Smart Health – CSE 40816

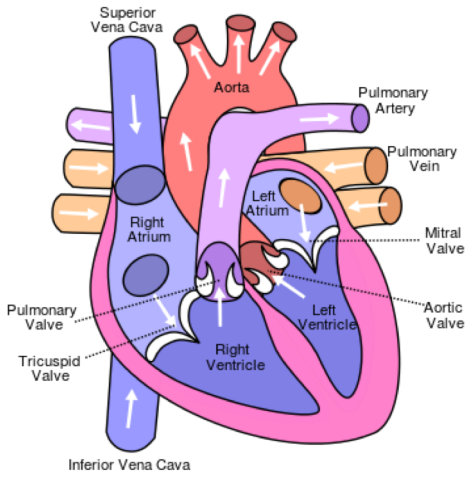
University of Notre Dame

Spring 2020

Electrocardiogram (Heart Activity)

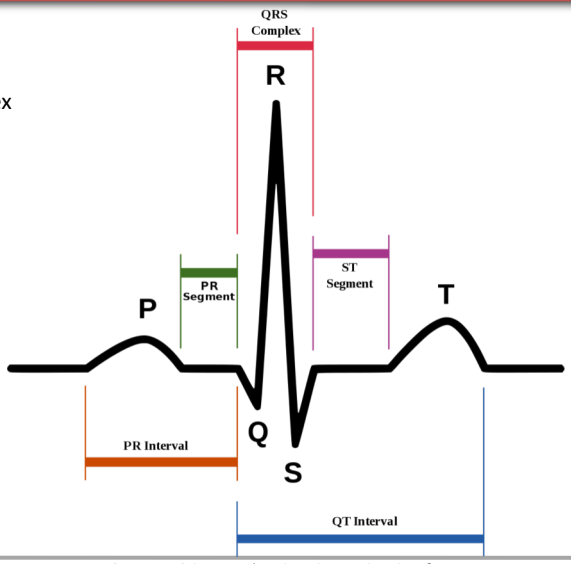
- With each heartbeat, an electrical signal spreads from the top of the heart to the bottom
- As it travels, the signal causes the heart to contract and pump blood
- The process repeats with each new heartbeat
- The heart's electrical signals set the rhythm of the heartbeat
- This can be measured by placing two electrodes at different points on the chest, and measuring the electrical activity between these electrodes

Electrocardiogram (Heart Activity)

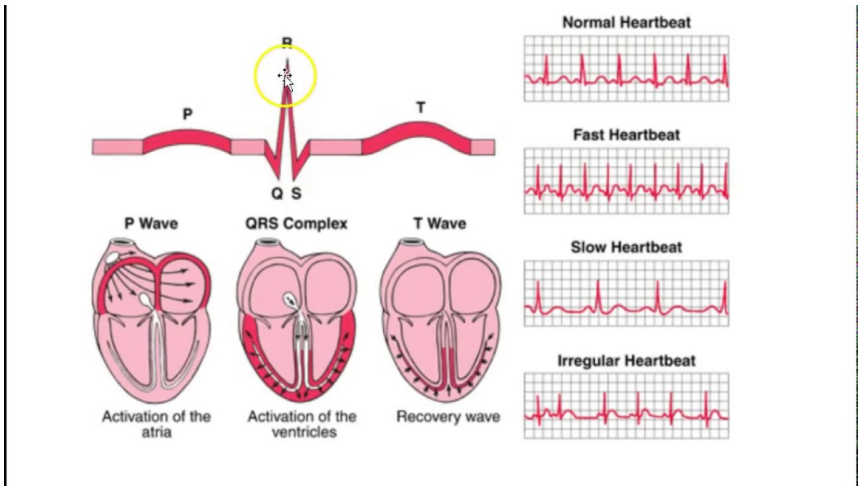


PQRST Diagram

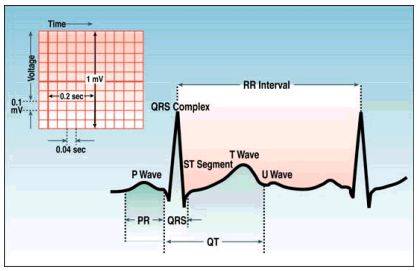
P Wave
QRS Complex
T Wave

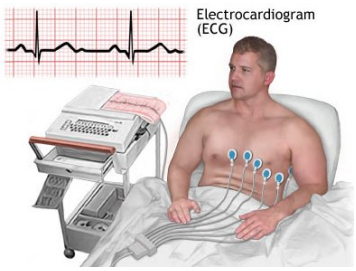


Electrocardiogram (Heart Activity)



Electrocardiogram (Heart Activity)





The P wave is associated with the contractions of the atria (the two chambers in the heart that receive blood from outside)

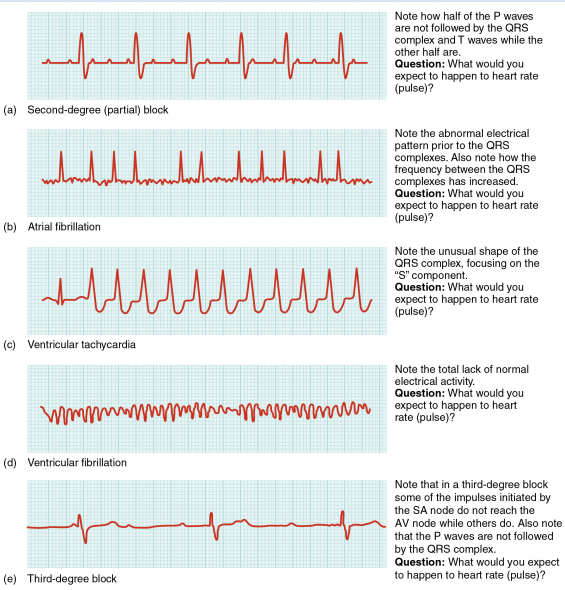
The QRS is a series of waves associated with ventricular contractions (the ventricles are the two major pumping chambers in the heart)

The T and **U waves** follow the ventricular contractions

Analysis: comparable to pedometer/step analysis discussed previously!

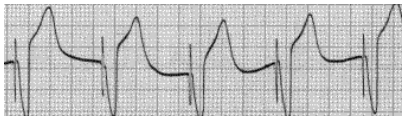
https://www.youtube.com/watch?v=gWakpOAxWAU

Use Case: ECG Abnormalities



Use Case: Implants (Pacemaker)

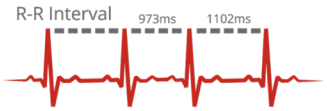
- A pacemaker is indicated when electrical impulse conduction or formation is dangerously disturbed
- ECG shows pacemaker spikes, which are vertical signals that represent the electrical activity of the pacemaker



- Different types, e.g., atrial paced rhythm or ventricular paced rhythm

Use Case: Biofeedback

- Heartrate Variability (HRV)
  - Heart rate (HR) is measured in beats per minute
  - Variation in the time interval between heartbeats
    - R-R Interval or Inter-Beat Interval (IBI)



  - Low HRV: body is under stress from exercise, psychological events, or other internal or external stressors
  - High HRV: body has a strong ability to tolerate stress or is strongly recovering from prior accumulated stress
  - **At rest: high HRV is generally favorable**
  - **When active: lower relative HRV is generally favorable**

Heartrate Variability (HRV)

- HRV is an umbrella term for many different calculations and analysis methods
- Used to measure the Autonomic Nervous System (ANS), which controls the body's stress and recovery processes
  - Blood sugar, body temperature, blood pressure, sweat, digestion, …
- More difficult to measure accurately (compared to heart rate)
- Tool for understanding overall health, resilience, and ability to tolerate stress from all sources

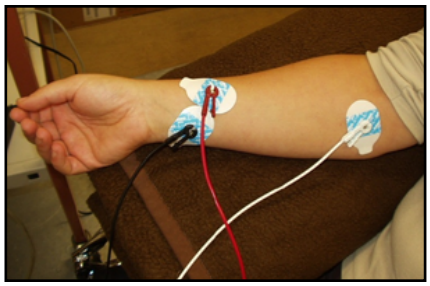
Applications

- Irregular heartbeat (known as arrhythmia)
- Blocked arteries
- Heart damage
- Heart failure
- Heart attack
- …
- Other applications:
  - Peak performance training, monitoring
  - Biometrics

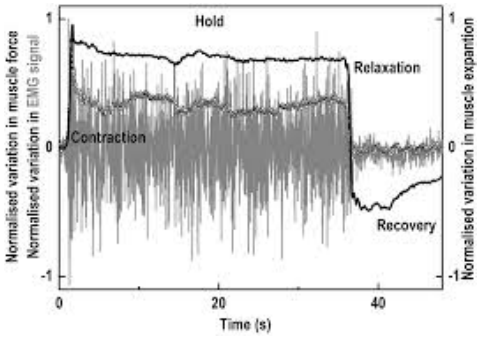
Electromyogram (EMG)

- Electrical activity of muscles
- Assesses the health of muscles and the nerve cells that control them
- Muscle weakness, muscular dystrophy, and other neuromuscular abnormalities
- Electrodes are inserted into the muscle, or placed on the skin overlying a muscle or muscle

Electromyogram (EMG)

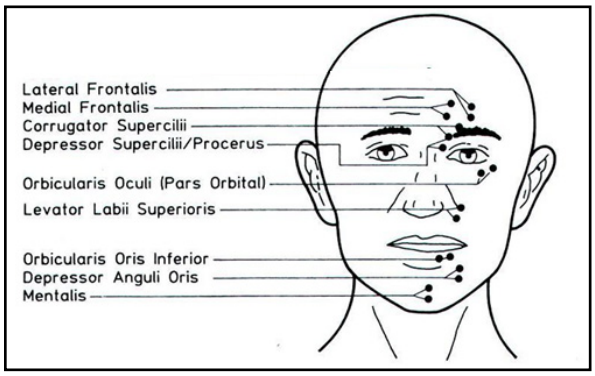


EMG surface (glue-)electrodes



EMG - signal (up to 3mV, 1kHz)

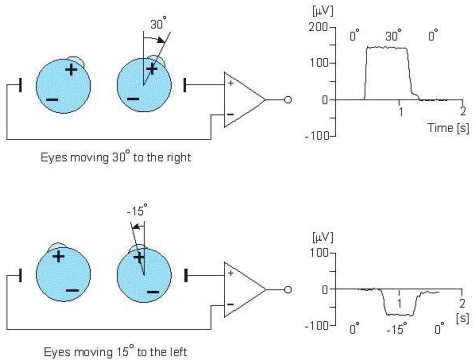
Electromyogram (EMG)

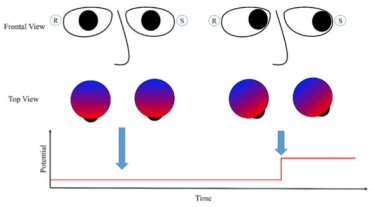


Recording locations for facial EMG

Used for emotion research

Electrooculogram (EOG)

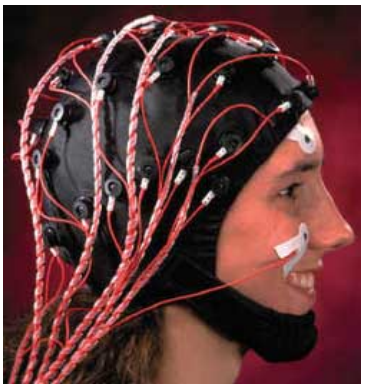




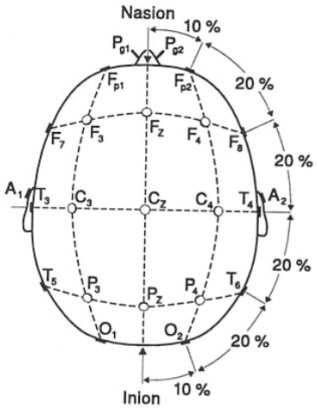
EOG Applications

- Ophthalmological diagnostics; functional analysis
- Also:
  - Human-computer interfaces
  - Robotic eye implant

Electroencephalogram (EEG)

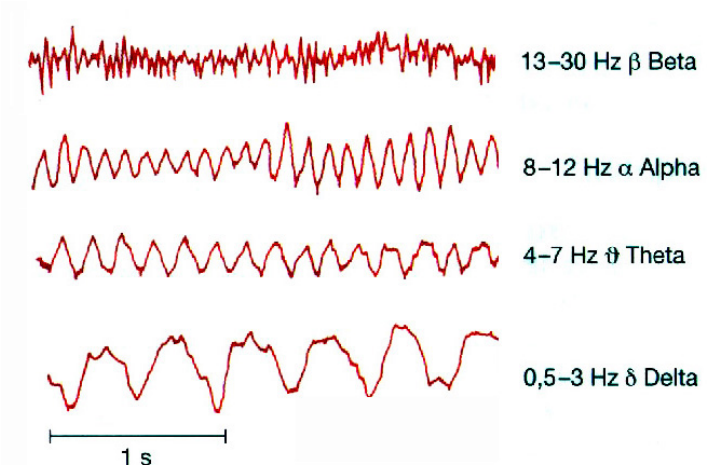


EEG electrode cap



Locations of 10/20 system

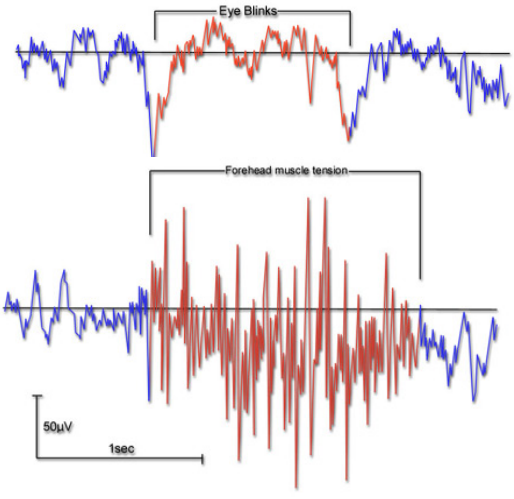
Electroencephalogram (EEG)



Electroencephalogram (EEG)

- Delta (up to 4Hz)
  - Front in adults, back in children
  - Sleep, babies, during some continuous attention tasks
  - (subcortical lesions, diffuse lesions, …)
- Theta (4-8Hz)
  - Locations not related to task at hand
  - Young children, drowsiness or arousal, idling
  - (focal subcortical lesions, deep midline disorders, …)
- Alpha (8-13Hz)
  - Posterior regions, both sides
  - Relaxed, reflecting, closing eyes, inhibition control
  - (coma)
- Beta (13-30Hz)
  - Both sides, symmetrical distribution
  - Alert/working; active, busy or anxious thinking, active concentration
  - (benzodiazepines)

Electroencephalogram (EEG)

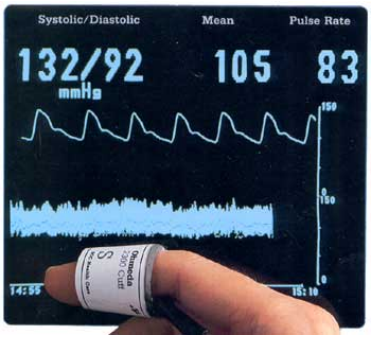


EEG artifacts: Eye blinks, muscle tension

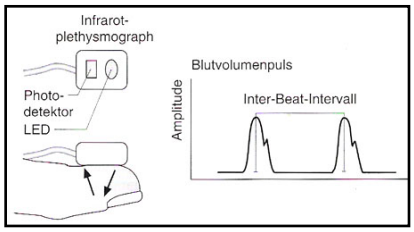
EEG Applications

- Diagnostics (epilepsy, oncology, ..)
- Cognitive sciences
- Sleep analysis
- Human computer interfaces (BCIs)
- Pharmacology
- Intensive care, monitoring

Other Biosignals

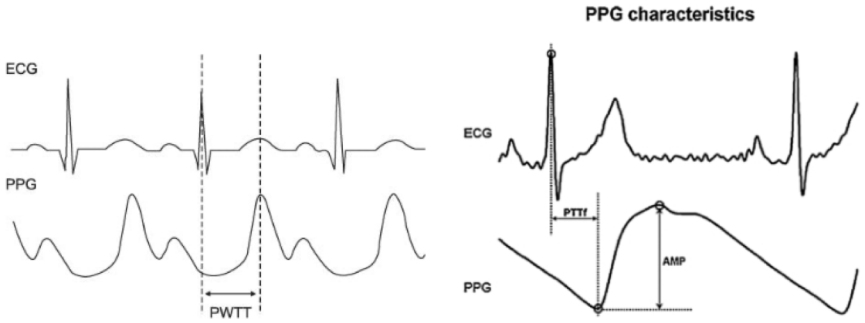


Blood volume



Infrared plethysmography

Other Biosignals

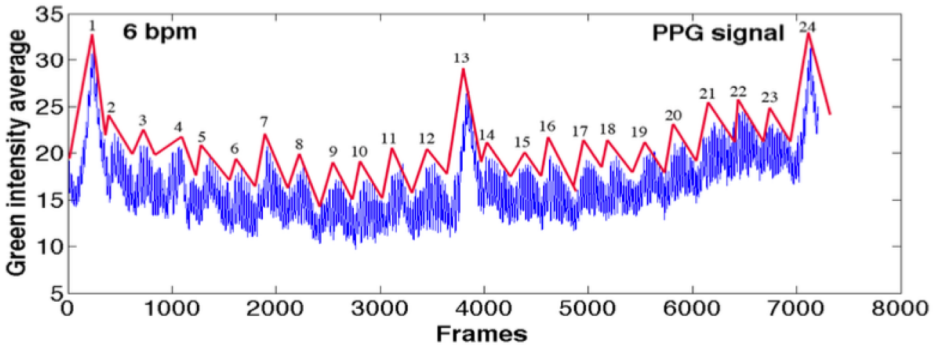


Other Biosignals

- Pulse oximeter:
  - Non-invasive technology used to measure the **heart rate (HR)** and **blood oxygen saturation (SpO_2)**
  - Project infrared and near-infrared light through blood vessels near the skin
  - Detect the amount of light absorbed by hemoglobin in the blood at two different wavelengths to help determine level of oxygen
  - Blood vessels contract and expand with the patient's pulse which affects the pattern of light absorbed over time
  - Computation of HR and SpO_2 from the light transmission waveforms can be performed using standard digital signal processing algorithms

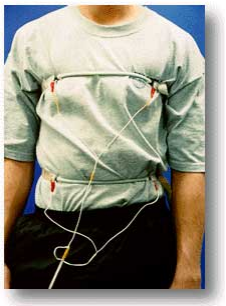
Other Biosignals

- Breathing rate
  - naturally occurring variation in heart rate that occurs during a breathing cycle

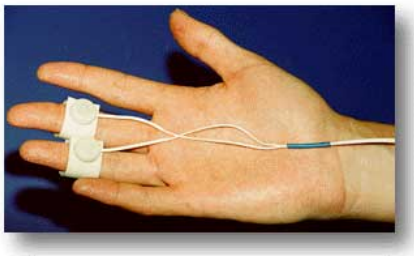


Other Biosignals

- Breathing sensors (thermal/optical/mechanoresistive)



Other Biosignals



Galvanic skin response (GSR)
Electrodermal activity (EDA)
Skin conductance level (SCL)

Peripheral body temperature

Biomedical Measurements

Biomedical measurements	Voltage range (V)	Number of users = *K* (sensors)	Bandwidth (Hz)	Sample rate (samples/s) = (Hz)	Resolution [b/sample]	Information rate [b/s]
ECG	0.5–4 m	5–9	0.01–250	1250	12	15,000
Heart sound	Extremely small	2–4	5–2000	10,000	12	120,000
Heart rate	0.5–4 m	2	0.4–5	25	24	600
EEG	2–200 μ	20	0.5–70	350	12	4200
EMG	0.1–5 m	2+	0–10,000	50,000	12	600,000
Respiratory rate	Small	1	0.1–10	50	16	800
Temperature of body	0–100 m	1+	0–1	5	16	80

Bandwidth = $f_{max} - f_{min}$
Sample rate = 5_f_{max}
Information rate = R_b = Resolution_Sample rate

S. Arnon, et al., "A Comparative Study of Wireless Communication Network Configurations for Medical Applications," IEEE Wireless Communications, pp. 56-61, February 2003