Introductory ECG Guide

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Introduction to Electrocardiogram (ECG)

Welcome to BIOPAC's* Introduction to Electrocardiogram, the aim of which is to offer a glimpse into concepts behind Electrocardiography (ECG), plus demonstrate guidelines for collecting high-quality ECG data. In addition to the basic steps outlined in this guide, links to detailed instructional videos, webinars, and other BIOPAC resources are included. These can be of assistance in offering an enhanced level of instructional detail about acquiring and analyzing ECG data.

What is ECG?

ECG (**Electrocardiography)** is the electrical measurement of heartbeat activity. This continuous electrical activity—occurring an average 60 to 80 beats per minute and repeated some two and a half billion times over an average human lifespan—can be non-invasively detected and recorded by attaching leads and electrodes to the skin. The flow of electricity associated with heart activity can then be accurately displayed as a waveform on a computer screen or a chart recorder. The ECG waveform can be used to reliably determine the normality or abnormality of a heartbeat by analyzing various "components," or noted electrical and mechanical events generated during each cardiac cycle. Modern methods of recording ECG using life science equipment such as BIOPAC's array of wired or wireless data acquisition systems allows for great flexibility in viewing ECG data. In addition, the ECG wave can be easily magnified, rescaled, copied, pasted, saved and analyzed using advanced automated analysis transformations found in BIOPAC's Acq*Knowledge* and Biopac Student Lab software.

*Cited in over 33,000 peer-reviewed journal articles and trusted by the world's premier laboratories and leading researchers, BIOPAC's world-class life science research and education platforms provide the most advanced acquisition and analysis of ECG, EDA (GSR), EEG, EGG, EMG, EOG, and over 300 other signals and physiological measurements. *Over 99% of the world's top universities use BIOPAC equipment.*

A Brief History of ECG

In 1901, Dutch physician Willem Einthoven developed a "string galvanometer" that could record the electrical activity of the heart. Although it was not the first such recorder, it was a breakthrough in that it was accurate enough to duplicate the results on the same patient. Einthoven's work established a standard configuration for recording the ECG and won him the Nobel Prize in 1924. Since then, ECG has become a powerful tool in diagnosing disorders of the heart.

> ***About Willem Einthoven:***
> 1860-1927
> Born in Semarang, Java, Indonesia
> Dutch physician
> Professor, University of Leiden,
>   1885-1927
> Nobel Prize: 1924

How does ECG work?

In order to understand ECG, it's helpful to have a basic understanding of heart activity.

The main function of the heart is to pump blood through two circuits:

1. **Pulmonary circuit**: through the lungs to oxygenate the blood and remove carbon dioxide; and

2. **Systemic circuit**: to deliver oxygen and nutrients to tissues and remove carbon dioxide.

Because the heart moves blood through two separate circuits, it is sometimes described as a dual pump.

In order to beat, the heart needs three types of cells:

1. **Rhythm generators**, which produce an electrical signal (SA node or normal pacemaker);

2. **Conductors** to spread the pacemaker signal; and

3. **Contractile cells** (myocardium) to mechanically pump blood.

The Electrical and Mechanical Sequence of a Heartbeat

The heart has specialized **pacemaker** cells that start the electrical sequence of **depolarization** and **repolarization**. This property of cardiac tissue is called **inherent rhythmicity** or **automaticity**. The electrical signal is generated by the **sinoatrial node (SA node)** and spreads to the ventricular muscle via particular conducting pathways: **internodal pathways** and **atrial fibers**, the **atrioventricular node (AV node**,) the **bundle of His**, the right and left **bundle branches**, and **Purkinje fibers** (Fig. 1).
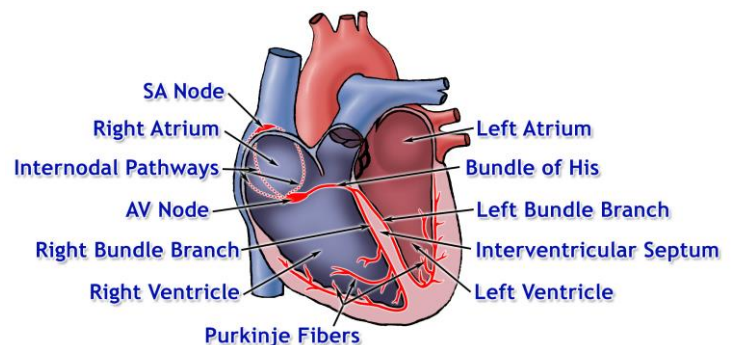

Fig. 1: The Heart

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When the electrical signal of a depolarization reaches the contractile cells, they contract—a mechanical event called **systole**. When the repolarization signal reaches the myocardial cells, they relax—a mechanical event called **diastole**. Thus, the electrical signals cause the mechanical pumping action of the heart; mechanical events always follow the electrical events (Fig. 2).

The **SA node** is the normal pacemaker of the heart, initiating each electrical and mechanical cycle. When the SA node depolarizes, the electrical stimulus spreads through atrial muscle causing the muscle to contract. Thus, the SA node depolarization is followed by atrial contraction.

The SA node impulse also spreads to the **atrioventricular node (AV node)** via the **internodal fibers**. (The wave of depolarization does not spread to the ventricles right away because there is nonconducting tissue separating the atria and ventricles.) The electrical signal is delayed in the AV node for approximately 0.20 seconds when the atria contract, and then the signal is relayed to the **ventricles** via the **bundle of His, right** and **left bundle branches**, and **Purkinje fibers**. The Purkinje fibers relay the electrical impulse directly to ventricular muscle, stimulating the ventricles to **contract** (ventricular **systole**). During ventricular systole, ventricles begin to repolarize and then enter a period of diastole (Fig.2).

Although the heart generates its own beat, the heart rate (<u>b</u>eats <u>p</u>er <u>m</u>inute or BPM) and strength of contraction of the heart are modified by the **sympathetic** and **parasympathetic** divisions of the autonomic nervous system.

- The sympathetic division increases automaticity and excitability of the SA node, thereby increasing heart rate. It also increases conductivity of electrical impulses through the atrioventricular conduction system and increases the force of atrioventricular contraction. Sympathetic influence increases during inhalation.

- The parasympathetic division decreases automaticity and excitability of the SA node, thereby decreasing heart rate. It also decreases conductivity of electrical impulses through the atrioventricular conduction system and decreases the force of atrioventricular contraction. Parasympathetic influence increases during exhalation.

The average resting heart rate for adults is between 60-80 beats/min. (Average 70 bpm for males and 75 bpm for females.) Slower heart rates are typically found in individuals who regularly exercise. Athletes can pump enough blood to meet the demands of the body with resting heart rates as low as 50 beats/min. Athletes tend to develop larger hearts, especially the muscle in the left ventricle—a condition known as "left ventricular hypertrophy." Because athletes (usually) have larger and more efficient hearts, their ECGs may exhibit differences other than average resting heart rate. For instance, low heart rate and hypertrophy exhibited in sedentary individuals can be an indication of heart failure, but these changes are "normal" for well-trained athletes.

ECG Activity

Just as the electrical activity of the pacemaker is communicated to the cardiac muscle, "echoes" of the depolarization and repolarization of the heart are sent through the rest of the body. By placing a pair of very sensitive receivers (**electrodes**) on other parts of the body, the echoes of the heart's electrical activity can be detected. The record of the electrical signal is called an **electrocardiogram (ECG).** You can infer the heart's mechanical activity from the ECG. Electrical activity varies through the ECG cycle as shown below in the ECG Components figure on the following page (Figure 2).

The ECG represents electrical events of the cardiac cycle whereas Ventricular Systole and Ventricular Diastole represent mechanical events (contraction and relaxation of cardiac muscle, passive opening and closing of intracardiac valves, etc.).

Electrical events occur quickly, mechanical events occur slowly. Generally, mechanical events follow the electrical events that initiate them. Thus, the beginning of ventricular diastole is preceded by the beginning of ventricular depolarization. In fact, in a normal resting Lead II, ventricular repolarization normally begins before the completion of ventricular systole in the same cardiac cycle. That is why the end of ventricular systole/beginning of ventricular diastole is marked in Figure. 2 about 1/3 of the way down the T-wave.

Because the ECG reflects the electrical activity, it is a useful "picture" of heart activity. If there are interruptions of the electrical signal generation or transmission, the ECG changes. These changes can be useful in diagnosing changes within the heart.

Components of the ECG

The electrical events of the heart (ECG) are usually recorded as a pattern of a baseline (isoelectric line,) broken by a **P** wave, a **QRS** complex, and a **T** wave. In addition to the wave components of the ECG, there are intervals and segments (Fig. 2).

- The **isoelectric line** is a point of departure of the electrical activity of depolarizations and repolarizations of the cardiac cycles and indicates periods when the ECG electrodes did not detect electrical activity.
- An **interval** is a time measurement that includes waves and/or complexes.
- A **segment** is a time measurement that does not include waves and/or complexes.
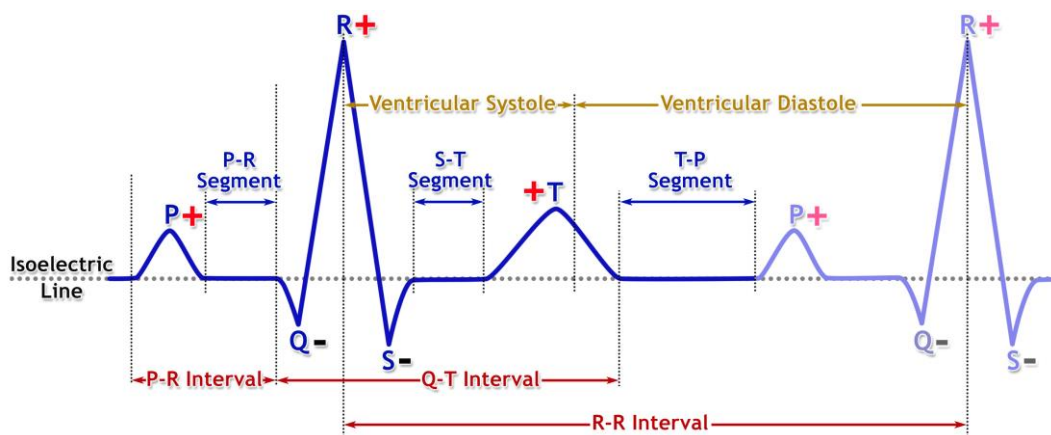
Fig. 2: Components of the ECG (Lead II) & Electrical and mechanical events of the cardiac cycle

Table 1 Components of the ECG & Typical Lead II Values*

ECG COMPONENT		Measurement area…	Represents…	Duration (seconds)	Amplitude (millivolts)
Waves	P	begin and end on isoelectric line (baseline); normally upright in standard limb leads	depolarization of the right and left atria.	0.07 – 0.18	< 0.25
	QRS complex	begin and end on isoelectric line (baseline) from start of Q wave to end of S wave	depolarization of the right and left ventricles. Atrial repolarization is also part of this segment, but the electrical signal for atrial repolarization is masked by the larger QRS complex (see Fig. 5.2)	0.06 – 0.12	0.10 – 1.50
	T	begin and end on isoelectric line (baseline)	repolarization of the right and left ventricles.	0.10 – 0.25	< 0.5
Intervals	P-R	from start of P wave to start of QRS complex	time from the onset of atrial depolarization to the onset of ventricular depolarization.	0.12-0.20	
	Q-T	from start of QRS complex to end of T wave	time from onset of ventricular depolarization to the end of ventricular repolarization. It represents the refractory period of the ventricles.	0.32-0.36	
	R-R	from peak of R wave to peak of succeeding R wave	time between two successive ventricular depolarizations.	0.80	
Segments	P-R	from end of P wave to start of QRS complex	time of impulse conduction from the AV node to the ventricular myocardium.	0.02 – 0.10	
	S-T	between end of S wave and start of T wave	period of time representing the early part of ventricular repolarization during which ventricles are more or less uniformly excited.	< 0.20	
	T-P	from end of T wave to start of successive P wave	time from the end of ventricular repolarization to the onset of atrial depolarization.	0.0 – 0.40	

*   Notes: Tabled values represent results from a typical Lead II setup (wrist and ankle electrode placement) with Subject heart rate ~75 BPM. Values are influenced by heart rate and placement; values for torso placement would be different.

Leads

The particular **bipolar** arrangement of two electrodes (one **positive**, one **negative**) with respect to a third electrode (the **ground**) is called a **lead**. The electrode positions for the different leads have been standardized. Typical Lead II values are shown above in Table 1.

The dominant ECG component in any normal standard lead record is the QRS complex. Usually, in a Lead II recording the Q and S waves are small and negative and the R wave is large and positive as shown in Fig. 2. However, it is important to note many factors, normal and abnormal, determine the duration, form, rate, and rhythm of the QRS complex.

- Normal factors include body size (BSA) and distribution of body fat, heart size (ventricular mass,) position of the heart in the chest relative to lead locations, metabolic rate, and others.

For example, in a person who has a high diaphragm, the apex of the heart may be shifted slightly upward and to the person's left. This change in the position of the heart alters the "electrical picture" of ventricular depolarization seen by the Lead II electrodes, resulting in decreased positivity of the R wave and increased negativity of the S wave. In other words, the positive amplitude of the R wave decreases and the negative amplitude of the S wave increases.

Similar changes in the Lead II QRS complex may be observed in a person, an athlete for example, who has no cardiac disease but does have a larger than normal left ventricular mass. In fact the decrease in R wave positivity coupled with the increase in S wave negativity may be so extreme as to give rise to the mistaken impression that the R wave has become inverted, when in reality the inverted spike is an enlarged S wave preceded by a much smaller but still positive R wave. When the amplitudes of Lead II Q, R, and S waves are all negative, the result is an abnormal inverted QRS complex.

To learn more, see: www.biopac.com/application/ecg-cardiology.

What is Required to Measure ECG?

Depending on lead configuration, most commonly three to six adhesive skin electrodes are attached to the participant's wrist and ankles, although in certain applications, electrodes can be applied to the chest or torso. A lead set is then attached to the electrodes and connected to an ECG amplifier, data acquisition unit or wireless transmitter or logger. Further discussion of electrode placements and lead configurations appear on page 11.

Common Applications for ECG Measurement

Determining Heart Health

ECG is used in clinical applications determining heart heath by examining the various ECG components for normal and abnormal activity.

Exercise Physiology

ECG is invaluable to the study of exercise physiology (study of the body's response to physical activity), which also incorporates a wide range of physical parameters such as ventilation, oxygen uptake, carbon dioxide production, blood pressure and core/surface temperature data.

Psychophysiology

Record and analyze BP, ECG, HRV, EDA, EMG, EEG, EOG, RSP, etc. Synchronize with stimulus presentation programs...use automated analysis routines to easily score and analyze data.

Physiology Education

ECG is an important component in physiology education and one of the many physiological signals fully explored in Biopac Student Lab 4, BIOPAC's Educational System. Comprehensive ECG Lessons include basic electrocardiography (Lead I), multiple-lead cardiography (Lead I, II, and III), electrocardiography and pulse, aerobic exercise, and more.

Preparing for an ECG Recording

There are two types of BIOPAC ECG electrodes, **reusable** and **disposable**. Decide which type of ECG electrodes best suits your testing environment. Whichever type is used, proper preparation and application of electrodes/leads is vital for obtaining great ECG data.

Reusable ECG Electrodes such as BIOPAC EL250 Series and EL650 Series.

Disposable ECG Electrodes such as BIOPAC EL500 Series.

Electrode leads are cables that attach to the skin electrodes in various arrangements depending on whether Lead I, Lead II, or Lead III ECG is to be recorded. Electrode leads, such as BIOPAC's SS2LB and BioNomadix Lead-3 series are color coded red (positive), white (negative), and black (ground.) Some electrode lead sets (such as BIOPAC's TSD155C), also include a green lead connection to the right leg and a brown lead connected to the chest, called a "precordial" lead.

Figure 3: SS2LB Lead Set   **Figure 4: MEC110C Module Extension Cable**   **Figure 5: TSD155C Lead Set**

Tips for Preparing Subject prior to Recording ECG

- Clean skin with alcohol or BIOPAC ELPREP skin prep gel or use BIOPAC ELPAD abrasive pad to gently abrade the skin where electrodes are to be placed.

- Remove any jewelry on or near the electrode sites

- Always apply a drop of electrode gel (GEL100) to the sponge portion of electrodes before attaching

- Place electrodes at least 5 minutes in advance of recording.

- Once electrodes are placed on the skin, an impedance check should be made to determine the resistance between all the applied electrodes. Impedance checking, with BIOPAC's ELCHECK, should be performed between Vin+ and GND, Vin- and GND and Vin+ to Vin-. For best electrode-based measurement performance, impedance levels should be 5 K ohms or less.

- Use BIOPAC TAPE1 surgical tape to hold electrode leads in place and prevent them from tugging on electrodes.
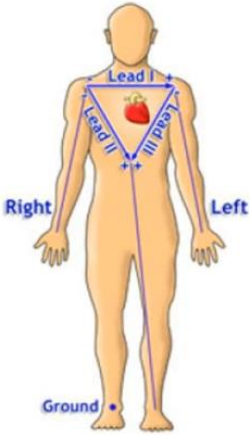
Tips for Ensuring Great Data

- Make sure electrodes, leads or transducers are properly attached and cables secured.

- If the data appears distorted or as a flat line, check to make sure the connections are in place and that the electrodes have not lost adhesion.

Click to watch a Webinar about recording ECG data.

Figure 6: Basic Lead I, II, and III Configurations
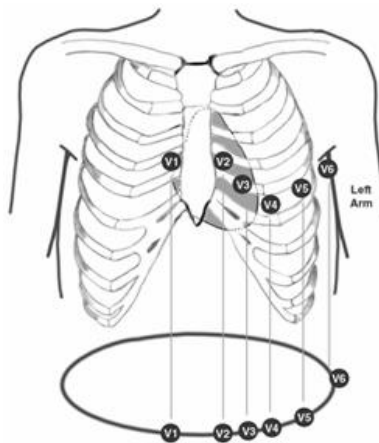
Figure 7: Precordial Chest Lead placement for 12-lead ECG

ECG Lead Configurations

It is useful to make a distinction between ECG lead configurations and the physical electrode "leads" shown on the previous pages. As stated on page 7, the particular **bipolar** arrangement of two electrodes (one positive, one negative) with respect to a third electrode (the ground) is called a **lead**. The electrode positions for the different leads have been standardized into Lead I, Lead II and Lead III. These lead configurations are illustrated in Figure 8 (right) and detailed further in the next section, "1-Lead ECG."

One common placement of ECG electrodes is based on **Einthoven's triangle**, which is an imaginary triangle drawn around the volume of the heart. Each apex of the triangle represents where the body's composition connects electrically with the limbs around the heart. Einthoven's law states that if the values for any **two points** of the triangle are known, the **third** can be computed.

Mathematically expressed: **LEAD II - LEAD I = LEAD III**

Furthermore, three-lead or six-lead configurations are possible through the addition of calculation channels available in BIOPAC's Acq*Knowledge* and Biopac Student Lab software. Three and six-lead configurations are possible when only two leads are connected and recorded by using calculation channels in the Acq*Knowledge* or Biopac Student Lab software.

OTHER LEAD CALCULATIONS

If you record LEAD I and LEAD III, you can calculate LEAD II.

LEAD I + LEAD III = LEAD II

Figure 8: Einthoven Triangle LEAD Connections (Note Polarity)

The Expression calculation in the Acq*Knowledge* or BSL software can be used to calculate the 3rd lead, plus the augmented, or **Goldberger** leads (aVR, aVL and aVF).

$$aVR = - (Lead\ I + Lead\ II)/2$$
$$aVL = (Lead\ I - Lead\ III)/2 = Lead\ I - ((Lead\ II)/2)$$
$$aVF = (Lead\ II + Lead\ III)/2 = Lead\ II - ((Lead\ I)/2)$$

Note that this introductory guide touches upon basic ECG lead configurations. To read about more advanced lead setups, such as the 12-lead ECG shown on the previous page, see BIOPAC's Application Note 109.
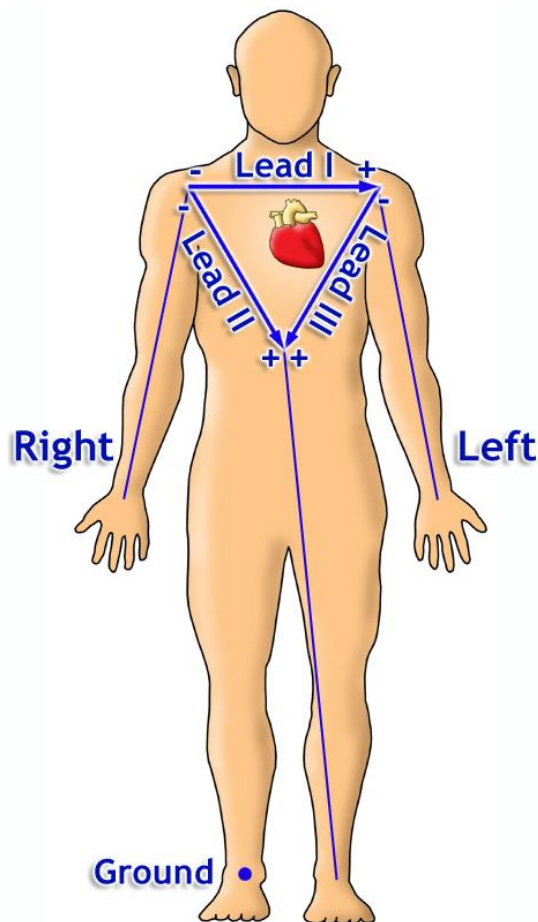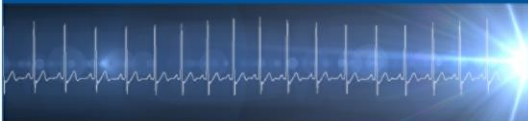
Subject Setup

1-Lead ECG

For a single channel, 1-Lead ECG, Lead II is the most commonly collected vector. Lead II is collected from the electrode attachment points of Lower Left Rib to Right Clavicle. The Lower Left Rib electrode site is considered positive and the Right Clavicle electrode site is considered negative.

NOTE: For convenience or if modesty dictates, electrodes can be attached to corresponding points on the wrists and ankles, but chest leads are the preferred placement for research applications.

For LEAD I: Right Arm or clavicle (WHITE = Vin-) and Left Arm or clavicle (RED = Vin+)

For LEAD II: Left Leg or lower left rib (RED = Vin+) and Right Arm or clavicle (WHITE = Vin-)

For LEAD III: Lower Left Leg or lower left rib (RED = Vin+) and Left Arm or clavicle (WHITE = Vin-)
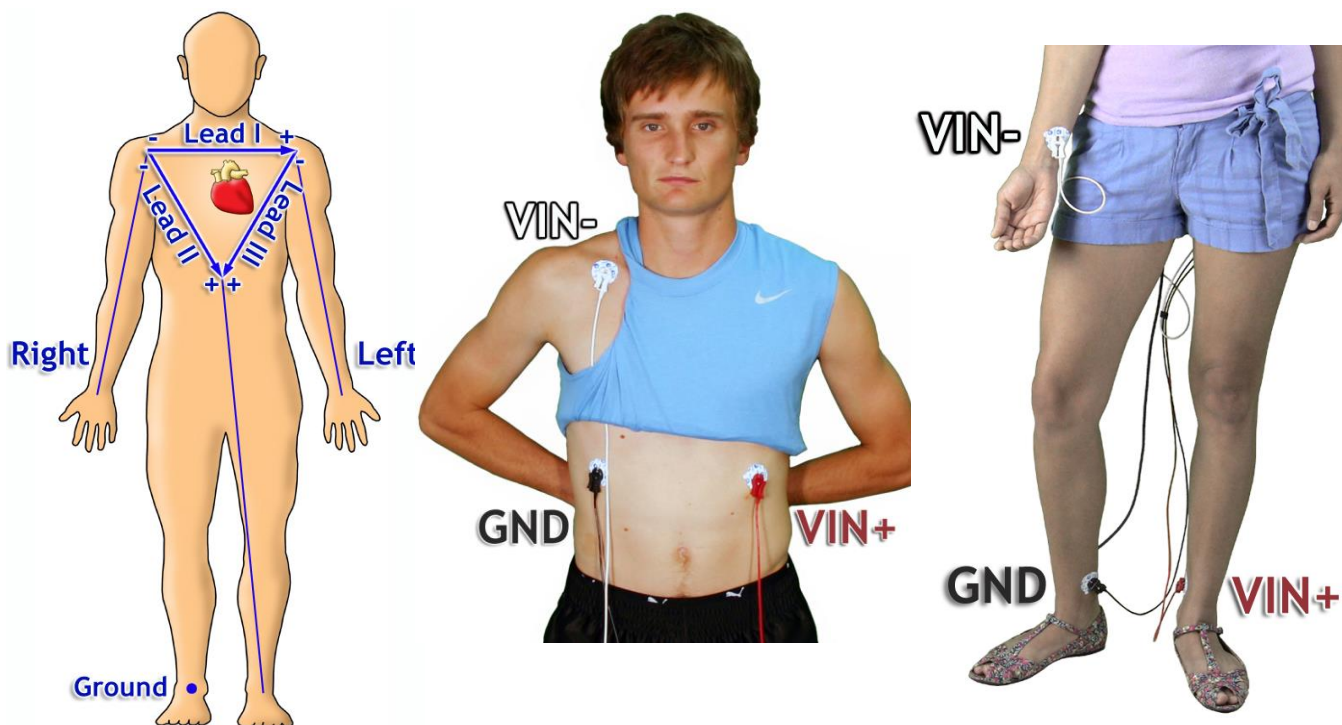

Figure 9: 1-Lead ECG Recording (LEAD II)

Hardware Setup - Hardware required to record ECG

BIOPAC hardware provides three basic methods for acquiring ECG data. Wired, wireless, and cabled in the MRI environment.

Hardware Components – Wired Methods

Wired methods for collecting ECG data are appropriate for experiments where participants remain relatively still and in close proximity to the data acquisition system.

MP160 System

The MP160 System is a 16-channel Data Acquisition System with Acq*Knowledge* software specifically designed for the Research market. New small-form 100D Series **Smart Ampifiers** provide the same advanced functionality as the proven BIOPAC 100C Series modules and support 11 biopotential and transducer signals.

Basic ECG*

New Smart Amplifiers –smaller size, same advanced functionality!

| MP160 | ECG100C or ECG100D | MEC110C | Reusable: EL250 Series / Disposable: EL500 Series / LEAD110 Series or BN-EL30-LEAD3 |

BIOPAC MP160 Research System with ECG100C or ECG100D Amplifier Module, MEC110C Module Extension Cable, plus ECG Leads/Electrodes

***For 6-lead ECG** connect a 2nd ECG100C/ECG100D and use calculation channels to compute the augmented leads as shown on page 11.)

6-Lead ECG + 1 Precordial Lead

MP160 | 3 × ECG100C or ECG100D | MEC110C

Reusable: EL650 Series

Disposable: EL500 Series

LEAD110 Series or BN-EL30-LEAD3

BIOPAC MP160 System for recording 6-lead ECG + 1 Precordial Lead; with 3x ECG100C or ECG100D, TSD155C Multi-Lead Cable, plus ECG Electrodes
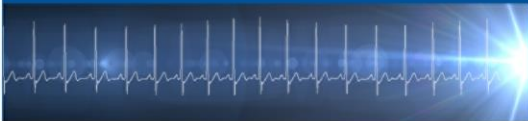
12-Lead ECG

MP160 | 8 × ECG100C or ECG100D | WTC100C

Reusable: EL250 Series

Disposable: EL500 Series

LEAD110 Series or BN-EL30-LEAD3

MP160 System for recording 12-lead ECG; with 8x ECG100C or ECG100D, WT100C Wilson Terminal, plus ECG Electrodes Record Lead I and Lead III and calculate Lead II plus aVR, aVL and aVF

The above configuration will provide a full 12-lead ECG recording.

Click to learn more about the BIOPAC MP160 System.
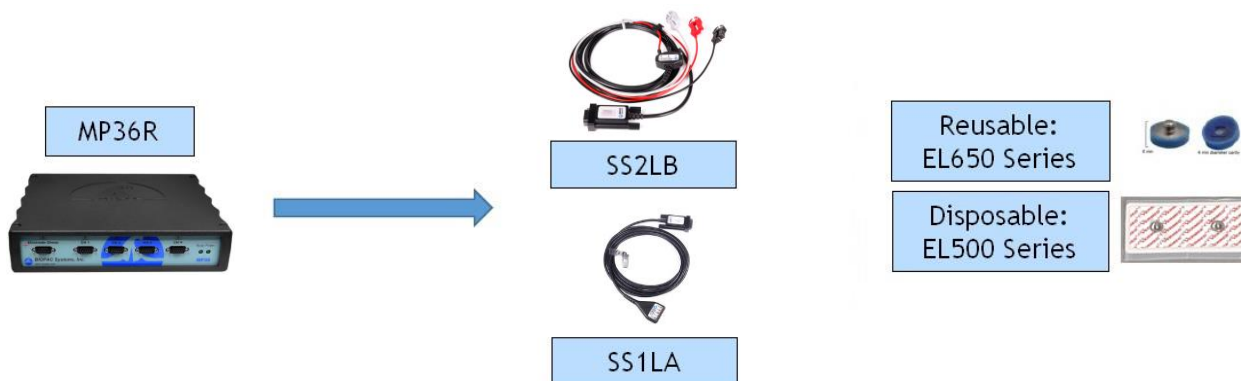
Click to learn more about 6-Lead and 12-Lead ECG setups

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MP36/36R Systems

BIOPAC's 4-channel Data Acquisition System is available for

Educators: MP36 unit for Biopac Student Lab software	**Researchers:** MP36R unit for Acq*Knowledge* software

*Basic ECG**

BIOPAC MP36/36R System, plus ECG Leads/Electrodes

*For 6-lead ECG connect a 2nd SS2LB and use calculation channels to compute the augmented leads as shown on page 11.)

6-Lead ECG + Precordial Lead

BIOPAC MP36/36R System, with SS29L Multi-Lead Cable, and Electrodes
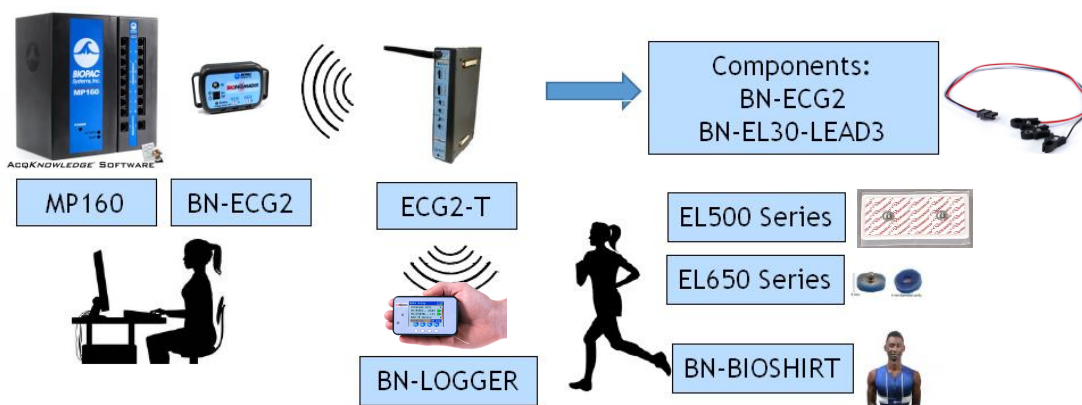
Click to learn more about the BIOPAC MP36R System.

Hardware Components - Wireless Methods

BioNomadix with MP160

The BioNomadix System allows ECG data to be collected from ambulatory or untethered participants. The ECG Transmitter is attached to the participant with a Velcro strap, and the data wirelessly streamed to an ECG receiver unit attached to the MP160 System. The dual-channel BioNomadix ECG Transmitter wirelessly measures electrocardiogram (ECG) data on one or two channels. Collect data from Lead I, Lead II, and calculate Lead III and all augmented leads (aVR, aVL and aVF).
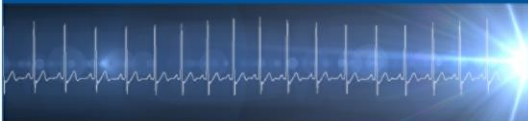
Or use the BioNomadix BN-RSPEC Transmitter to record a single channel of ECG and a single channel of Respiration.

The BioNomadix BioShirt enables you to record single channel ECG and single channel Respiration. The Smart Fabric® electrodes are part of the shirt, simplifying setup and providing subject comfort.

BIOPAC MP160 Research System with BioNomadix Receiver, Transmitter, or BioNomadix Logger

Click to learn more about the BIOPAC BioNomadix ECG System.

BioNomadix Smart Center and BioNomadix Logger

BioNomadix Smart Center (lower left) is a portable small-form data acquisition system that allows ECG data to be collected from untethered participants. The ECG Transmitter is attached to the participant with a Velcro strap, and the data wirelessly streamed to the Smart Center unit.

Offering the industry's only system that delivers a comprehensive, 24-hour data logging solution in an easy-to-use, easy-to-wear package, the BioNomadix Logger (lower right) truly delivers "physiology anywhere." The BioNomadix Logger is the perfect tool for applications that demand greater degrees of subject freedom and complex experimental design. The BioNomadix transmitter sends the data wirelessly to the Logger where it is saved for later download.

Hardware Components – MRI Environment

Special cabling, filters, and a BIOPAC ECG100C-MRI Smart Amplifier module are required for acquiring ECG data in the MRI chamber. BIOPAC MRI Smart Amplifiers incorporate advanced signal processing to remove signal artifacts introduced by the MRI environment. Only components rated "MR Safe" are used inside the chamber with non-MRI components isolated outside the chamber.

The following figure depicts the BIOPAC MP160 System with components necessary for recording in the MRI.
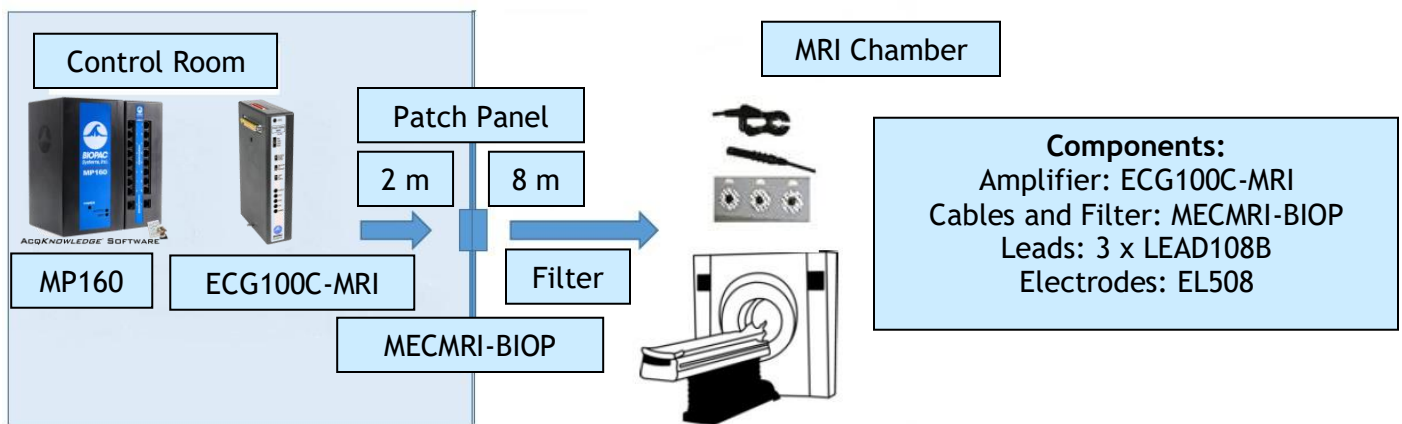
BIOPAC MP160 Research System with ECG100C-MRI Amplifier Module cabled for MRI environments

Click to learn more about recording in the MRI environment.

Software Setup

BIOPAC Data Acquisition and Analysis Software

Acq*Knowledge* Research software or Biopac Student Lab Educational software is used to record, view and analyze ECG data.

Acq*Knowledge* Research Software

Acq*Knowledge* is used by thousands of research labs around the world and has been cited in thousands of peer reviewed publications. Acq*Knowledge* is included with each MP160, MP36R, BioNomadix Smart Center System, and BioNomadix Logger.

AcqK*nowledge* is an interactive, intuitive program that allows you instantly view, measure, transform, replay, and analyze data.

With the wired or wireless MP160 Systems, up to 16 channels of physiological data can be recorded simultaneously, ECG, EMG, EEG, EDA, EEG, EOG, Respiration, and more. Additionally, up to 16 digital and 16 online calculation channels are available.
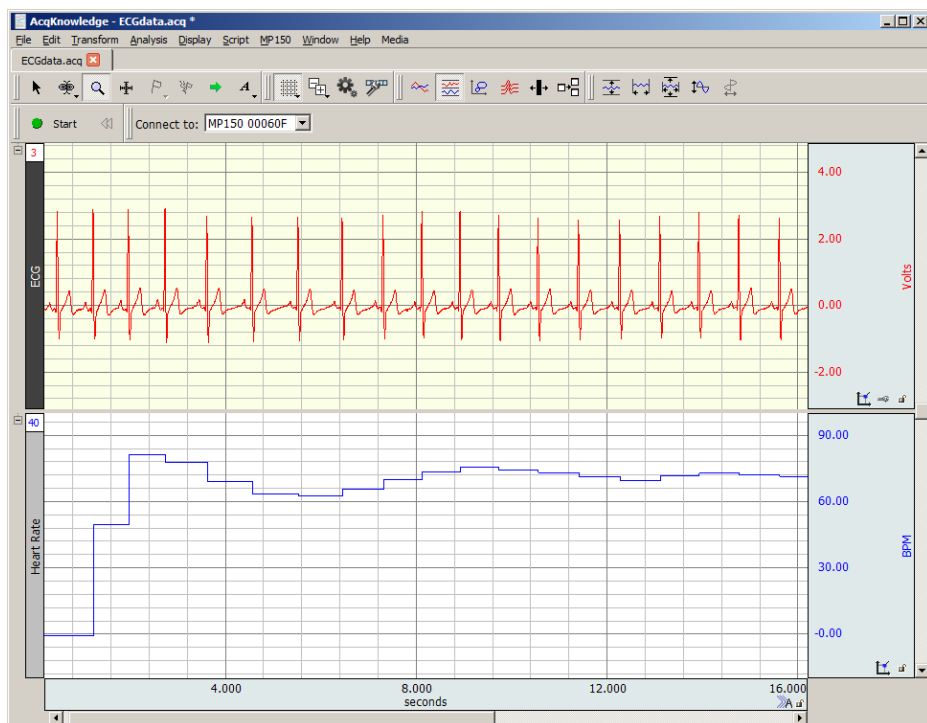
With the MP36R System, up to 4 channels of physiological data, 8 digital channels, and 16 online calculation channels are available. Pre-configured software presets assist in simplifying setup.

Click for more information about Acq*Knowledge* Software.

Click to watch a Webinar about recording ECG data

Click to view or download a full ECG Product Resource Sheet

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The Smart Center System supports up to 9 channels of physiological data from up to three BioNomadix transmitters at a time. Online calculation channels are available for many transmitters, easily selectable by checking a box. The full range of 14 BioNomadix transmitter types are supported. Guided prompts in Acq*Knowledge* for Smart Center software assist with setup and pairing to have you recording data within minutes.

The BioNomadix Logger wirelessly records physiological data as subjects freely and naturally live their lives. Connect up to three transmitters to the Logger for data logging or use with BioNomadix receivers operating in the lab and view data in Acq*Knowledge*. Or sync the BioNomadix Logger with GPS for a correlation between physiological and location data.

So, regardless of which system you choose, ECG data can be easily and accurately recorded in conjunction with other body signals.

With Acq*Knowledge*, perform complex data acquisition, stimulation, triggering and analyses using simple pull-down menus and dialogs—no need to learn a programming language or new protocol.

Online analysis settings, filters, and transformations provide real-time feedback, or choose from a wide variety of off-line analysis tools. Multiple display options are available during and after acquisition—click an icon to flip between Chart, Scope, X/Y, Overlapped segments. Histograms, FFTs, and other essential transformations are easily applied, offering enhanced data analysis.

Biopac Student Lab Educational System

The Biopac Student Lab system is an integrated life science teaching solution that includes MP36 hardware, BSL 4 software and curriculum materials that students use in undergraduate laboratories to record data from their own bodies, animals or tissue preparations. The system includes over sixty-five complete lessons that educators use as part of undergraduate lab courses.

Use BSL Lessons for lab curriculum or powerful BSL *PRO* for advanced lessons, custom experiments and analysis. Both applications are included in the BSL 4 software.
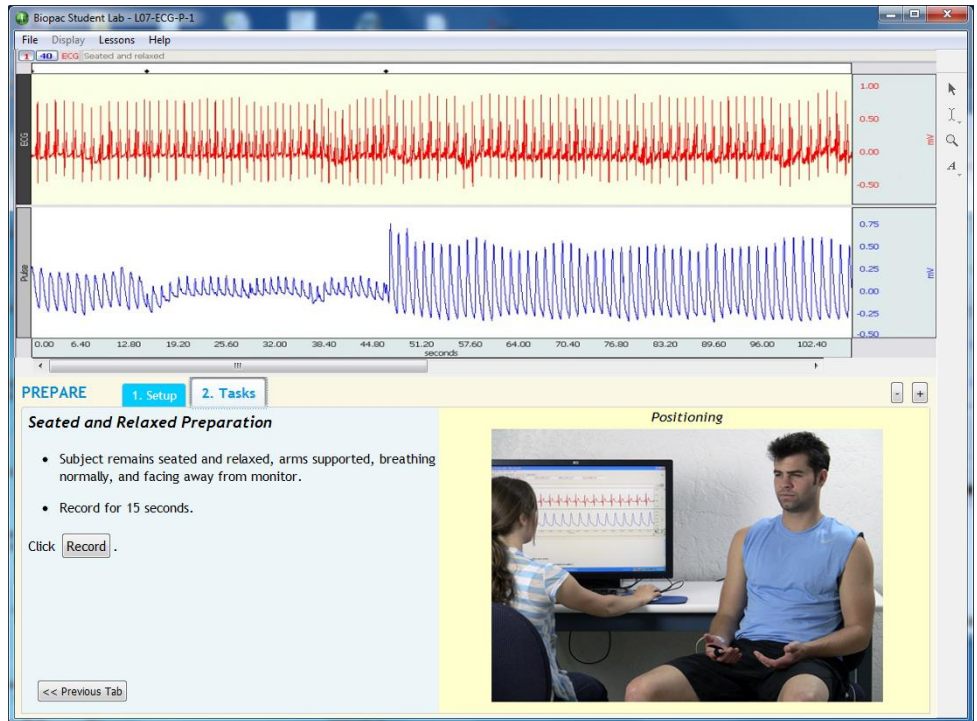
ECG Lessons for Education include:

Lesson 5 – Electrocardiography I

Lesson 6 – Electrocardiography II

Lesson 7 – ECG & Pulse

Lesson 16 – Blood Pressure

Lesson 17 – Heart Sounds

PRO Lesson H01 – 12-lead ECG

And more!

With the MP36 System, up to 4 channels of physiological data, 8 digital channels, and 16 online calculation channels are available. Pre-configured software presets assist in simplifying setup.

Click to review the Biopac Student Lab Curriculum page.

Click for more information about the Biopac Student Lab Educational Systems.

ECG Data Analysis

In Acq*Knowledge* Research and Biopac Student Lab Educational software, powerful viewing tools allow for the selection, editing, and magnification of data. More than 40 measurement types can be extracted, and over 20 transformations and filters can be applied to clean the data.

There are three main ways to approach, explore and analyze ECG data.

1. Manually, by using the software's I-Beam selection tool in conjunction with selected measurements.

2. Via a series of ECG automated analysis routines included in Acq*Knowledge* software.

The I-Beam tool in BIOPAC software allows highlighting of specific regions of the signal for analysis. This tool works in conjunction with the measurement boxes (which provide the output from the region highlighted by the I-Beam tool), which can be configured to provide specific mathematical information via individual pop-up menus.
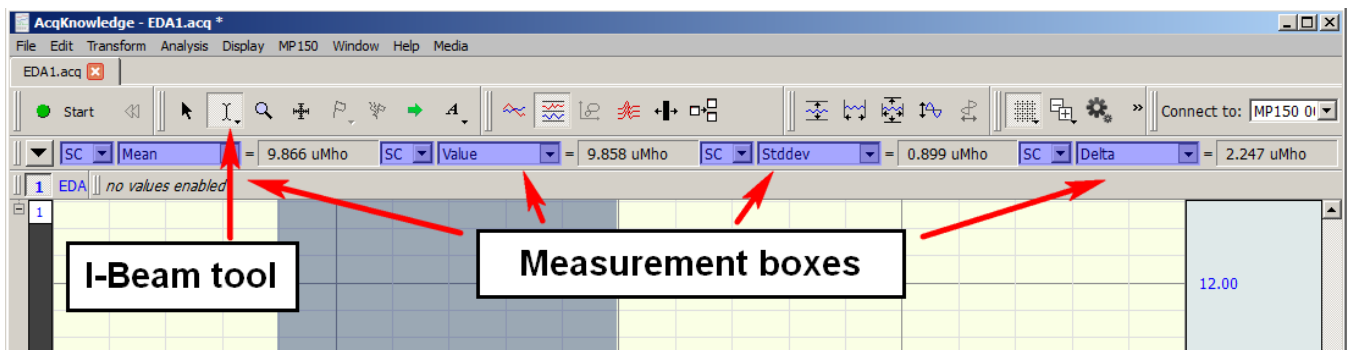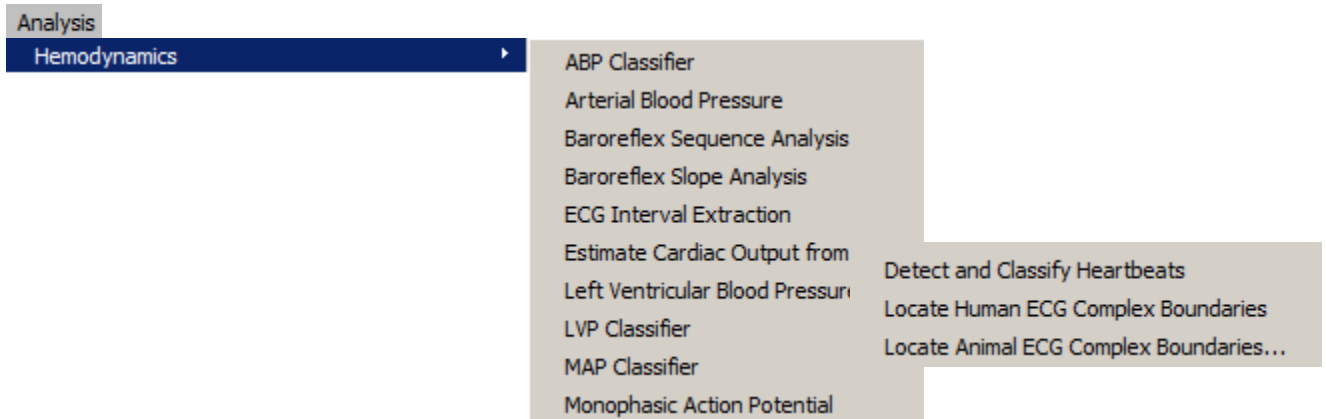
Measurements useful for analyzing ECG data

- **Mean:** returns the arithmetic mean for the whole area highlighted by the I-Beam (averaged across peaks, troughs, etc).

- **BPM:** first calculates the difference in time between the beginning and end of the selected area (seconds/beat,) and divides this value into 60 seconds/minute.

- **Value:** returns the exact value (level of the signal) at the point where the mouse button was last released.

- **Peak-to-Peak:** Subtracts the minimum value from the maximum value found in the selected area.

- **Delta:** provides the difference between the values at the left and right edges of the selected data. Particularly useful when used in conjunction with the "Find Cycle" routine.

- **Delta T:** provides an accurate time period of the area being highlighted.

- **Min / Max:** provides values for the minimum and maximum values encountered in the highlighted areas and is useful for calculating the range of values.

- Additionally Acq*Knowledge* software includes the following Automated Analysis Routines for extracting, enhancing and adding events to ECG data.

Analysis
  Hemodynamics ▶
        ABP Classifier
        Arterial Blood Pressure
        Baroreflex Sequence Analysis
        Baroreflex Slope Analysis
        ECG Interval Extraction
        Estimate Cardiac Output from   Detect and Classify Heartbeats
        Left Ventricular Blood Pressure   Locate Human ECG Complex Boundaries
        LVP Classifier   Locate Animal ECG Complex Boundaries…
        MAP Classifier
        Monophasic Action Potential

- Comprehensive suite of Hemodynamic analysis routines - Sophisticated algorithms provide on- and off-line, beat-by-beat analysis of the primary cardiovascular signals such as blood pressure, cardiac output, left ventricular pressure, and more.

- Automatically locate and isolate ECG complex boundaries and other heartbeat classifications. This automated routine is also included in Biopac Student Lab software.

- Heart Rate Variability - Fully-automated analysis tool with flexible options for extracting a wide range of heart rate variability (HRV) and respiratory sinus arrhythmia (RSA) measures. This automated routine is also included in Biopac Student Lab software.

- Noninvasive Impedance Cardiography – Acq*Knowledge* offers a comprehensive array of noninvasive impedance cardiography (ICG) tools for recording parameters associated with virtually any kind of electrical bioimpedance (EBI) monitoring and bioimpedance analysis (BIA). Extracted measures can be displayed as new channels in the recording, or exported to an Excel spreadsheet or Journal file for further analysis.

Click to watch a webinar about ECG Analysis including Heart Rate Variability and Respiratory Sinus Arrhythmia Essentials.
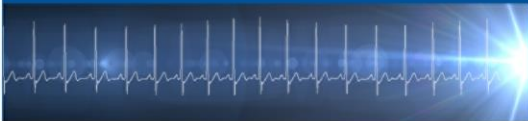
Click to read a comprehensive list of ECG FAQs.

Click to watch a Lead II Automated Analysis tutorial video

How to get great ECG Data
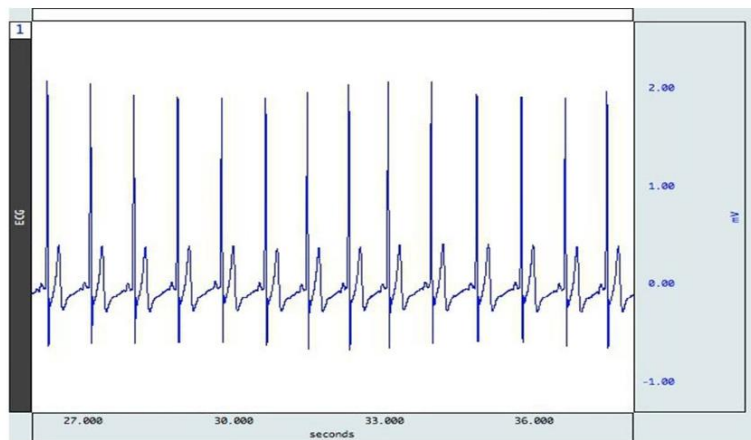
We also encourage you to review the linked ECG resources on the following pages.

Automated Analysis with Acq*Knowledge*

Einthoven Triangle and 6 Lead ECG

Ventricular Late Potentials (VLPs)

ECG Complex Boundaries

Heart Rate Variability

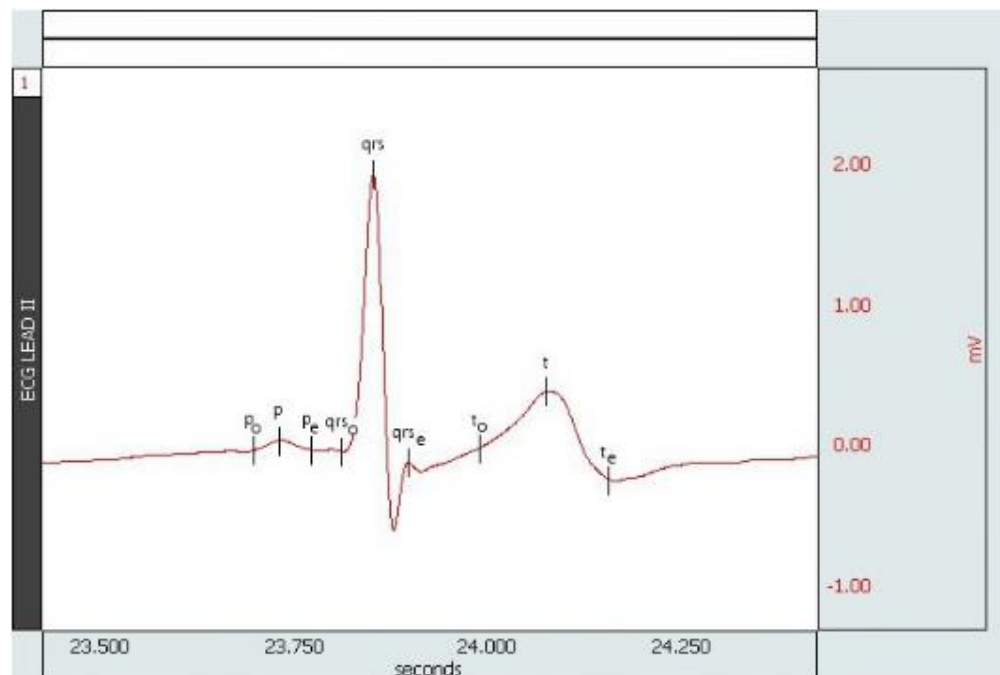Respiratory Sinus Arrhythmia (RSA) Analysis

Heart Sounds

Subject Mobility

Chaos Plot

Epoch Analysis- Automated Data Reduction

Acq*Knowledge* also includes tools for automated HRV analysis, both frequency-based and time series. There are also options for respiratory sinus arrhythmia (RSA), both frequency and time series when a respiration signal is also recorded.

Video Tutorials for Analysis

Automated ECG Analysis- Lead II

Classifying Heartbeats

Dual-Channel MRI Gating Systems-DTU200/300 Data

Locate Animal ECG Complex Boundaries in Acq*Knowledge*

EL- CHECK Portable Impedance Checker from BIOPAC

BioHarness Data Logger in Action

Knowledge Base

Clinical Chart Grid Settings For ECG

ECG Analysis

ECG Artifact in EMG Signal

ECG R-Wave Detector

Extracting Heart Rate From a Noisy ECG Signal

Application Notes

109 - 3-,6-,and 12- Lead ECG

129 - Heart Rate Variability

148 - Automated ECG Analysis

172 - Multilead ECG Cable-SS29L

177 - ECG Analysis Using the Offline Averaging Mode

206 - Continuous 12- Lead ECG

233 - Heart Rate Variability- Preparing Data for Analysis

242 - Recording ECG Data in an FMRI

279 - ECG and EDA Recording in 7-Tesla FRMI

281 - ECG Timing Delay Associated with Amplifier Filter Selections

Hardware Options for ECG

WIRED

ECG100C Advanced Amplifier for Research

MP36RWSW 4-Channel Data Acquisition System

MP160WSW 16-Channel Data Acquisition System

SS29L Multi-Lead ECG CBL

TSD155C Multi-Lead ECG CBL C-Series

EL502 Disposable Long Term Electrodes

WTC100C Wilson Terminal for ECG100C TP, 20 cm

EL513 Disposable Cloth Facial Electrodes

LEAD110 Lead Wire with Clip for EL500 Series

WIRELESS

BN-ECG2 2 CH Wireless ECG Amplifier Set

BN-ECG2-T 2 CH Wireless ECG Transmitter

BN-RSPEC Wireless RSP with ECG Amplifier

BN-BioShirt Wireless, Wearable Smart Shirt

BN-LOGGER Logger supports complex experimental design

BN Smart Center Essentials System includes BioNomadix ECG, Enhanced System includes extra transmitters and BN-Logger

EPOCH-ECG-SYS Wireless ECG Systems

EPOCH-ECG-SEN Wireless ECG Transmitters

MRI

Human and Animal

ECG100C-MRI Wired MRI ECG

DTU200 MRI Gating System for Two Signals (Small Animal)

DTU300 MRI Gating System for Two Signals (Large Animal)

GATE-CARD-E(L) Complete Dual-Channel Gating System

EL508 Disposable Radiotranslucent Electrode

LEAD108B/C Clip Lead, Unshielded, 15 cm or 30 cm options

Research Citations

Selected citations below—search online for more than 8,250 BIOPAC Citations for ECG.

A Wearable Context-Aware ECG Monitoring System Integrated with Built-in Kinematic Sensors of the Smartphone

Fen Miao, Yayu Cheng, Yi He, Qingyun He and Ye Li

Body Dissatisfaction and Mirror Exposure: Evidence for a Dissociation Between Self-Report and Physiological Responses in Highly Body-Dissatisfied Women

Fátima Servián-Franco, Silvia Moreno-Domínguez, Gustavo A. Reyes del Paso

Characterizing Psychological Dimensions in Non-Pathological Subjects Through Autonomic Nervous System Dynamics

Nardelli, et al

Differences in Kinematics and Heart Rate Variability Between Winner and Loser of Various Skilled Levels During Competitive Golf Putting Tournament

Choi, et al

Rapid Stress System Drives Chemical Transfer of Fear from Sender to Receiver

Jasper H.B. de Groot, Monique A.M. Smeets, Gün R. Semin

Reduced Room for Cardiac Vagal Modulation to Increase and Cardiac Sympathetic Modulation to Decrease by Resting in Football Players

Wan-An Lu, Yu-Chung Chen and Cheng-Deng Kuo

Simulating Murder: The Aversion to Harmful Action

Fiery Cushman, Kurt Gray, Allison Gaffey & Wendy Berry Mendes

The Effects of Measuring Emotion: Physiological Reactions to Emotional Situations Depend on Whether Someone Is Asking

Karim S. Kassam, Wendy Berry Mendes

The Psychology of Common Knowledge: Coordination, Indirect Speech, and Self-Conscious Emotions

Thomas, Kyle

Transforming or Restraining Rumination: The Impact of Compassionate Reappraisal Versus Emotion Suppression on Empathy, Forgiveness, and Affective Psychophysiology

Charlotte Van Oyen Wityliet

Unified Frame of Reference Improves Inter-Subject Variability of Seismocardiograms

Mikko Paukkunen, Petteri Parkkila, Raimo Kettunen and Raimo Sepponen

Unstable Power Threatens the Powerful and Challenges the Powerless: Evidence from Cardiovascular Markers of Motivation

Daan Scheepers, Charlotte Röell and Naomi Ellemers