ECE4081: Lab 1

Preliminary Questions

1.

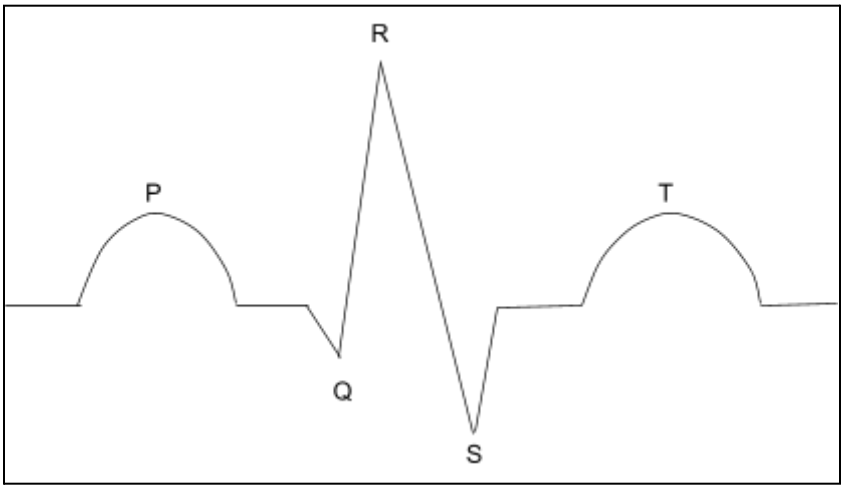

Fig 1: PQRST Wave

P wave - The first deflection is the P wave associated with right and left atrial depolarization. This causes atrial contraction [p-q section] (atrial fills with blood).

QRS complex - The QRS complex shows ventricular depolarisation. It is the electrical activity that first runs through the AV node, then through the interventricular septum, and finally through the ventricle walls.

T Wave - Shows ventricular repolarization. Before this, the s-t segment denotes ventricular contraction, i.e. blood flows out of ventricles.

2.

The three lead system is used to measure the differences between electrical potentials at different sites of the body on the frontal plane. The leads used are bipolar and are placed on the right arm, left arm and left leg (forming the einthoven's triangle).

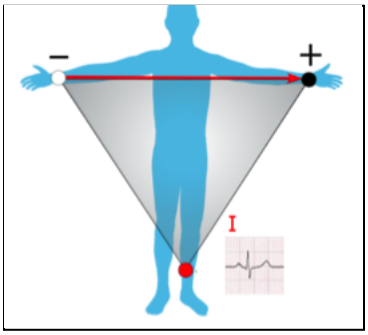

Fig 2. Einthoven's triangle [1]

It can be seen from the image below that each channel reads a slightly different PQRST complexes.That is, depending on the voltage read between two of the electrodes, the depolarisation and repolarisation electric vectors are seen from different views (some specific artifacts of the complex are more amplified from a certain view). Therefore looking at the same signal from different views gives us a better overall understanding of the complex.

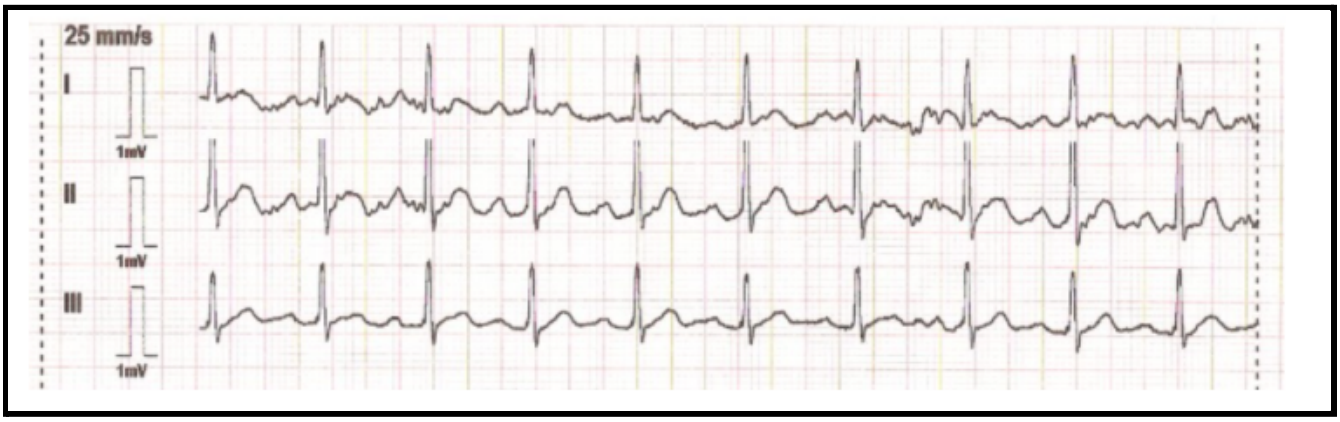

Fig 3. 3-Lead ECG from different reference points [2]

a) We use the direction of electrical flow across the cardiac tissue, referenced to the apex (Right to Left, lead 1) to get a clearer upright QRS complex (Specifically the P wave). This is because the direction of depolarization (electric vector) heads towards the positive electrode, which leads to the largest deviation in voltage magnitude [3, 4].

b) To view an electrical signal, we need to zero reference it to some known voltage to measure a potential difference.

3.

An **RCD**, or residual current device, is a life-saving device which is designed to prevent you from getting a fatal electric shock.

RCDs operate by measuring the current balance between two conductors using a differential current transformer. This measures the difference between current flowing through the live conductor and that returning through the neutral conductor.

Therefore, if there is a faulty medical device, which is not grounded correctly, that comes in contact with a lower resistance path to ground (victim of electrocution), it can trip the power supplied to the room which can reduce risks significantly.

Data Collection and Recording

ECG

1. **Take a screenshot and identify the PQRST waveforms. What would happen if the two electrode leads were swapped?**

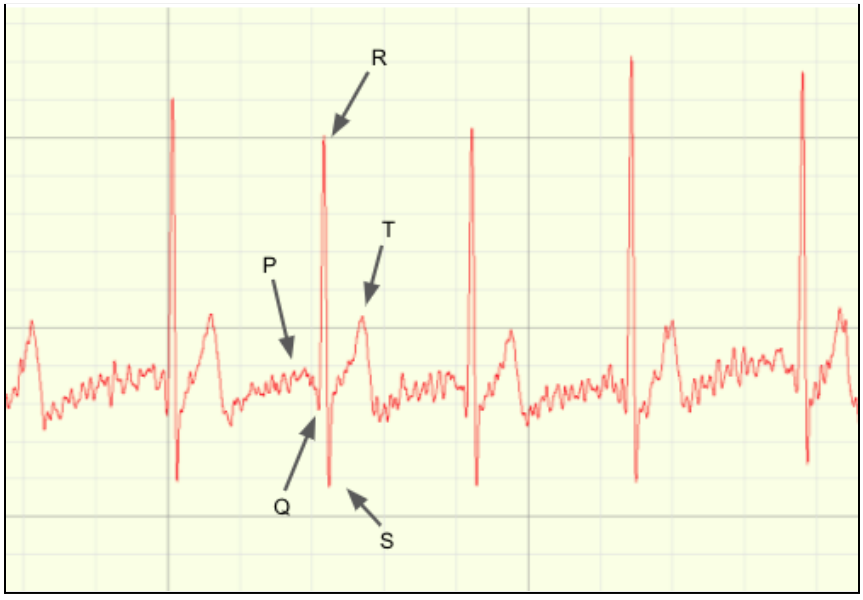

Fig 4. ECG sample

If the electrodes are swapped, the signal would be flipped, as shown in figure 5.

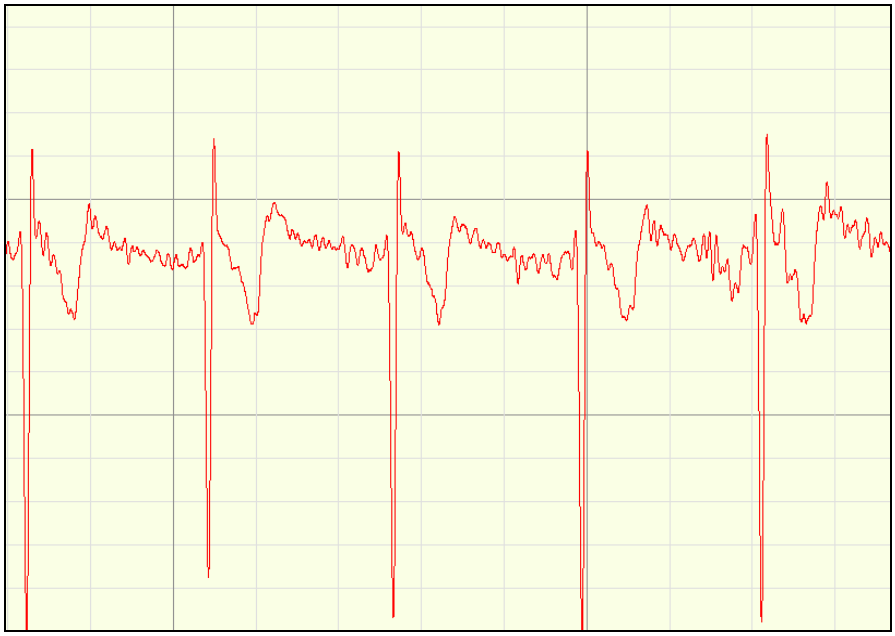

Fig 5. Flipped ECG signal sample

2. **Turn off the 35-Hz LPN filter and take another recording. Observe what happens to the signal. Explain why.**

   Turning off the 35-Hz low pass filter allows all the 50-Hz noise generated by the power source to appear at the signal. In the case of this lab we used an isolation transformer as the pseudo power source.

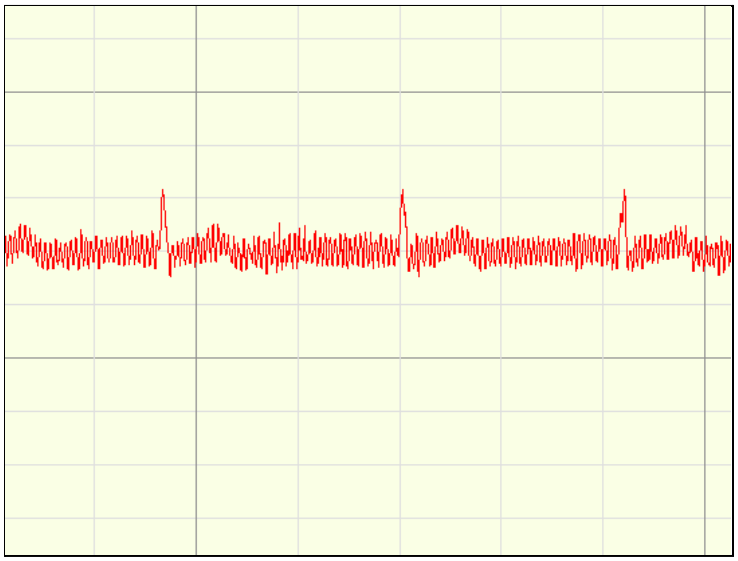

Fig 6. 35-Hz LPF turned off

3. **Turn the 35-Hz LPN filter back on. Now turn off the HP filter and take another recording. Observe what happens to the signal. Why?**

   The HP filter removes the slow oscillation frequencies introduced into the signal due to respiration. So, Turning it off introduces a low frequency component that causes the whole ECG signal to slow oscillations.

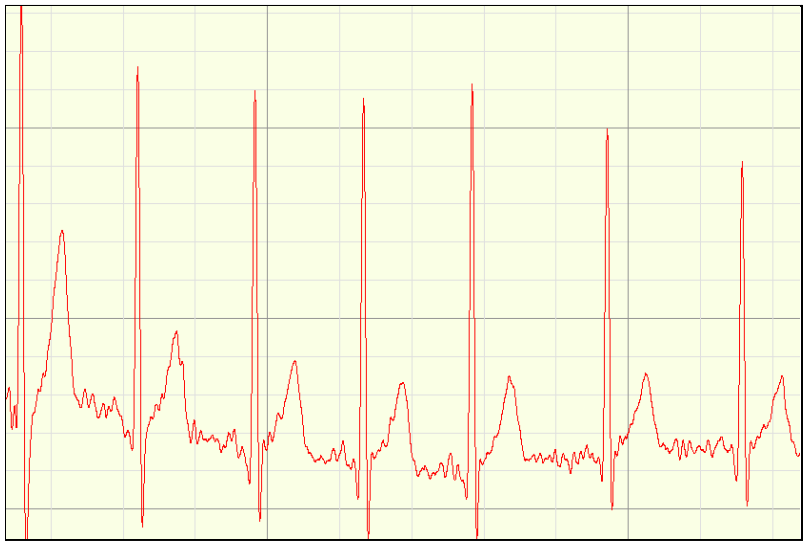

Fig 7. HP filter turned off

4. **Disconnect the shield to one of the shielded electrodes. What happens?**

   Disconnecting the shield on one of the electrodes introduces the surrounding electromagnetic interference into the ECG signal.

Fig 8. One shield disconnected

5. **Disconnect the shield to the other electrode so that both shields are now disconnected. What happens?**

   Disconnecting both shields ignores most of the EM interference. Probably due to the differential instrumentation amplifier in the monitors circuitry that rejects the common EM disturbance.

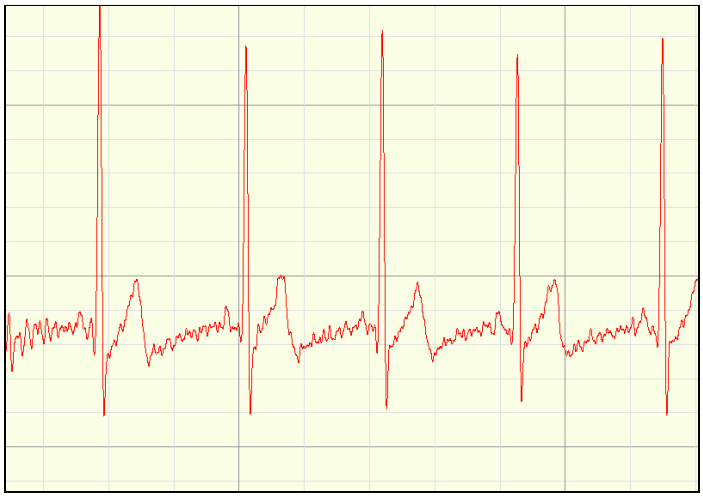

Fig 9. Both shields disconnected

6. **Remove the gel from the electrode surfaces and take another recording. What happens?**

   Removing the gel from the electrode surfaces didn't cause much change when stationary. But, slight movements caused erroneous readings due to the conducting path between the skin and electrode not being consistent.

Fig 10. Removed gel from electrode surface

7. **Use the Data Acquisition button to collect both ECG and R-R interval data for a 5 minute time interval. Is this what you would expect to see and why?**

   The R-R interval is the time difference between two R peaks in an ECG PQRST complex. The reading provided is what we expected, this is because it was constant for the most part, but as the heart rate increased the R-R interval decreased and vice-versa.

SpO2

1. **Observe the SpO2 waveform. How does it compare to the ECG waveform? What are the differences? Why is it different?**

   The SpO2 waveform measures the concentration of oxygen under the tissue being measured. This concentration of oxygen is related to the amount of hemoglobin in the blood (oxygenated blood) being pumped by the heart to that tissue. Therefore, this signal has nothing to do with the electric vectors measured during an ECG.

Fig 11. SpO2 waveform.

   This distinction makes it clear that there would be no PQRST complex in an SpO2 waveform, but just the amount of oxygen over time. Hence, the signal is a lot smoother and has distinct peaks.

2. **Manually calculate the interval between the peaks of SpO2 waveform. What can you do to make this measurement more accurate?**

   In figure 3, there are almost 4 peaks in the 3 second interval. Therefore, there are 1.33 peaks per second. Which calculates to about 80 bpm.

Discussion Questions

1. **Import the ECG data into MATLAB by loading the appropriate .mat file from Recording Instructions step 15. Plot an example segment of the ECG waveform (20 seconds).**

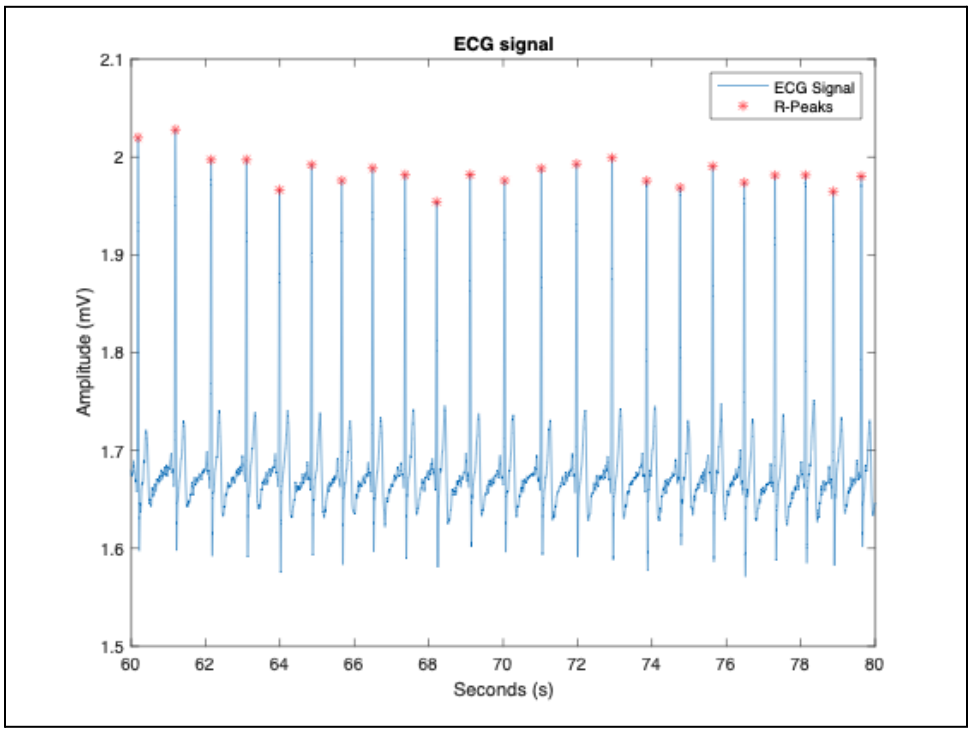

Fig 12. ECG sample from 60-80 seconds (20s)

```
load ECG_Graph2.mat
data = data(:, 1);      % use only 5 minute data

%% ECG signal sample
Fs = 2*10^3;

%ECG signal specification
seg_start = 100000; % random sample start
ECG_signal = data(seg_start:seg_start+(20*Fs)-1); % 22 sec ECG signal taken
                                                  % due to padding issue
% time specification
time = 0:1/Fs:length(ECG_signal)/Fs-1/Fs;
```

2. **Plot the average heart-rate using the 5 second moving average of the R-R interval in a 20 sec sample. Also plot the heart-rate over the whole sample data.**

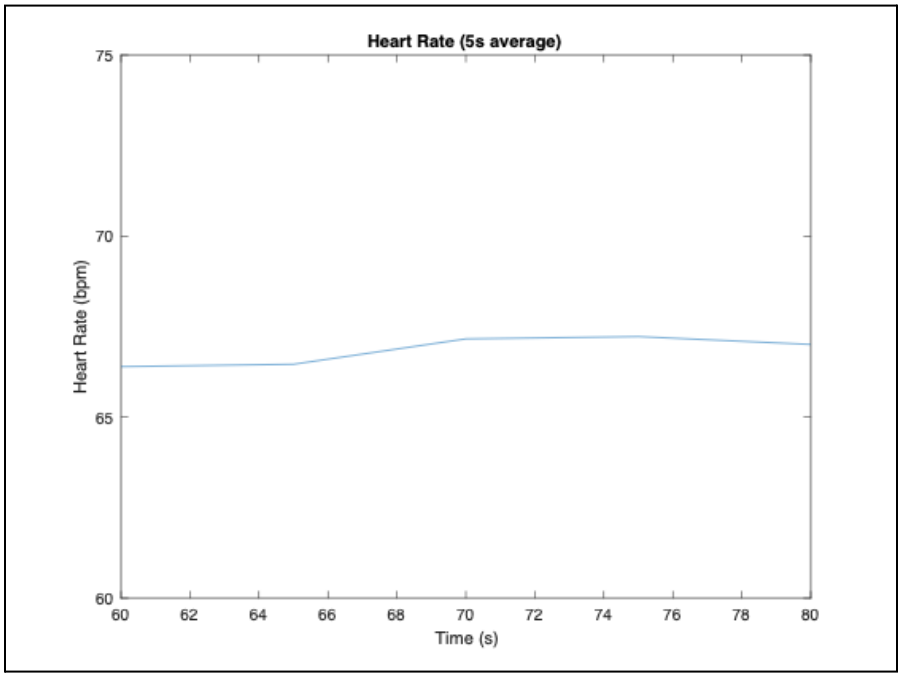

Fig 13. Heart-rate data (20 s)

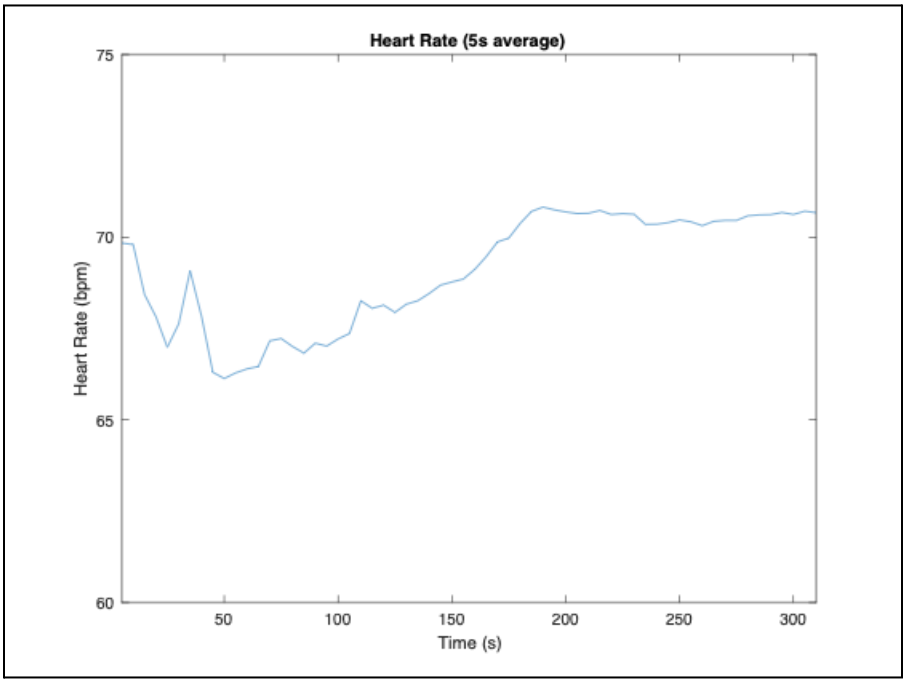

Fig 14. Heart-rate data (5 min)

```
%% R-R interval extraction
avg_RR_intervals = ones(1, 20); % 20 sec

% pad signal to avoid moving average edge case
ECG_signal_filtered = [ECG_signal_filtered' zeros(1, Fs*5)];
time                = [time zeros(1, Fs*5)];

for i = 1:Fs:(220*Fs + Fs)
    ECG_section = ECG_signal_filtered(i:i+5*Fs-1);    % 1 sec -> 5 sec avg
    time_section = time(i:i+5*Fs-1);
    R_peaks    = islocalmax(ECG_section) & (ECG_section > 1.9);
    peak_times = time_section(R_peaks);

    if i == 1
        avg_RR_intervals(i) = mean(diff(peak_times));
    else
        avg_RR_intervals(((i-1)/Fs) + 1) = mean(diff(peak_times));
    end
end

figure;
avg_hr = (1./avg_RR_intervals).* 60; % BPM
plot(avg_hr)
xlabel("Seconds (s)")
ylabel("Heart Rate (bpm)")
title("Heart Rate")
xlim([60, 80])
ylim([65, 75])
```

3. Plot the R-R interval of the entire dataset.

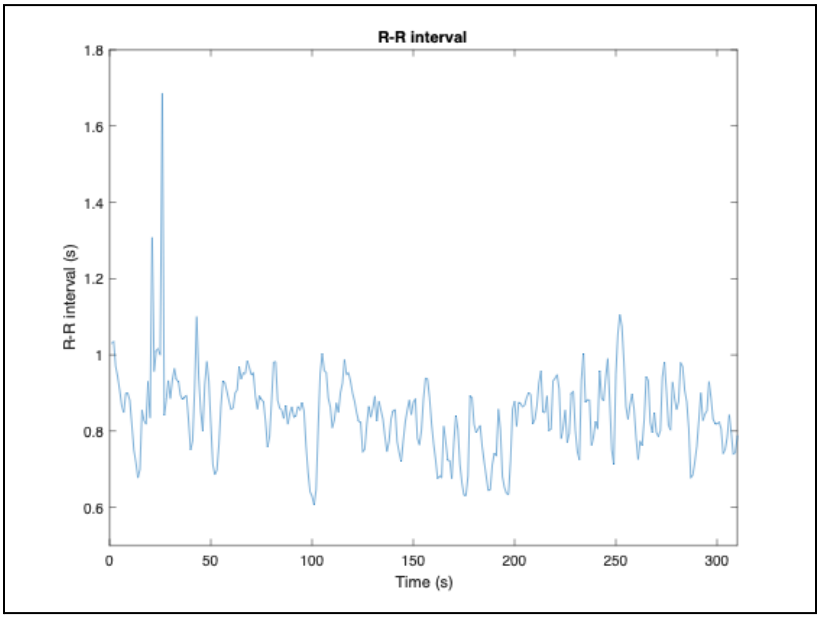

Fig 15. R-R interval of the whole dataset

4. **Plot the frequency power spectrum.**

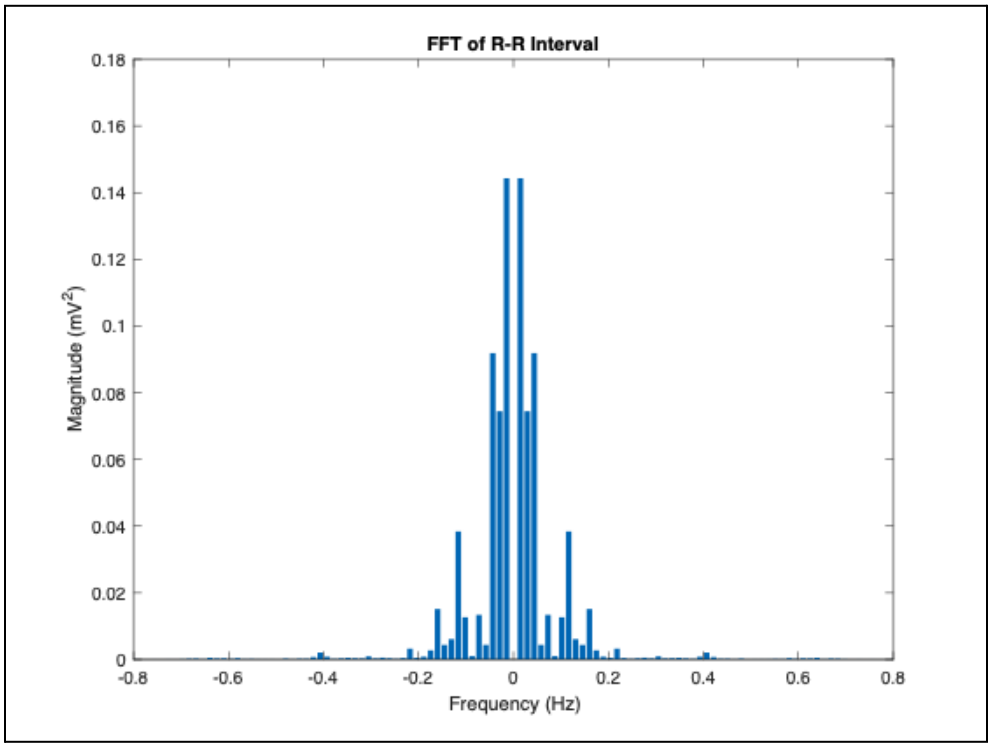

Fig 16. Frequency Spectrum of the R-R interval

```
%% FFT of R-R intervals

% remove large signal offset
rr_signal = avg_rr_interval - mean(avg_rr_interval);

% FFT variables
n = length(rr_signal);
fshift = (-n/2:n/2-1)*(5/n);

% do an FFT and shift frequencies
fft_rr = fftshift(fft(rr_signal));
p = abs(fft_rr).^2 * (1/n); % mV^2

figure;
bar(fshift, p)
ylim([0, 0.18])
xlim([-0.8, 0.8])
xlabel("Frequency (Hz)")
ylabel("Magnitude (mV^2)")
title("FFT of R-R Interval")
```

5. **Is there any interference from the mains in the frequency plot? Describe what typical interference looks like.**

   There is no mains interference in the frequency plot as this is not the ECG frequency spectrum, but the DTFT of the R-R intervals. Also, even if the ECG's DTFT was plotted, we won't see any mains interference as we used an analog 35-Hz low pass filter when collecting the data.

6. **List three sources of noise that interfere with ECG recording.**

   The three sources of noise are:

   (a) 50 Hz mains interference
   (b) High frequency electromagnetic interference.
   (c) Action potentials generated for respiration.

7. **What would happen if you used a simple ECG lead with only 2 electrodes to record? Where would you place those electrodes?**

   If there are only two electrodes, we'll place them on either wrist. The only difference would be the wrong normalized voltage readings as we don't have a reference, which is fine if we only care about the heart rate (peaks).

8. **Plot the R-R interval spectrum and find the peak frequency in the below bands of R-R interval spectrum.**

   The frequency power spectrum is plotted in figure 6 above.

Measurement	Frequency at which max occurs
Very Low Frequency (0 to 0.04Hz)	0.01Hz
Low-Frequency (0.04 to 0.15Hz)	0.11 Hz
High-Frequency (0.15 TO 0.4Hz)	0.159 Hz

9. **Repeat from step 12 for a second subject.**

Measurement	Frequency at which max occurs
Very Low Frequency (0 to 0.04Hz)	0.013Hz
Low-Frequency (0.04 to 0.15Hz)	0.2 Hz
High-Frequency (0.15 TO 0.4Hz)	0.13 Hz

10. **Spectral analysis of heart rate variability can be a useful tool for diagnosing different heart conditions. What physiological events do the peaks in the different frequency bands reflect?**

    Very Low - Indicates use of the renin-angiotensin system [6, 8]

    Low Frequency - indicates anxiety and panic, and/or coronary heart disease [8]

    High Frequency - indicates resilience from stress. [7]

11. **List three factors that may account for any variation between subjects?**

    The following factors may account for variation between subjects:

    (a) Physical attributes (height, weight, etc)
    (b) Exercise prior to measurement
    (c) Caffeine and/or smoking prior

12. What would the ECG look like for various irregular heartbeat conditions such as arrhythmia? Describe two.

There are two kinds of arrhythmia, Bradycardia and Tachycardia. In bradycardia, The heart rate is slow (under 60 bpm). It can indicate a heart abnormality like heart block and sick sinus syndrome. On the other hand, when someone has tachycardia, the heart rate is fast (over 100 bpm). These show Atrial fibrillation, frill, and Wolff-Parkinson-White syndrome. [5]

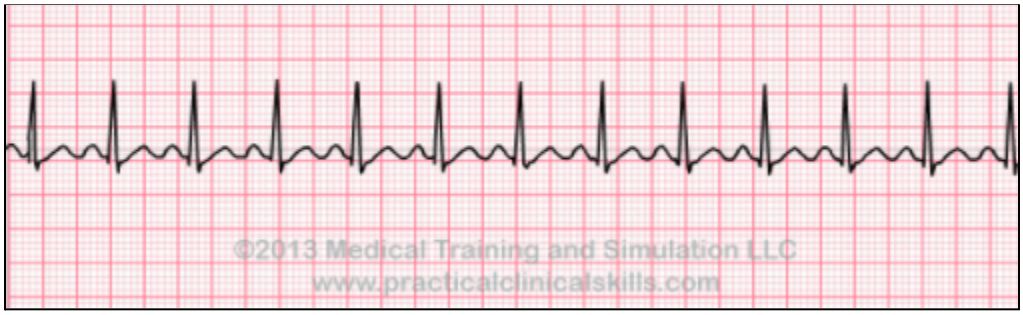

Fig 17: Tachycardia [5]

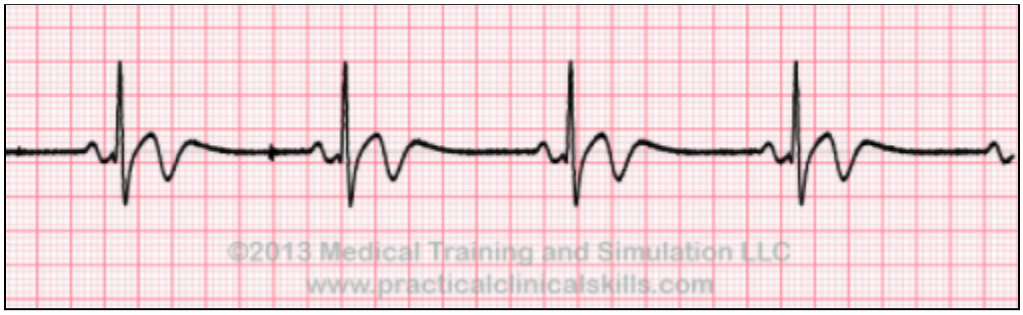

Fig 17: Bradycardia [5]

13. Describe the difference between how ECG and a SpO2 monitor measure heart rate. Focus on the sensors and physiological measurements that are being made.

An SpO2 monitor uses pulse oximetry to measure blood oxygen saturation with the use of a photo optic sensors placed on the fingertips of the patient. More specifically, this sensor measures the percentage of hemoglobin in the blood being pumped to that tissue over time (see figure 11).

An ECG on the other hand uses electrodes placed on the body to measure the depolarisation and repolarisation of the heart, due to action potentials, as a voltage.

Therefore, SpO2 monitor measures heart rate using the time intervals between the peak times of when there is maximum oxygen in the tissue, and an ECG monitor measures heart rate using the time intervals between the peak times of the electric vectors (PQRST waves).

14. **Describe a situation in which you might elect to use an SpO2 monitor to measure heart-rate.**

    In a commercial situation (eg: a wearable fitness device) when ease of use and cost are the parameters of interest, using a SpO2 sensor is preferred.

    In a medical situation, it might be easier to use an SpO2 monitor when it's an operation/surgical scenario or when quick and easy readings are required.

15. **List two advantages of SpO2 over ECG. List two disadvantages**.

    Advantages of SpO2 over ECG:

    (a) Cost: SpO2 monitors are usually cheaper than ECG monitors.
    (b) Safety from electrocution: As we are using pulse optometry (no electrical path through the body) and not electricity to measure HR as done in ECG.

    Disadvantages of SpO2 over ECG:

    (a) Accuracy: ECG monitors are highly accurate, whereas SpO2 monitors just estimate HR using tissue hemoglobin concentration.
    (b) Heart condition detection: We can't use an SpO2 monitor to diagnose heart conditions like arrhythmia and fibrillation precisely.

Note: click here for full code

References

[1] Y. Wong, *Sensors_basics*. .

[2]"Lead systems – how an ECG works | CardioSecur", *Cardiosecur.com*, 2021. [Online]. Available: https://www.cardiosecur.com/magazine/specialist-articles-on-the-heart/lead-systems-how-an-ecg-works. [Accessed: 26- Mar- 2021].

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[7]"Heart Rate Variability vs. Heart Rate - Elite HRV", *Elite HRV*, 2021. [Online]. Available: https://elitehrv.com/heart-rate-variability-vs-heart-rate. [Accessed: 26- Mar- 2021].

[8] Alexander Gersten, Ori Gersten, Adi Ronen and Yair Cassuto (March 23rd 2019). The RR Interval Spectrum, the ECG Signal, and Aliasing, Fourier Transforms - Century of Digitalization and Increasing Expectations, Goran S. Nikoli? and Dragana Z. Markovi?-Nikoli?, IntechOpen, DOI: 10.5772/intechopen.85327. Available from: https://www.intechopen.com/books/fourier-transforms-century-of-digitalization-and-increasing-expectations/the-rr-interval-spectrum-the-ecg-signal-and-aliasing