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Biomedical Signal Processing and Analysis Techniques: Challenges and Applications

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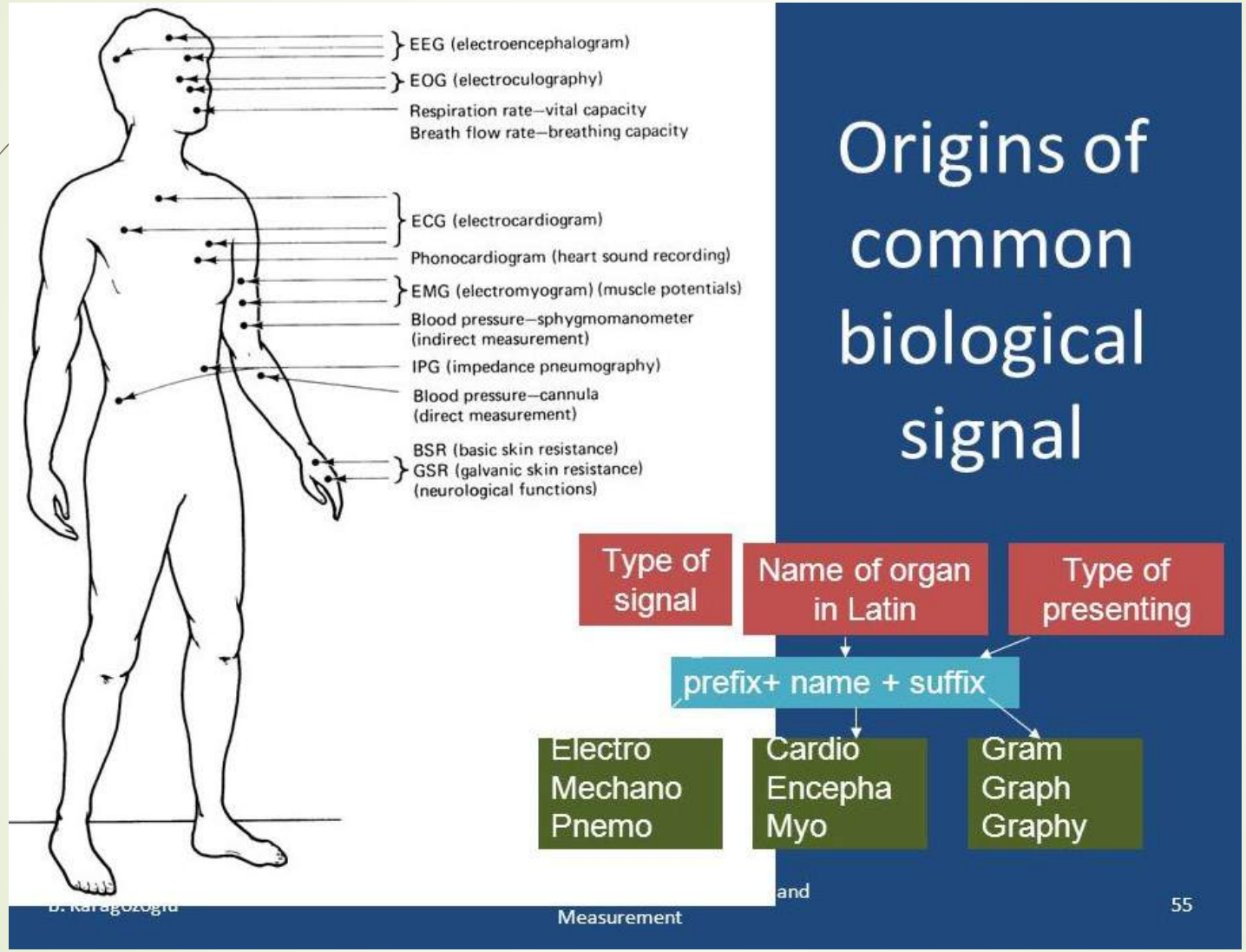
About Us!

Biomedical Instrumentation and Signal Processing Lab

Featured Projects:

1. **EOG** based Computer **Mouse Cursor Control** for Physically Challenged People
2. Design and Development of a **EOG**-based System to **Control Electric Wheelchair** for People Suffering from Quadriplegia/Quadriparesis
3. Design and Implementation of a Low-cost **EMG** Signal Recorder for Application in **Prosthetic Arm** Control for Developing Countries.
4. Development of a Low Cost and Portable **ECG Monitoring System** for Rural/Remote Areas of Bangladesh
5. Video Category (**Emotion**) Classification using Wireless **EEG** Devices
6. Motion Artifact Removal from Ambulatory **EEG**

Background[1]



[1] https://slideplayer.com/slide/9446025/

Motivation (Application)

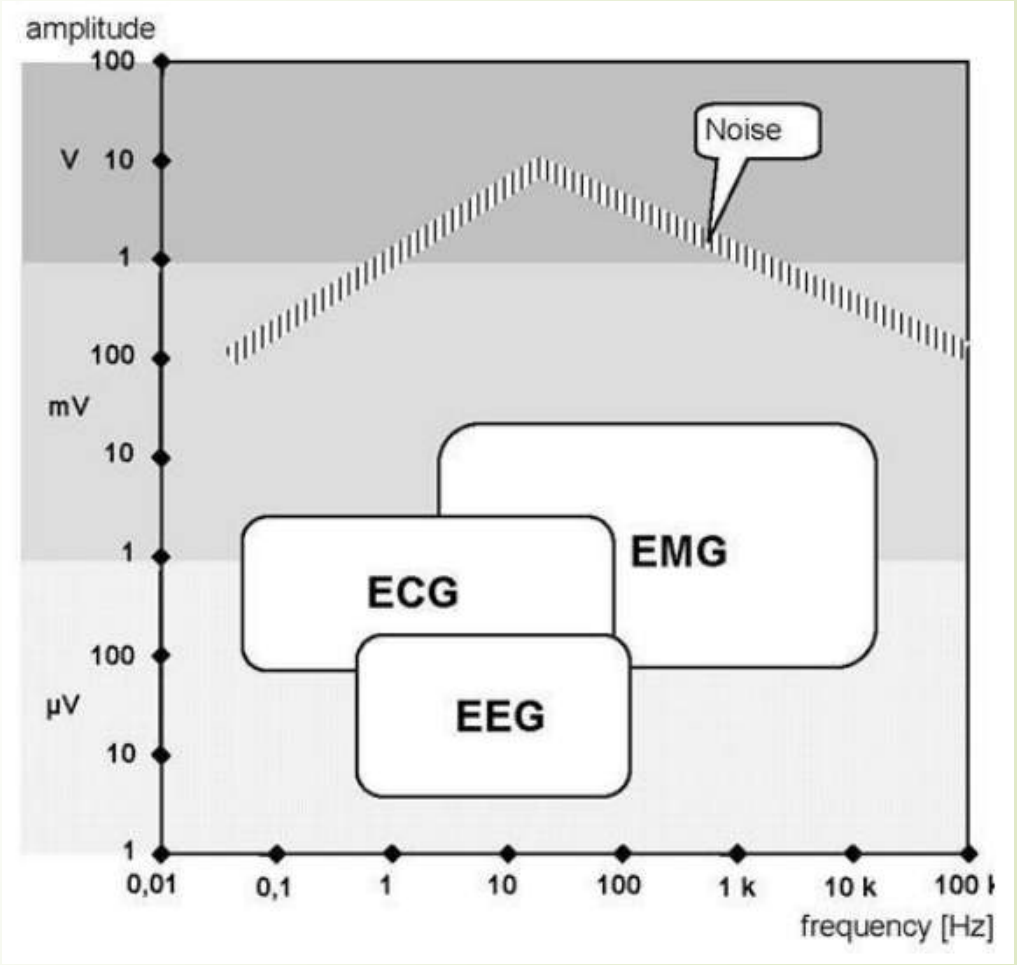
Patient › Signals › Processing › Decision[2]

- Patient Monitoring (critical care)
  - ICU, Coma, NICU
- Disease Detection/Diagnosis
  - Heart (ECG), Brain (EEG), Muscle (EMG), etc.
- Preventive Healthcare (Prediction)
- Human-Machine Interfacing (HMI)
  - BCI, BMI, HMI, etc.
  - Controlling wheelchair, prosthetic arm
- Treatment and Rehabilitation
- Basic understanding of the organ's physiology and function

[2] https://www.embs.org/about-biomedical-engineering/our-areas-of-research/biomedical-signal-processing/

Challenges with Biomedical Signals[3]

- Very **low** SNR
- **Non-stationarity** and **non-linearity** properties of biosignals
- **Diverse** types of noise
- Noise and Artifacts **overlap** both in Spectral and Temporal Domain
- False alarms and errors can **mislead** the diagnosis, treatment or control of any external devices
- **Traditional** Signal processing techniques fail

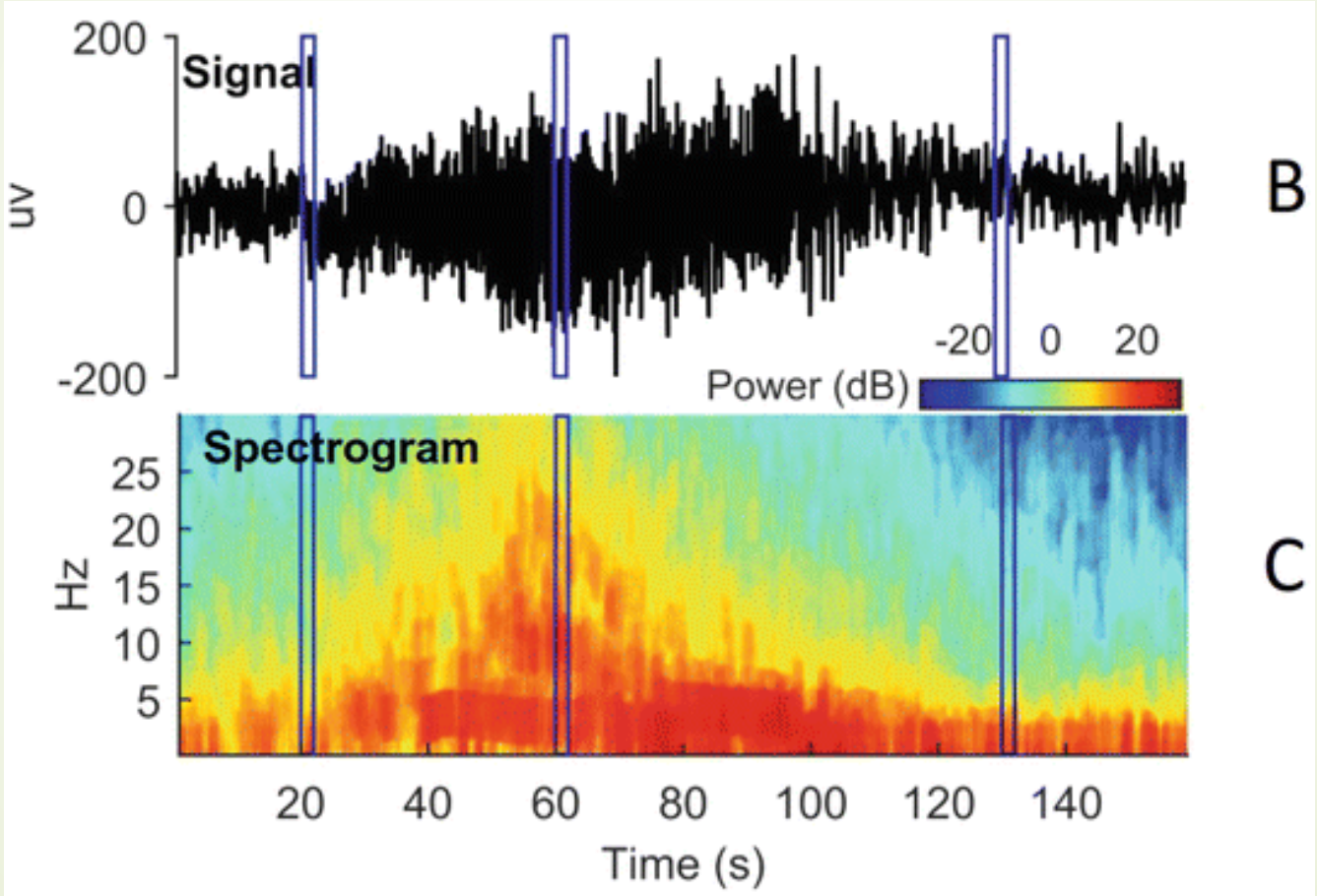


[3] Biomedical Instrumentation by Ákos Jobbágy and Sándor Varga

Advanced Signal Analysis & Processing Techniques

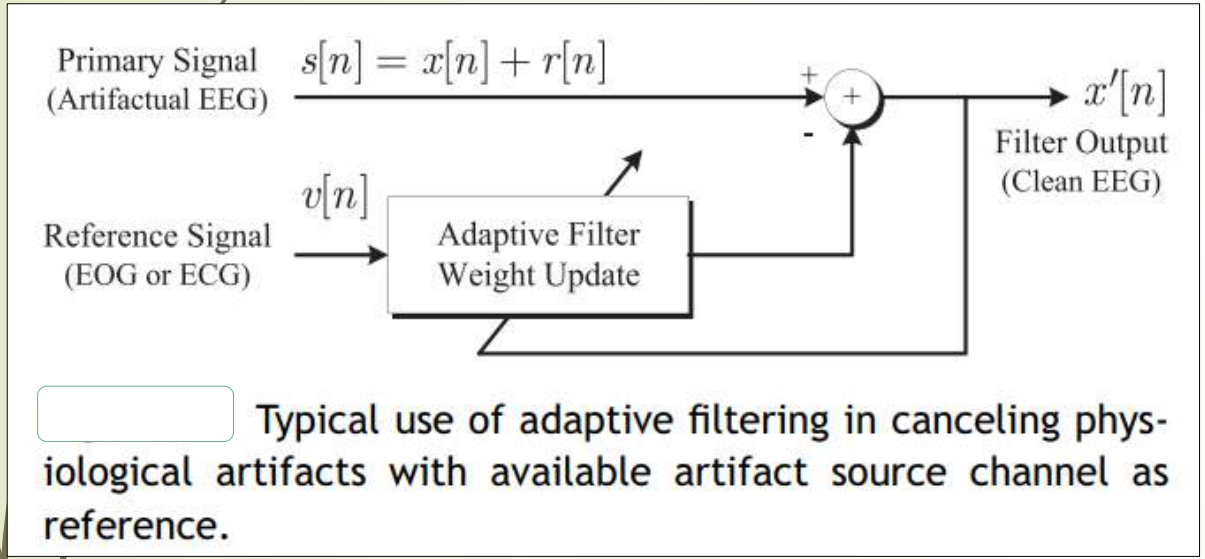
- Fourier Transform / PSD (pwelch)
- Adaptive filtering (use of **reference** channel)
- A-priori user input required
  - Wiener/Kalman/Particle Filtering
- Blind Source Separation
  - **ICA**/CCA/MCA
- Time-series Analysis
  - Wavelet transform / Spectrogram (STFT)
- Empirical Techniques
  - HHT/EMD/EEMD

Spectrogram (using STFT)[4]

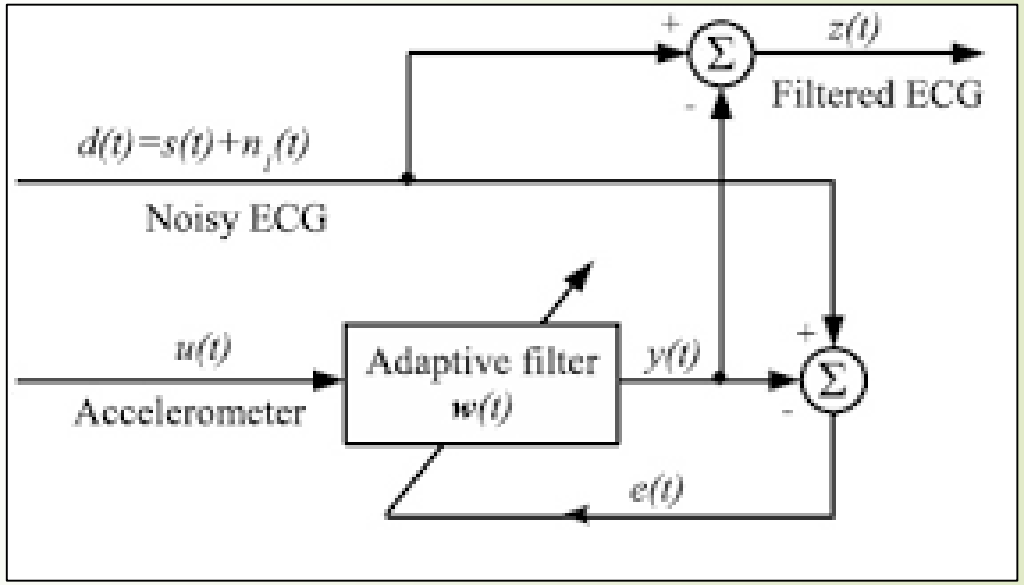


[4] https://neupsykey.com/seizures-and-quantitative-eeg/

Adaptive Filtering (for ECG Noise Removal[5] and EEG Artifact Removal[6])



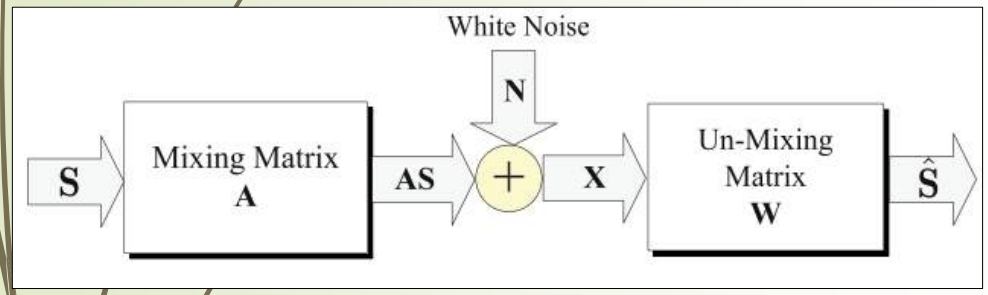
Typical use of adaptive filtering in canceling physiological artifacts with available artifact source channel as reference.

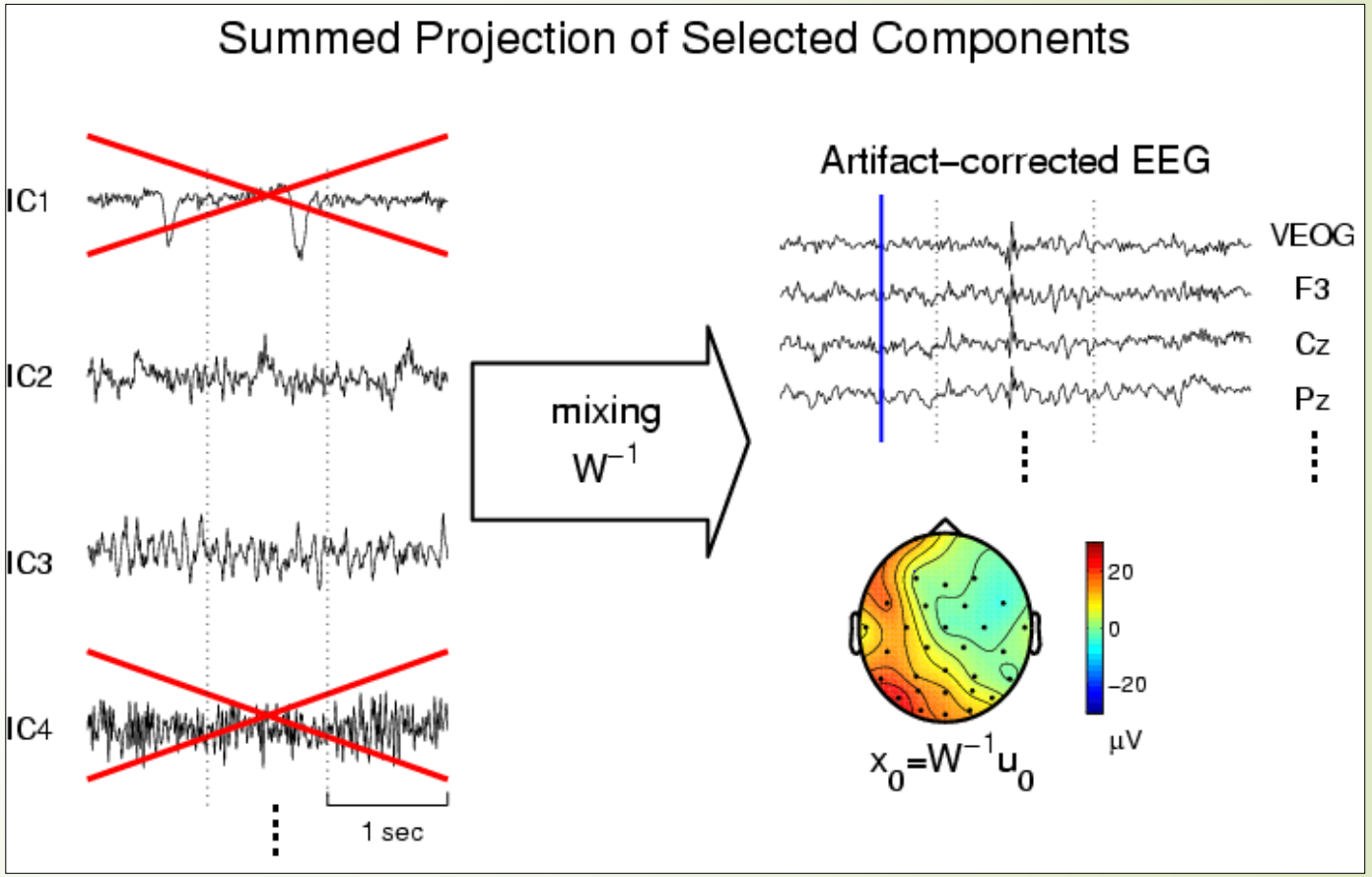


[5] http://www.jscholaronline.org/articles/JBER/Signal-Processing.pdf
[6] https://www.sciencedirect.com/science/article/pii/S098770531630199X

Independent Component Analysis (ICA)

(for EOG and EMG artifact removal from EEG[7])





[7] https://sccn.ucsd.edu/~jung/Site/EEG_artifact_removal.html

Wavelet Transform
(A Multi-resolution Analysis)

- Split Up the Signal into a Bunch of Signals
- Representing the Same Signal, but all Corresponding to Different Frequency Bands
- Only Providing What Frequency Bands Exists at What Time Intervals

$$CWT_x^{\Psi}(\tau, s) = \Psi_x^{\Psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int x(t) \bullet \psi^*\left(\frac{t-\tau}{s}\right) dt$$

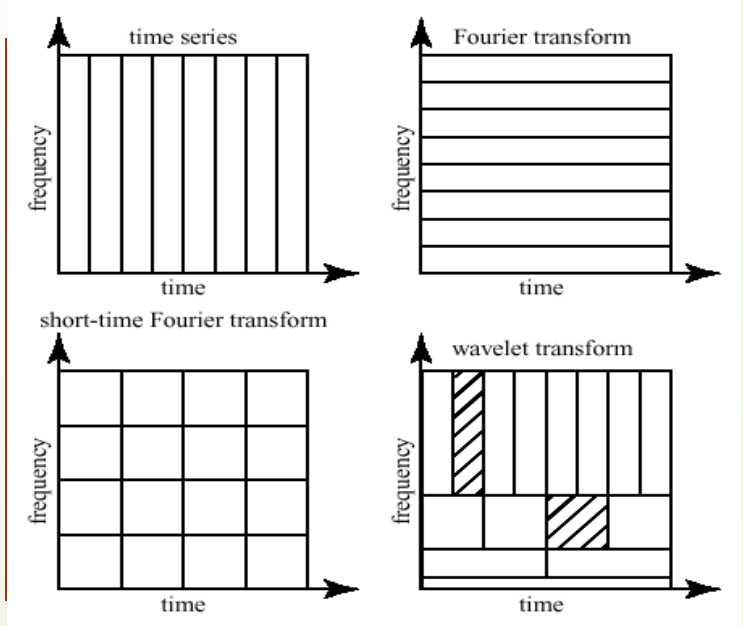
Translation

(The location of the window)

Scale

Mother Wavelet

Scale S>1: dilate the signal
S<1: compress the signal



Wavelet

- Small wave
- Means the window function is of finite length

Mother Wavelet

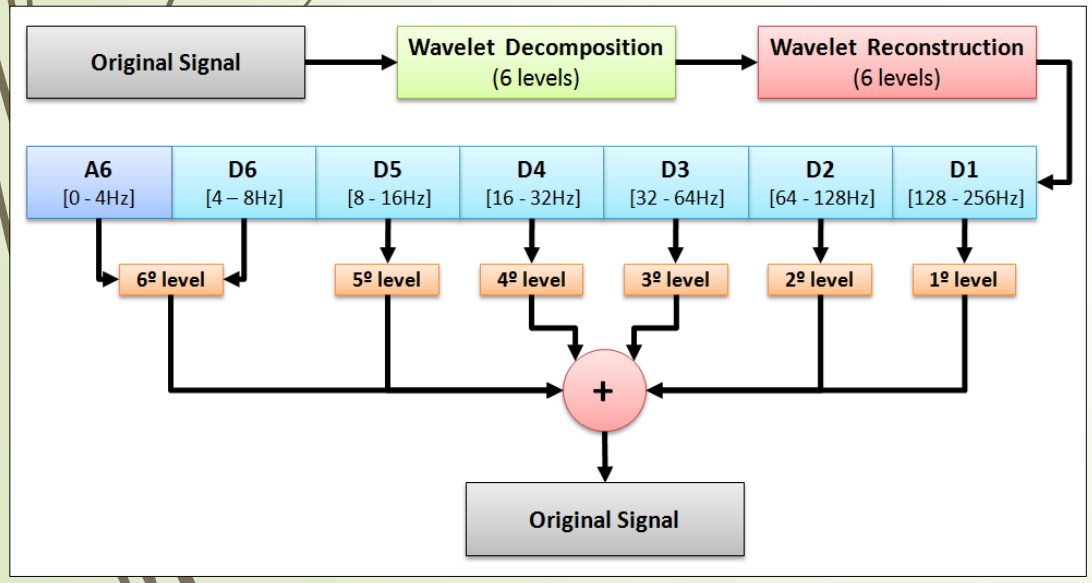
- A prototype for generating the other window functions
- All the used windows are its dilated or compressed and shifted versions

From http://www.cerm.unifi.it/EUcourse2001/Gunther_lecturenotes.pdf, p.10

Wavelet Transform on EEG Signals

(for separating different EEG sub-band rhythms[8])

Rhythm or Transient	EEG Signal Component	Freq. Band (Hz)
Rhythm	Delta	< 4
	Theta	4 – 8
	Alpha	8 – 13
	Beta	14 – 30
	Gamma	> 30
	Mu	7.5 – 12.5
Transient	Seizure Activities	0.5 – 30



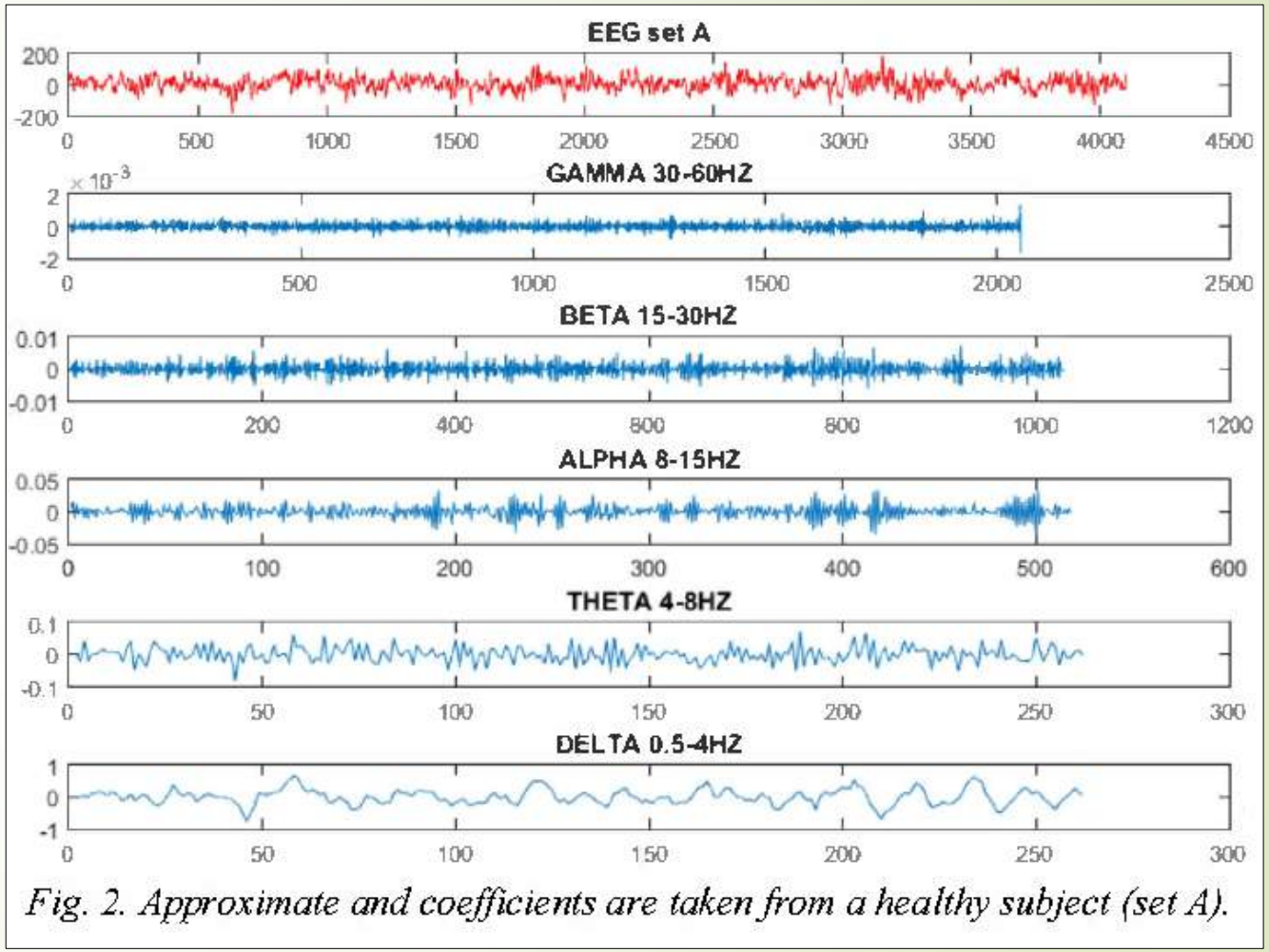


Fig. 2. Approximate and coefficients are taken from a healthy subject (set A).

[8] http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7856467

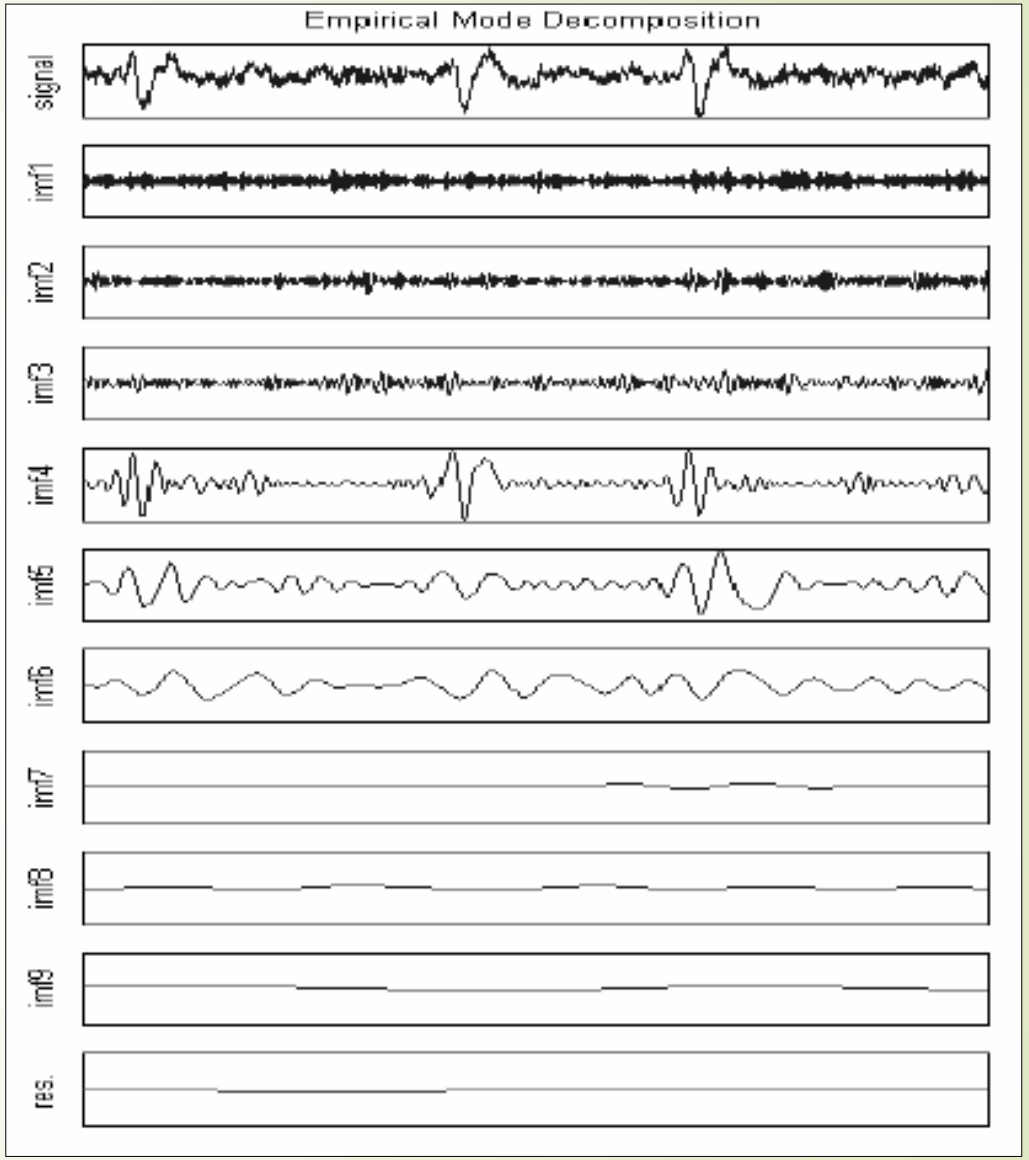
EMD on EEG Signals

(for detecting Eye-blink artifacts[9])

Process flow of EMD algorithm to generate IMFS.

Input: data sequence $s[n]$

1. Identify all the local extrema
2. Separately connect all the maxima and minima with natural cubic spline lines to form the upper, $u[n]$, and lower, $l[n]$, envelopes
3. Find the mean of the envelopes as $z[n] = [u[n] + 1[n]]/2$
4. Take the difference between the data and the mean as the proto-IMF, $h[n] = s[n] - z[n]$
5. Check the proto-IMF against the definition of IMF and the stoppage criterion to determine if it is an IMF
6. If the proto-IMF does not satisfy the definition, repeat step 1 to 5 on $h[n]$ as many time as needed till it satisfies the definition
7. If the proto-IMF does satisfy the definition, assign the proto-IMF as an IMF component, $c[n]$
8. Repeat the operation step 1 to 7 on the residue, $q[n] = s[n] - c[n]$, as the data
9. The operation ends when the residue contains no more than one extremum



[9] https://www.researchgate.net/publication/228524659_Real_time_characterisation_of_neural_signals_with_application_to_neonatal_monitoring/figures?lo=1

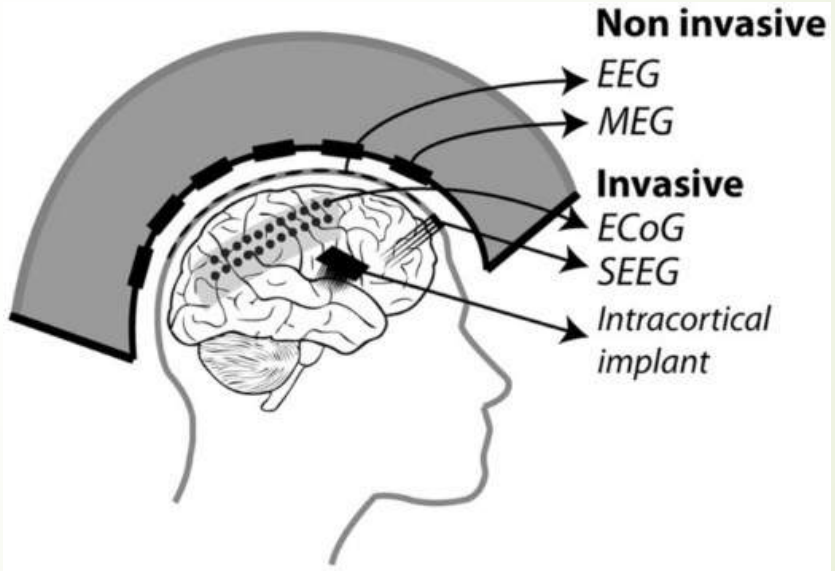
Brain Recordings!

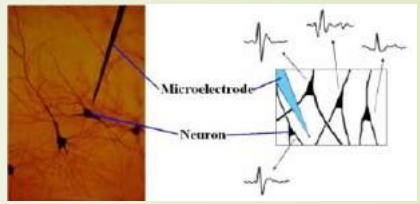
- Non-Invasive
  - **EEG** (electrical) and MEG (magnetic)
- Invasive
  - Sub-scalp EEG (S-EEG)
  - ECoG / iEEG
  - Intracortical Implant
    - Better signal quality but …!?

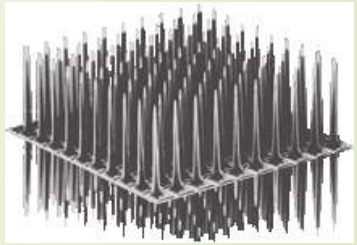
Signal Type	Bandwidth (Hz)	Range (mV_{pp})
ECoG	0.1 ~ 64	0.02 ~ 1
EMG	1 ~ 128	0.02 ~ 1
LFPs	0.1 ~ 100	0.1 ~ 1
EAPs	100 ~ 10K	0.04 ~ 0.2
IAPs	100 ~ 10K	~ 100

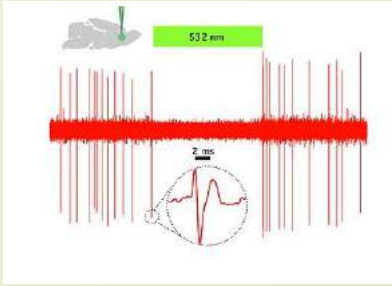
Motivation to record brain signals:

- How brain works?
  - Information processing
  - Memory formation
- Understanding neurological disorders & providing treatment





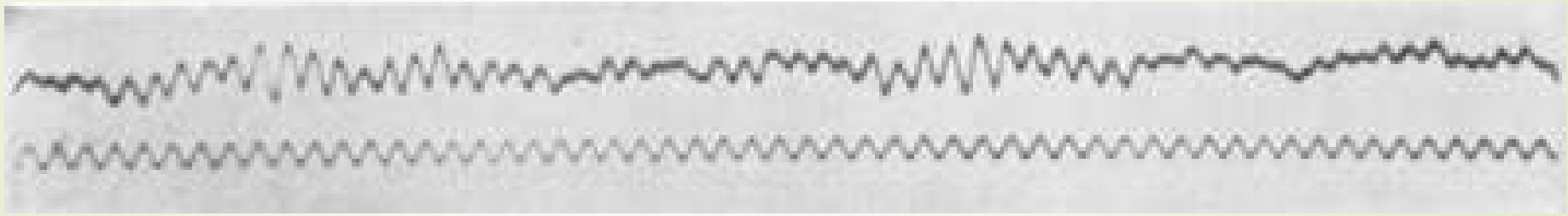




What is **EEG**?

Electro-encephalo-gram = Electrical-Brain-Picture

- Recording of the brain's spontaneous electrical activity over a period of time by placing flat metal discs (electrodes) attached to the scalp.
- Measures voltage fluctuations resulting from ionic current within the neurons of the brain.
- Scalp-EEG: Most popular brain recording technique
  - Low cost
  - Non-invasive
  - Portable
  - Reasonable temporal resolution

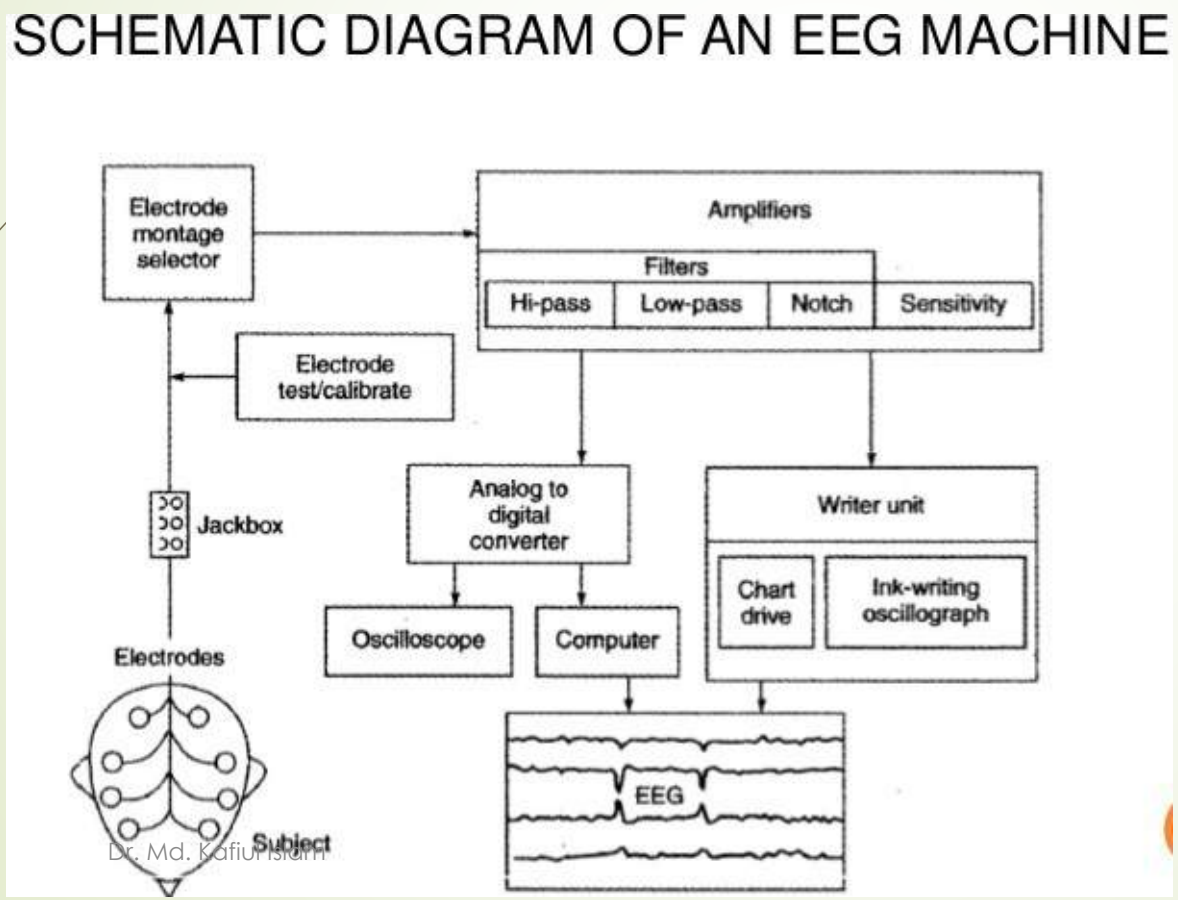


The first human EEG recording obtained by **Hans Berger** in **1924**. The upper tracing is EEG, and the lower is a 10 Hz timing signal.

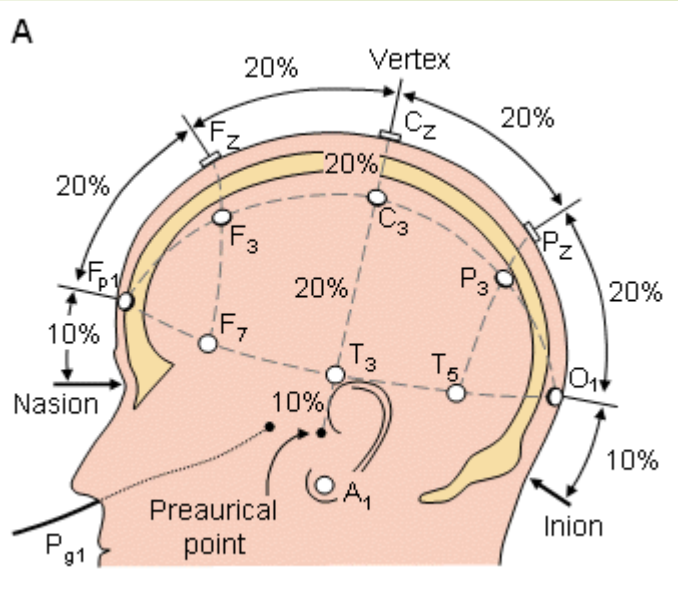
EEG Acquisition

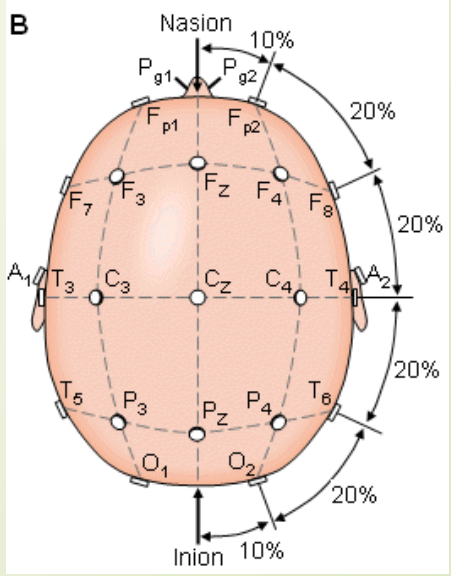
- Acquisition involves
  - Electrodes
  - Amplification (IA)
  - Filtering (Active)
  - Digitizing (ADC)
  - Storage

Challenge: To detect signal as low as **10 μV**!



Standard 10-20 Electrode Montage

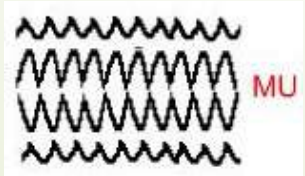


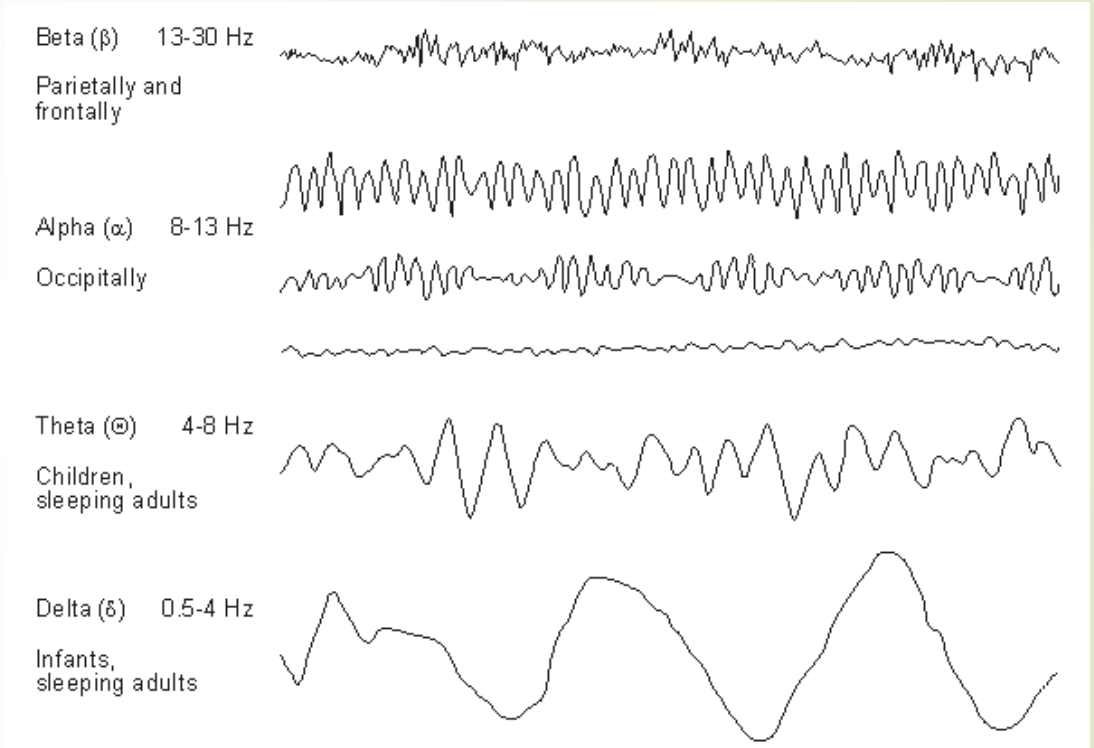


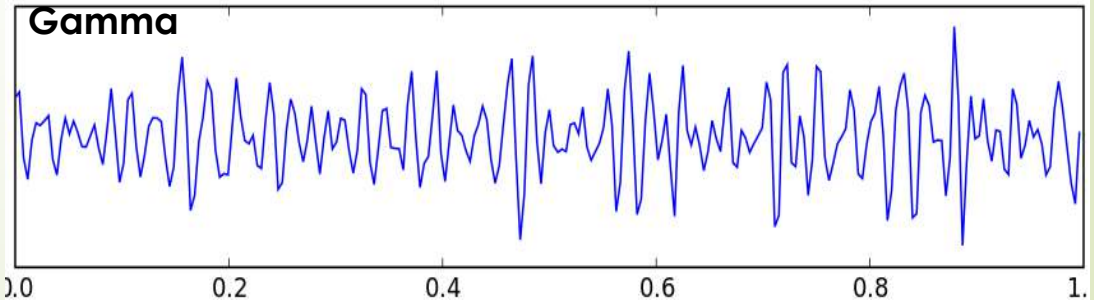
EEG Rhythms (Frequency Bands)

•**Rhythmic**: EEG activity consisting in waves of approximately constant frequency.
•**Arrhythmic**: EEG activity in which no stable rhythms are present.
•**Dysrhythmic**: Rhythms and/or patterns of EEG activity that characteristically appear in patient groups or rarely or seen in healthy subjects.

- **Delta: (< 4 Hz)**
  - adult slow-wave sleep
  - in babies
  - continuous-attention tasks
- **Theta: (4 - 8 Hz)**
  - higher in young children
  - drowsiness in adults and teens
  - idling
- **Alpha: (8 - 13 Hz)**
  - relaxed/reflecting
  - closing the eyes
- **Beta: (14 - 30 Hz)**
  - active thinking, focus, high alert, anxious
- **Gamma: (> 30 Hz)**
  - Displays during cross-modal sensory processing
- **Mu: (7.5 - 12.5 Hz)**
  - Shows rest-state motor neurons

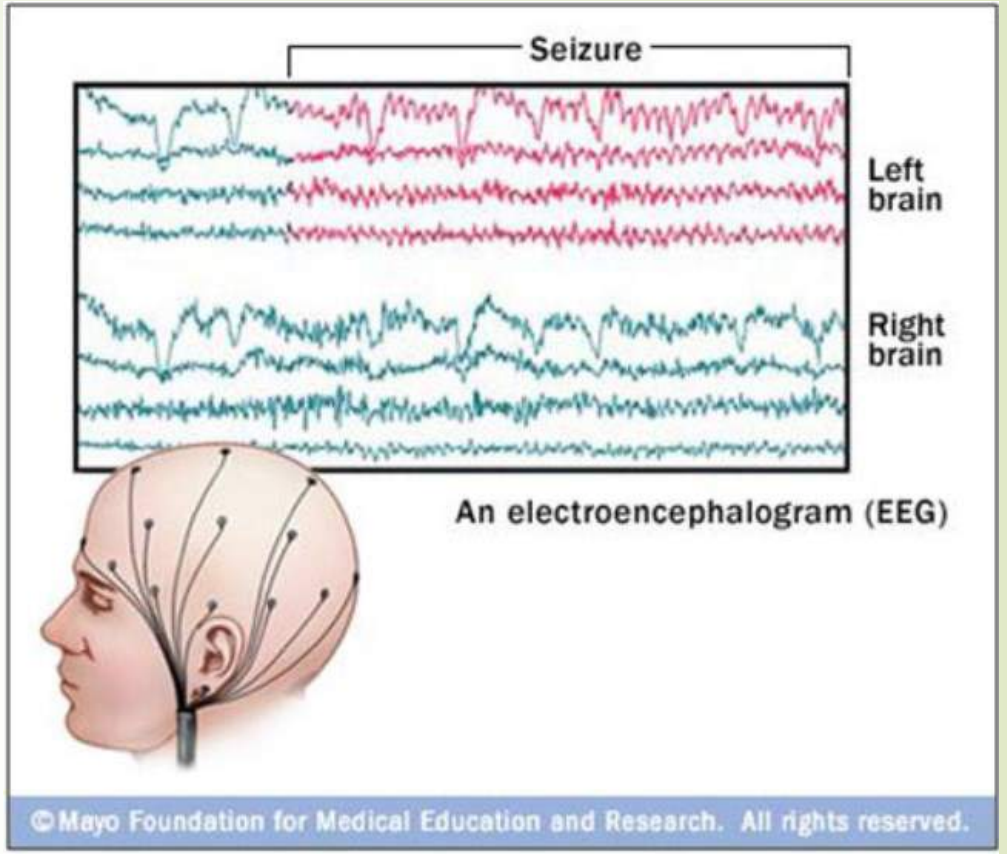






Applications of EEG

- Epilepsy Diagnosis: Seizure Detection (Most Common)
- Also to diagnose sleep disorders, coma, encephalopathies, and brain death
- Brain-Computer Interface (BCI) / Neural Prosthesis
- Basic Neuroscience Research
- cognitive science, cognitive psychology, and psychophysiological research.



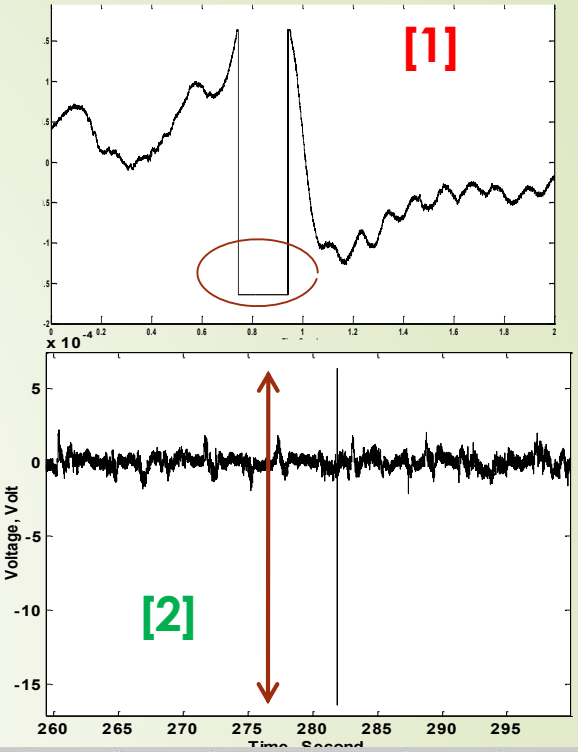
Artifacts & Interferences in EEG[10]

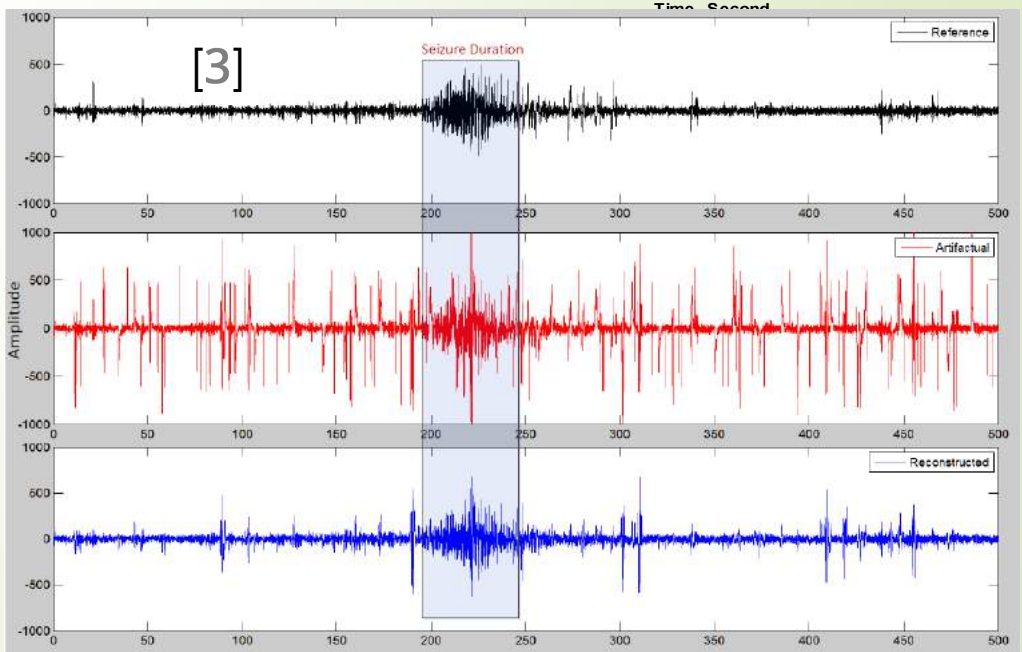
Sources of Artifacts

- Environmental factors (e.g. power noise, sound/optical interference, EM-coupling from earth, etc.)
- Experiment factors (e.g. electrode position altering, connecting wire movement, etc. due to mainly subject motion)
- Physiological factors (e.g. EOG, ECG, EMG, etc.)

Problems with Artifacts

- Can cause electronics saturation [1]
- High dynamic range required (Higher ENOB in ADC) **[2]**
- Increase false alarms in epileptic seizure detection [3]
- Mistakes in BCI classifications





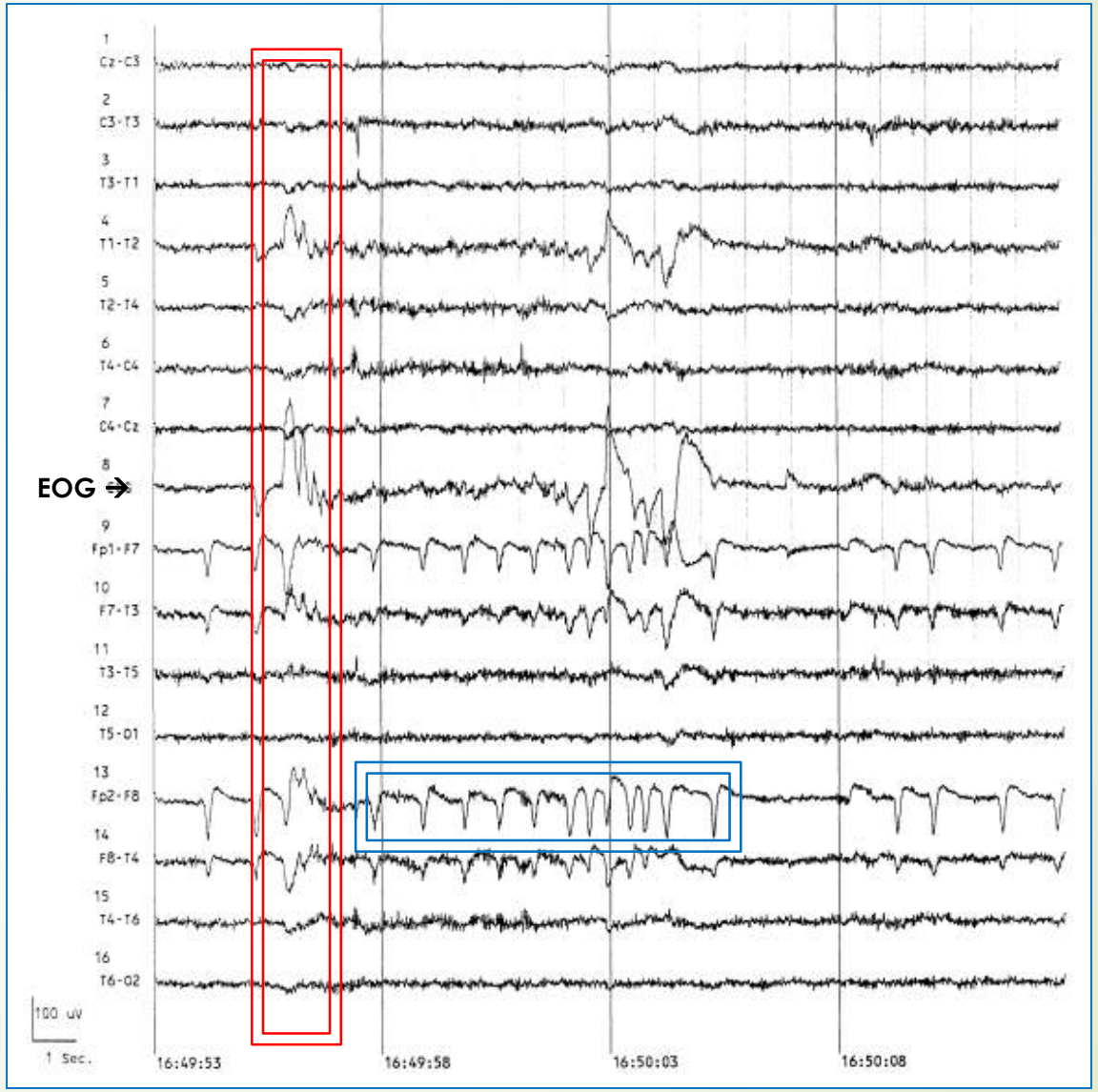
[10] https://emedicine.medscape.com/article/1140247-overview

Summery of Existing EEG Artifact Removal Methods

- Single artifact type
- Reference channel
- Mostly general purpose
- Often Manual or Semi-automatic
- Often suitable for Multi channel
- Real-time/Online processing capability
- Not enough quantitative evaluation
- Often after-effects not reported
- Lack of adequate dataset used
- Often hybrid methods (wICA, EEMD-CCA, etc.)

Artifacts Found in EEG* (1)

Horizontal Eye Movement (T1-T2) and Blink Artifacts (Frontal channels)



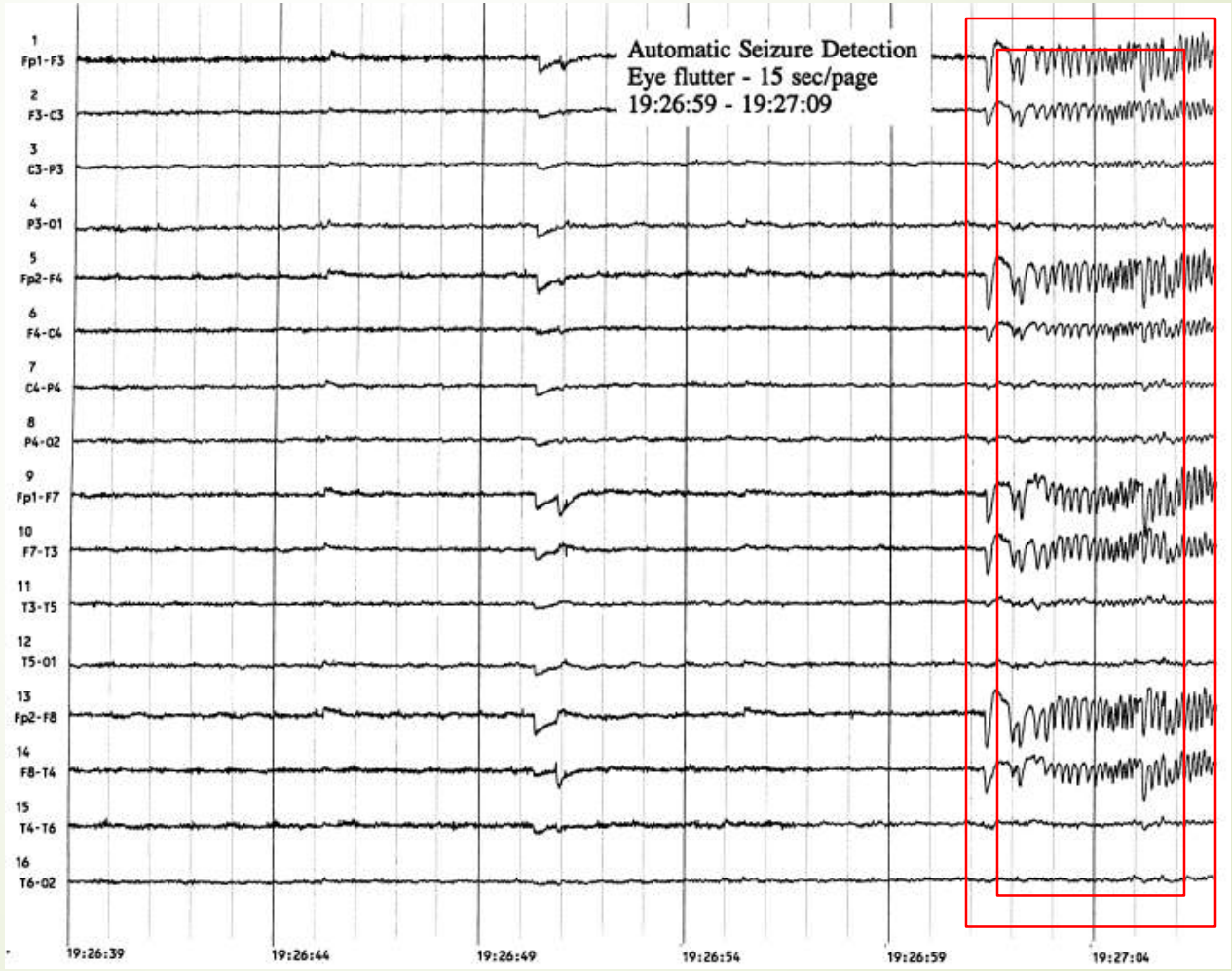
*Chang, B. S., Schachter, S. C., & Schomer, D. L. (2005). *Atlas of ambulatory EEG*. Amsterdam ; London: Amsterdam ; London : Elsevier Academic Press, c2005.

Artifacts Found in EEG (2)

- Rhythmic eye flutter can occur at quite high frequencies, in this case 5–8 Hz, and trigger automated seizure detection algorithms.

- This artifact can be distinguished from ictal events in different ways, including the lack of evolution in frequency or amplitude over time.

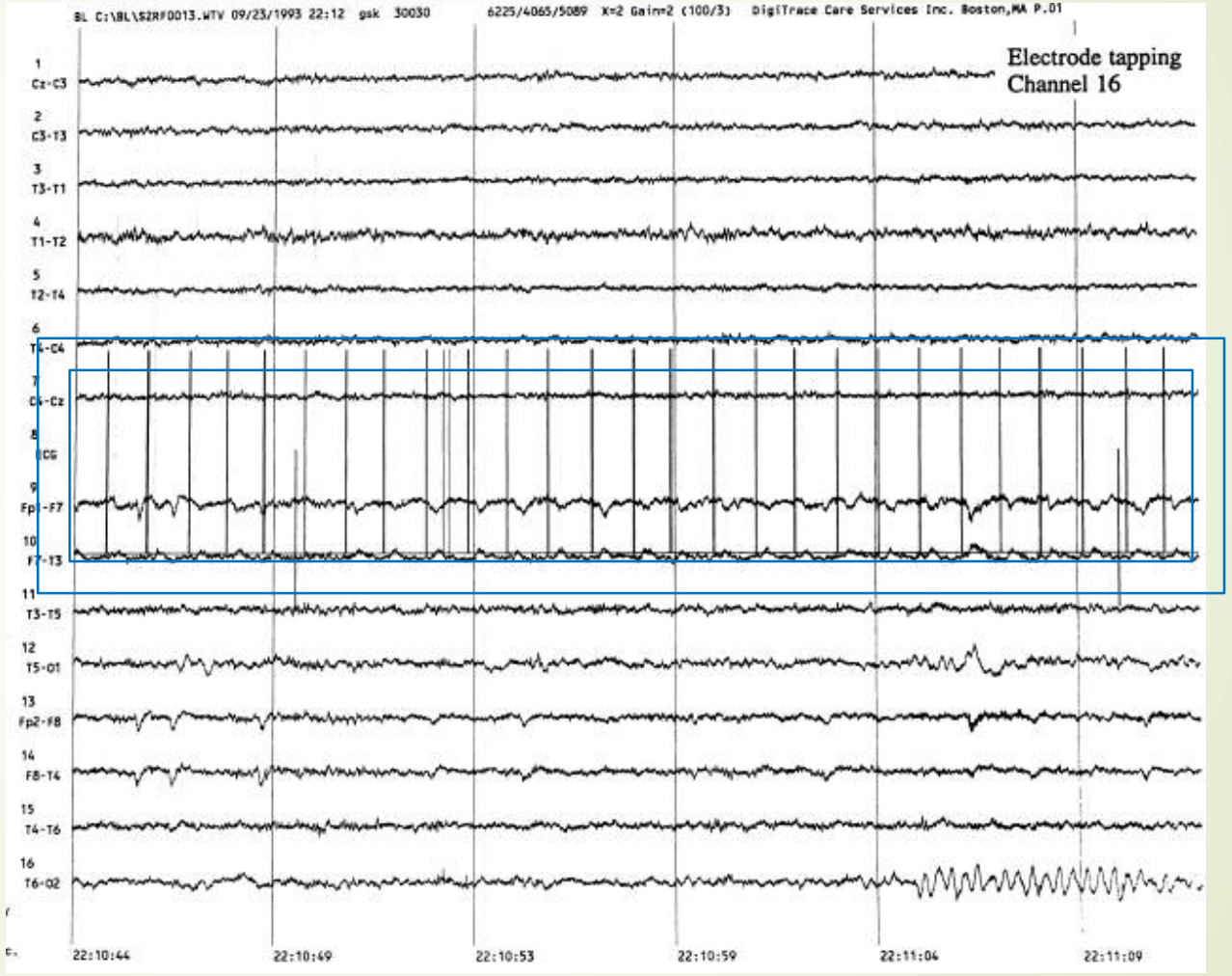
Eye Flutter Artifact recorded by Seizure Detection Algorithm



Artifacts Found in EEG (3)

With ambulatory EEG recording, there may be periods in which the patient is scratching or pressing on the scalp electrodes.

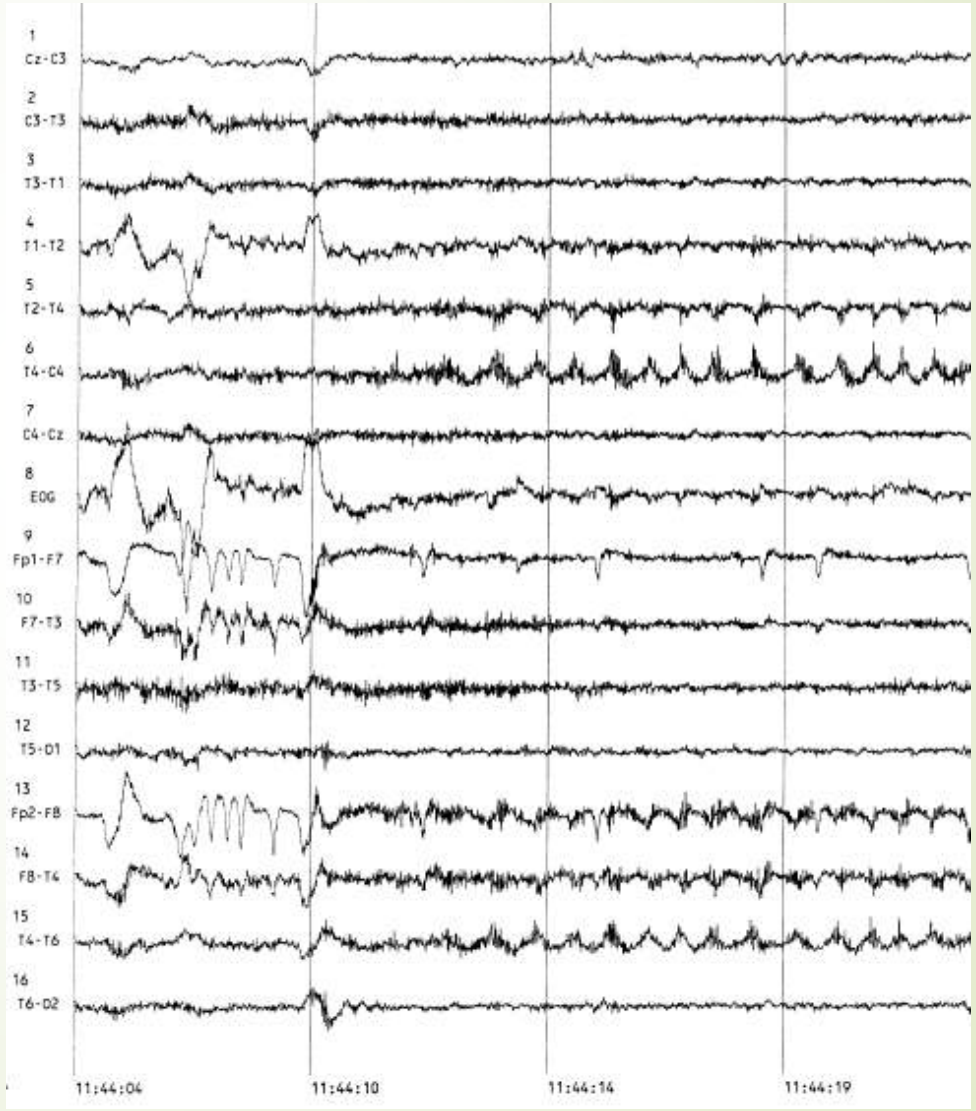
Electrode Tapping Artifact



Artifacts Found in EEG (4)

- Periods of jaw clenching and biting during ambulatory EEG recording can be associated with artifact.
- This activity is often most prominent over the **temporal regions**, presumably due to temporalis or masseter muscle contraction.

Jaw-Clenching Artifact

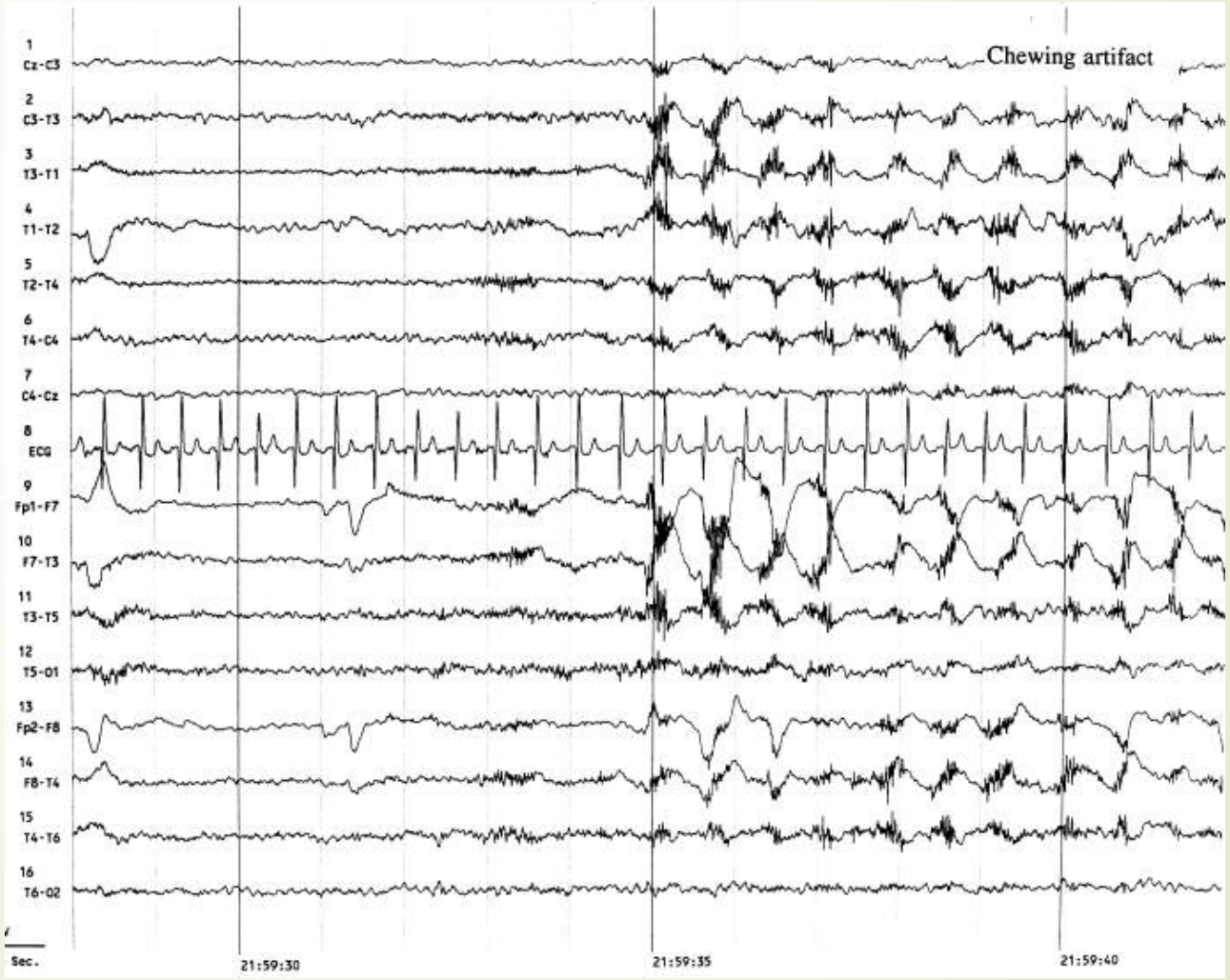


Artifacts Found in EEG (5)

- Chewing artifact can often have rhythmic features and at times may resemble ictal activity.

- This artifacts are characterized by the rhythmic appearance of muscle artifact centered mostly over the **temporal** regions bilaterally.

Chewing Artifact



Artifacts Found in EEG (6)

- Chewing artifact can have rhythmic and sharp features, and can thus be picked up by automated detection algorithms.

- Here, the spike detections at 23:53:23 and at 23:53:34 capture high frequency sharp waveforms that are artifactual in nature, in association with a nighttime snack.

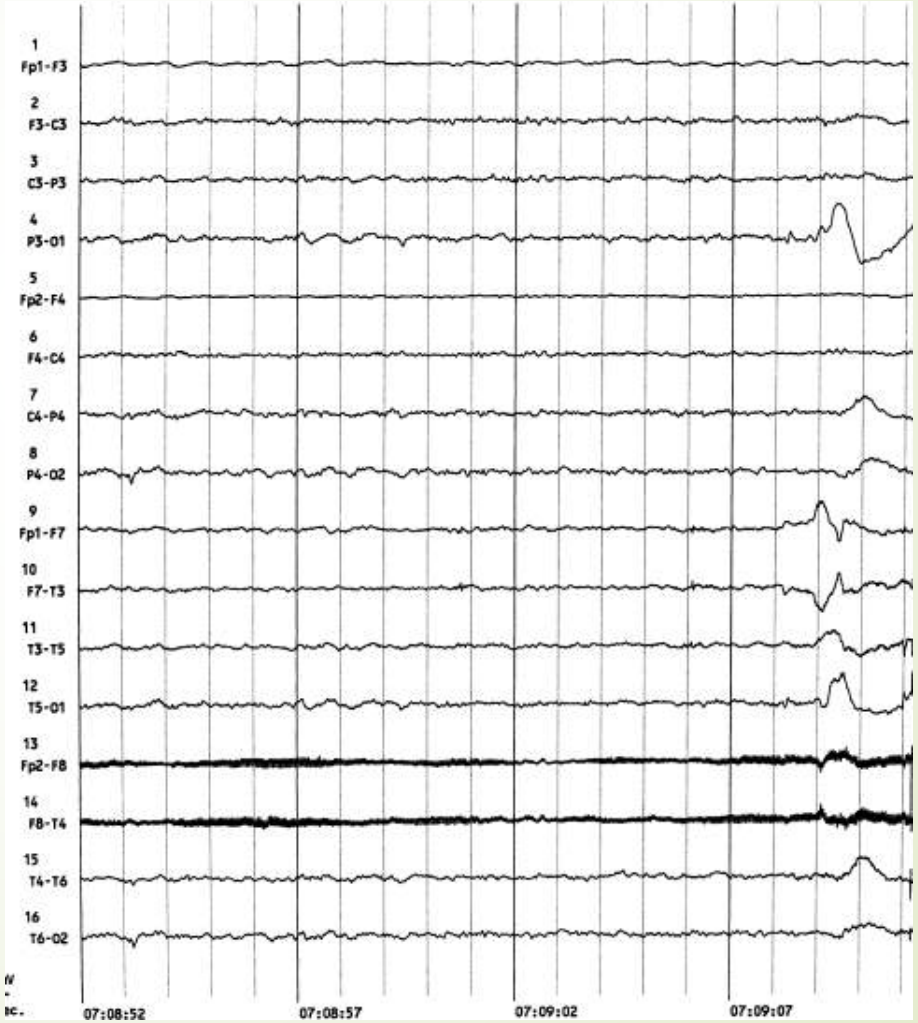
Chewing Artifact Recorded by Spike Detection Algorithm

Artifacts Found in EEG (7)

- One disadvantage of ambulatory EEG monitoring is the inability of technologists to check on recording quality frequently in real time and to respond with appropriate technical adjustments as needed throughout the day, as would typically occur in an inpatient monitoring unit.

- Here, a dry electrode at F8 causes an artifact seen throughout this excerpt.

Dry Electrode Artifact

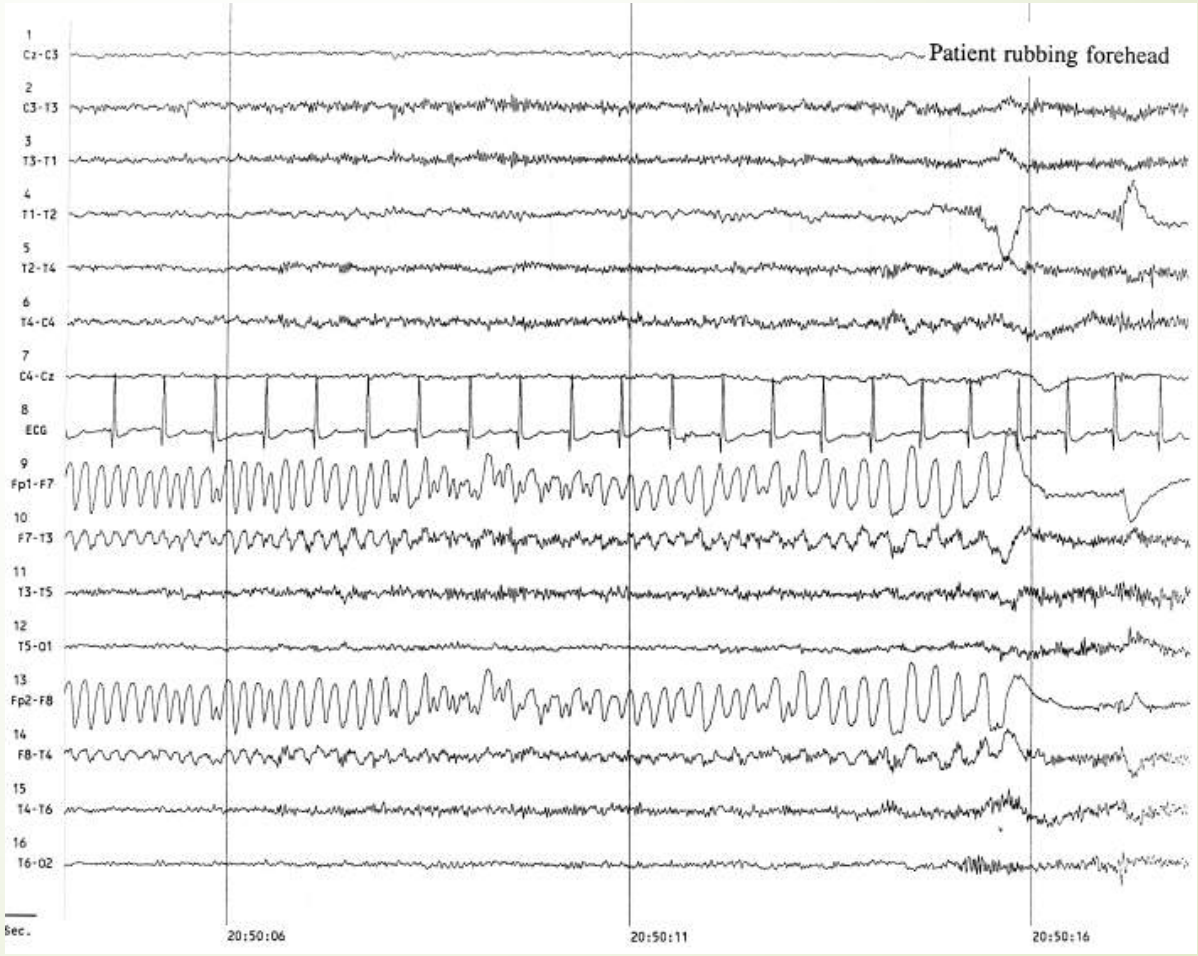


Artifacts Found in EEG (8)

❑ As with many other patient movement artifacts, rhythmic rubbing artifact can be a potentially confusing finding on ambulatory EEG monitoring, particularly in the absence of concomitant video recording. Here, rhythmic rubbing of the forehead produces an artifact in the anterior channels, extending from the beginning of this excerpt through 20:50:16.

❑ Differentiation of such artifact from an ictal event, based on the lack of evolution of the artifact in frequency or amplitude, is critical.

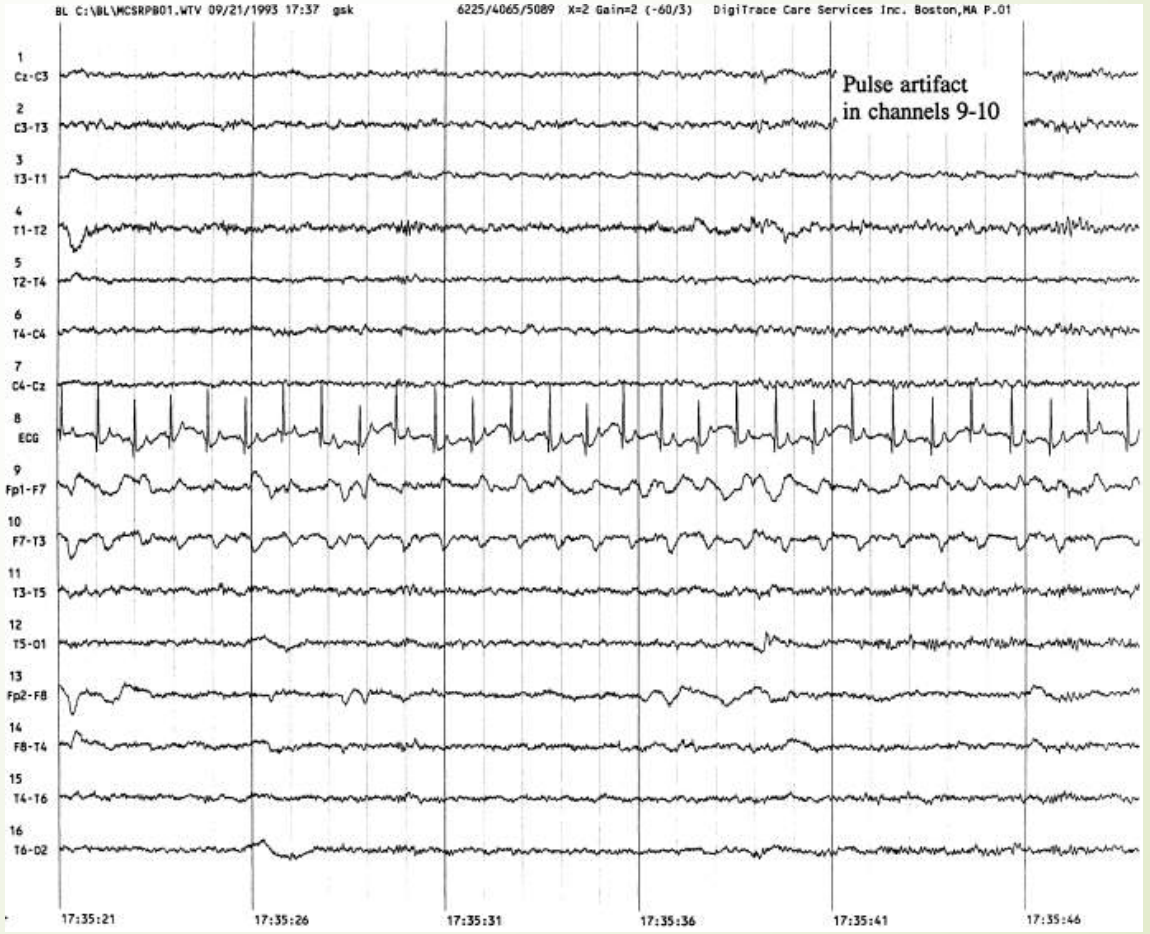
Forehead Rubbing Artifact



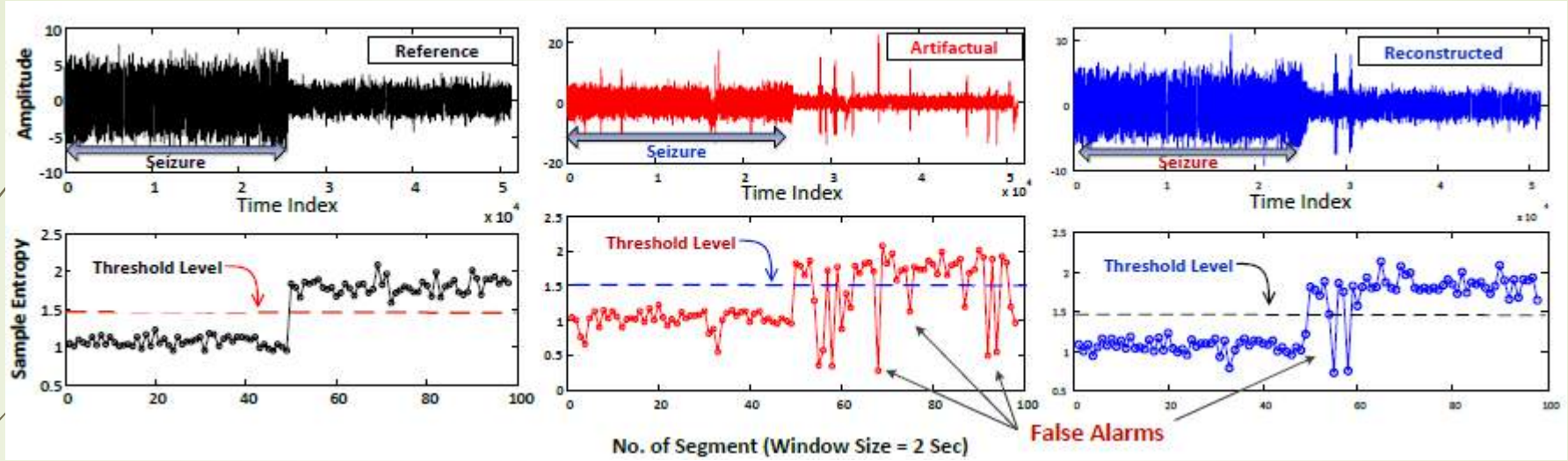
Artifacts Found in EEG (9)

- Pulse artifact is caused by the rhythmic movement of scalp electrodes, usually over the temporal regions, by the pulsations of blood through vessels close to the skin, such as the superficial temporal artery.
- It is to be distinguished from the more common electrocardiographic (EKG) artifact in that pulse artifact is typically not as sharply contoured, resembles a slow wave, and follows the QRS complex rather than being simultaneous to it.
- Here, pulse artifact is seen in channels 9 and 10 over the left temporal region throughout this entire excerpt.

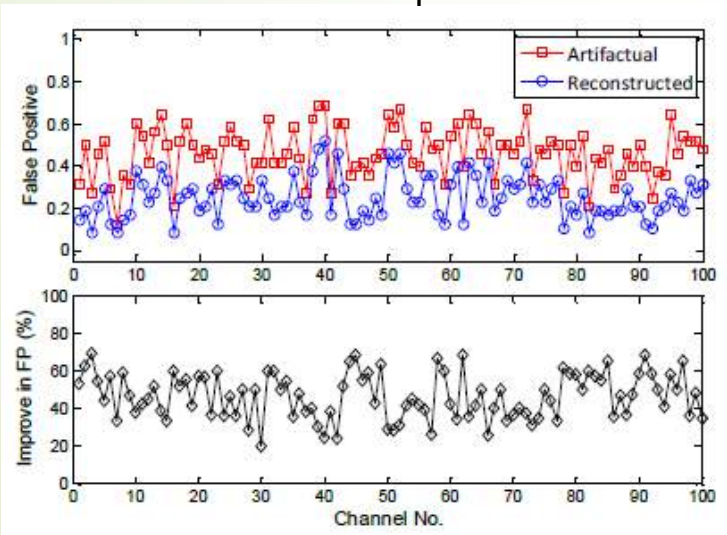
Pulse Artifact

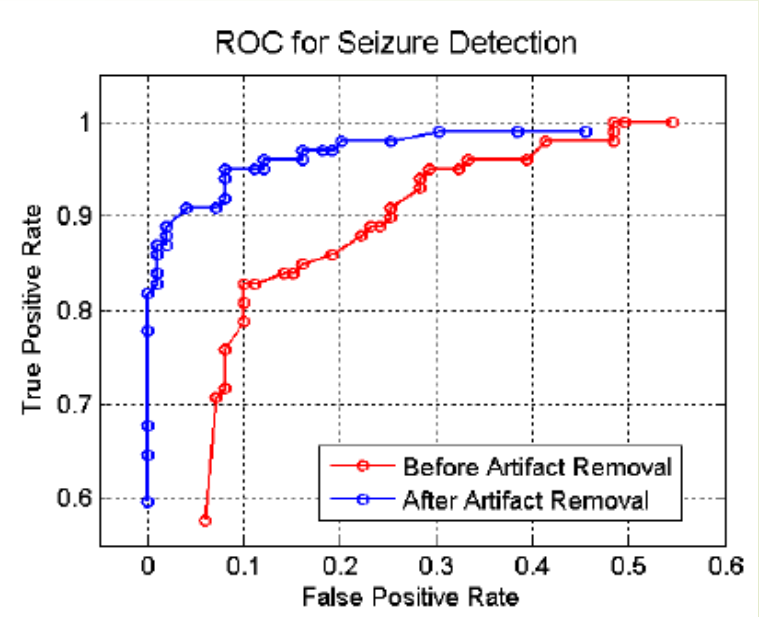


Effect of Artifact Removal from EEG (Diagnosis)

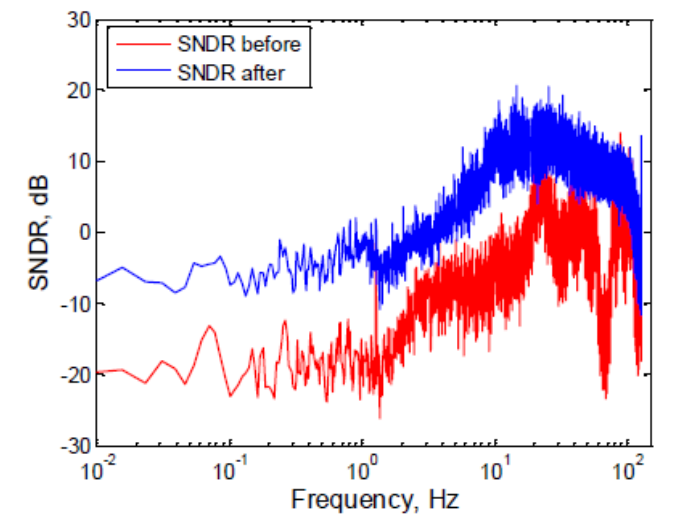


False alarms improvement



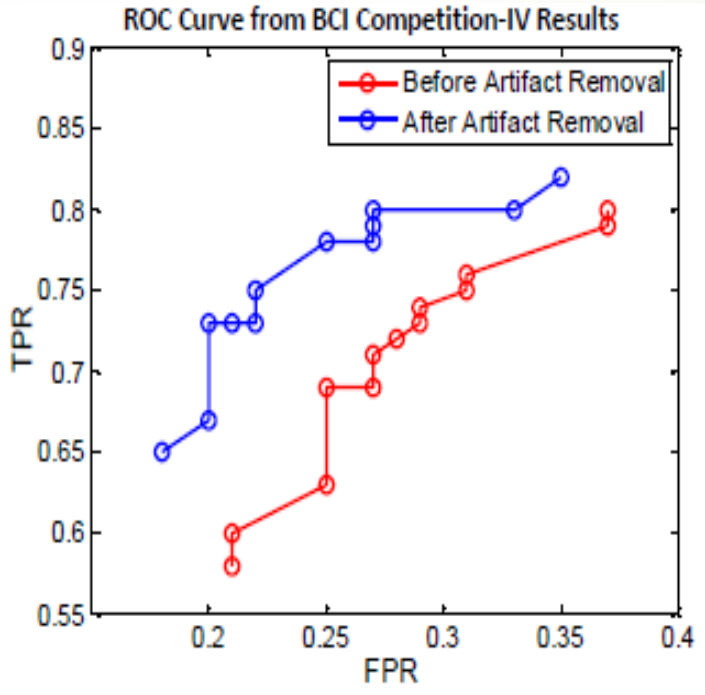


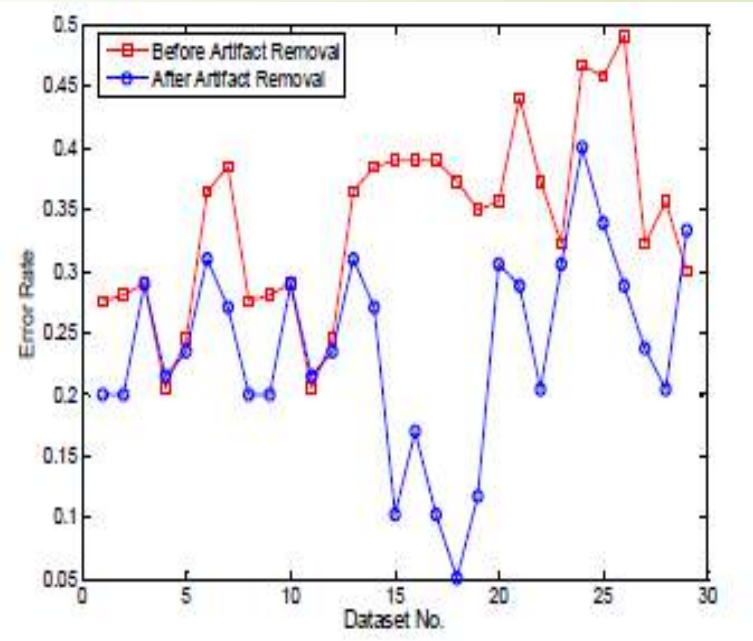
Effect of Artifact Removal from EEG (BCI)



SNDR Improvement

BCI Performance Improvement





Thank You