International Electronic Conference on Sensors and Applications
1 - 16 June 2014

Soft, Comfortable Polymer Dry Electrodes for High Quality ECG and EEG Recording

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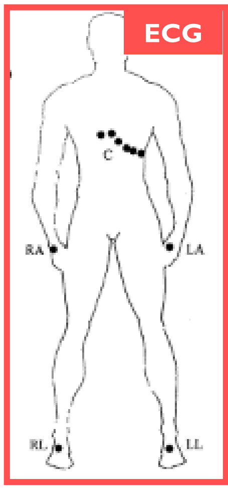
28/05/2014

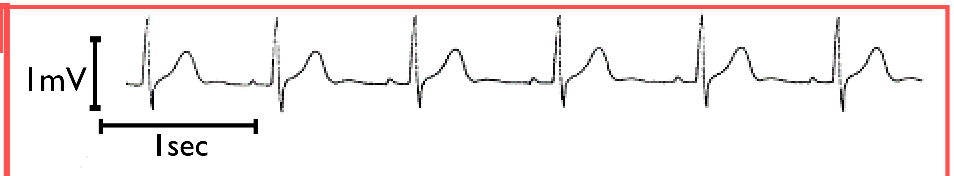
Outline

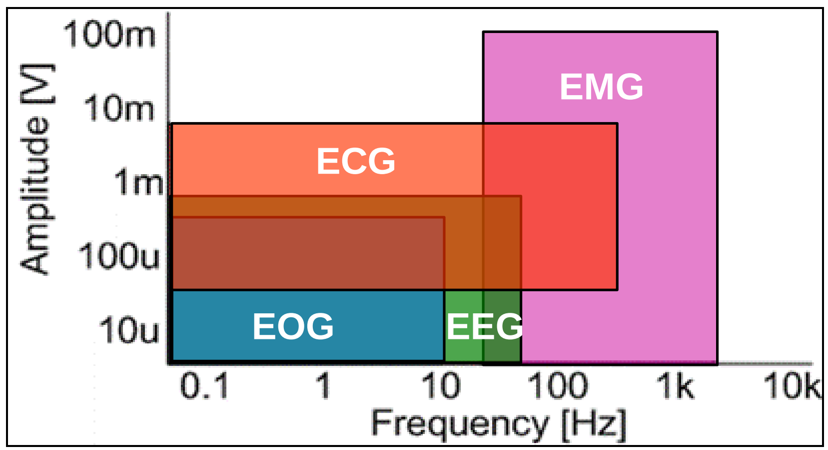
- **Biopotential signals**
- **Dry electrodes**
  - ◇ **Motivation**
  - ◇ **Types**
- **Polymer-based dry electrodes**
  - ◇ **Materials and shape**
  - ◇ **Impedance measurements**
  - ◇ **ECG monitoring**
  - ◇ **EEG monitoring**
- **Conclusions**

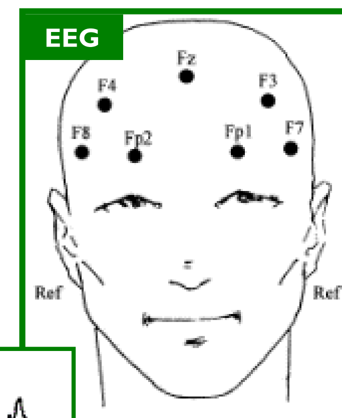
Main Types of Biopotential Signals

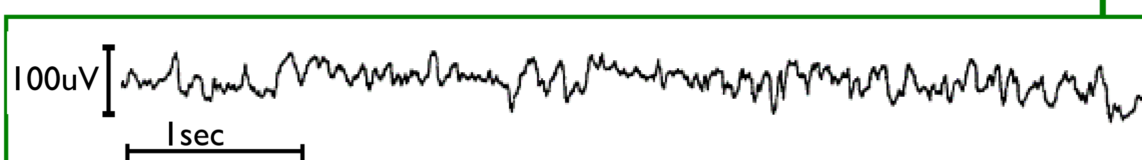
- **The frequency and amplitude distribution are different for each biopotential signal.**
- **in this work: focus on recording of ECG & EEG signals.**











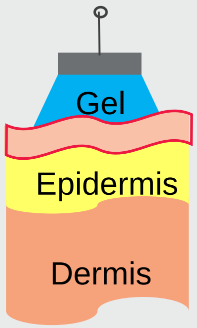
Motivation: why dry electrodes are needed?

	Conventional Wet-gel electrodes	Dry electrodes
preparation	• abrasive gel • cleaning by alcohol • use conductive gel	No need for preparation
Set-up	• expertise needed • time consuming	• easier • faster
Long-term usage	signal degradation due to gel drying	no signal degradation
User comfort	• irritation • discomfort when cleaning gel after use	depends on design and material

Types of Electrodes

Wet Contact

10-40 µm Stratum Corneum (SC) → high impedance

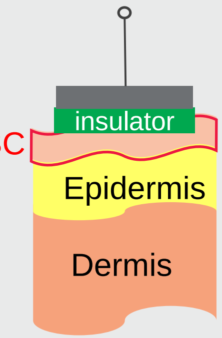


Gel: Reduce electrode-skin impedance and motion artifact

Dry Non-contact

Capacitive

SC

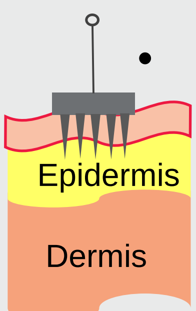


- Extremely sensitive to motion artifact
- signal very small → active electrodes (pre-amplification) and shielding needed
- safe

Dry Contact

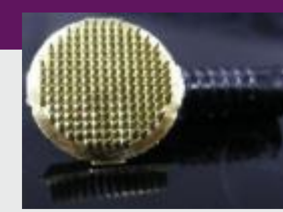
Invasive

SC

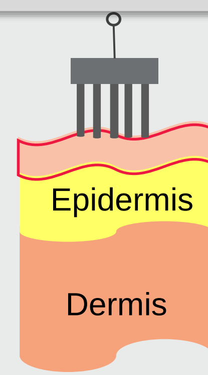


- biomedical safety issue
  → biocompatible materials needed
  → more expensive fabrication

Non-invasive



SC

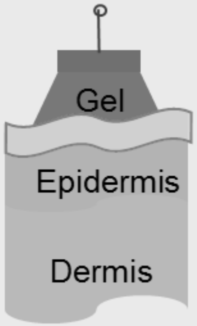


- high impedance (electrode-SC layer)
- prone to motion artifact
- active electrodes needed for weaker biopotential signals

Types of Electrodes

Wet Contact

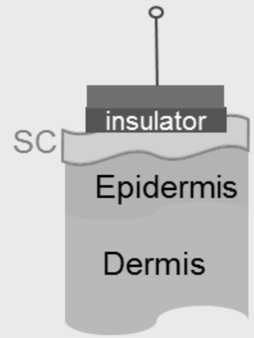
10-40 µm Stratum Corneum (SC) → high impedance



Gel: Reduce electrode-skin impedance and motion artifact

Dry Non-contact

Capacitive

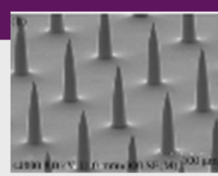


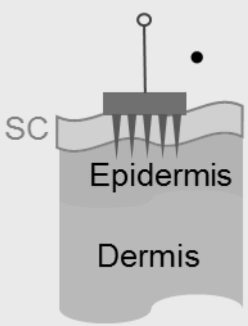
- Extremely sensitive to motion artifact
- signal very small → active electrodes (pre-amplification) and shielding needed
- safe

Dry Contact

Topic of this paper.

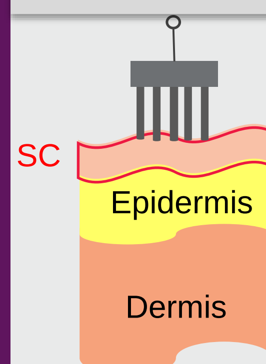
Invasive

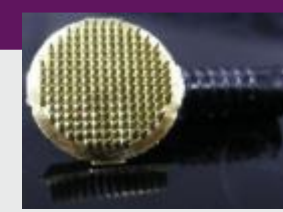




- biomedical safety issue
  → biocompatible materials needed
  → more expensive fabrication

Non-invasive





- high impedance (electrode-SC layer)
- prone to motion artifact
- active electrodes needed for weaker biopotential signals

Commercially Available Dry Contact Electrodes

- **Flat foam electrodes**

  Conductive material or with conductive coating layer
  ➔ suitable for hairless position (forehead)

- **Metal electrodes**

  Hard ➔ uncomfortable

- **Metal electrodes + spring**

  Complex ➔ expensive

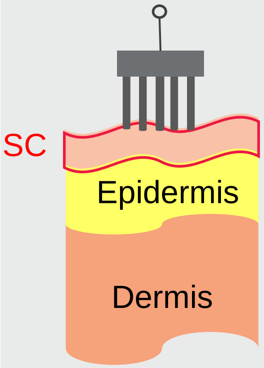
➔ polymer-based

electrodes are presented

- ◇ **flexible**
- ◇ **comfortable**

Dry Contact

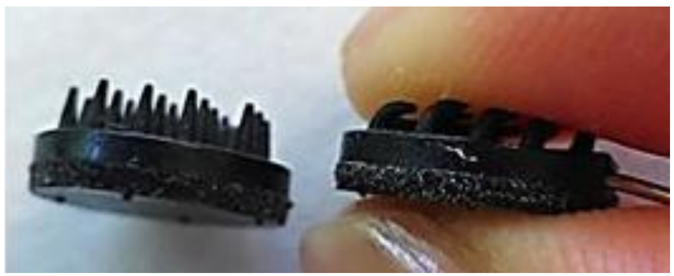
Non-invasive



- high impedance
  (electrode-SC layer)
- prone to motion artifact
- active electrodes needed for weaker biopotential signals

Soft and Flexible Polymer-Based Dry Electrodes

- **Non-conductive polymer electrodes + coating: coating flakes off**
- **Conductive polymer electrodes: comfortable + stable**



Conductive polymer:

EPDM rubber + additives

For conductivity

For other properties

(mechanical, molding, de-molding...)

Various pin configurations are investigated.

Electrodes Characterization

- **Impedance**

  Lower impedance ➔ higher signal quality

- **Mechanical properties**

  hardness and elastic modulus are defined

- **ECG & EEG monitoring**

  compare correlation, coherence and signal to noise ratio of signals recorded using wet and polymer dry electrodes

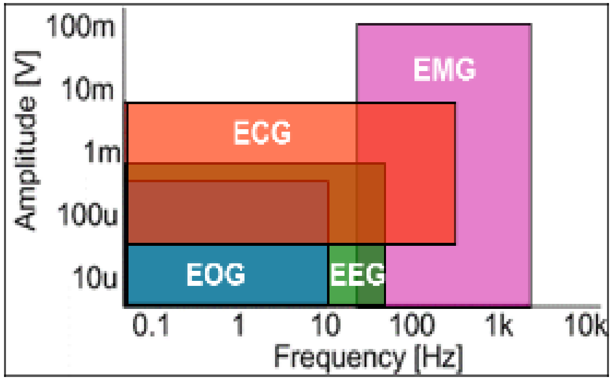
Electrodes Characterization: Impedance

- **Impedance sweep though frequency**

normalized value at 10 Hz will be shown

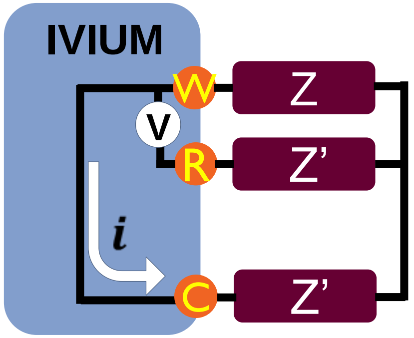
Surface normalization since impedance decreases with larger contact area

frequency distribution of ECG & EEG



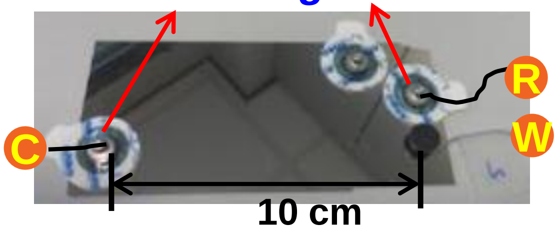
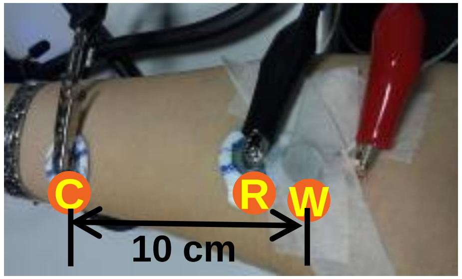
- **measurement equipment: IVIUM**

potentiostat with built-in impedance analyzer



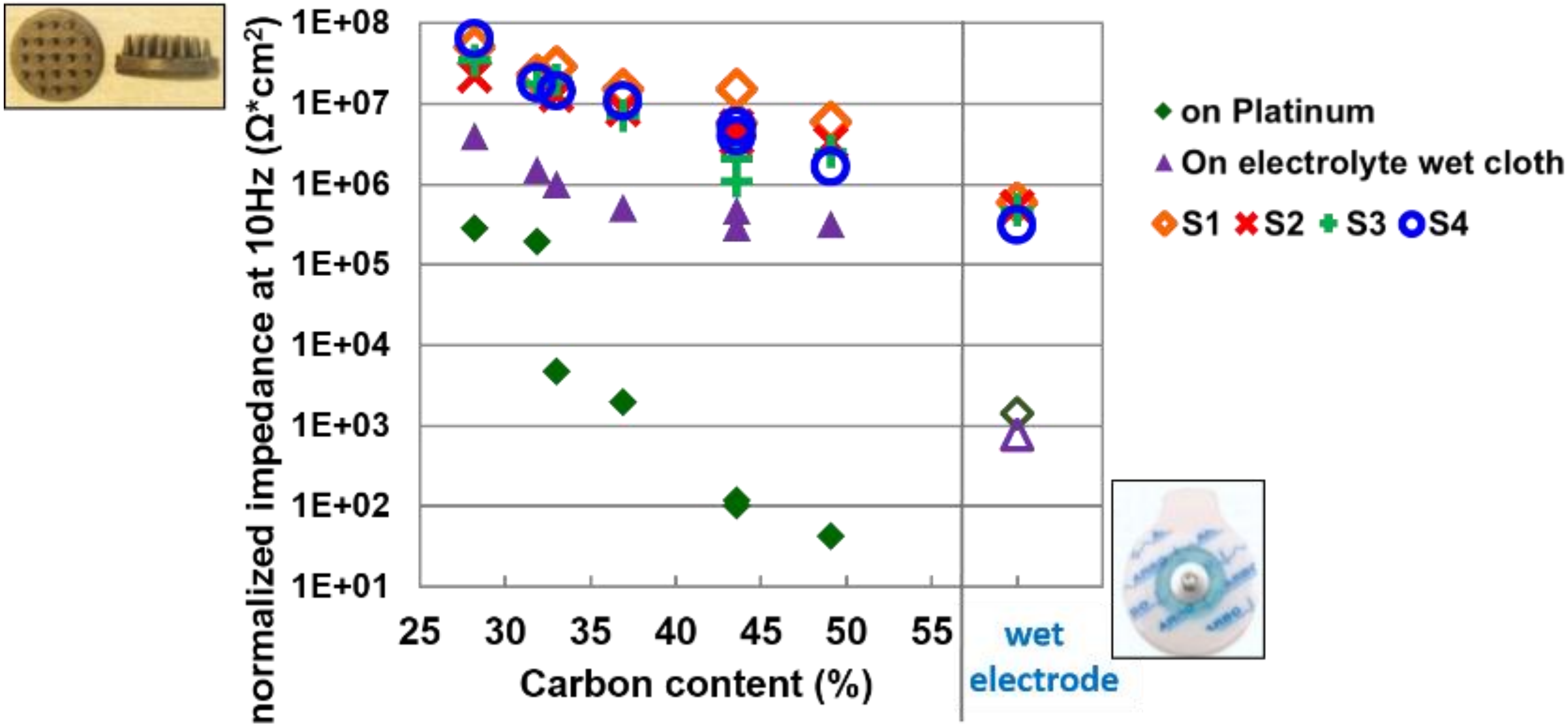
- standard wet electrodes as reference (R) and counter (C) electrodes
- impedance of working electrode (W) is calculated by the voltage and current acquired by IVIUM

Impedance Measurements

Back to back	Phantom (Pt metal film and electrolyte wet cloth)	human test subjects (on forearm)
Material impedance	Material / phantom impedance	Material / skin impedance
characterization	For Reproducibility	Variation between subjects
		

Optimization of additive composition: by impedance measurements. Results of various additive compositions will be discussed further.

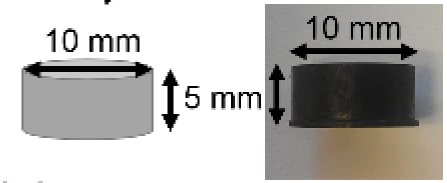
Impedance Influenced by Conductive Additives (Carbon)

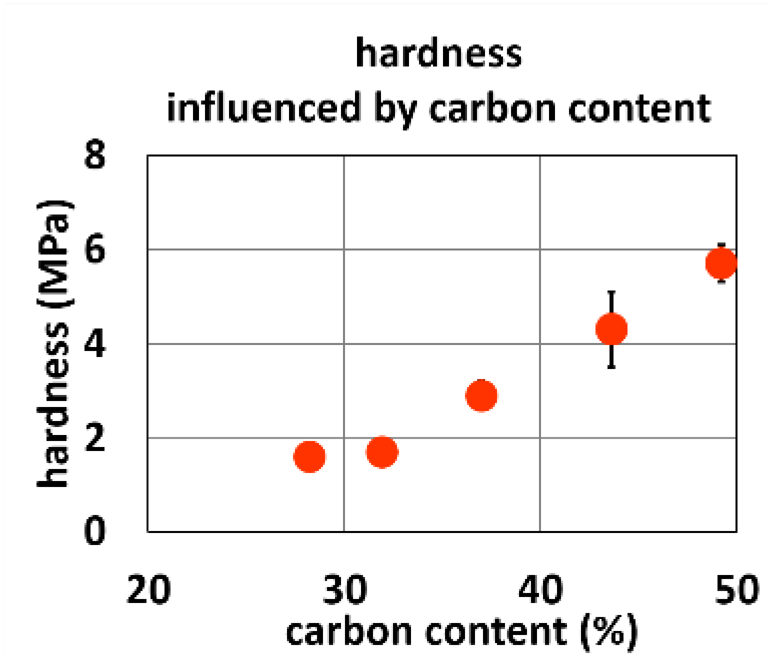


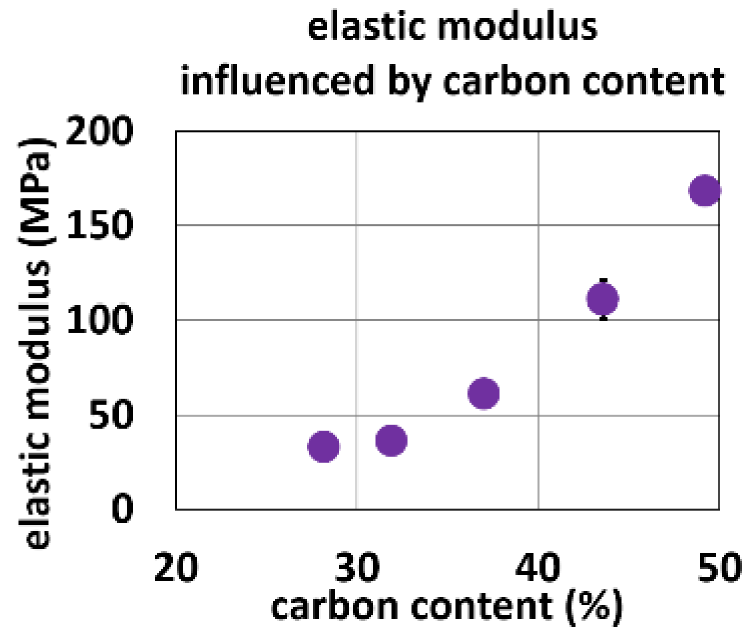
- impedance decreases with higher carbon content
- Impedance of electrode with ~50% carbon content is 10-fold higher than conventional wet electrode

Mechanical Properties

polymer test cylinder





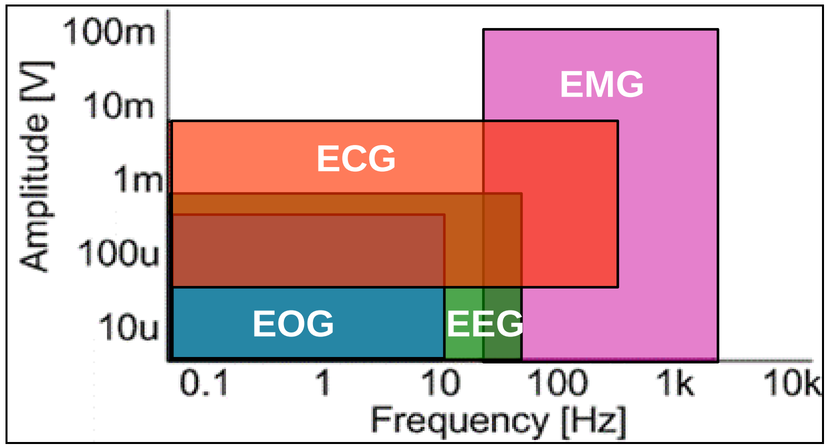


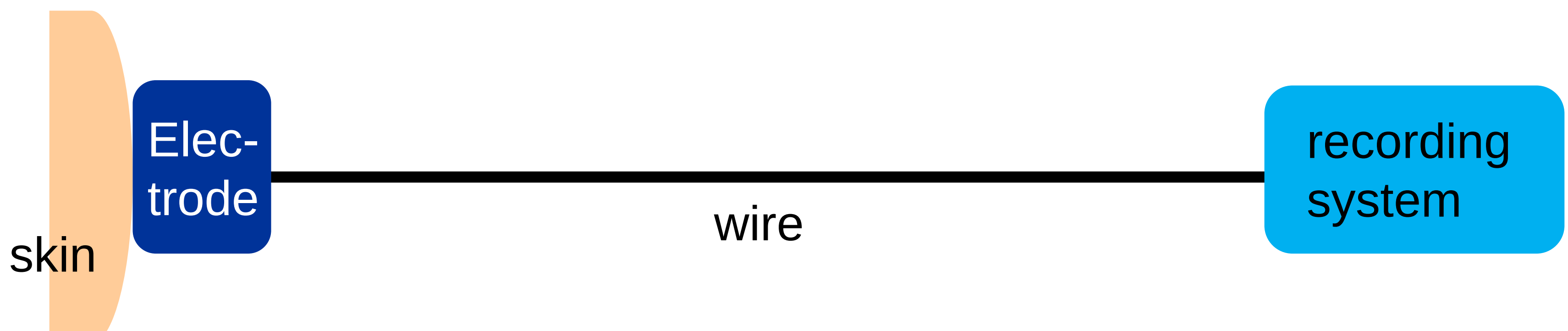
- **Hardness and elastic modulus both increase with increasing carbon content in the polymer electrodes**
- **Electrodes with ~ 45% of carbon are sufficiently hard for support when mounting into EEG recording systems and offer still sufficient patient comfort during monitoring**

Electrode Characterization: ECG Monitoring

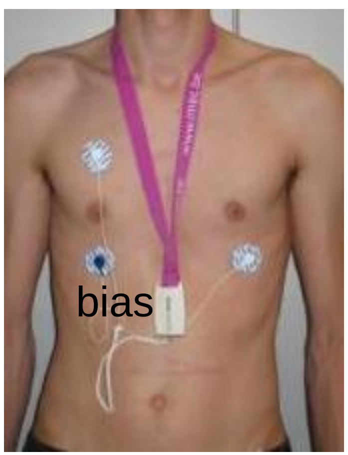
- **Stronger signals**

  ➔ **passive electrode is OK**

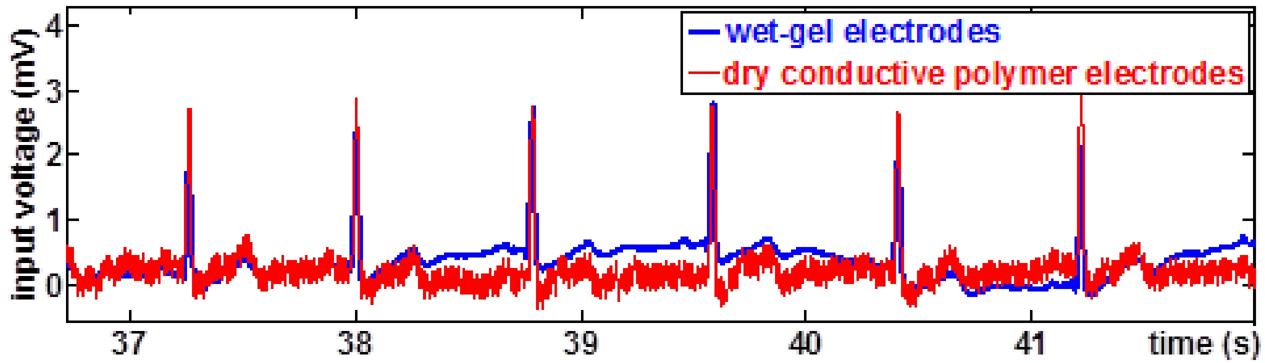




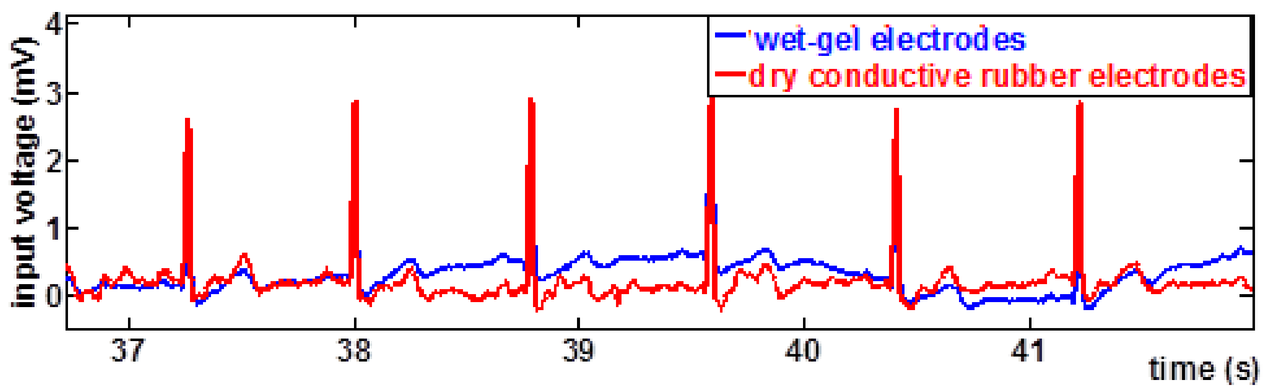
ECG Monitoring on Chest



No filtering



With 50Hz filter

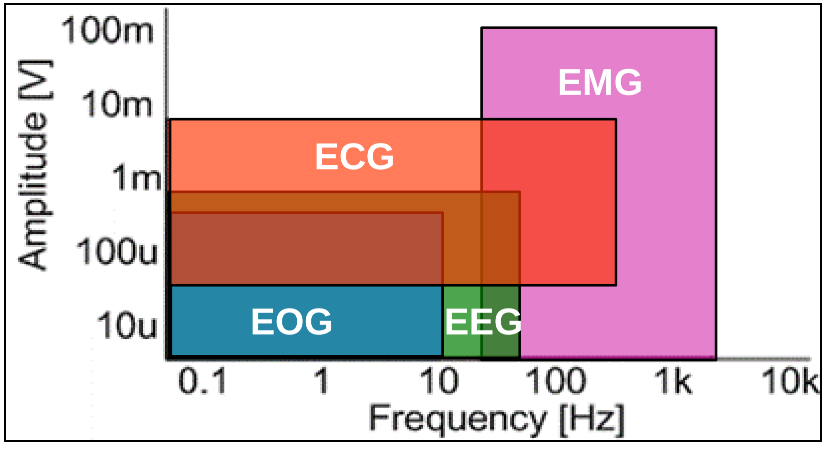


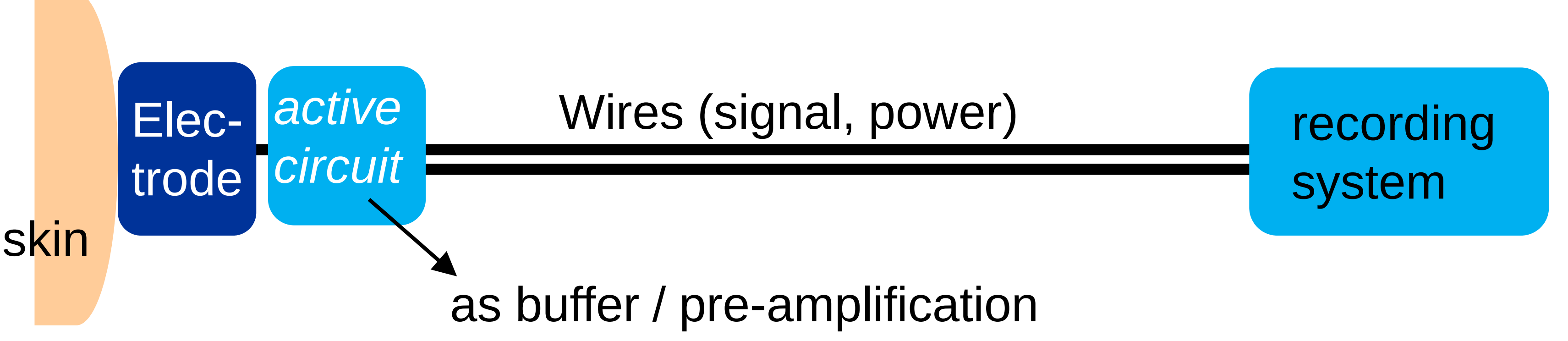
- **signals from both electrode types are similar**
- **R peaks can be easily detected**

Electrode Characterization: EEG Monitoring

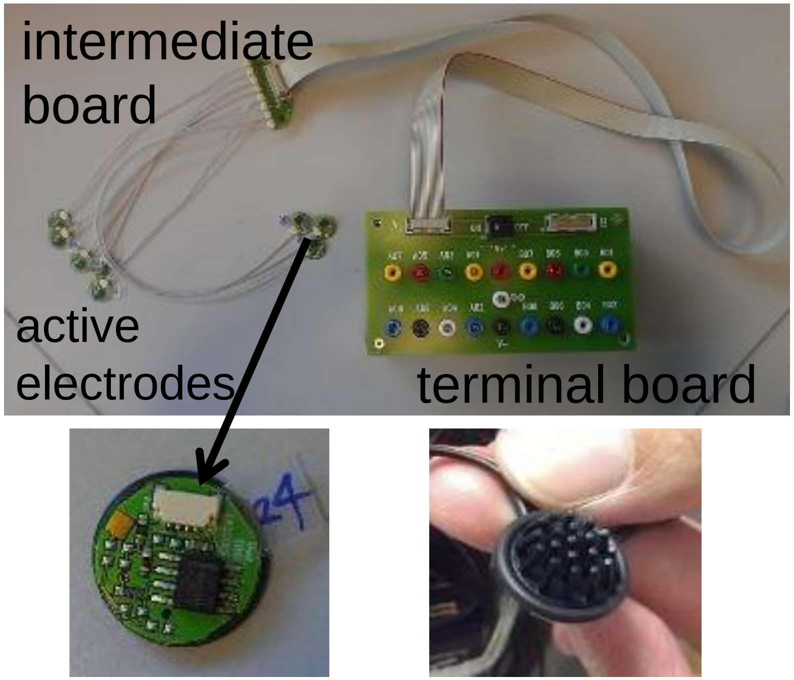
- **Weaker signals**

  ➔ **active electrodes are needed**





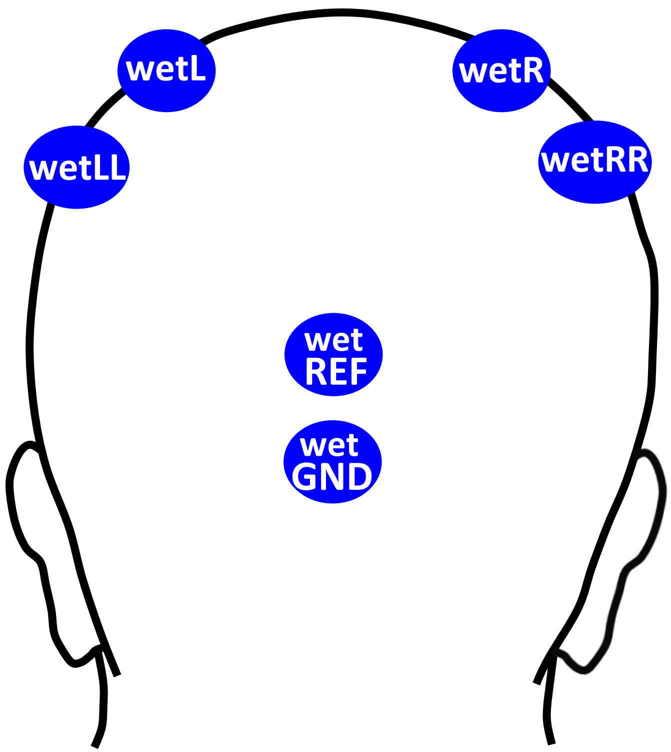
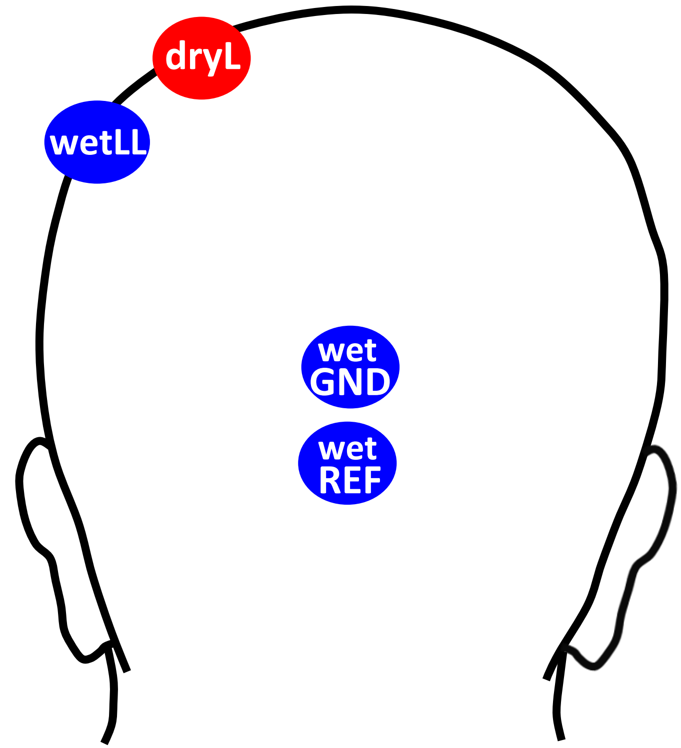
EEG Monitoring with Clinical System



active electrodes used as buffer/ pre-amplification

clinical system used for signals recording

Location of electrodes for EEG monitoring

Reference recording	Dry electrode recording
	
Look for typical signal correlation for wet electrodes, check influence of electrode distance on signal correlation	Compare signal correlation between wet and dry electrode with typical correlation for 2 wet electrodes

Signal analysis

- **Filter**
  - ◇ **Chebyshev typeII Bandpass 2-30 Hz filter was applied forward and backwards on the data to eliminate distortion**

- **Pearson's product moment correlation (correlation)**
  - ◇ **quantify the similarity between the recordings as they provide information on the time coupling and wave morphology**

- **Coherence (at alpha wave range: 8-13 Hz)**
  - ◇ **the stability of the similarity by looking at the frequency content**

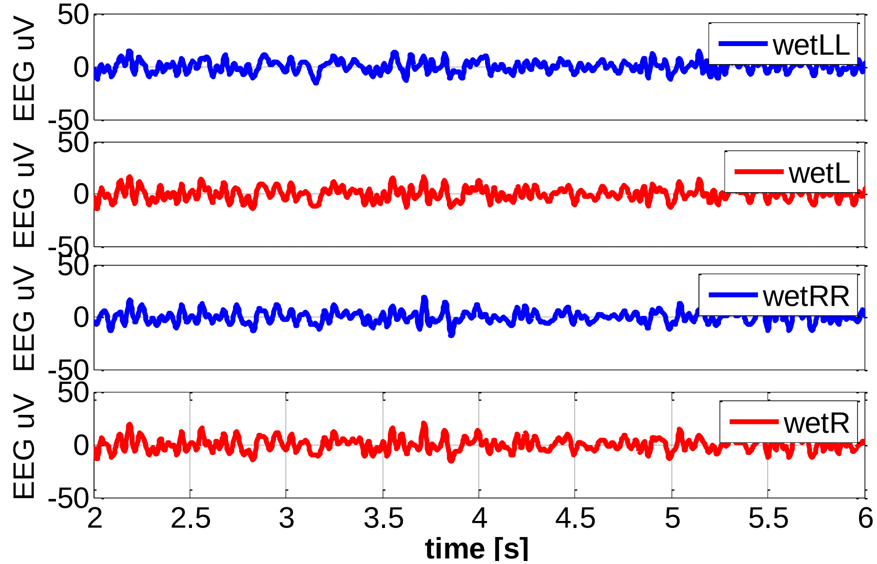
- **Signal to noise ratio (SNR)** **(PSD = power spectrum density)**

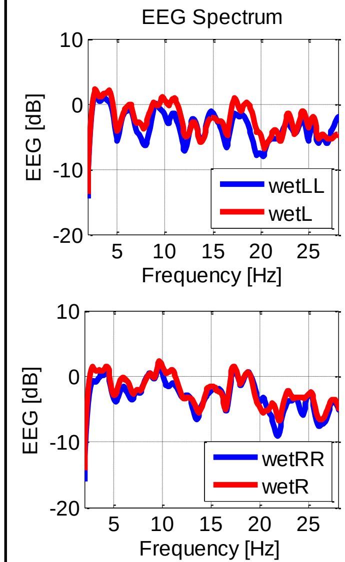
$$SNR = \frac{mean\ (PSD_{band\ of\ interest})}{mean\ (PSD_{signal\ band - band\ of\ interest})} = \frac{mean\ (PSD_{(8-13Hz)})}{mean\ (PSD_{(2-30Hz)-(8-13Hz)})}$$

SNR is typically calculated by comparing recordings with open and closed eyes. The 'frequency band of interest' corresponds to EEG frequencies of alpha waves present when eyes are closed (between 8 and 13Hz).

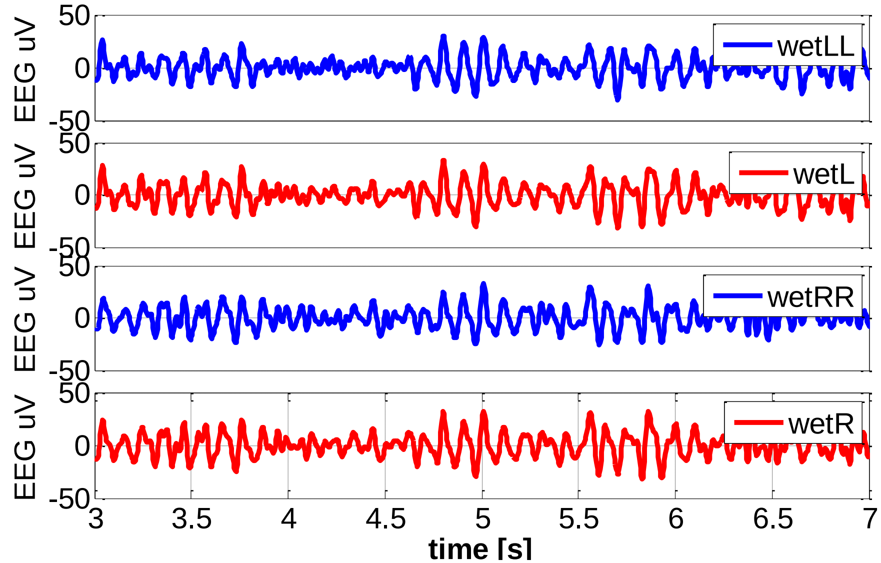
Reference EEG recording (wet electrodes only)

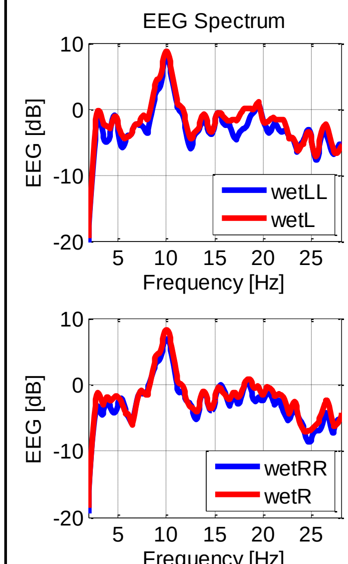
eyes open





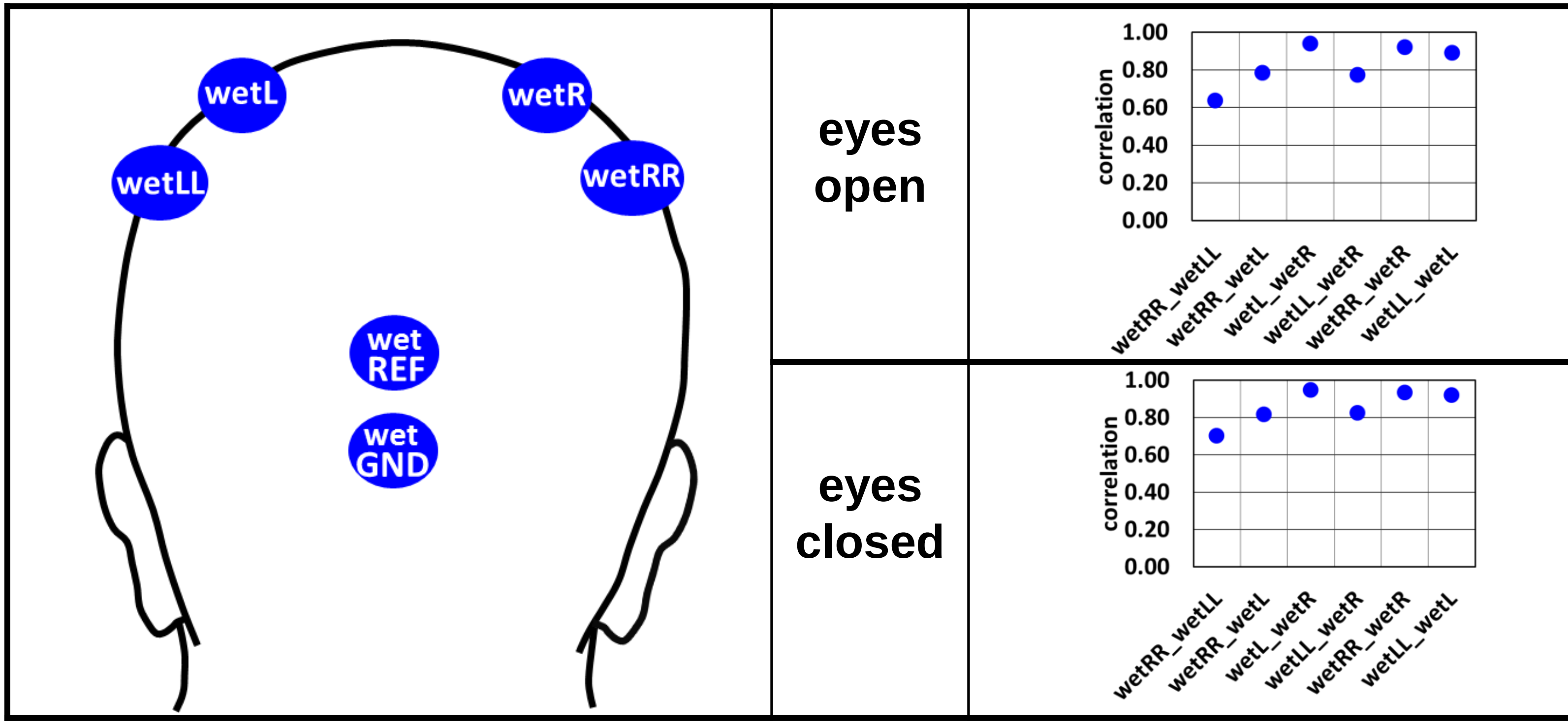
eyes closed





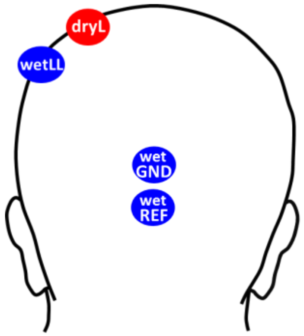
The alpha waves (~10Hz) are clearly visible

Correlation of reference recording (wet electr. only)

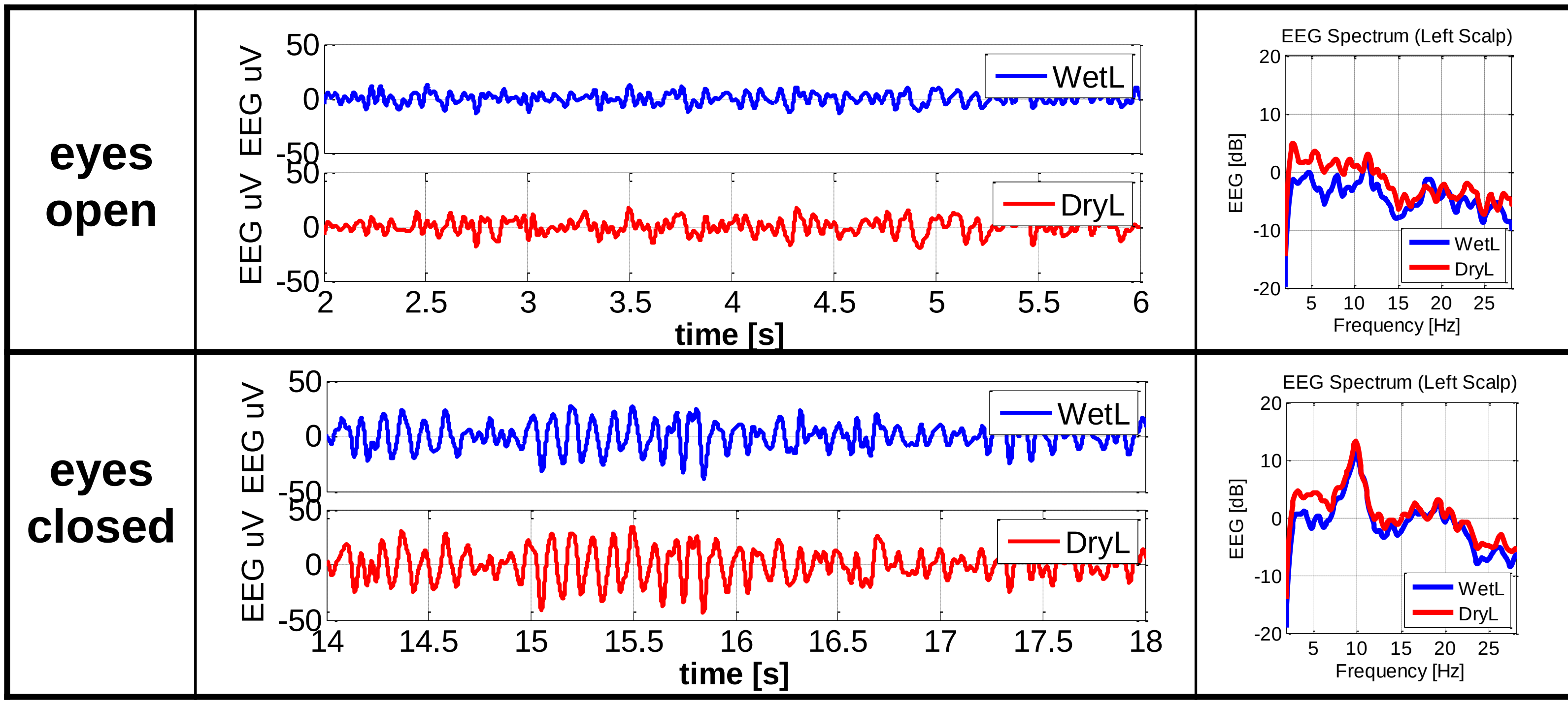


- **Correlation of electrodes placed at shorter distance is higher than that of electrodes placed at longer distance.**
- **Correlation of electrodes next to each other is around 0.9**
- **Impossible to have two signals from the same position**
  → correlation of 1 is not expected

EEG monitoring: dry electrode recording

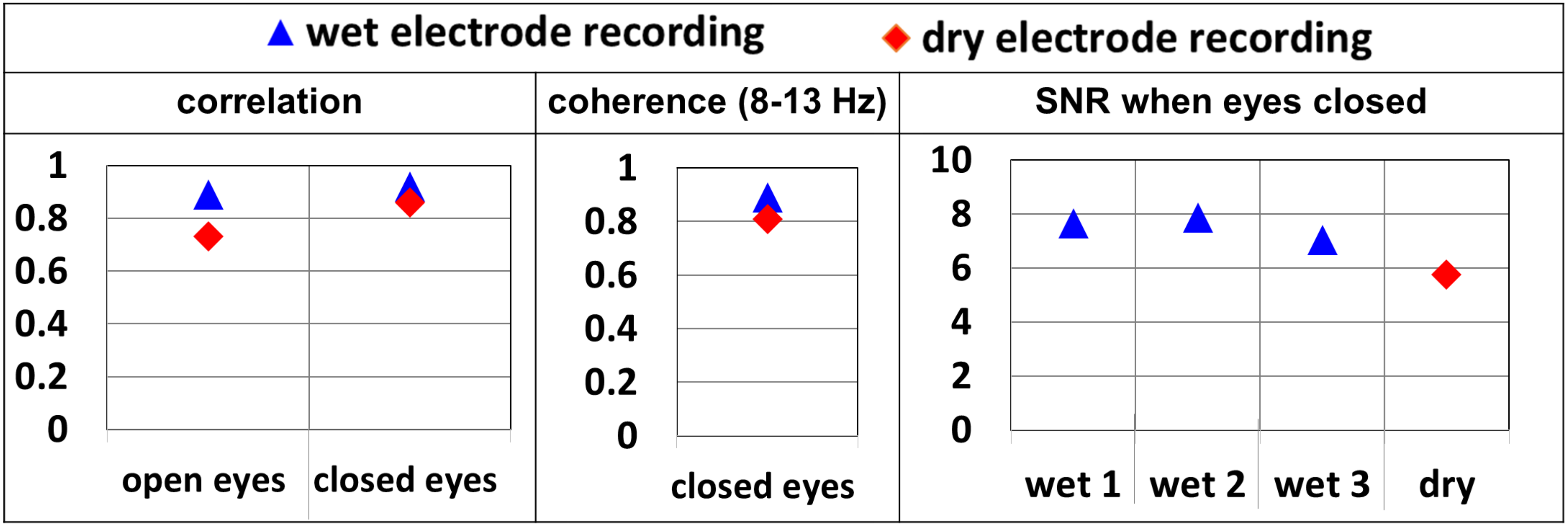


Polymer dry electrode was mounted at the same location as wetL, now called dryL



➢ **The alpha waves present when subject's eyes are closed can be clearly be detected for both wet and dry electrodes.**

EEG monitoring: signal analysis



- correlation and coherence of wetLL and dryL signals are close to that of wetLL and wetL signals.
- The SNR of polymer dry electrode when eyes closed are slightly lower than wet electrode.

Conclusions (1)

- **Soft and flexible conductive polymer-based dry electrodes were fabricated.**
- **Shapes and composition optimization was done by impedance measurement and nano-indentation test.**
  - ◇ **Impedance of the polymer electrode with ~50% carbon content is 10-fold higher than conventional wet electrode.**
  - ◇ **The hardness and elastic modulus increase with increasing carbon content.**

Conclusions (2)

- **These polymer electrodes have strong potential to be good alternatives of conventional wet electrodes.**
  - ◇ **All subjects reported that these polymer-based dry electrodes are more comfortable than the conventional wet ones as well as the hard metal dry ones.**
  - ◇ **ECG and EEG signals acquired from the polymer dry electrodes are very promising.**
    - **Very high quality of ECG signal recording using polymer dry electrodes, R peaks of ECG signal can be easily detected.**
    - **In EEG signals, an active electrode configuration is used.**
      - **the correlation and coherence of wet-dry electrodes are similar to that of wet-wet electrodes.**
      - **alpha waves can be easily detected using dry electrodes, proving a high SNR**

ASPIRE
INVENT
ACHIEVE