BITalino (r)evolution ~~Lab~~ Home Guide

EXPERIMENTAL GUIDES TO MEET & LEARN YOUR BIOSIGNALS

ATTENTION

The present document includes experimental protocols to be shared with customers who have PLUX products.
This document should not be distributed through alternative routes unless the customer chose to acquire our biosignals acquisition systems.

The information contained in this manual has been carefully checked and were made every effort to ensure its quality. PLUX reserves the right to make changes and improvements to this manual, especially during the initial phases of the creation of this document.

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OD.LB.03.04 | OD.LB.03.04 - BITalino_HomeGuide | M. Proença, K. Mrotzeck | 15/02/2021

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HOME-GUIDE #2

ELECTROCARDIOGRAPHY (ECG)

Exploring Cardiac Signals at the Skin Surface

1. GOALS

At the end of this lesson you will understand the physiological processes underlying heart functioning, how to properly analyze the electrocardiographic signal, how to use BITalino (r)evolution to acquire ECG signals and finally how the positioning of the sensors can affect the acquired signals

In this Home-Guide you will explore the ECG signals in detail. The main goals of this lesson will be the following:

- Perform a set of ECG acquisitions in real-time.
- Test different electrode positions and explore various derivations specific of ECG.
- Understand the physiological changes that originate the ECG signal.

2. REVIEW HOME-GUIDE #1

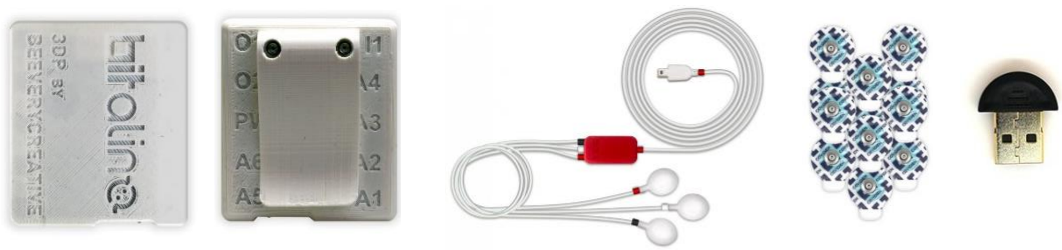
All information of Home-Guide #1 can be found here: HOMEGUIDE#1

In the Home-Guide #1 we can find a thorough introduction to specific biosignals, namely, the EMG, which corresponds to the electrical signal that is produced by the muscles both at rest (muscular tonus) and during activity. Moreover, different electrode positions provided with information regarding multiple muscular groups and the general procedure of how to place electrodes and the usage of the BITalino (r)evolution system was demonstrated, allowing for real-time acquisitions. In this Home-Guide, we will use similar procedures regarding how to place the electrodes, how their position influences the acquired signal and how to reduce noise sources that may be very common and hindering on ECG data acquisition.

3. MATERIALS

OpenSingals (r)evolution software is available on: https://bitalino.com/en/software

- OpenSignals (r)evolution software
- 1 x BITalino (r)evolution Assembled Core BT
- 1 x Assembled Electrocardiography (ECG) Sensor
- 3 x Gelled Self-adhesive Disposable $Ag/AgCl^-$ Electrodes
- 1 x Bluetooth dongle



(a) (b) (c) (d) (e)

Figure 1: BITalino (r)evolution Assembled Core BT - Front View (a) and Back View (b); Assembled Electrocardiography (ECG) Sensor (c); Gelled Self-adhesive Disposable Ag/AgCl electrodes (d) and Bluetooth dongle (e).

**for each experiment you must use 3 gelled electrodes for the ECG sensor. Each time you want to repeat your experiment, or each time you see the electrodes are not in a good condition it is recommended to change them for new ones. Also make sure that you clean the skin area with alcohol before adjusting the electrodes to remove skin particles and improve the skin conductivity.*

4. RELATED DOCUMENTATION

BITalino (r)evolution Quick Start Guide

BITalino Assembled Core BT Datasheet

Assembled Electrocardiography (ECG) Datasheet

5. INTRODUCTION TO ELECTROCARDIOGRAPHY (ECG)

5.1. ECG Basics

The heart is composed of various tissues, among which the cardiac muscle, which can produce electrical signals that are detectable at the skin surface using an ECG sensor.

5.1.1. How does the Heart work? A Physiological Overview

The heart pumps the oxygen-rich blood from the left atrium to the left ventricle to the aorta into the body. The oxygen-poor blood is pumped from the right atrium to the right ventricle to the lungs. Regular and repetitive myocardial contractions, which result from action potentials (AP), as well as the spread of these are the source of the heart to function as an efficient pump. The sinoatrial (**SA node**) is responsible for the initiation of electrical activity, which is located on the posterior right atrium, see Figure 2 and is also known as the pacemaker of the heart. After initiation of an AP, it spreads to the atrioventricular (**AV node**) via both atria. The AV node delays the spread of AP to the ventricles due to its slow conduction. From the AV node the action potentials reach the **left and right bundle branches** and the **Purkinje fibers**. The spread of APs through the Purkinje fibers is very fast enabling the activation of ventricular cells simultaneously and hence an effective pumping of blood out of the ventricles. The speed of spread as well as size of APs is dependent on the type of channels and its speed of opening and closing.[1] [2]

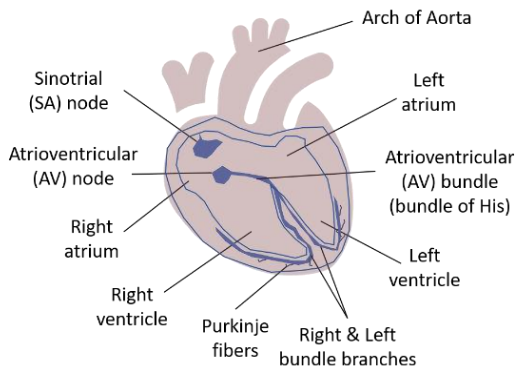


Figure 2: Cardiac cycle: Heart areas.

The cardiac cycle includes a **diastole** which is the refilling of the heart chambers with blood and the **systole** which is the contraction and emptying of the heart chambers from blood. The excitation of a heart muscle cell during the cardiac cycle leads to a dipole because the cell becomes more positive compared to neighboring cells which leads to the generation of an electric vector. Through the spread of the excitation to the neighboring cells, a sum vector generates. During the spread as well as the regression of excitation, the shifts of the charges can be measured from the skin surface [3]. Each part of the heart has a different timing for the excitation and spread of it which effects the components of the ECG signal.

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[1] *Rhoades, Rodney A., and David R. Bell, eds. Medical phisiology: Principles for clinical medicine. Lippincott Williams & Wilkins, 2012.*

[2] *https://openstax.org/books/anatomy-and-physiology/pages/19-2-cardiac-muscle-and-electrical-activity, 26/10/2020*

[3] *Georg Thieme Verlag, https://viamedici.thieme.de/lernmodul/541063/subject/physiologie/herz/elektrophysiologie+des+herzens/ekg+physikalische+grundlagen*

5.1.2. How to acquire an ECG?

Figure 3 illustrates each step of the cardiac cycle that leads to a new component of the ECG signal. In this case, the signal is measured between the two points B and A. The first component is the **P**-wave which represents the contraction and spread of excitation (blue) of the atria (depolarization), see Figure 3 (1). The **PQ**-interval is the spread of excitation from the atria to the ventricle, see Figure 3 (2). During the **QRS** complex, the ventricle contracts and spreads the excitation, see Figure 3 (3) In the **ST**-interval, the ventricle is fully excited, see Figure 3(4), and the excitation begins to regress, see Figure 3 (5). The **T**-wave represents the regression in the ventricle, see Figure 3 (5) and the **TP**-complex the unexcited atria and ventricle, see Figure 3 (6).[1 4]

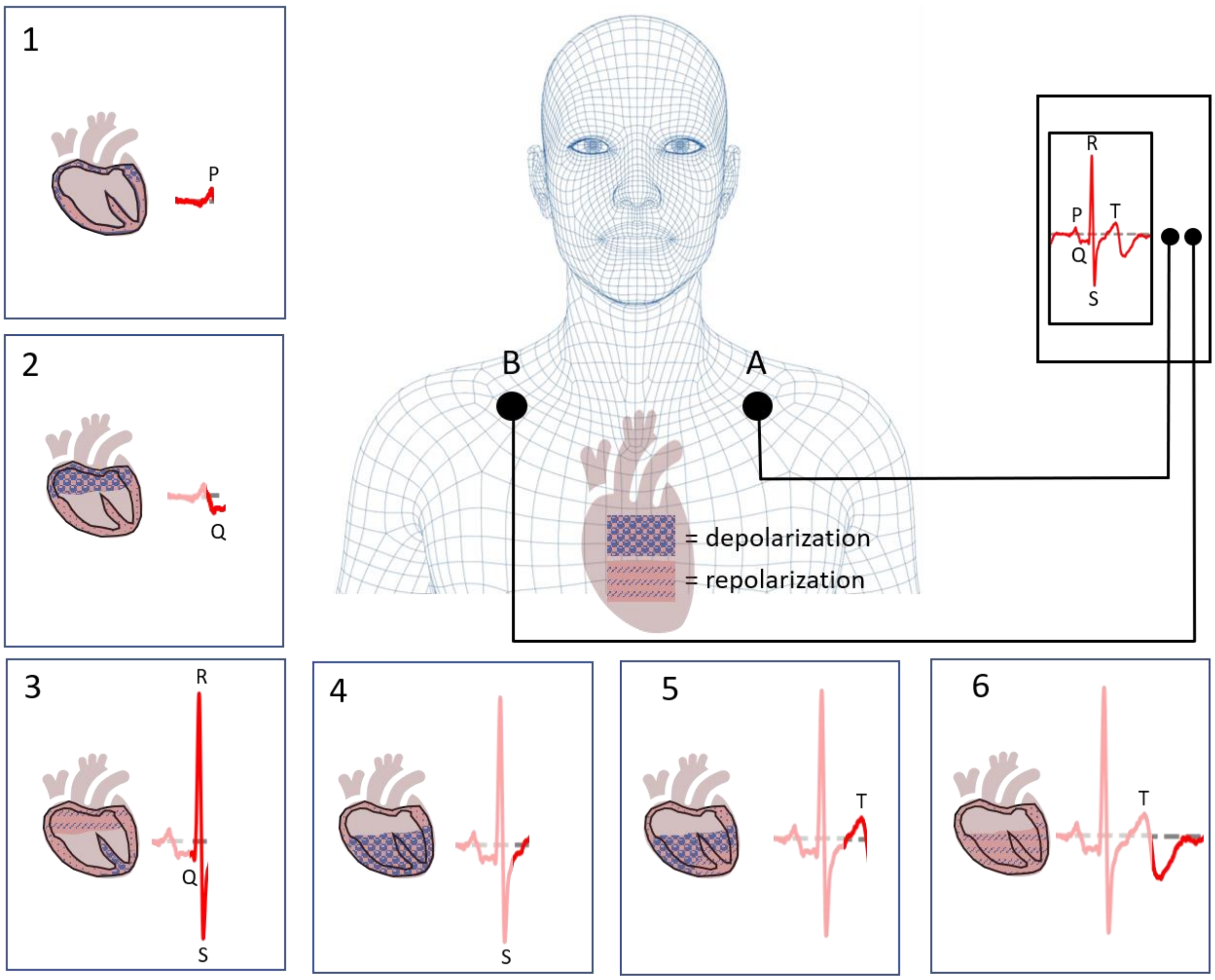

Figure 3: Heart physiology: Cardiac Cycle and signal generation of ECG.

Let's have a closer look at the dipole direction and its influence on the ECG signal, see Figure 4. The signal is measured from the negative electrode (B) to the positive electrode (A). The dipole from the left to the right represents the ECG

[4] *Georg Thieme Verlag, https://viamedici.thieme.de/lernmodul/541065/subject/physiologie/herz/elektrophysiologie+des+herzens/ekg+verlauf+der+ekg-kurve+und+vektorschleife*

component of the QRS complex as it is very high amplitude and positive. The size of amplitude depends on the angle of direction whereas the direction of amplitude (positive or negative) depends on the direction of the dipole.

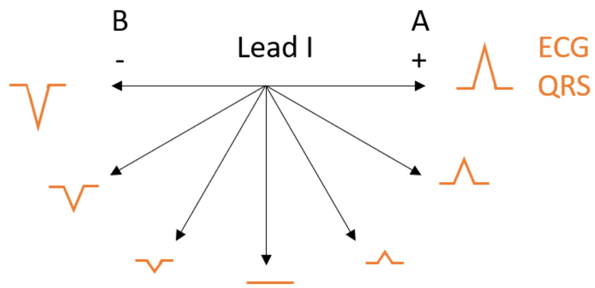

Figure 4: Influence of dipole direction on the ECG signal for bipolar lead I.

The standard measurement technique of the ECG is the application of 12-leads to cover all information of the heart in three directions. The first three leads are the bipolar leads according to Einthoven, which represent the frontal plane with both arms (right arm = RA, left arm = LA) and left leg (LL). The augmented unipolar limb leads (aVR, aVL, and aVF) also represent the frontal plane and the unipolar chest leads (V1-V6) represent the horizontal plane with electrodes positioned in six locations on the chest.

We will have a closer look at the Einthoven leads I-III, see Figure 5. The first lead (**I**) is the measurement from RA (-) to LA (+), as our example above. The second lead (**II**) measures from RA (-) to LL (+) and the third lead (**III**) measures from LA (-) to LL (+).

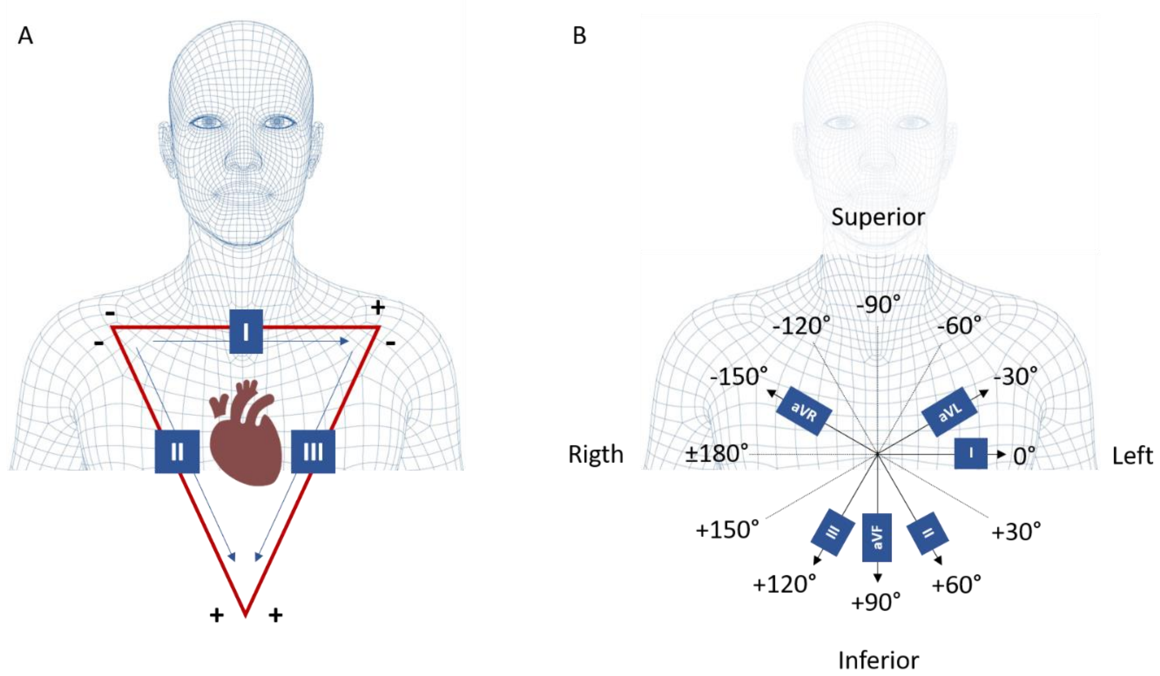

Figure 5: Einthoven Leads I-III (A) and angles (B).

5.1.3. How to acquire an ECG with BITalino?

Now that we know the technique of ECG measurement let's have a look on how to apply the electrodes. As we already know from Home-Guide #1, what to consider before placing the electrodes on the skin, we only need to find out the exact locations. Figure 6 illustrates three different electrode locations to measure the ECG signal for leads I-III. As you can see, the electrodes can be placed on both wrists and the left ankle (left), on both clavicles and the left iliac crest or all on the chest (right). These electrode locations can now be used for each of the three leads.

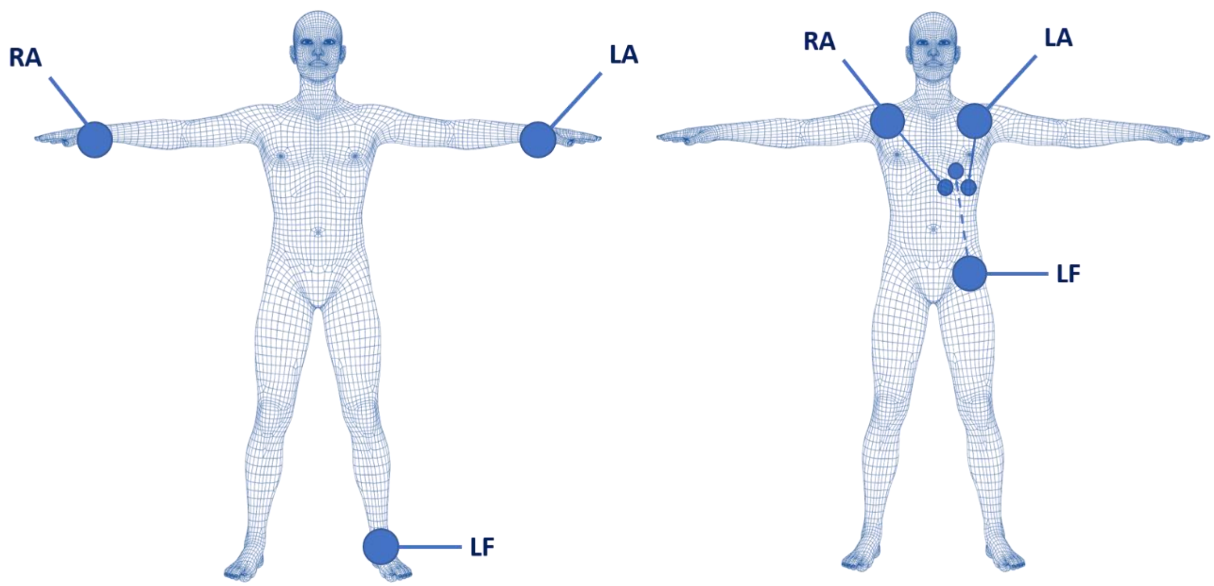

Figure 6: Electrode positioning for lead I: wrists and ankle (left), clavicles and iliac crest or chest (right).

Let's have a look at your assembled BITalino ECG from the inside, see Figure 7. Other than the EMG that we have been using in Home-Guide #1, the ECG has both measuring electrode cables (IN +/-) plus the reference (REF) cable connected. The two measuring and the reference cable can now be connected to the pre-gelled electrodes and placed on the lead positions.

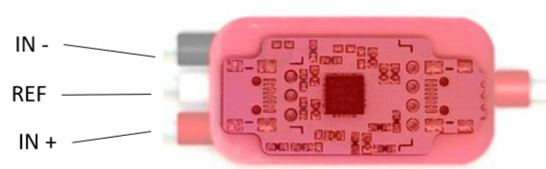

Figure 7: Assembled ECG sensor from the inside.

IMPORTANT NOTES:

- ✓ In the case of ECG recording we want to place the electrodes in regions of low muscular activity (bones) to reduce the noise of muscular activations (movement artefacts).

5.2. Applications – What is ECG used for?

Now that we know how an ECG works, let´s have a look at some applications in which the ECG is used. For medical applications, the ECG signal plays a major role in detecting abnormalities such as an ST elevation when the signal does not return to the baseline after the QRS complex. This information gives us insight to the occurrence of restrictions in the cardiac tissues blood oxygen supply which can lead to a myocardial infarction (heart attack).

The heart rate variability (HRV) can give us insights about the overall cardiac health in which a high variability is positive. The HRV can be measured by checking a series of time intervals in between R peaks. Using the R peaks, the heart rate can be measured in beats per minute (bpm).

Did you know?

- *Additionally to heart parameters such as heart rate and heart rate variability, other body parameters can be extracted from the ECG signal as well such as the* ***respiration rate.***
- *The* ***respiration rate*** *can be detected by examination of R-Peak amplitudes because the movement of the thorax changes the distance between the electrodes on the skin surface and the heart.*

In some applications, ECG sensors are not applied on the skin surface but instead integrated on objects that we are using throughout the day such as steering wheels, keyboard, console controllers and other. If you are interested in exploring such applications, you can have a look at the following paper which gives an example with PLUX sensors: https://www.sciencedirect.com/science/article/abs/pii/S0169260713003891

6. PROTOCOL

6.1. Body Sensor Setup Using Einthoven Leads

We will have a closer look into the effects of different electrode positions now and will try to acquire ECG signals with the three Einthoven leads I-III.

6.1.1. Einthoven Lead I

Figure 8 illustrates one possible setup of the BITalino ECG sensor for Einthoven Lead I on the collarbones and the iliac crest. The positive electrode (red) is located on the left collarbone (LA) and the negative (black) electrode on the right collarbone (RA). The reference (REF) in white is placed on the iliac crest.

Figure 8: Electrode placement for lead I: IN+ (red) & IN-(black) on the collarbones and REF (white) on the iliac crest.

You can also place the electrodes on the wrists, see Figure 9:

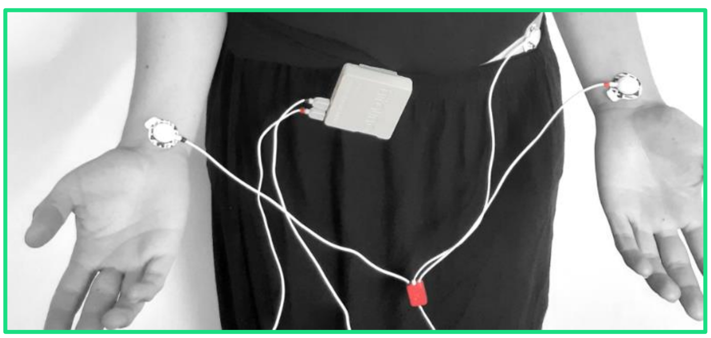

Figure 9: Electrode placement for lead I: IN+ (red) & IN-(black) on the wrists and REF (white) on the iliac crest.

To receive the most qualitative ECG signal and to distinguish all PQRS complexes from each other, the electrodes need to be placed near the heart on the chest as previously explained in Figure 6 (right).

6.1.1. Einthoven Lead II-III

When acquiring ECG data using the Einthoven Lead II, exchange the positive (red) and the reference (white) electrodes with each other according to Figure 5 (left). For Einthoven Lead III exchange the negative (black) and the reference (white) from the setup of Lead II with each other according to Figure 5 (left).

6.2. Data Acquisition

Review: Follow the device setup (1-2) as already explained in Home-Guide #0 and continue with steps 3-13.

1. Connect your BITalino (r)evolution Core BT
2. Testing your set-up

Live Heartbeat with Elecardiography (ECG):

1. Connect the Assembled ECG Sensor to one of the analog channels available.
2. Place the Gelled Electrodes on the snaps of the three ECG sensors.
3. Place the Assembled ECG on the three positions, explained in Section 1.
4. Start recording data on OpenSignals (r)evolution (if needed, check Home-Guide #0 Section 2 to recall how this is done).
5. Start recording a signal baseline with low noise and no movements (normal breathing) for 30 seconds.
6. Repeat a cycle of INHALATION-HOLD-EXHALATION-HOLD three times, maintaining the breathing and resting phases for five seconds.
7. Record another baseline phase of 30 seconds.
8. Perform 10 burpees and observe your heart rate before, during and after the workout.
9. Record another baseline phase of 30 seconds.
10. Perform a long inhalation (~10 seconds) followed by holding the breath for several seconds (~10 seconds).
11. Stop the recording and save your data.

6.3. Repeat Activities for different Leads and Locations.

Preform an acquisition using Einthoven lead I with the three different electrode locations:

1. Collarbones and Iliac Crest
2. Wrists and Iliac Crest
3. Chest

Perform an acquisition for lead II and lead III for the same electrode locations (choose the one in which you received the clearest signal).

For additional information review the last Home-Guide which is available here:

HOMEGUIDE#1 and the documentation available on the previous section "RELATED DOCUMENTATION"

6.4. Elaborate your Report and answer the Quiz.

Write a report on the performed acquisitions of each muscle group, following the acquisition steps mentioned in section 2. Finally, fill out the quiz and check out the additional documents for help.

IMPORTANT NOTES:

- ✓ Learn more about basic principles on ECG at: https://www.sciencedirect.com/science/article/pii/B0323040381500020
- ✓ Learn more about the ECG specifications and working principle on the data sheet available at: ECG Sensor Datasheet

7. QUIZ

In this section you can find some questions for you to work on during your Home Session and to explore the ECG sensor.

Q1. What are the most typical types of noise sources affecting ECG?

Q2. Why does the change of the positioning of the sensors (lead I-III) change the ECG signal components? How do the components change?

Q3. Describe if there are major differences in the signal when acquiring the signal from different body locations (e.g., wrist / collarbone/ chest). What could be the cause? Did you expect such changes in the signal? Store a signal segment of each to visualize the differences.

Q4. The cardiac and the respiratory systems are well interconnected as is well known. Do you expect that different types of breathing (e.g. faster, deeper) to influence the ECG signals? Show screenshots of ECG signals in different respiratory circumstances and described the variations if there are any.

Q5. In Home-Guide #1 you have seen that different amounts of force produced in the muscle generated signals with different amplitudes. How does movement influence your ECG signal?

Q6. To the best of your knowledge, how can you detect bradycardia and tachycardia in the ECG signal?