

Sources of signal artifacts in EEG

One of the main challenges in working with electroencephalographic (EEG) data is ensuring that the recorded signals are clean and exhibit a high signal-to-noise ratio (SNR). Because EEG amplitudes are typically in the microvolt range, they are highly susceptible to various sources of contamination, commonly referred to as artifacts.

These unwanted signals can obscure the underlying neural activity and compromise the quality of the data, making artifact detection and removal essential for accurate analysis and reliable applications. In this article, we examine the most common types of EEG artifacts and the primary techniques and tools employed to minimize their impact and recover meaningful brain signals.

What is an EEG artifact?

Neurons communicate by generating electrical signals, but a single neuron's activity is too weak to measure from the scalp. Only when millions of neurons fire synchronously does the resulting electric field become strong enough to pass through tissue, bone, and hair and reach EEG electrodes, though it remains significantly attenuated.

An EEG artifact is any recorded signal that does not originate from neural activity. This includes physiological sources (such as eye movements, muscle activity, and heartbeats) and non-physiological sources including electrical interference, electrode issues, and movement artifacts. Artifacts contaminate EEG recordings by injecting brain signals, which can mimic or obscure genuine neural activity and significantly reduce signal quality.

Types of EEG artifacts

Identifying artifact types is the first step toward effectively removing them. EEG artifacts are generally categorized by their origin:

Physiological artifacts (originated from the body):

- **Ocular activity:** Eye blinks or movement distort scalp recordings through corneo-retinal potentials and eyelid effects.
- **Muscle activity:** Facial or neck muscle contractions produce broadband noise overlapping EEG frequencies (20–300 Hz).
- **Cardiac activity and ballistocardiogram (BCG):** Pulsatile signals from the heart or within EEG–fMRI setups can introduce rhythmic artifacts.

- **Respiration and Perspiration:** Slow drifts or electrode impedance changes due to breathing or sweat can contaminate EEG.

Non-physiological (technical) artifacts:

- **Electrode pop and cable movement:** Sudden impedance changes cause transient spikes.
- **Incorrect reference placement or poor contact:** Leads to baseline shifts or exaggerated noise.
- **AC power and electromagnetic interference:** Ambient 50/60 Hz coupling common in non-shielded environments.
- **Subject motion:** Head or body movements can introduce large, non-linear noise bursts.

Physiological artifacts

Physiological artifacts originate from the body's own activity and are not related to brain signals, but they frequently contaminate EEG recordings. Below are the most common sources, their origin, impact, and signature in the time and frequency domains.

Ocular activity (EOG Artifact)

- **Origin:** The eye behaves like an electric dipole due to the charge difference between the cornea and retina. When the eye moves, this dipole shifts, generating a field disturbance measurable on the scalp.
- **Why it affects EEG:** This disturbance, called the Electrooculogram (EOG), typically reaches **100–200 μV** , often an order of magnitude larger than EEG signals.
- **Typical causes:** Eye blinks, saccades, lateral gaze movements.
- **Time-domain effect:** Sharp, high-amplitude deflections, especially over frontal electrodes (e.g., Fp1, Fp2). Lateral movements affect electrodes near the temples. Artifact amplitude is proportional to the gaze angle.
- **Frequency-domain effect:** Dominant in low frequencies, especially in the delta (0.5–4 Hz) and theta (4–8 Hz) bands, potentially mimicking cognitive processes.

PHYSIOLOGICAL ARTIFACTS

Eye blinks

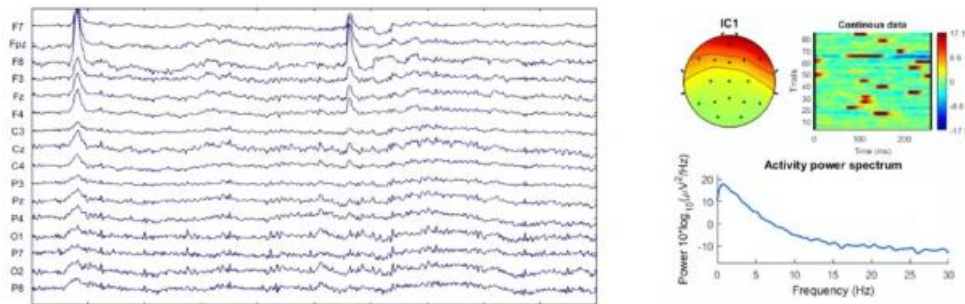


Figure. Notice the high amplitude voltage peaks (blinks) affecting mainly frontal electrodes (F7, Fpz, F8), and the higher power in low frequencies (delta and theta bands).

PHYSIOLOGICAL ARTIFACTS

Lateral eye movement

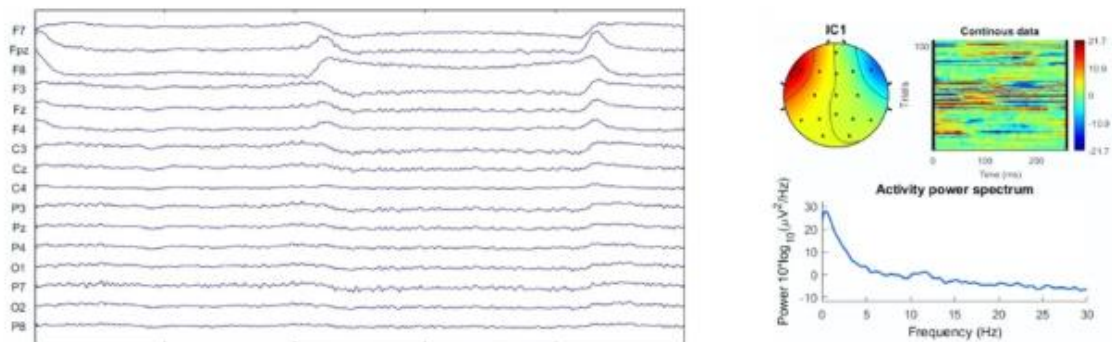


Figure. Notice the effect in F7, F8, with quick changes in amplitude and different direction as a result of the dipole created by the eye in the sensors (this artifact is also denoted phase reversal as the artifact may mimic a change of phase). Higher power in low frequencies (delta and theta bands).

Muscle activity (EMG Artifact)

- **Origin:** Muscle contractions generate electric signals, recorded as Electromyography (EMG).
- **Why it affects EEG:** MG signals are broadband and high in frequency, often overlapping EEG rhythms and introducing significant noise.
- **Typical causes:** Clenching jaw, neck tension, swallowing, chewing, talking, frowning, sniffing, or even hiccupping.
- **Time-domain effect:** High-frequency noise superimposed on EEG, with amplitude proportional to contraction strength.
- **Frequency-domain effect:** Artifacts dominate **beta (13–30 Hz)** and **gamma (>30 Hz)** ranges, masking important cognitive and motor activity signals.

PHYSIOLOGICAL ARTIFACTS

Jaw clenching

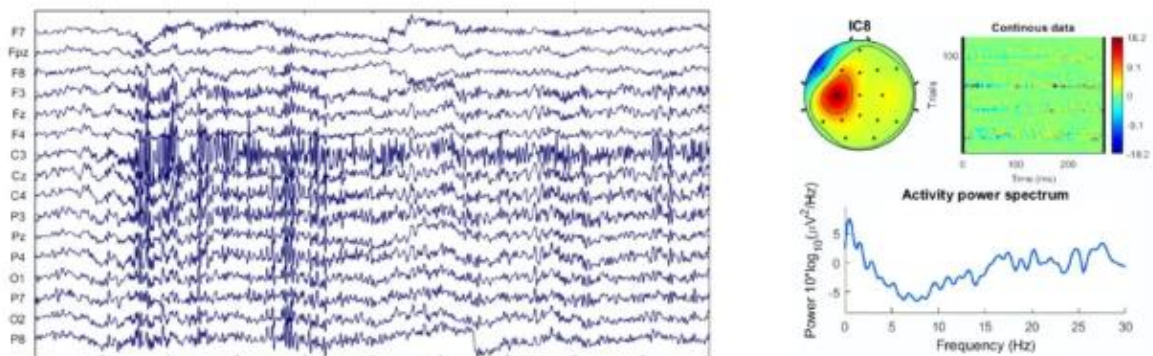


Figure. Notice the high frequency artifact that occurs when clenching the jaw. In this example the main effect is observable in C3. Higher power in high frequencies (beta and gamma bands).

Cardiac activity (ECG or Pulse Artifact)

- **Origin:** The heart's electrical signal, or Electrocardiogram (ECG), sometimes appears on scalp EEG.
- **Why it affects EEG:** Though usually weak, ECG artifacts become visible depending on body shape, electrode location, or amplifier sensitivity.
- **Typical causes:** Heartbeats (pulse artifact).
- **Time-domain effect:** Rhythmic waveforms recurring at the heart rate, often in central or neck-adjacent channels.
- **Frequency-domain effect:** ECG overlaps several EEG bands and may go undetected without cross-channel analysis or an ECG reference.

PHYSIOLOGICAL ARTIFACTS

Cardiac activity

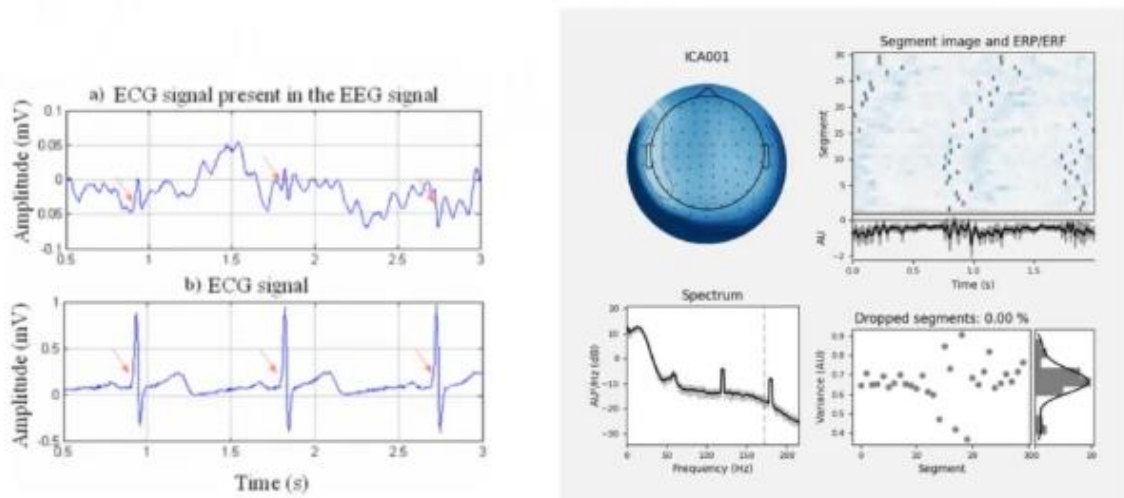


Figure. (Left) Effect of ECG signal in EEG. From Correa, et al., 2007; (Right) ICA component related to ECG channel. From: *Repairing artifacts with ICA – MNE 0.20.0 documentation*

Perspiration (Sweat Artifact)

Origin: Activity from sweat glands modifies local electrode impedance and creates potential shifts.

Why it affects EEG: Perspiration introduces slow baseline drifts or shorts between electrodes, especially during physical activity or in high temperatures.

Typical causes: Include heat, stress, and long-duration recordings.

Time-domain effect: Slow potential shifts, apparent over long epochs.

Frequency-domain effect: Contaminates the delta and theta bands, impairing sleep and low-frequency cognitive assessments.

PHYSIOLOGICAL ARTIFACTS

Perspiration

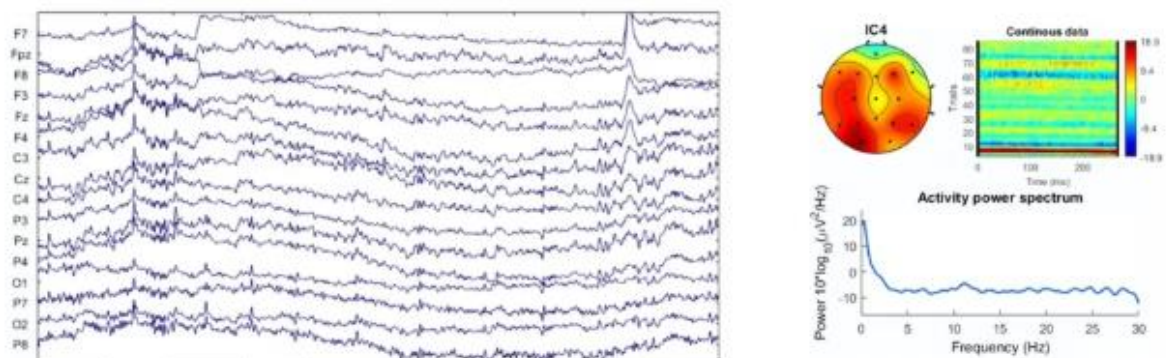


Figure. Notice the slow wave that overlaps the true EEG signal. High power in low frequencies (overlapping delta and theta bands).

Respiration

- **Origin:** Movements of the chest and head during breathing, particularly when lying down.
- **Why it affects EEG:** Breathing alters electrode-skin contact, especially in sleep studies.
- **Typical causes:** Include deep breathing and sleep respiration cycles.
- **Time-domain effect:** Slow waveforms synchronized with respiration rate (e.g., 12–20 breaths per minute).
- **Frequency-domain effect:** Mainly affects low-frequency bands, overlapping delta and theta rhythms.

PHYSIOLOGICAL ARTIFACTS

Respiration

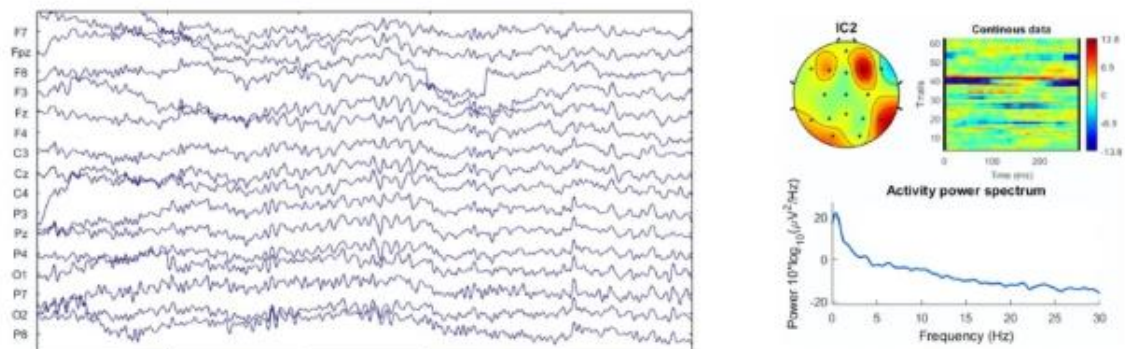


Figure. Notice the slow wave that overlaps the EEG signal when inhaling or exhaling. High power in low frequencies (overlapping delta and theta bands).

Non-Physiological (Technical) EEG Artifacts

Unlike physiological artifacts, technical artifacts originate from external or mechanical sources, such as hardware malfunctions, environmental interference, or improper setup. These can introduce significant distortions that are often mistaken for neural activity.

Electrode Pop

- **Origin:** Caused by a temporary disruption in contact between an electrode and the scalp. This can result from physical contact with the sensor, cable motion, or spontaneous changes in skin-electrode impedance, often due to drying gel or sweat accumulation.
- **Why it affects EEG:** Sudden shifts in contact potential lead to transient voltage spikes, unrelated to brain activity.
- **Typical causes:** Include touching the cap, head movement, pulling the electrode cable, or drying the electrolyte gel.

- **Time-domain effect:** Appears as abrupt, high-amplitude transients, often isolated to a single channel. The morphology can vary, ranging from sharp spikes to complex waveform distortions.
- **Frequency-domain effect:** Difficult to characterize consistently, as electrode pops produce broadband, non-stationary noise. Their irregularity challenges both manual and automated detection methods.

NON-PHYSIOLOGICAL / TECHNICAL ARTIFACTS

Electrode pop

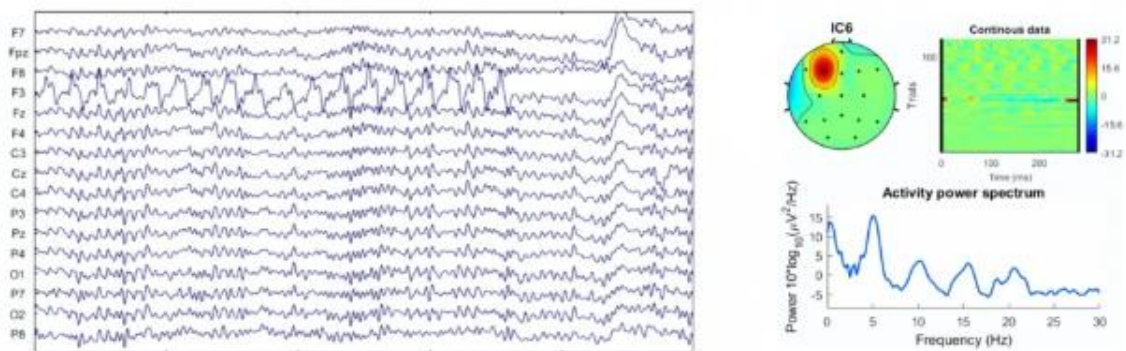


Figure. Notice the distortion in F3 produced by touching the sensor. The effect in time and frequency depends on the type of popping (touching, spontaneous...). In this case we can see the frequencies of the touching artifact on F3.

Cable Movement

- **Origin:** Occurs when electrode or amplifier system cables shift during a recording, whether due to participant movement, loose connectors, or external contact with the wiring.
- **Why it affects EEG:** Movement can cause electromagnetic interference and alter the impedance of scalp electrodes, especially in high-impedance systems.
- **Typical causes:** Tugging or brushing cables, participant repositioning, or external contact with electrode wires.
- **Time-domain effect:** Highly variable. If movement is rhythmic, the resulting artifacts can produce repetitive waveforms that mimic neural oscillations or eye blinks. Non-rhythmic cable shifts often create sudden deflections or drift.
- **Frequency-domain effect:** Depending on the periodicity of movement, cable artifacts can introduce artificial spectral peaks at low or mid frequencies, potentially mistaken for delta or alpha rhythms.

NON-PHYSIOLOGICAL / TECHNICAL ARTIFACTS

Cable movement

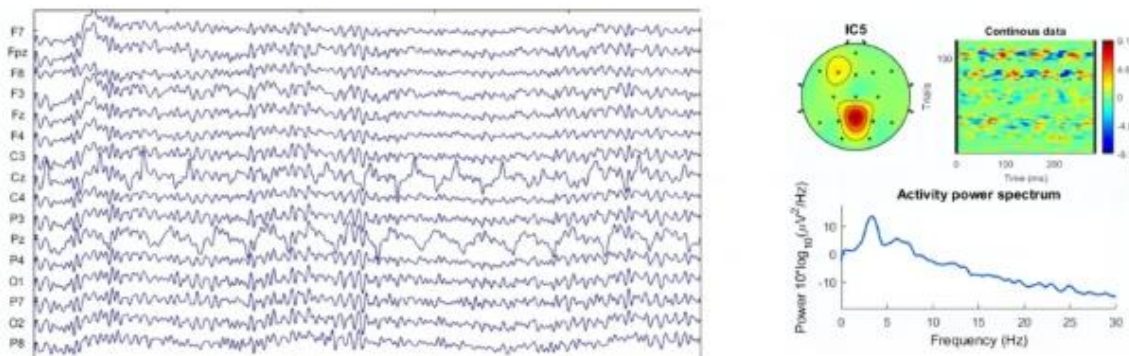


Figure. EEG collected with Bitbrain EEG versatile 16ch, band pass filtered between 0.5 and 30 Hz. Independent component extracted using logistic infomax ICA algorithm (Beli & Sejnowski, 1995). In this example a distortion in Cz or Pz appears when moving the cables. As mentioned before the effect in time and frequency may vary a lot depending on the cable movement and the changes in scalp-sensor contact. In this example we can find strange frequencies in Pz channel that are non eeg-related.

Incorrect Reference Placement

- **Origin:** Occurs when the reference electrode is not placed, improperly connected, or suffers from poor contact with the scalp.
- **Why it affects EEG:** Since all EEG channels are measured relative to the reference, a faulty reference results in signals that do not reflect actual brain activity, but instead amplify noise or baseline drift across all channels.
- **Typical causes:** Omitted reference electrode, dried conductive gel, loose connections, or excessive impedance at the reference site.
- **Time-domain effect:** Results in abrupt, high-amplitude shifts across all channels. When the reference is corrected mid-recording, signals typically return to normal values gradually due to the filtering and stabilization process.
- **Frequency-domain effect:** Produces abnormally high power across all channels, often accompanied by non-physiological peaks unrelated to actual EEG activity.

NON-PHYSIOLOGICAL / TECHNICAL ARTIFACTS

Reference incorrect placement

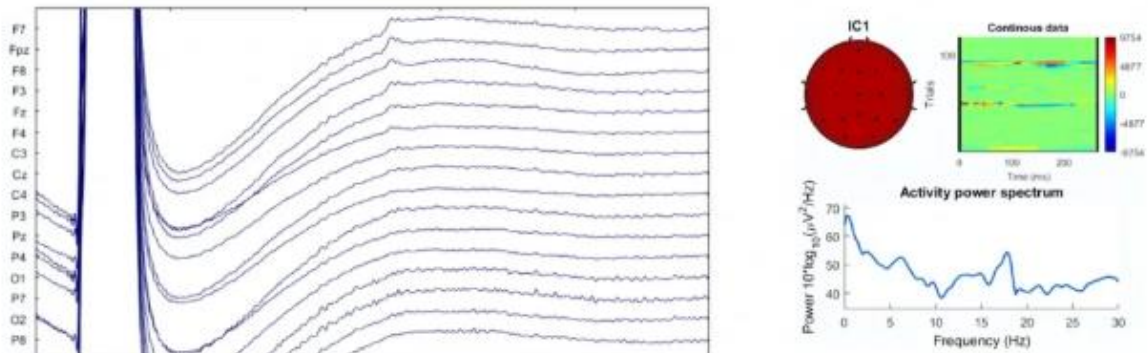


Figure. Notice the high amplitude abrupt change in all channels when the reference is withdrawn that slowly converge to actual eeg when placed again. Very high power in all frequencies and a logical topographic field of distribution covering the full head.

AC Electrical and Electromagnetic Interference

- **Origin:** Generated by nearby alternating current (AC) power lines, electrical devices, or wiring that emit electromagnetic fields.
- **Why it affects EEG:** When electrode cables lack proper shielding or when recordings are performed in electrically noisy environments, ambient electromagnetic radiation can couple into the EEG system, contaminating the signal.
- **Typical causes:** Fluorescent lights, monitors, power adapters, unshielded EEG cables, or proximity to AC mains wiring.
- **Time-domain effect:** Appears as persistent high-frequency noise that overlays the EEG signal, sometimes modulating with nearby device activity.
- **Frequency-domain effect:** Produces a sharp, narrow spectral peak at 50 Hz or 60 Hz, depending on the local power grid standard (e.g., 50 Hz in Europe, 60 Hz in North America). This is commonly referred to as line noise or a power-line artifact.

NON-PHYSIOLOGICAL / TECHNICAL ARTIFACTS

Powerline interference

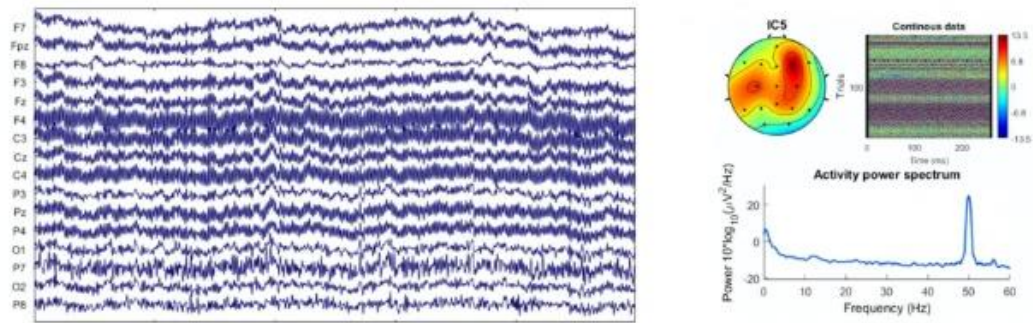


Figure. Notice the high frequency signal overlapping the eeg data in all channels. A clear peak appears in 50 Hz. The eeg was recorded in Spain and the powerline frequency is 50 Hz.

Body Movements

- **Origin:** Caused by gross motor activity, primarily head movements, but also includes arm swings, walking, or postural shifts.
- **Why it affects EEG:** Even subtle movements can disrupt the electrode–skin interface, altering contact impedance and distorting the EEG signal. In mobile or ambulatory EEG systems, movement artifacts are prevalent and challenging to distinguish from other signals.
- **Typical causes:** Head tilts, nodding, arm gestures, walking, or running during recordings.
- **Time-domain effect:** Manifests as slow, transient waveforms that often correlate with the rhythm of physical movement. These artifacts may resemble neural slow waves if not correctly identified.
- **Frequency-domain effect:** Primarily affects low-frequency bands, overlapping with delta (0.5–4 Hz) and theta (4–8 Hz) activity, which can obscure signals related to sleep, fatigue, or cognitive processing.

NON-PHYSIOLOGICAL / TECHNICAL ARTIFACTS

Body movements

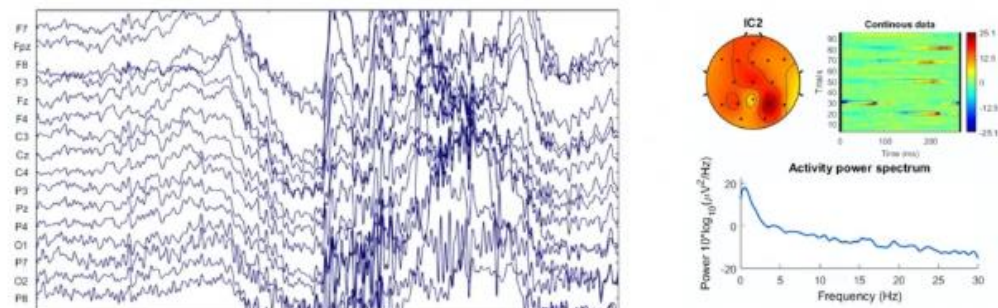


Figure. Notice the effect of moving the head overlapping the eeg data in all channels. Effect of movements overlaps low frequencies of the EEG.