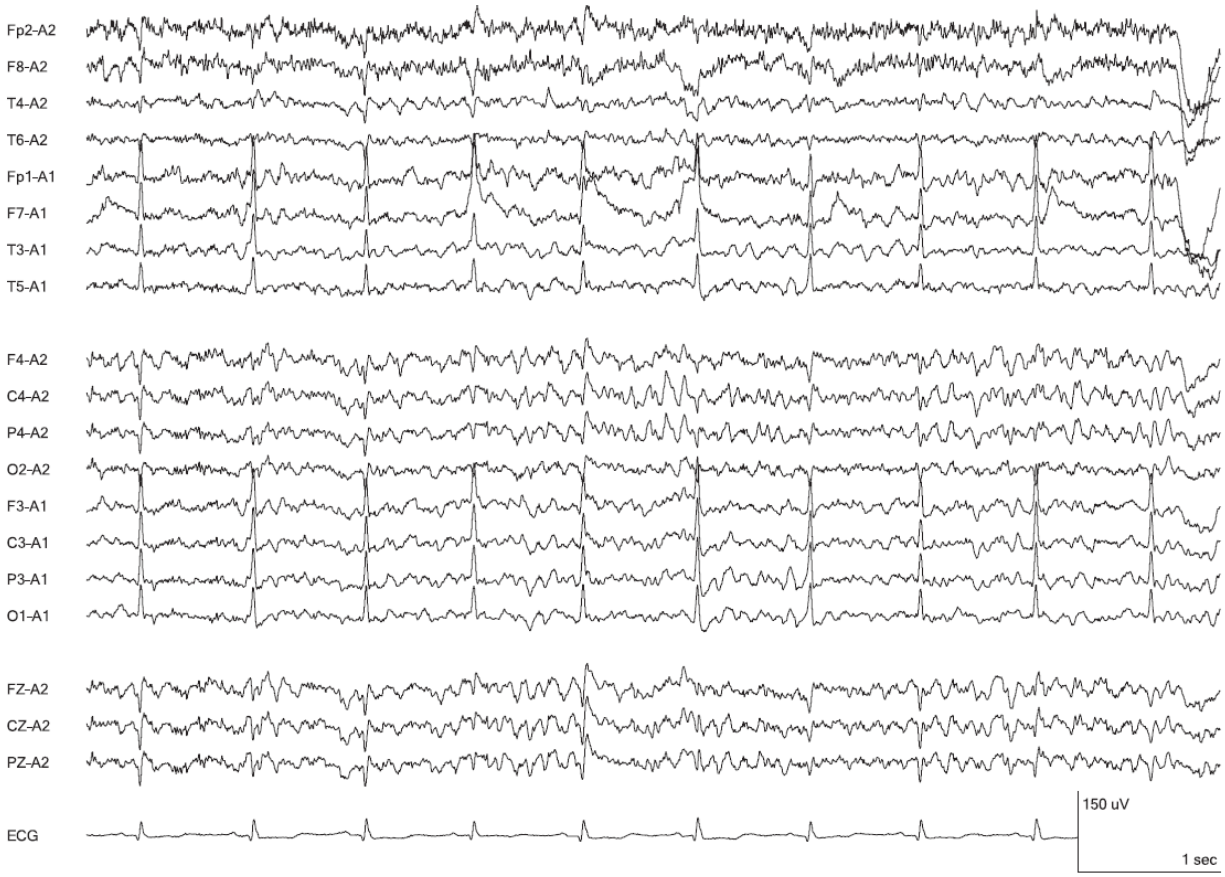


Figure 5 This EEG segment presented in an ipsilateral ear referential montage. The ECG artifact remains predominant on the left side, but now also is more evident on the right in channels with greater interelectrode distances. The ear electrodes demonstrate the opposite polarity for the artifact due to the heart's dipole. (LFF 1 Hz, HFF 70 Hz)

To reduce the ECG artifacts, we could re-reference the EEG data to a balanced or linked ear/mastoid (e.g: M1+M2/2) setup. If the reference electrode is too close to the neck, it will disproportionately pick up ECG

signals. On the other note, the ground electrode can sometimes pick up cardiac noise. In some recording setups, shifting the ground to the upper forehead helps reduce ECG pickup.

- **Pulse Artifact**

Pulse artifacts occur when an electrode lies directly over a pulsating artery. They appear as rhythmic slow waves occurring shortly after each QRS complex.

Slight repositioning of the electrode or the patient's head usually resolves the issue.

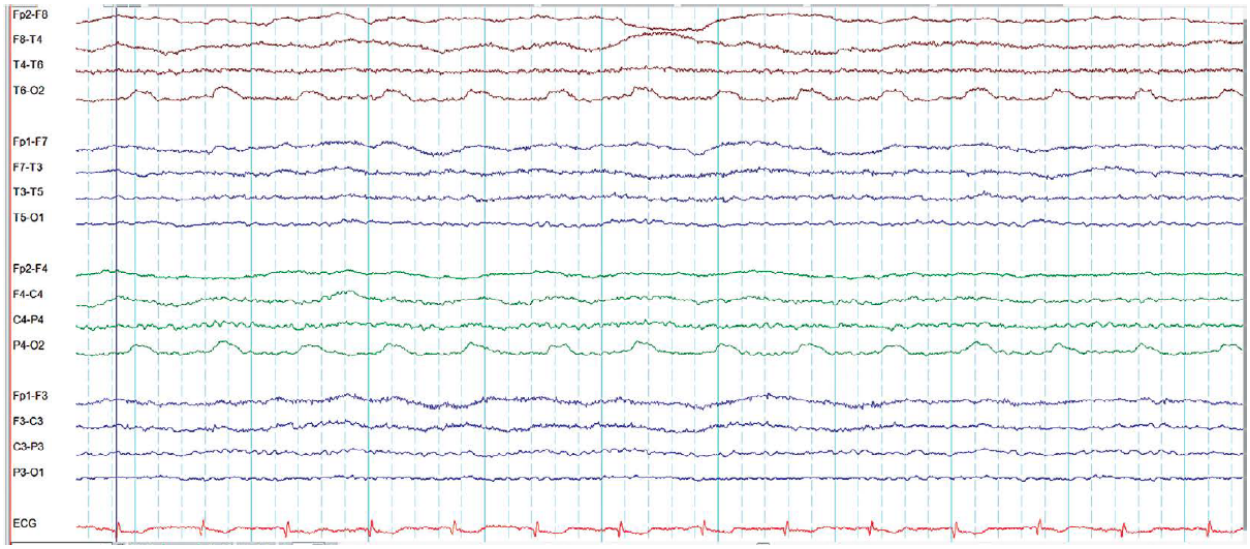


Figure 5.1 A pulse artifact captured by the right occipital electrode. Note slow-wave morphology, rhythmicity, and time-locked appearance after each QRS complex of the ECG.

- **Ballistocardiographic Artifact**

Strong cardiac contractions can produce subtle head movements, causing oscillation of electrode leads and resulting in rhythmic slow-wave artifacts. Proper bundling and stabilization of cables often reduces these artifacts.

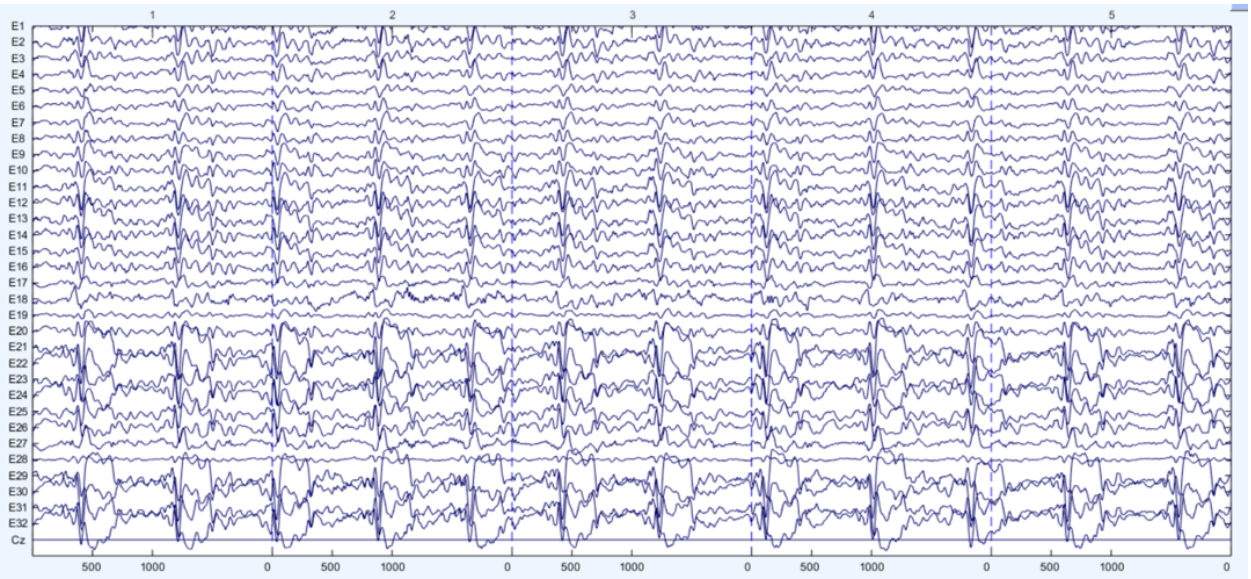


Figure 5.2 Ballistocardiographic Artifact on a 32 channels EEG recording

Sweat Artifacts

Sweating alters skin potentials and electrode impedance, producing very slow, high-amplitude undulating waveforms. These slow fluctuations can easily be mistaken for cerebral delta activity.

Sweat may also create a "salt bridge" between adjacent electrodes. When this occurs, the affected channel may become nearly flat because both electrodes record almost identical electrical potentials.

Cooling the patient, improving room ventilation, and cleaning the scalp with alcohol are effective methods of reducing sweat-related artifacts.

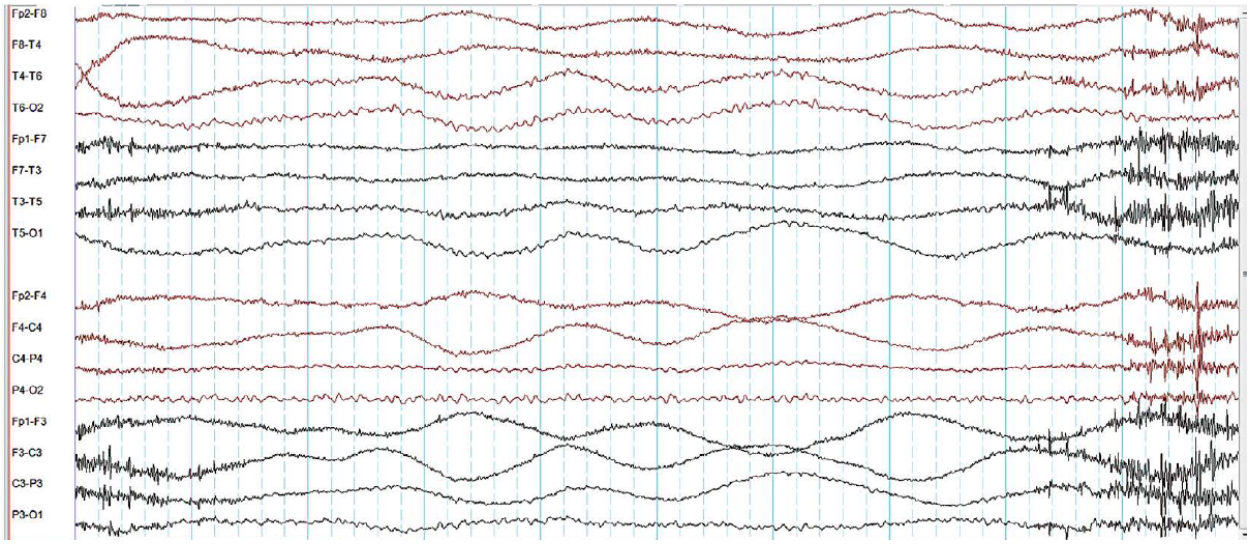


Figure 6 Sweat Artifacts

Non-physiological artifacts

Electrode Artifacts

Poor electrode contact remains one of the most common causes of EEG artifacts.

- **Electrode Pop**

An electrode pop occurs when an electrode-skin interface becomes unstable due to drying paste, poor contact, or mechanical disturbance. The resulting waveform may closely resemble a spike, sharp wave, or slow transient.

Re-gelling, repositioning, or replacing the electrode typically resolves the problem.

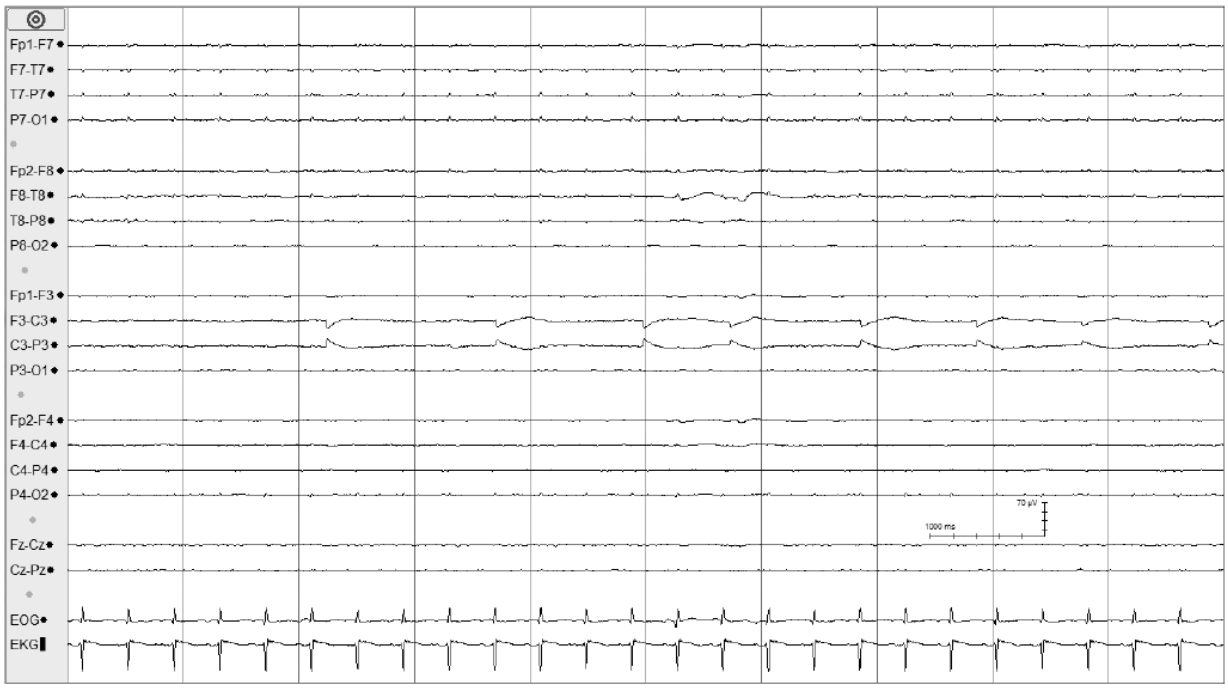


Figure 7 Electrode "pop" at C3. Recurrent, slowly repetitive, sharp waves are present in the left central region due to electrode instability. Each waveform begins with a steep deflection typical of electrode "pop."

- **Electrode Misconnection**

Incorrect connection of electrodes to the jackbox may create bizarre and confusing EEG patterns. For example, ECG activity may appear in an EEG channel if electrode inputs are accidentally swapped.

Each electrode is connected to amplifiers via the jackbox. If the electrode pin is plugged into the wrong receptacle of the jackbox, bizarre artifacts will appear as illustrated below.



Figure 7.1 Artifact generated by electrode swap at the jackbox. (a) High-amplitude ECG artifact is visible at T6 on the common average reference montage with reduced amplitude by changing the sensitivity.

Above, the ECG electrode is mistakenly plugged into the receptacle of T6 and vice versa, resulting in the ECG appearing on T6.

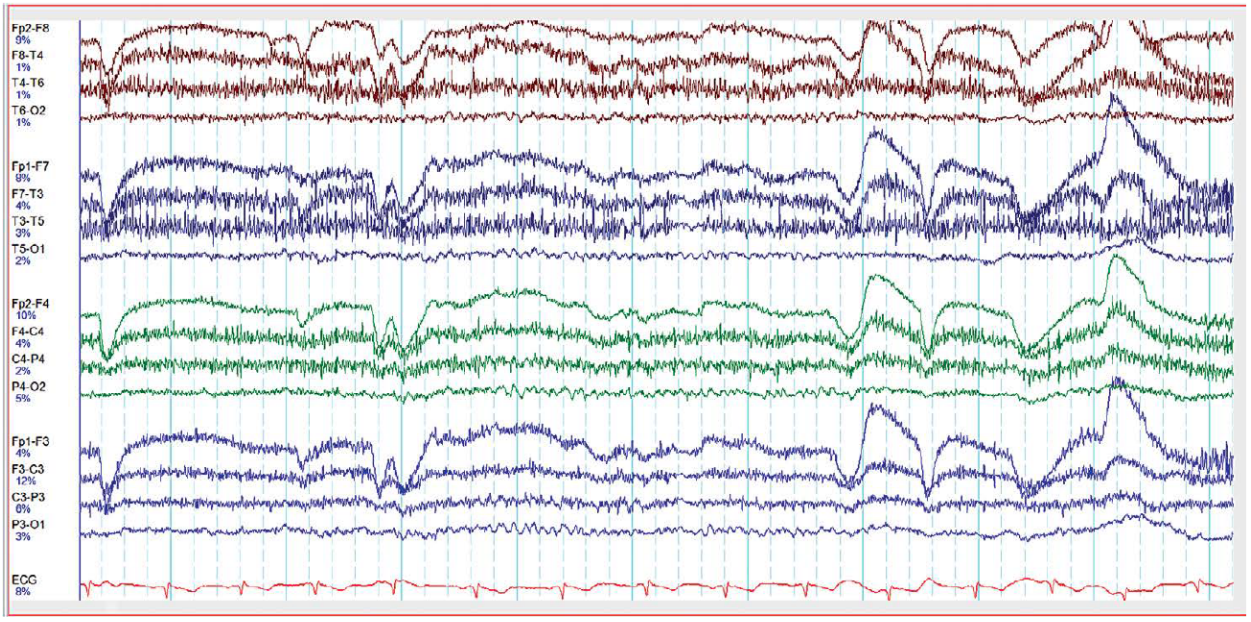


Figure 7.2 Normal EEG and ECG appearance after rectifying the swap.

When this swap is corrected, normal ECG and EEG activities can be seen over T6 and ECG channels. Whenever unusual patterns are observed, electrode connections should be verified immediately.

Power-Line Interference (50/60 Hz Artifact)

Power-line interference is among the most recognizable EEG artifacts. Depending on the region, electrical mains operate at either 50 Hz or 60 Hz and may contaminate EEG recordings.

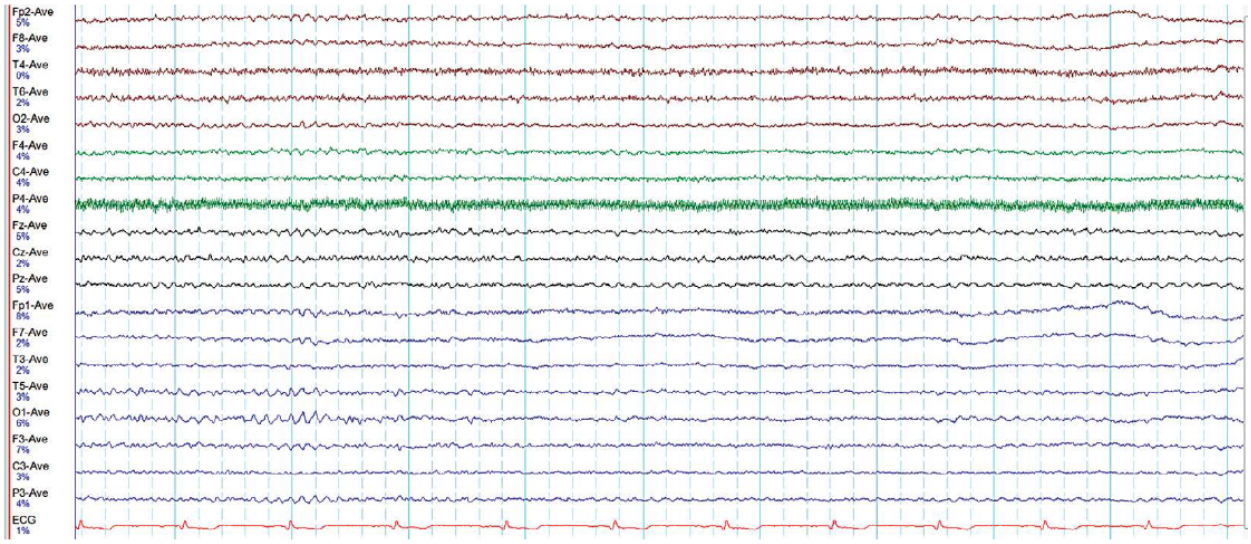


Figure 7.3 A 50-Hz artifact involving a single EEG channel in the common average reference montage. Note the 50-Hz artifact involving the P4 electrode due to its high impedance.

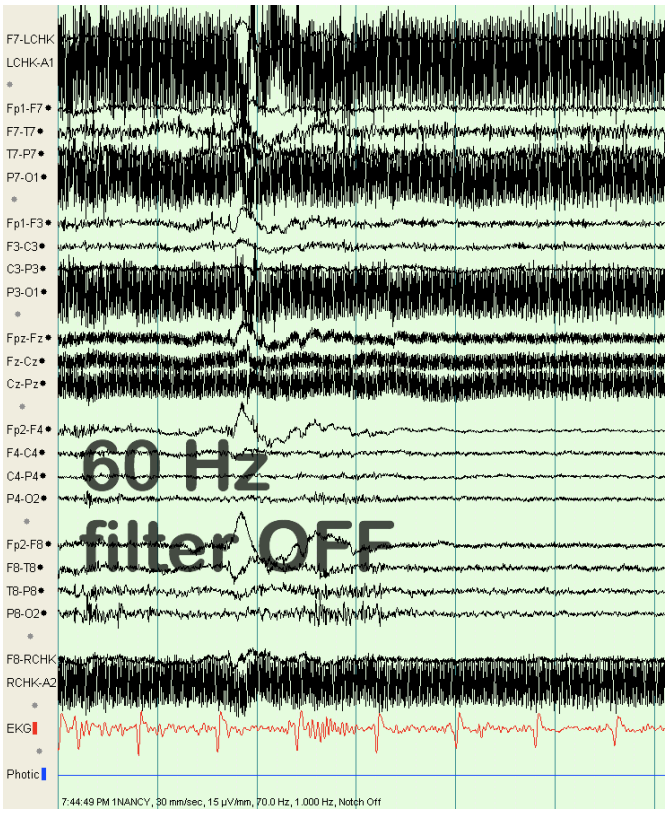


Figure 7.4 A 60-Hz artifact involving most EEG channels in a Longitudinal bipolar montage.

To minimize power-line interference, the EEG system should be installed away from strong electromagnetic sources such as electrical distribution panels, transformers, and wireless charging devices. Proper hospital grounding and adherence to electrical safety standards are essential, as poor grounding can significantly increase susceptibility to electrical noise. Environmental factors should also be considered during room planning; for example, elevator motors, HVAC equipment, or other heavy electrical machinery located behind walls or above ceilings may generate electromagnetic fields that introduce persistent interference into EEG recordings.

The use of an isolation transformer (box) is highly recommended because it electrically isolates the patient and acquisition system from potential ground loops and external electrical disturbances. By reducing common electrical noise entering the recording chain, the ISO box can substantially improve signal quality, particularly in electrically challenging environments such as intensive care units or operating rooms.

Modern EEG amplifiers also incorporate a high CMRR, an inherent amplifier characteristic that suppresses electrical signals that appear equally on all electrodes. A high CMRR helps reduce susceptibility to power-line interference and other environmental electrical noise. However, optimal CMRR performance depends on maintaining balanced electrode impedances and good electrode contact. Significant impedance differences between electrodes can reduce the effectiveness of common-mode noise rejection, allowing electrical interference to become more prominent in the EEG trace. For a more detailed technical explanation of CMRR and its role in EEG signal acquisition, refer to the Natus Technical Note on CMRR here.

When power-line interference is observed, corrective actions may include verifying electrode impedances, ensuring proper grounding, relocating cables away from power cords, eliminating unnecessary electrical devices near the patient, utilizing an ISO box, and investigating potential environmental noise sources within the room. Although notch filters can be used to attenuate 50/60 Hz noise, they should be applied cautiously because excessive filtering may distort physiological EEG signals. Therefore, addressing the source of interference remains the preferred approach whenever possible.

Instrumental Artifacts

The combination of EEG with other neuroscience techniques is now a frequent case in the field. However, many devices used in these other techniques unavoidably cause artifacts in the EEG. A “blocking artifact” occurs when the input signal momentarily exceeds the amplifier's operating range, causing the amplifier to saturate. During this period, the affected channel may appear flat (blocked) or clipped before gradually returning to baseline. Common causes include electrode pops, patient movement, electrostatic discharge, or abrupt impedance changes. Blocking artifacts typically affect only the channels connected to the saturated amplifier input. For instance, in simultaneous EEG-fMRI, the scanner environment induces diverse artifacts. Most notably, the magnetic gradient switching induces large currents in the EEG leads, which produce large artifactual voltages. Vibrations of the scanner further produce motion artifacts that are enhanced by the scanner’s magnetic field. Artifact handling in EEG-fMRI requires special techniques that cope with the particular nature of these artifacts.

TMS pulses generate large spikes that may lead to the saturation of the EEG amplifier. Effects on the hardware furthermore lead to a decay artifact for a few milliseconds [15]. If there is amplifier saturation,

it means that the EEG data is lost for a brief period, so the spike and decay are most frequently replaced by interpolated data.

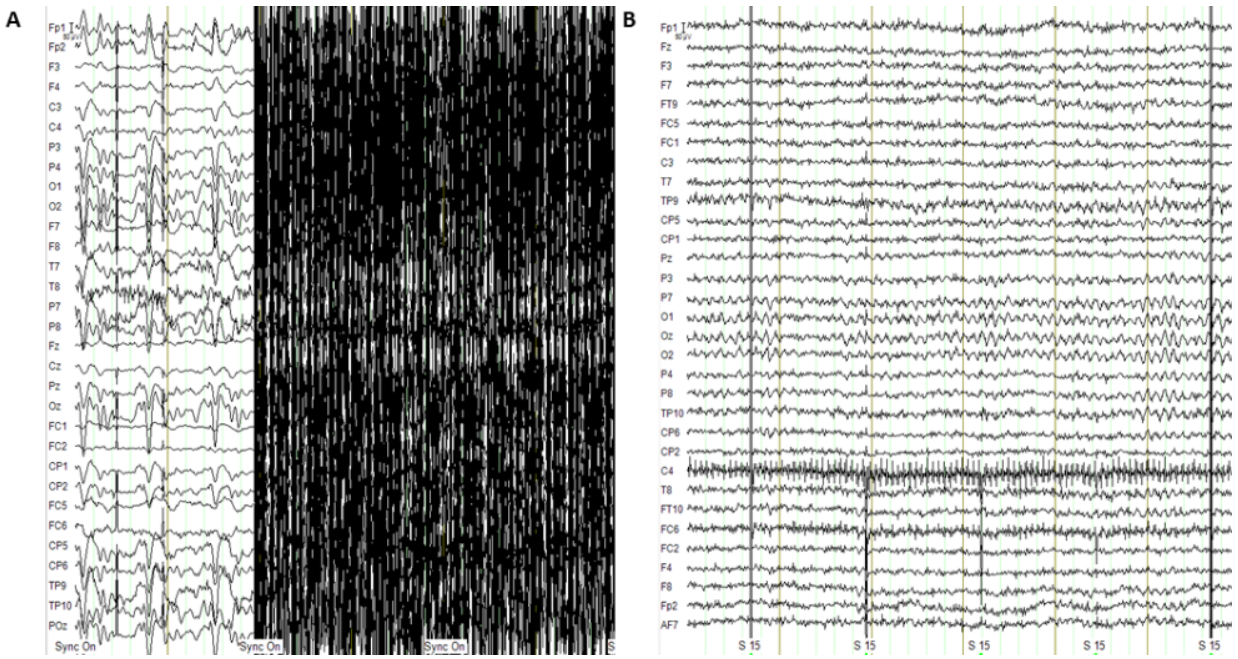


Figure 8 A. fMRI gradient artifact. **B.** TMS artifacts.

Multiplexing artifacts arise in digital EEG systems that rapidly sample multiple channels through a multiplexing circuit before analog-to-digital conversion. If the multiplexer or timing circuitry malfunctions, signals from one channel may be incorrectly assigned to another, resulting in duplicated or highly similar waveforms across multiple channels. Because these artifacts are generated by the acquisition hardware

rather than the patient, they often appear physiologically implausible and may involve many channels simultaneously.

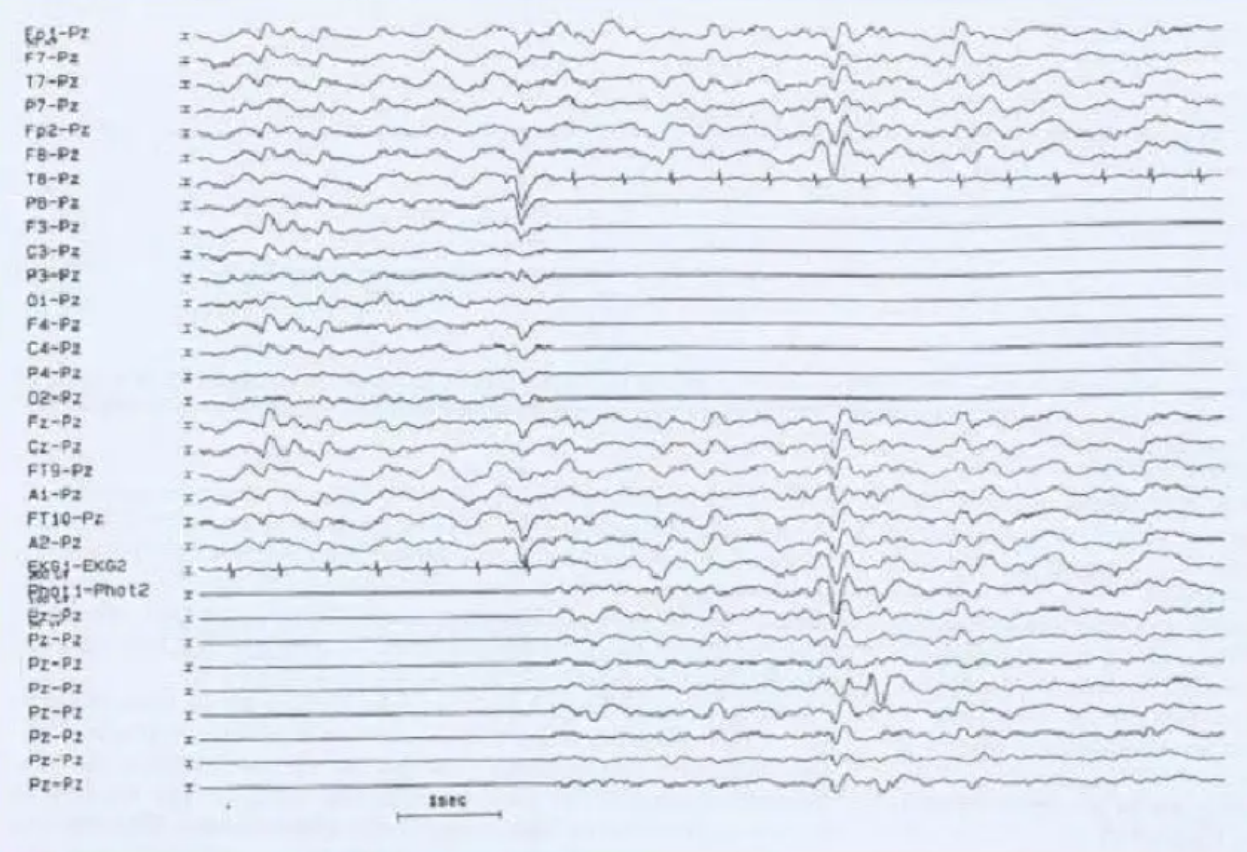


Figure 8.1 The Multiplexing artifact

Above is the multiplexing artifact formed when sampling is done on channels at a time instead of sampling the entire 32-channel amplifier simultaneously. A timing error occurs and the groups of 16 channels invert. This is clearly seen by observing the position of the ECG monitoring channel.

When one artifact appears in a single channel, it usually indicates high impedance in a specific electrode. When it affects all channels, problems with the ground electrode, reference electrode, or system grounding should be suspected.

Although notch filters can remove power-line interference during review, they should not routinely be used during acquisition because it can potentially camouflage a bad signal or an unstable electrical environment.

Environmental Artifacts

Modern hospital environments contain numerous sources of electrical interference, particularly in intensive care units.

Potential sources include:

- Ventilators
- Infusion pumps
- Cardiac monitors
- Electrical beds
- Mobile phones
- Paging systems

These artifacts may appear as rhythmic transients, spikes, or slow-wave activity. Careful observation of nearby equipment and correlation with timing of the artifact often identifies the source.

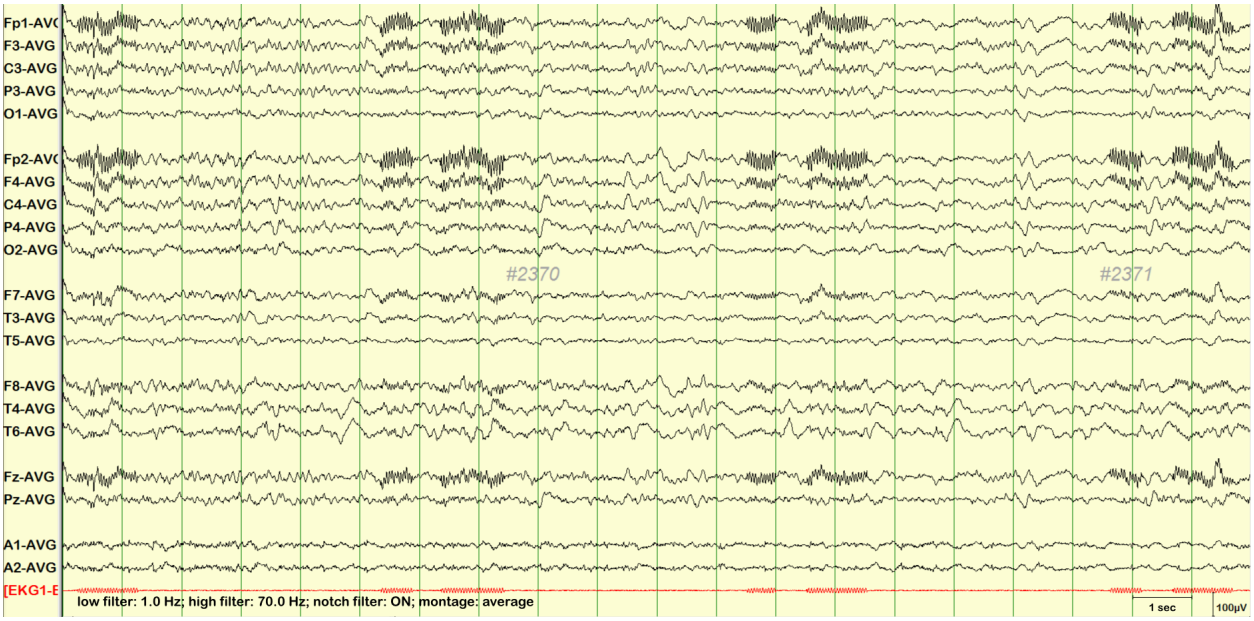


Figure 9 Telephone artifact involving EEG channels. A common average reference montage.

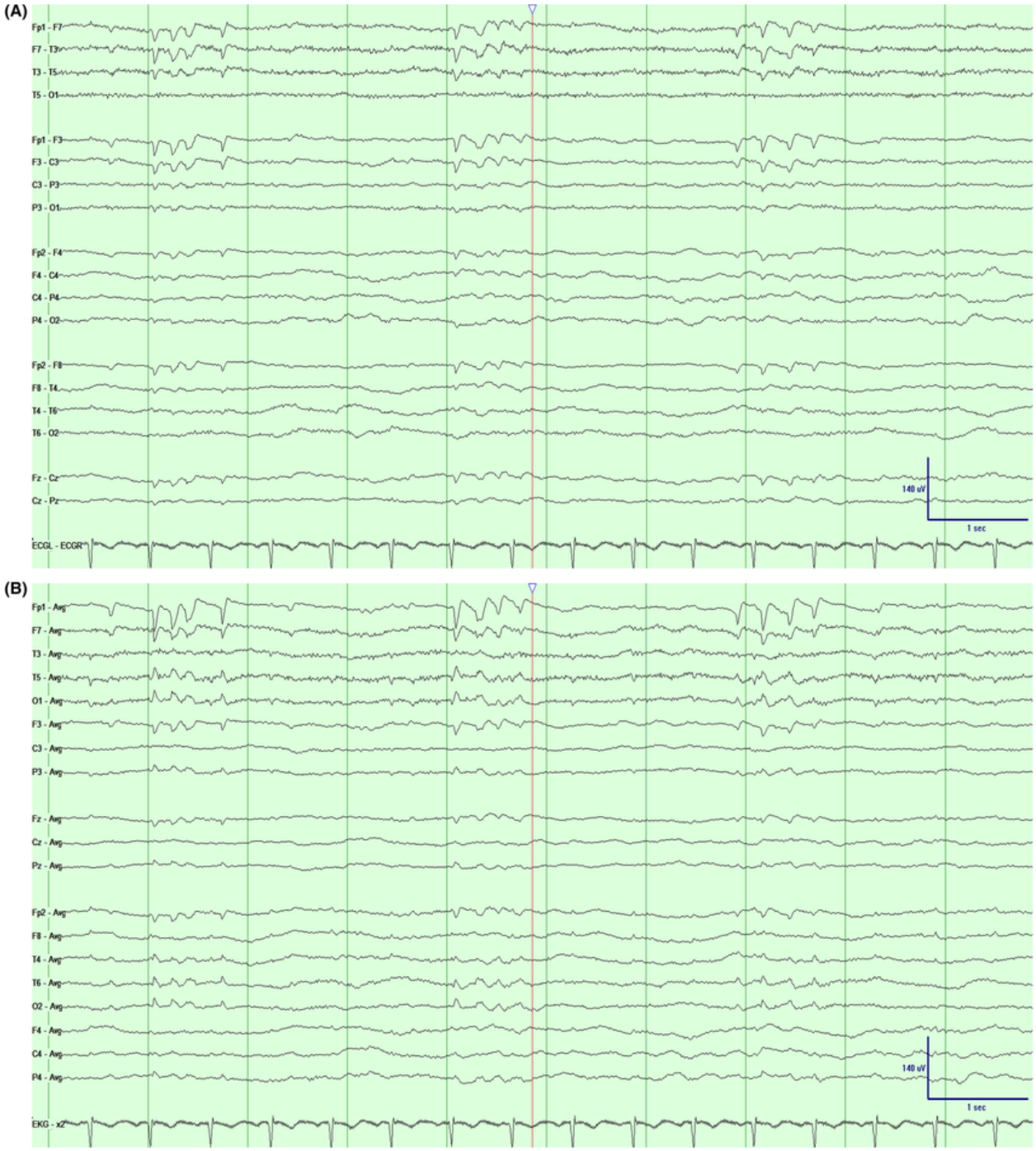


Figure 9.1 Ventilator artifact. Bipolar (upper panel) and average referential (lower panel) montages show a complex but uniform waveform occurring periodically but synchronously with fluid motion in the ventilator. Settings: Filter: 1–70 Hz, Time base 30 mm/s, Sensitivity: 7 μV/mm.

Implanted Stimulator Artifacts

Patients with implanted devices such as vagus nerve stimulators (VNS), deep brain stimulators (DBS), or spinal cord stimulators may demonstrate characteristic stimulation artifacts on EEG.

These artifacts are typically widespread, highly rhythmic, and remarkably uniform in morphology. Unlike cerebral discharges, they occur at precise intervals and maintain a fixed pattern.

Knowledge of the patient's medical history is often the key to correct identification.

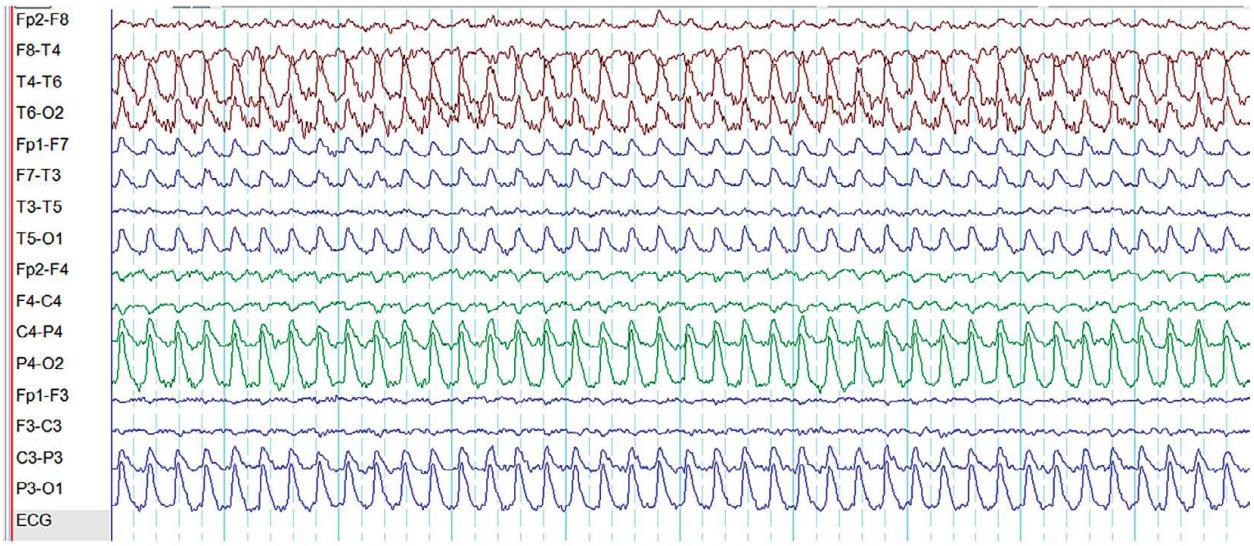


Figure 9.2 Artifact generated by deep brain stimulation in a patient with Parkinson's disease. (a) Note the widespread regular artifact with precise rhythmicity generated by the deep brain stimulator.

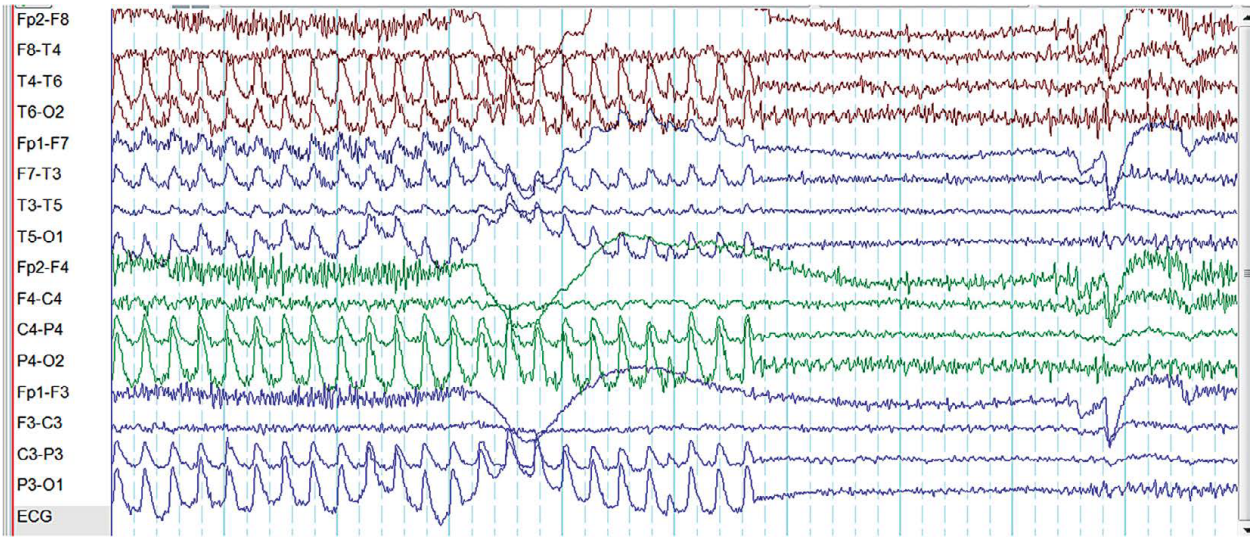


Figure 9.3 Once the device is turned off (mid-epoch), the EEG returns to its normal baseline instantly. (Continued)

Artifacts, Challenges, and Recording Issues Across Different Clinical Applications

Although the fundamental principles of EEG acquisition remain consistent across all applications, the types of artifacts and recording challenges vary depending on the clinical environment and recording duration. Understanding these differences helps technologists optimize signal quality and improve interpretation accuracy.

Routine EEG

Routine EEG recordings are typically performed in a controlled laboratory environment and commonly encounter artifacts include eye movements, muscle (EMG), sweat, movement, electrode, and powerline artifacts. Because patients are usually awake and supervised, most issues can be identified and corrected immediately through impedance checks, electrode maintenance, patient coaching, and proper cable management.

Long-Term Monitoring (LTM) and Epilepsy Monitoring Unit (EMU)

LTM and EMU recordings present additional challenges due to prolonged monitoring over hours or days. Electrode paste may dry over time, resulting in increased impedance and intermittent artifacts. Patient movement, chewing, scratching, repositioning, and seizure-related muscle activity can significantly affect signal quality. Regular impedance checks and continuous video correlation are essential for distinguishing artifacts from epileptiform activity.

Ambulatory EEG

Ambulatory EEG recordings are performed outside the controlled hospital environment, making them particularly susceptible to motion artifacts, electrode displacement, cable movement, and environmental electrical interference. Because immediate technical intervention is not possible, secure electrode application, effective cable management, reliable battery operation, and thorough patient education are critical to maintaining recording quality.

Intensive Care Unit (ICU)

ICU EEG monitoring is performed in electrically complex environments containing multiple bedside devices such as ventilators, infusion pumps, dialysis systems, and cardiac monitors. These devices may introduce significant electrical interference. Additional challenges include patient shivering, frequent nursing interventions, limited scalp access, and the presence of surgical dressings. Proper grounding, isolation devices, and high-performance amplifiers with strong common-mode rejection capabilities are particularly important in ICU settings.

Sleep Studies and Combined PSG-EEG Recordings

Sleep studies involve prolonged overnight recordings and multiple physiological sensors, increasing the likelihood of movement, sweat, cable-related, and electrode artifacts. Sleep technologists must also

differentiate physiological sleep phenomena from artifacts, as some artifact patterns may resemble normal sleep-related EEG activity.

General Considerations Across All Applications

Regardless of the clinical setting, maintaining low and balanced electrode impedances, securing electrodes and cables, minimizing environmental electrical interference, and ensuring proper grounding remain fundamental to obtaining high-quality EEG recordings. Video monitoring, impedance monitoring, isolation transformers, and advanced artifact-reduction tools (such as Persyst Artifact Reduction) can further assist in identifying and mitigating artifacts; however, proper recording technique remains the most important factor in achieving reliable EEG data.

Conclusion

Successful EEG interpretation depends not only on recognizing abnormal cerebral activity but also on identifying signals that do not originate from the brain. Most artifacts can be recognized by carefully assessing their morphology, distribution, physiological plausibility, and relationship to other recorded signals.

A systematic understanding of artifact recognition allows technologists to improve recording quality and helps clinicians avoid false diagnoses of epilepsy, cerebral dysfunction, or seizure activity.

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