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)

P Wave
QRS Complex
T Wave

PQRST Diagram

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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

- Second-degree (partial) block
  - Note how half of the P waves are not followed by the QRS complex and T waves while the other half are.
  - Question: What would you expect to happen to heart rate (pacer)?

- Atrial fibrillation
  - Note the abnormal electrical pattern prior to the QRS complexes. Also note how the frequency between the QRS complexes has increased.
  - Question: What would you expect to happen to heart rate (pacer)?

- Ventricular tachycardia
  - Note the unusual shape of the QRS complex, pointing on the “T” component.
  - Question: What would you expect to happen to heart rate (pacer)?

- Ventricular fibrillation
  - Note that in a third-degree block, some of the impulses initiated by the SA node do not reach the AV node while others do. Also note that the P waves are not followed by the QRS complex.
  - Question: What would you expect to happen to heart rate (pacer)?

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) measured in beats per minute
  - Variation in the time interval between heartbeats
    - R-R Interval or Inter-Beat Interval (IBI)
  - Low HRV: body under stress from exercise, psychological events, or other internal or external stressors
  - High HRV: body has 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)

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)

13–30 Hz β Beta

8–12 Hz α Alpha

4–7 Hz θ Theta

0.5–3 Hz δ Delta

1 s
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

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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

- Pulse oximeter:
  - Non-invasive technology used to measure the heart rate (HR) and blood oxygen saturation (SpO₂)
  - 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 SpO₂ 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

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

Bandwidth = \( f_{\text{max}} - f_{\text{min}} \)
Sample rate = \( s_{\text{max}} \)
Information rate = \( R_b = \text{Resolution} \times \text{Sample rate} \)