Computer-aided measurement techniques

Department of Medical Informatics
Faculty of Medicine
University of Szeged

MAGYARORSZÁG - ROMÁNIA
ÉS MAGYARORSZÁG - SZERBIA ÉS MONTENEGRÓ
Határon Átnyúló Együttműködési Program

Contents

- course outline
- aims
- structure
- lecture outline
- laboratory practicals
  - measurement design
  - electromyography
  - electrocardiography
  - blood pressure measurement
  - respiratory function

Course outline

- aims

To track the link between the world of the continuous analogue signals and the digital processing methods.

To address the main components of this link via the examples of typical non-invasive medical measurements.

Course outline

- structure

Lecture: basic module (4 hrs):
fundamentals and tools of measurement techniques and signal processing

Laboratory practicals (4x2 hrs):
measurement task • physiological background • joint measurements & data acquisition

Individual work (4x2 hrs):
off-line processing of recorded data • report preparation

Seminar (2 hrs):
discussion of findings • conclusions

Course outline

- Lecture: fundamentals and tools of measurement techniques and signal processing

basic concepts: signals vs data
classification of signals
transducers
signal conditioning
sampling
analog-to-digital conversion

pre-processing in the time domain
pre-processing in the frequency domain

LECTURE OUTLINE

Discrete (digital) data vs. continuous (analog) signals

SIGNALS:

Physical quantities changing (continuously) in time. They carry dynamic information.

Examples: blood pressure recordings, ECG, EEG, EMG, respiratory airflow and pressures.

Discrete (digital) data vs. continuous (analog) signals

DATA:

- Measured (numerical) values; they can be entered in the computer either manually or from an "intelligent" measuring device directly.

  Examples: blood gas concentrations determined from blood samples, readings of systolic and diastolic blood pressure values

- Sample sequences from a (continuous) signal.

DETERMINISTIC SIGNALS

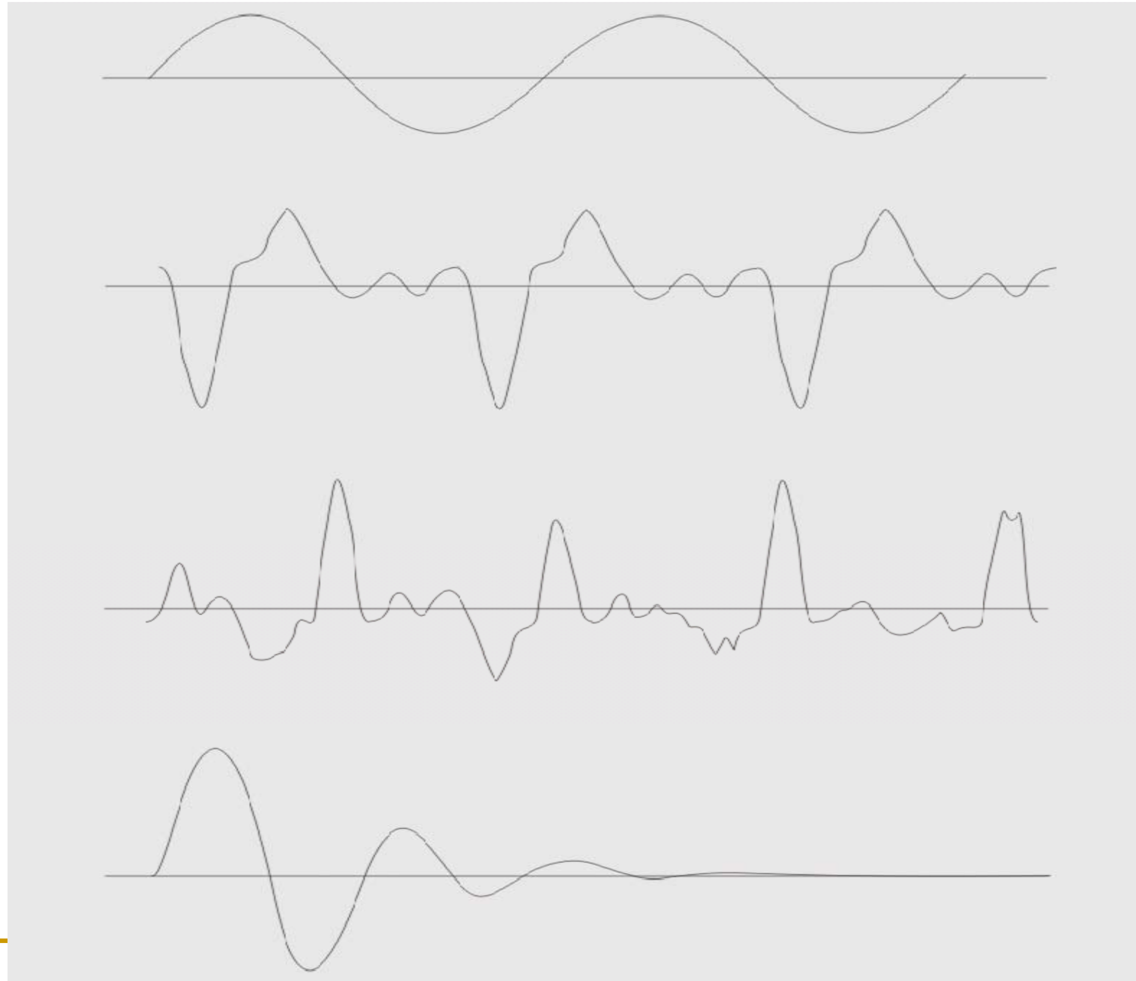
Any future value can be predicted on the basis of past values

HARMONIC

PERIODIC

QUASI-PERIODIC

TRANSIENT



NON-DETERMINISTIC SIGNALS

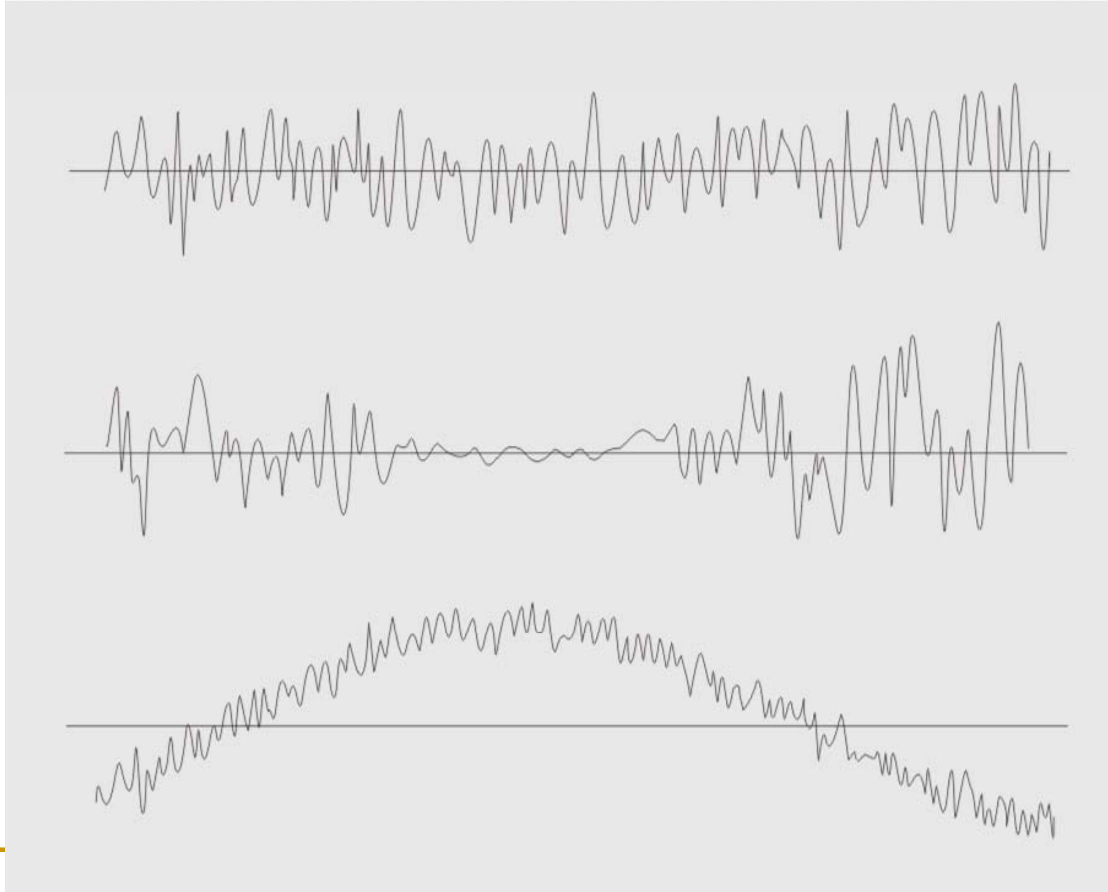
(random or stochastic processes)

The temporal change of the signal cannot be predicted by exact mathematical methods. There are statistical means of characterization.

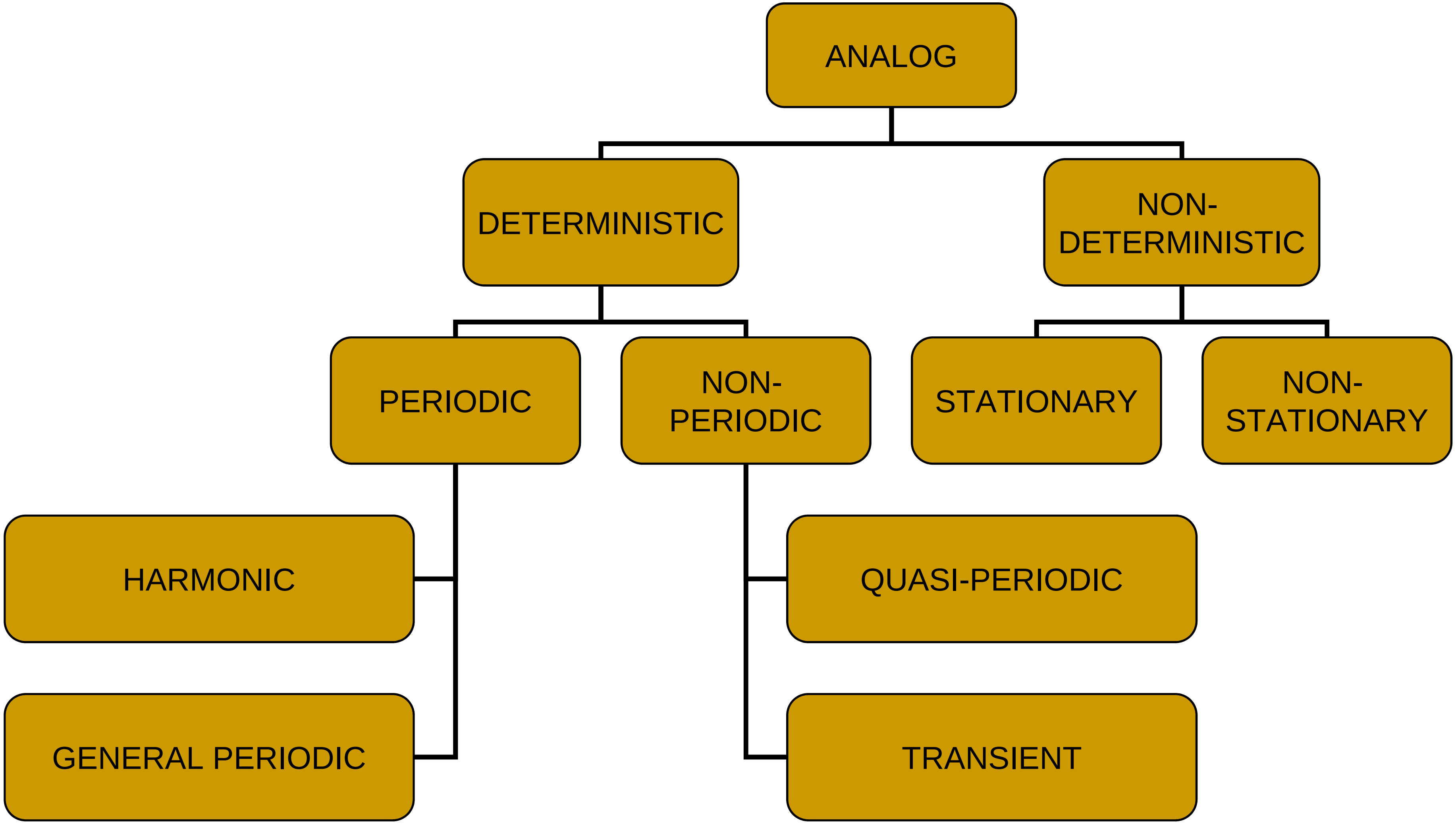
STATIONARY

NON- STATIONARY
(CHANGING POWER)

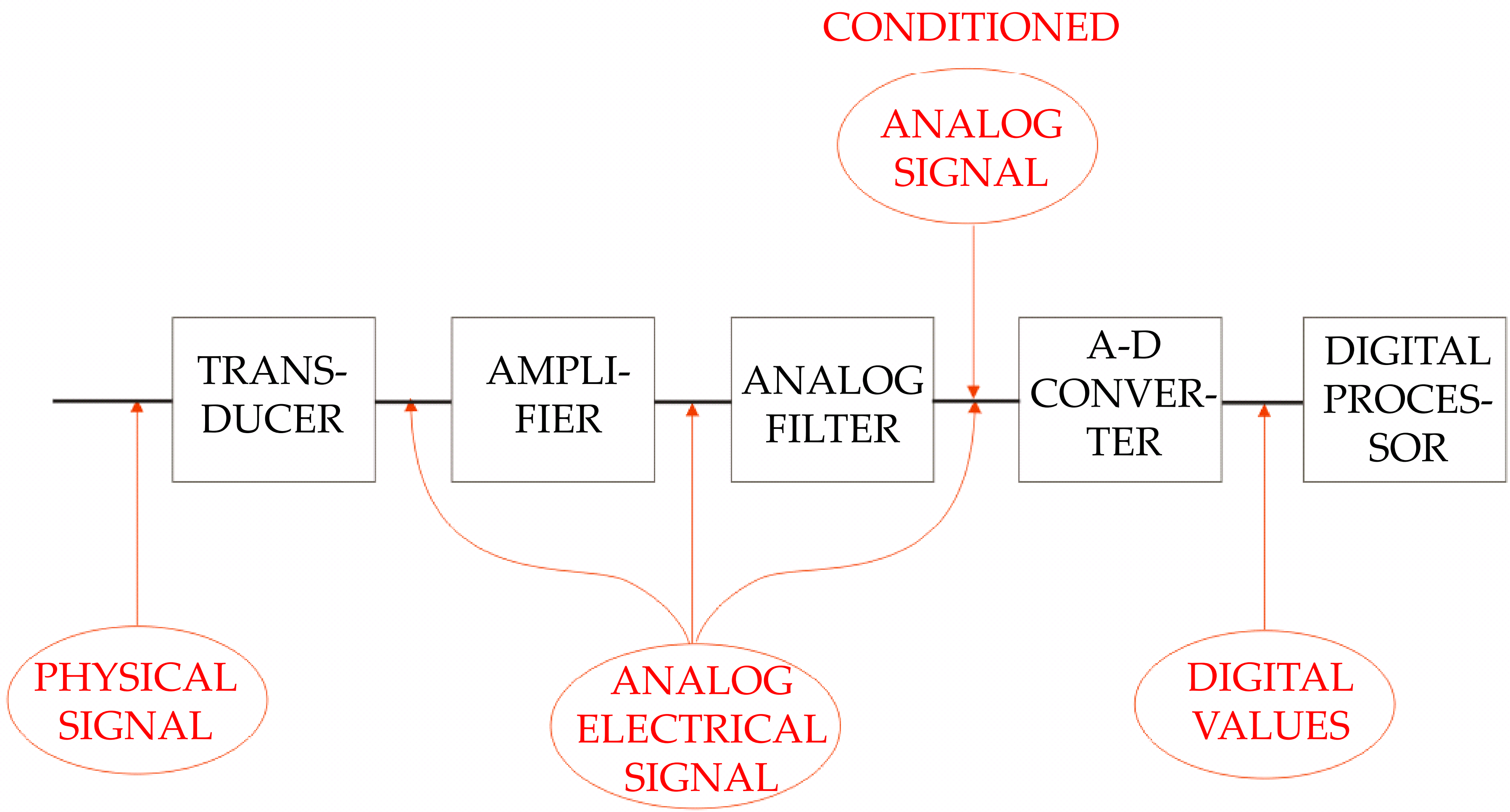
NON- STATIONARY
(CHANGING MEAN)



CLASSIFICATION OF ANALOG SIGNALS



SIGNAL ACQUISITION AND PRE-PROCESSING



TRANSDUCERS (SENSORS)

input (x) → *transducer* → output (y)

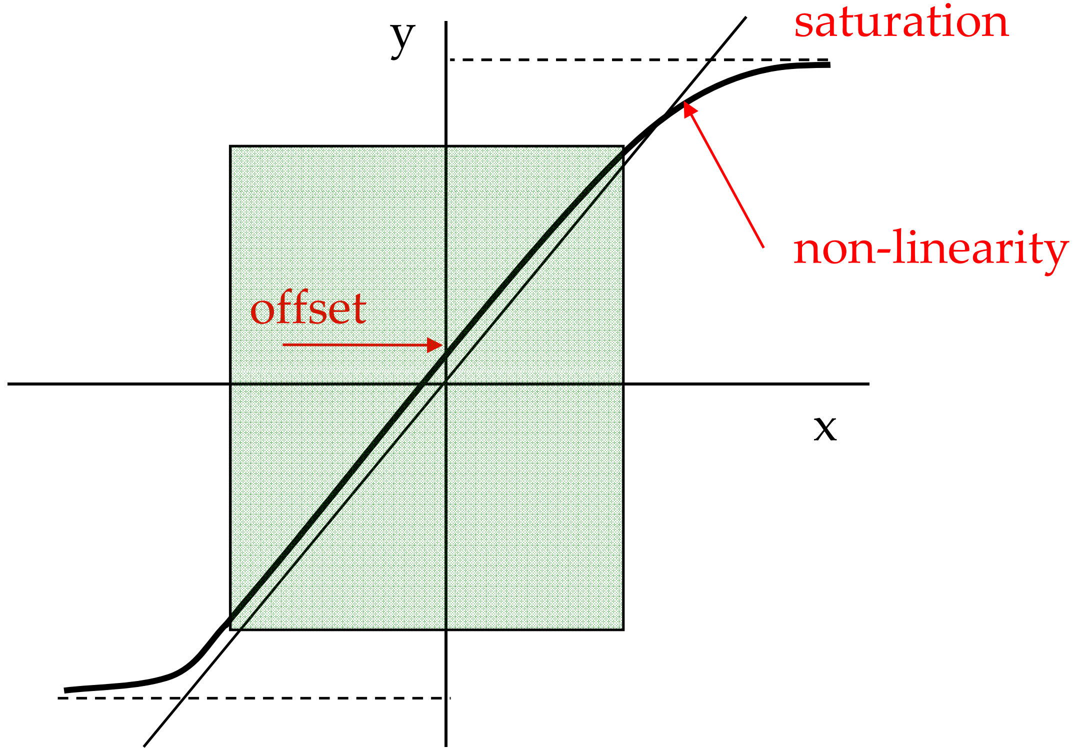
- *temperature*
- *force*
- *pressure*
- *velocity*
- *acceleration*
- *voltage*

etc.

voltage

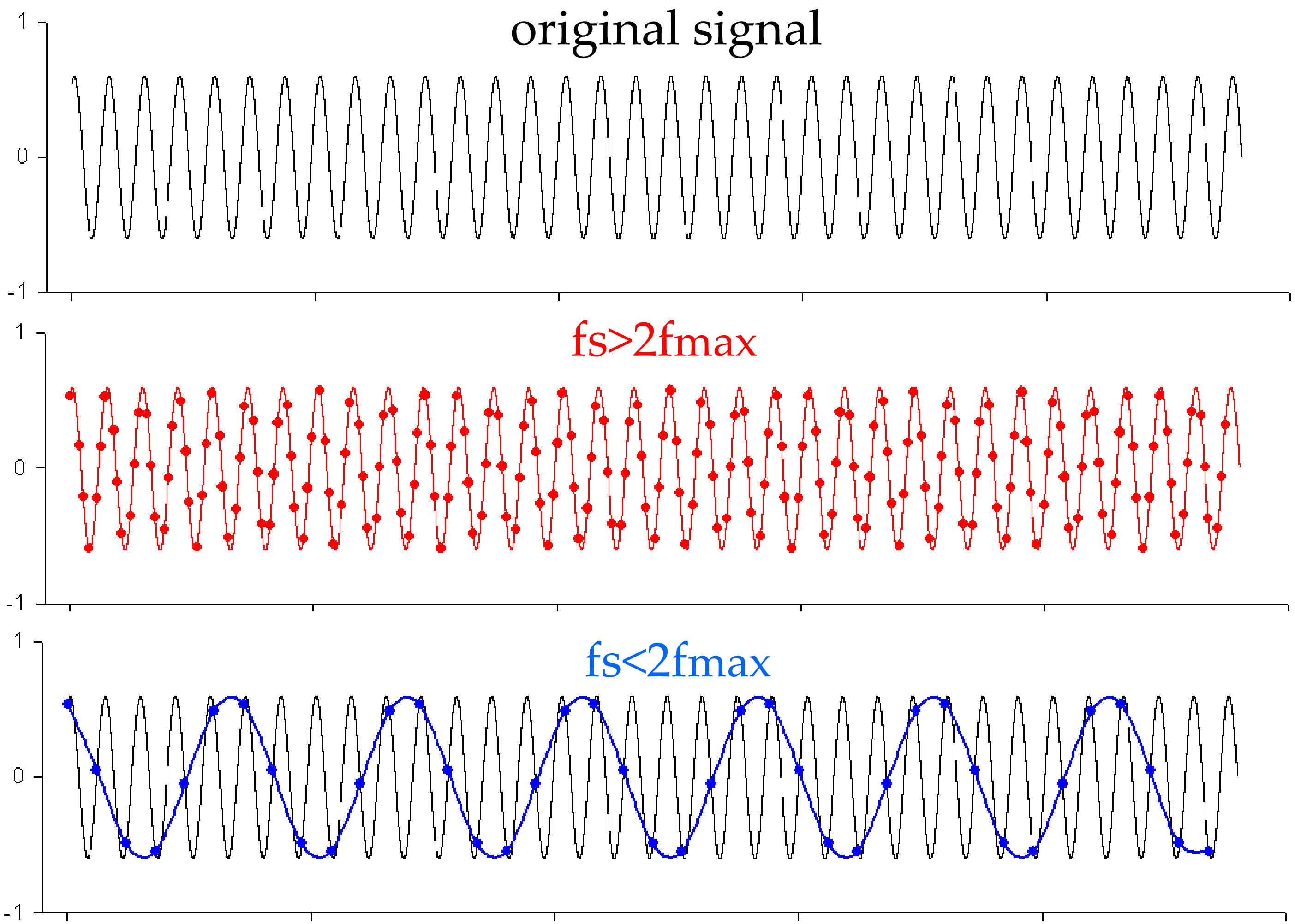
<u>characteristics</u>:

linearity
sensitivity
input range
(zero) stability
price

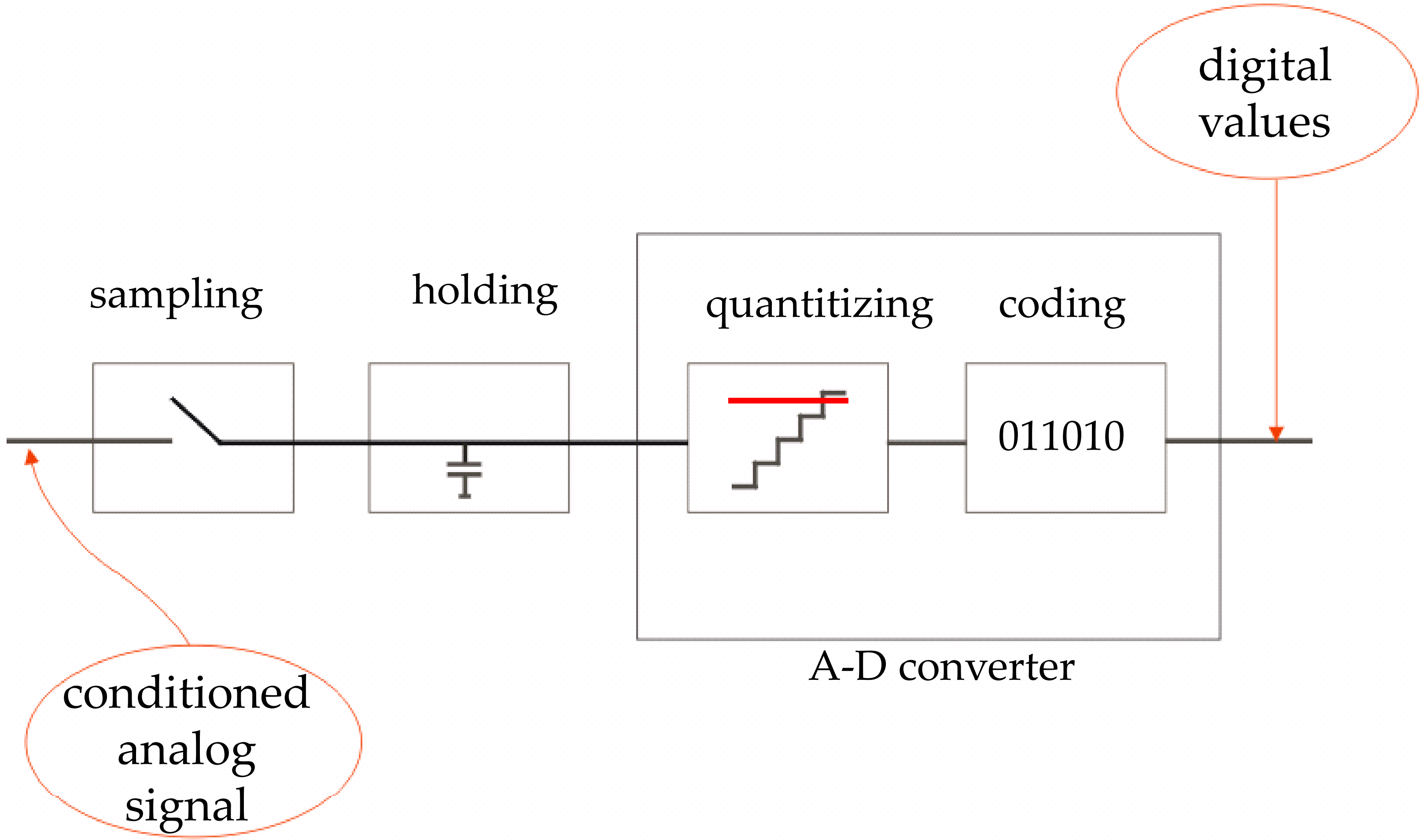


Shannon's Sampling Theorem:

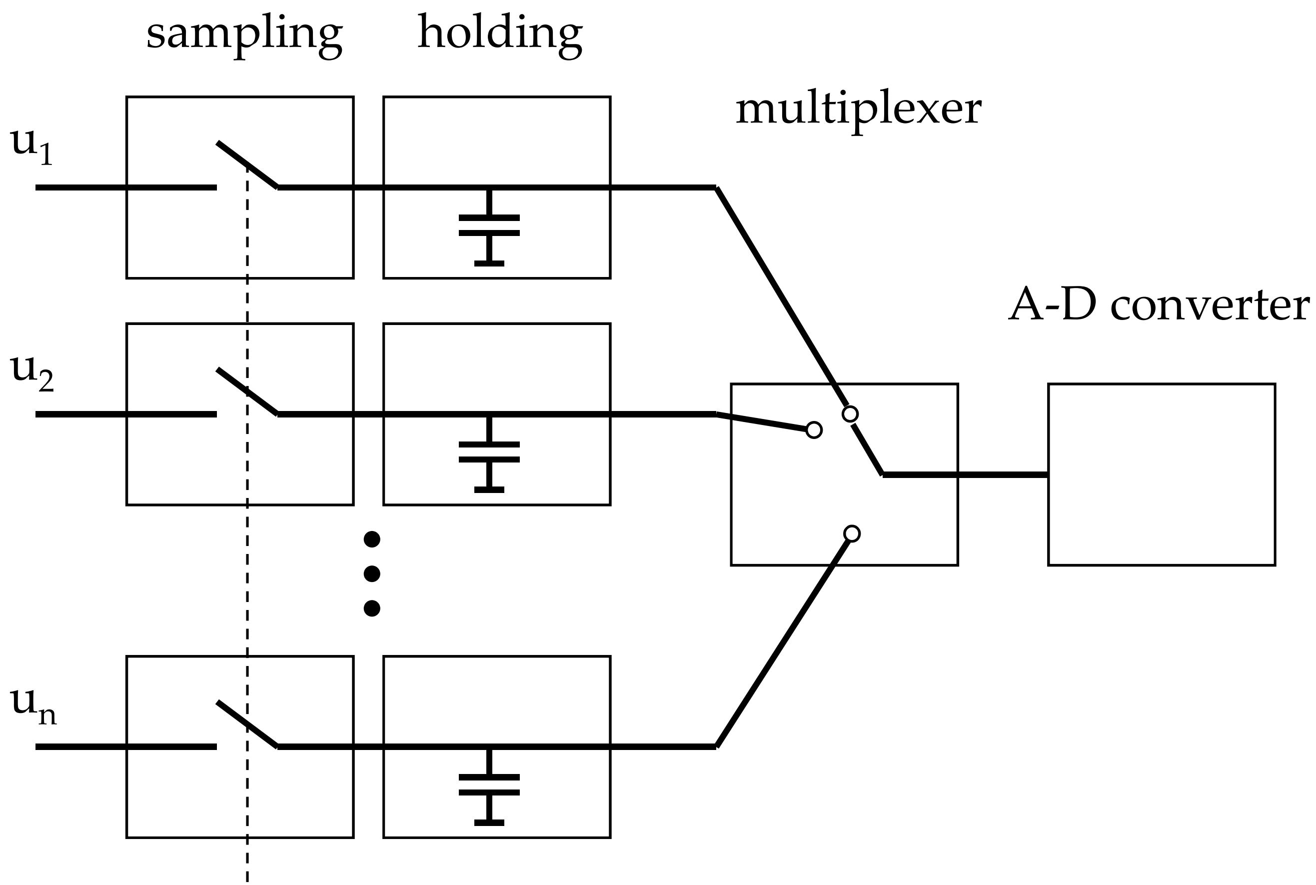
Sampling frequency ≥ 2(max. frequency)



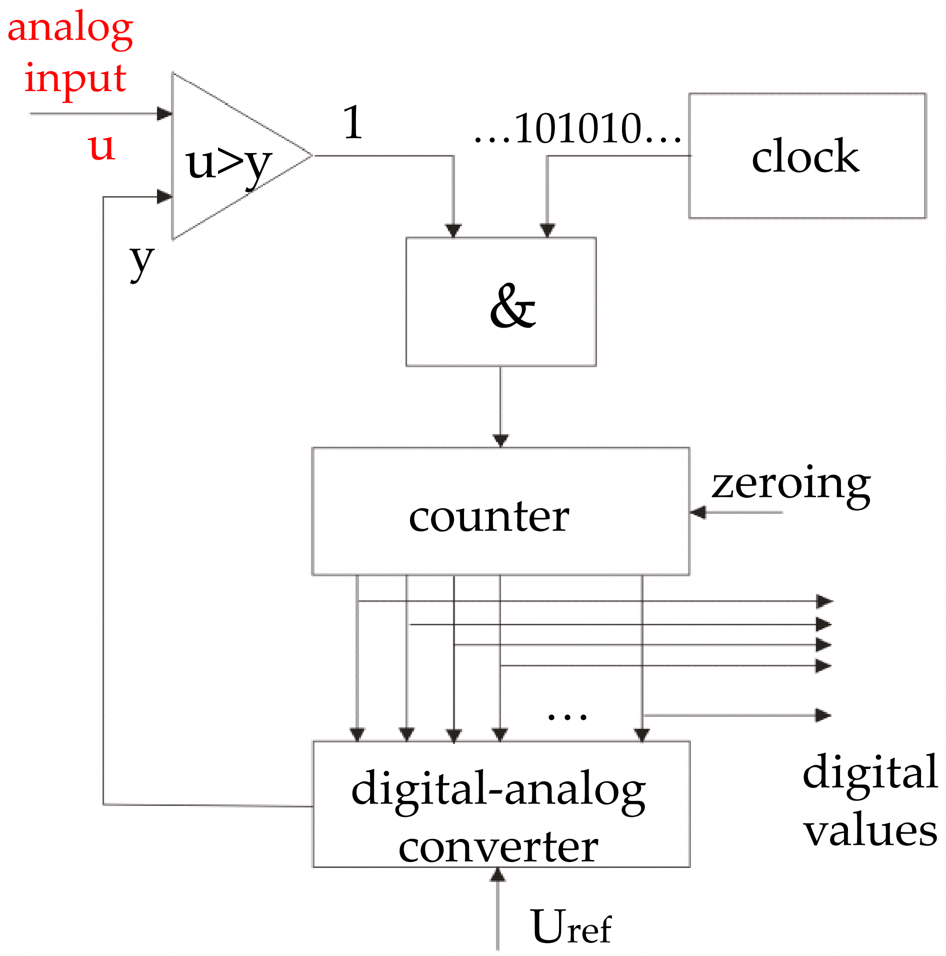
ANALOG-DIGITAL CONVERSION

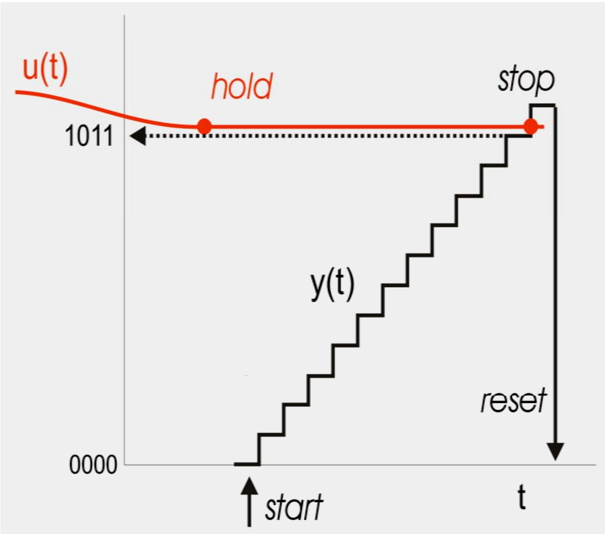


MULTICHANNEL CONVERSION

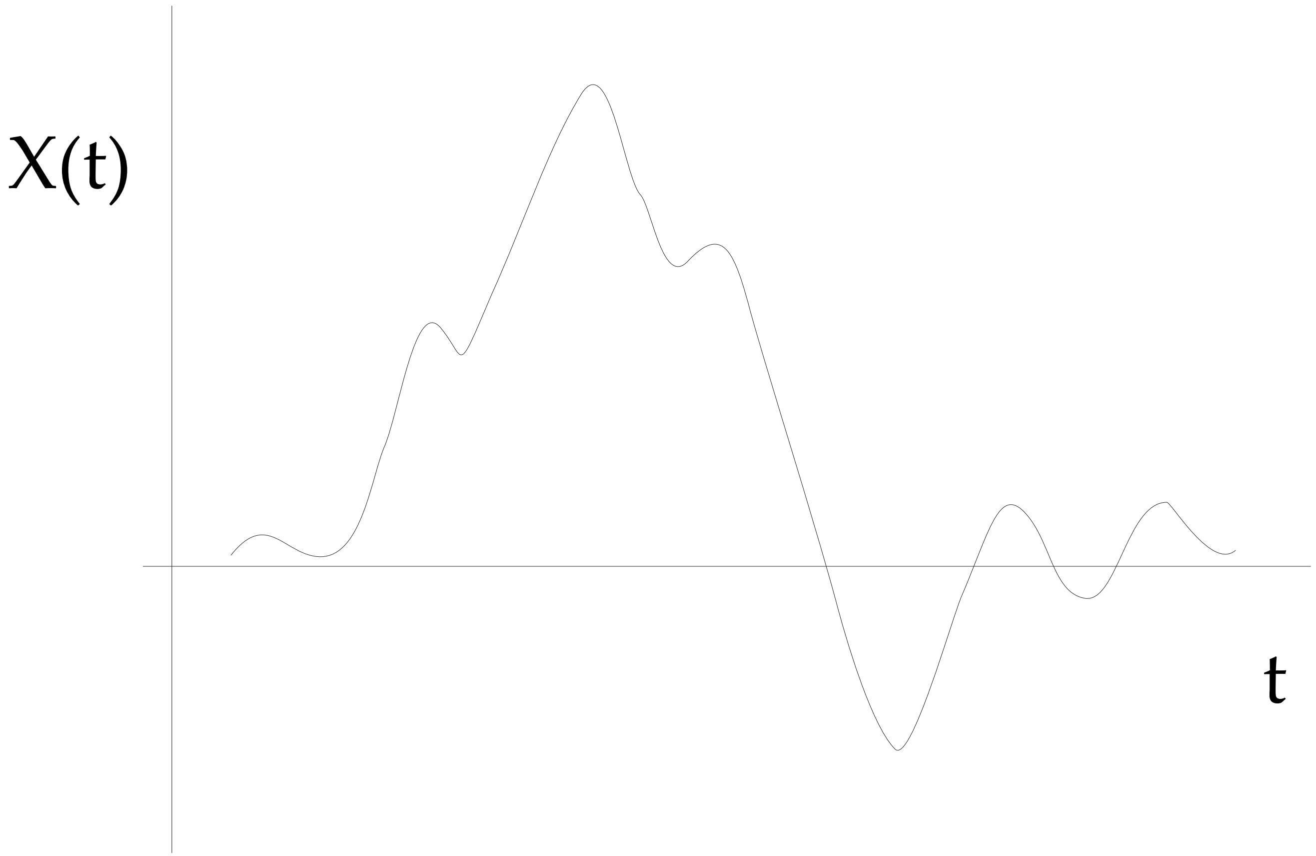


ANALOG-DIGITAL CONVERSION

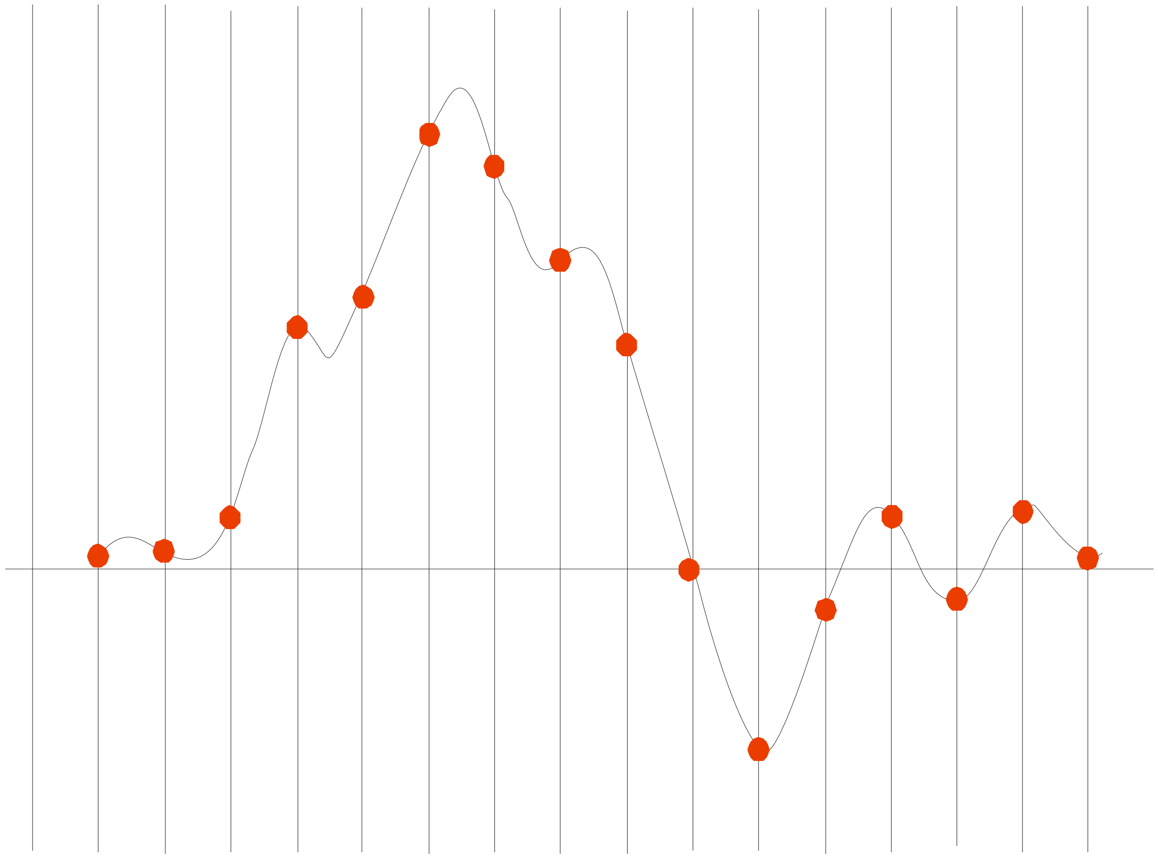




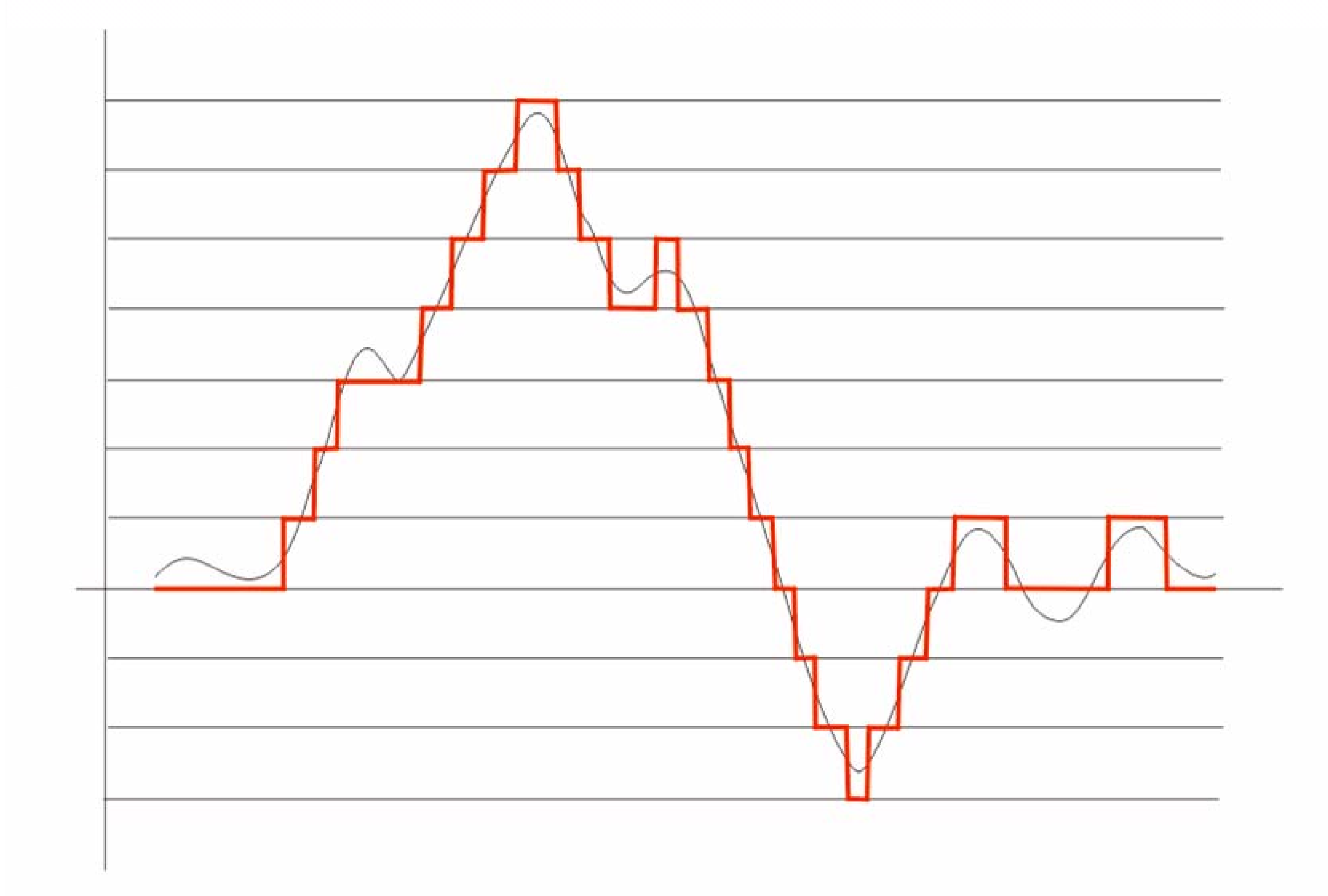
VALUES: CONTINUOUS
TIME: CONTINUOUS



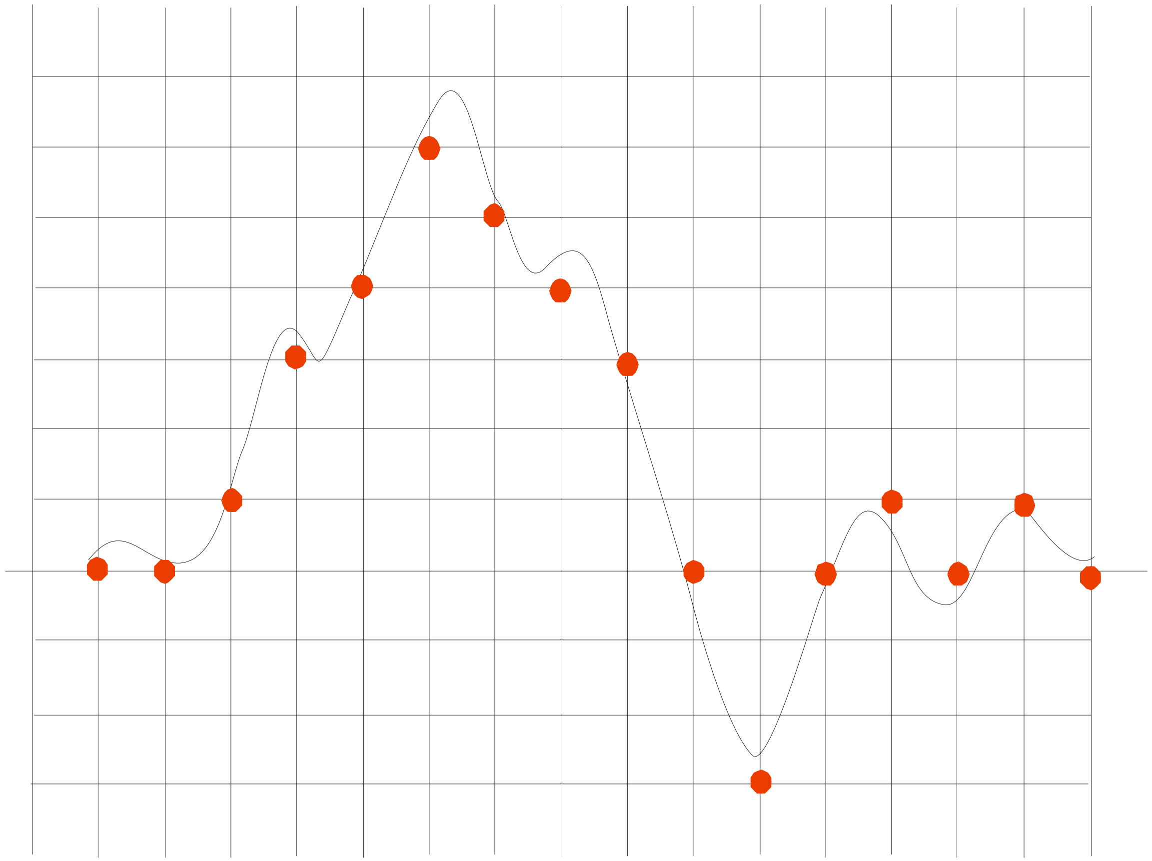
VALUES: CONTINUOUS
TIME: DISCRETE



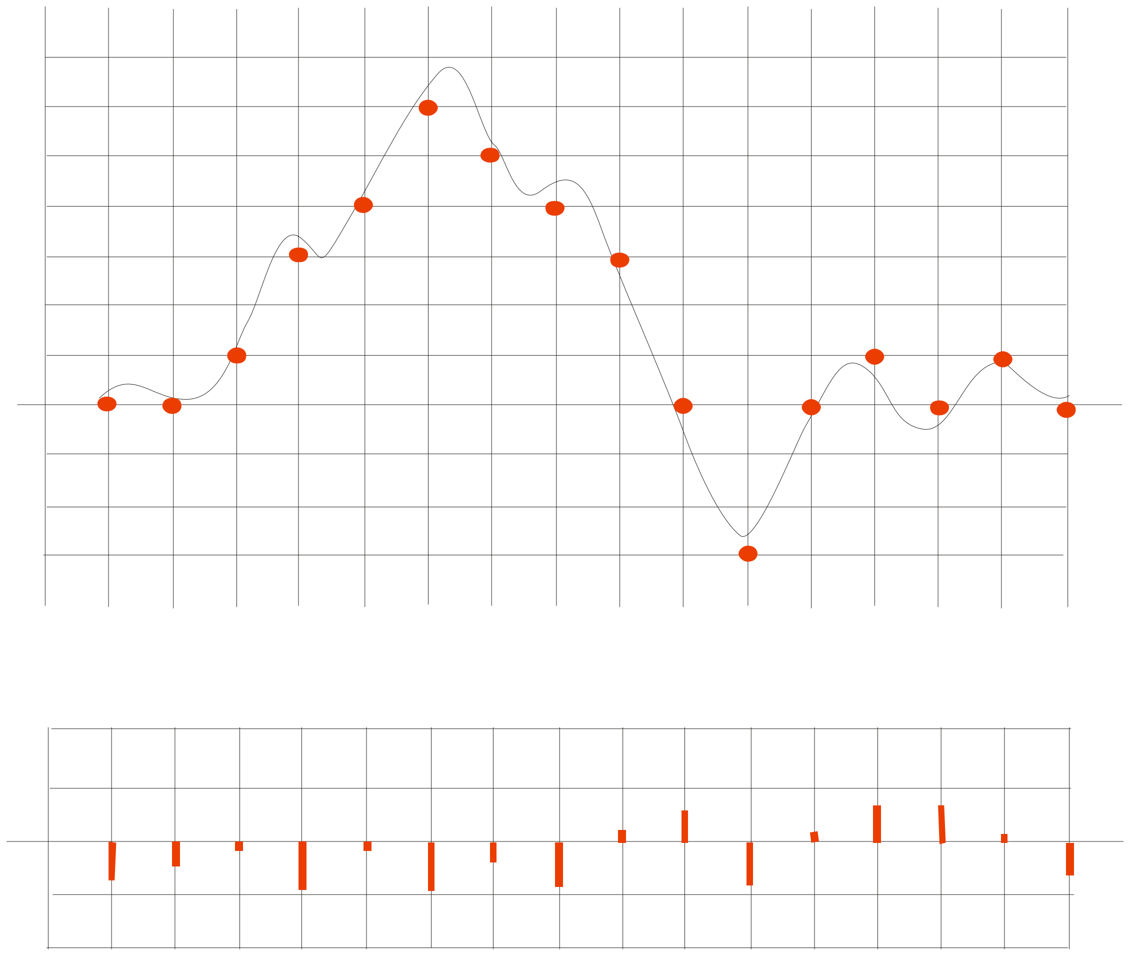
VALUES: DISCRETE
TIME: CONTINUOUS



VALUES: DISCRETE
TIME: DISCRETE



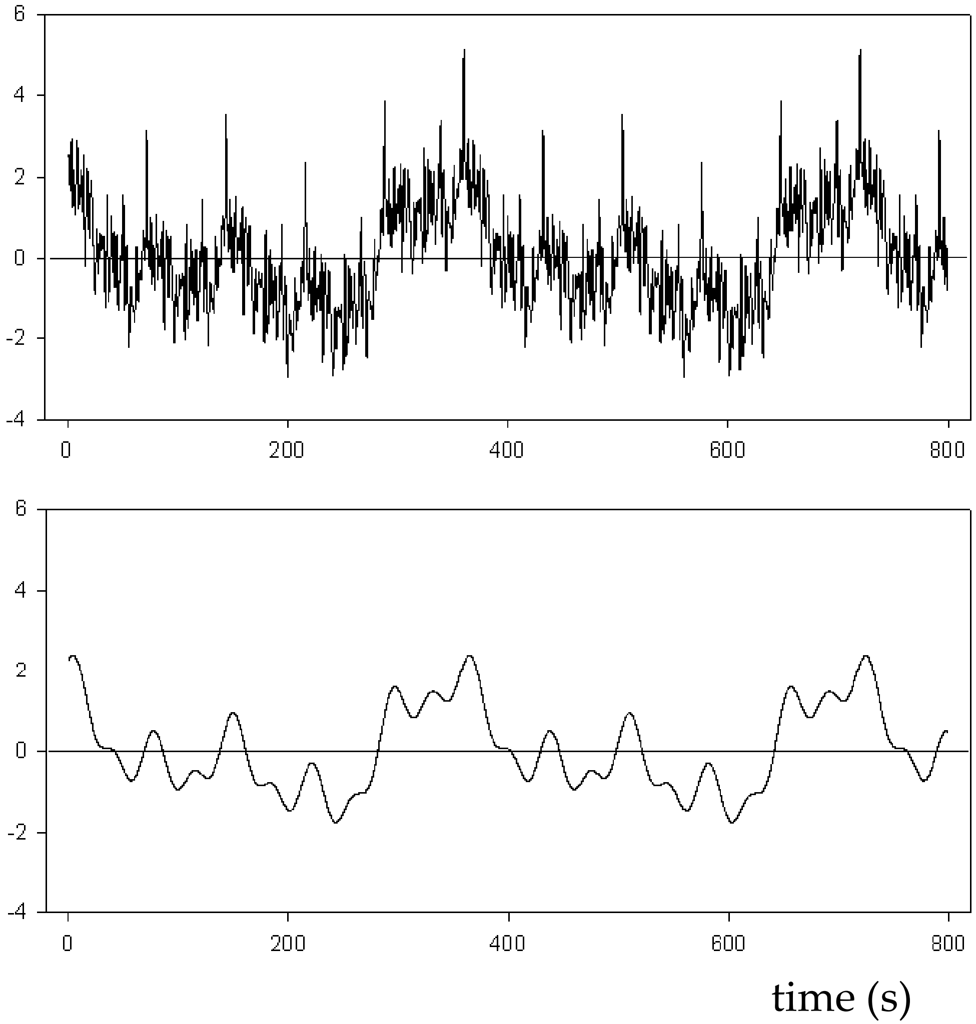
QUANTITATION ERROR

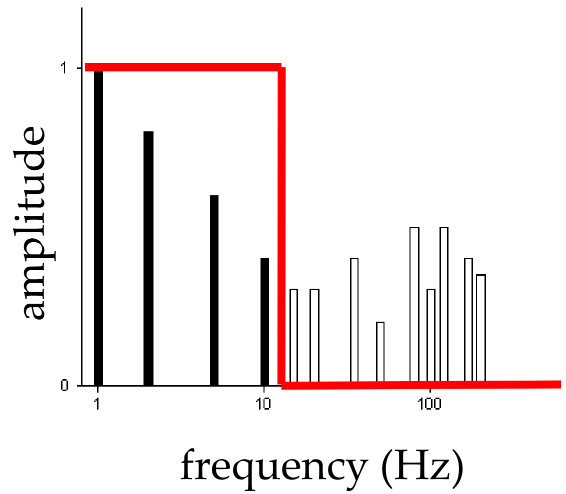


RESOLUTION OF THE A-D CONVERSION

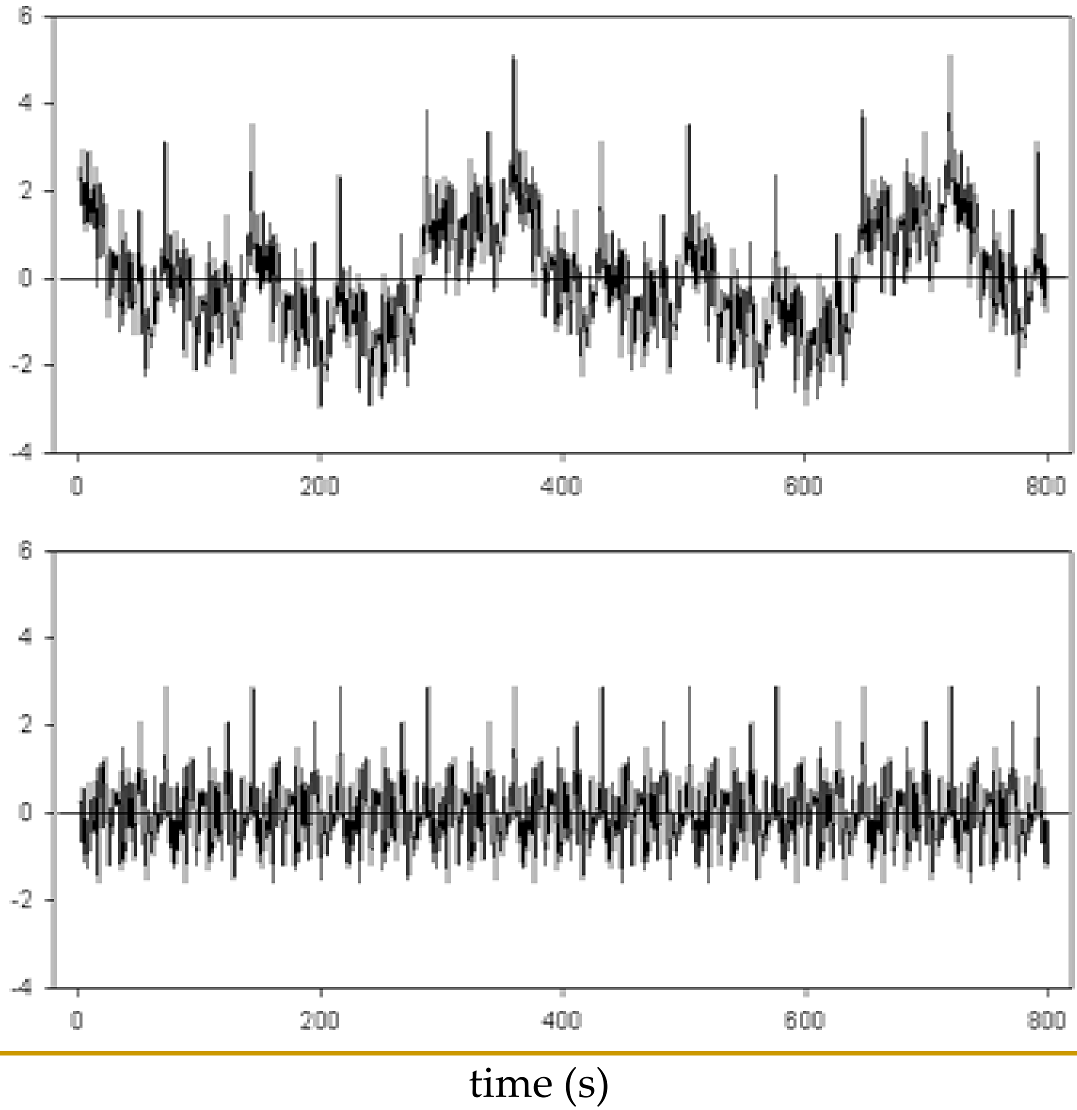
word length (bit)	No. of ranges	resolution (%)
1	2	50
2	4	25
3	8	12.5
…	…	…
8	256	0.391
10	1024	0.098
12	4096	0.024
16	65536	0.0015

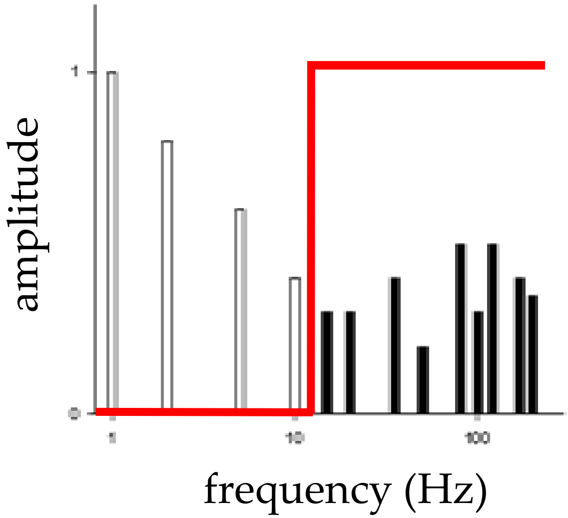
LOW-PASS FILTERING



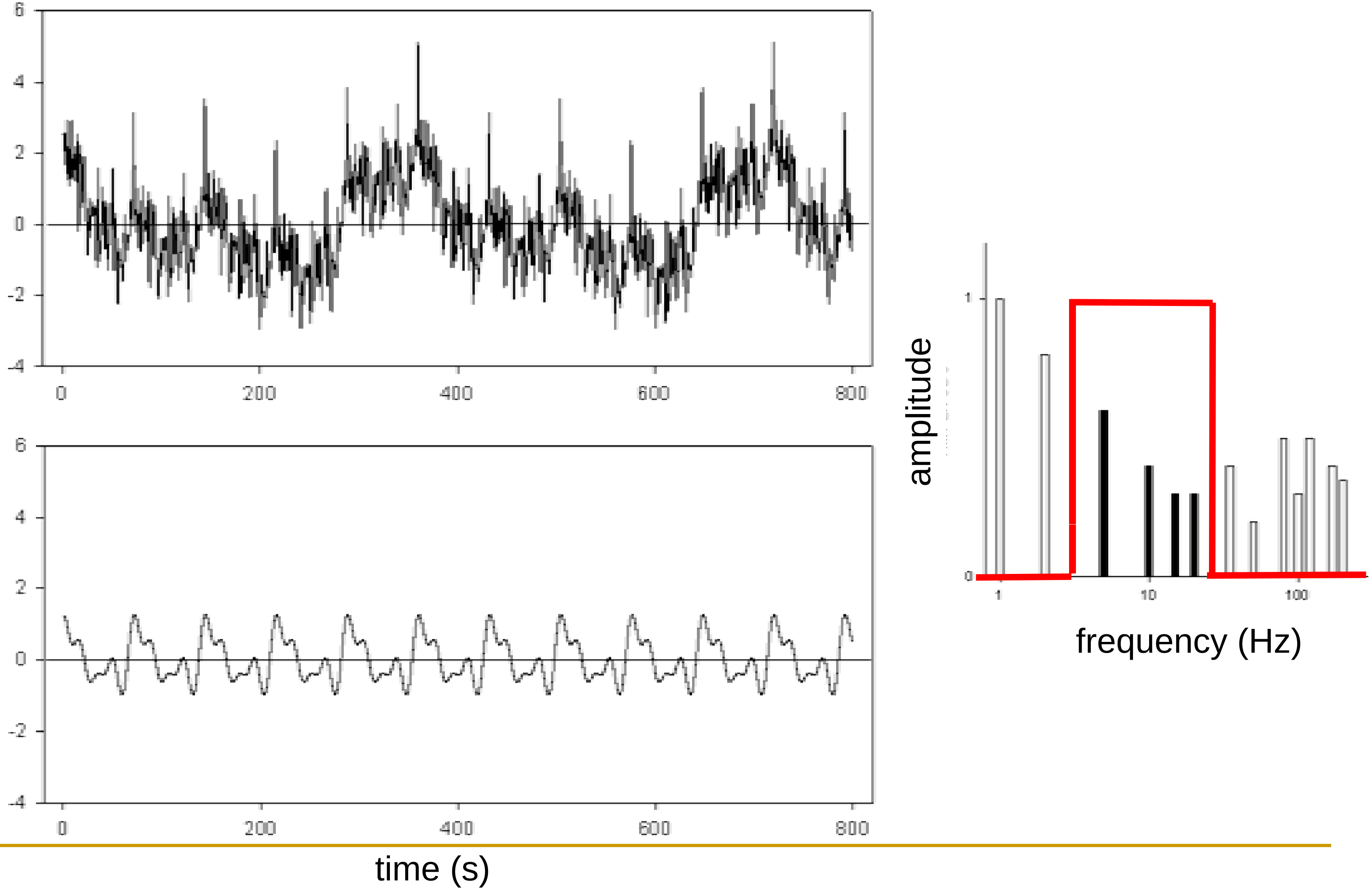


HIGH-PASS FILTERING

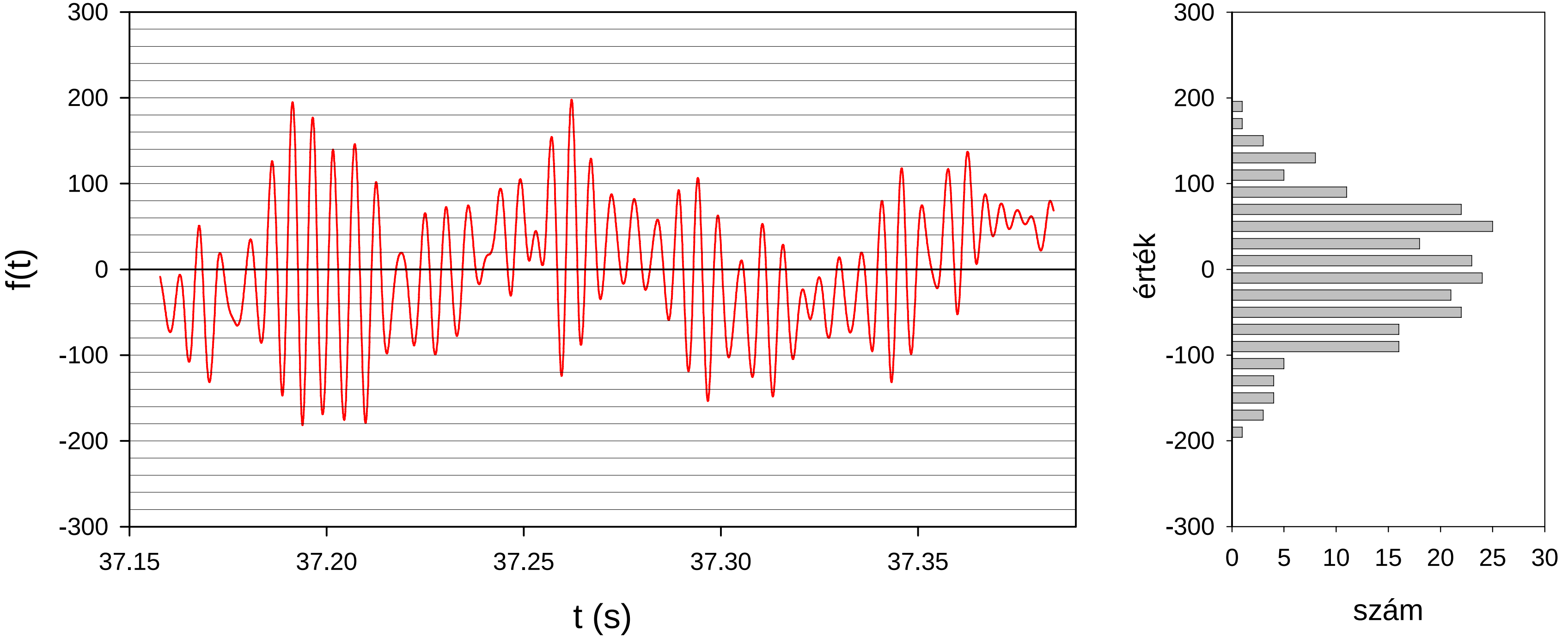




BAND-PASS FILTERING



Characterization of stochastic signals: amplitude distribution



LABORATORY PRACTICALS

Course outline

- structure

Lecture: basic module (4 hrs):
fundamentals and tools of measurement techniques and signal processing

Laboratory practicals (4x2 hrs):
measurement task • physiological background • joint measurements & data acquisition

Individual work (4x2 hrs):
off-line processing of recorded data • report preparation

Seminar (2 hrs):
discussion of findings • conclusions

Course outline

- topics and infrastructure

BIOPAC®
STUDENT LAB SYSTEM

1. electromyography (EMG)
2. electrocardiography (ECG)
3. non-invasive blood pressure (BP)

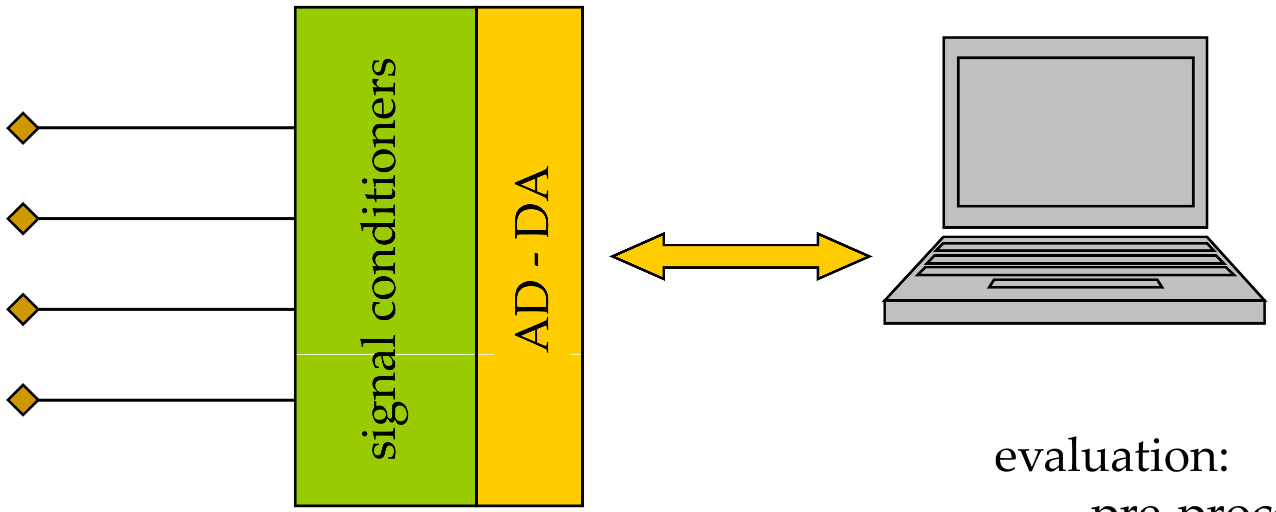
PISTON®
spirometry system

WinLung forced oscillation laboratory system

4. respiratory mechanics (RM)
5. electroencephalography (EEG)*
6. reaction time*
7. skin galvanic response*
8. respiratory cycle*
9. polygraphy*

* practicals ready for course extension

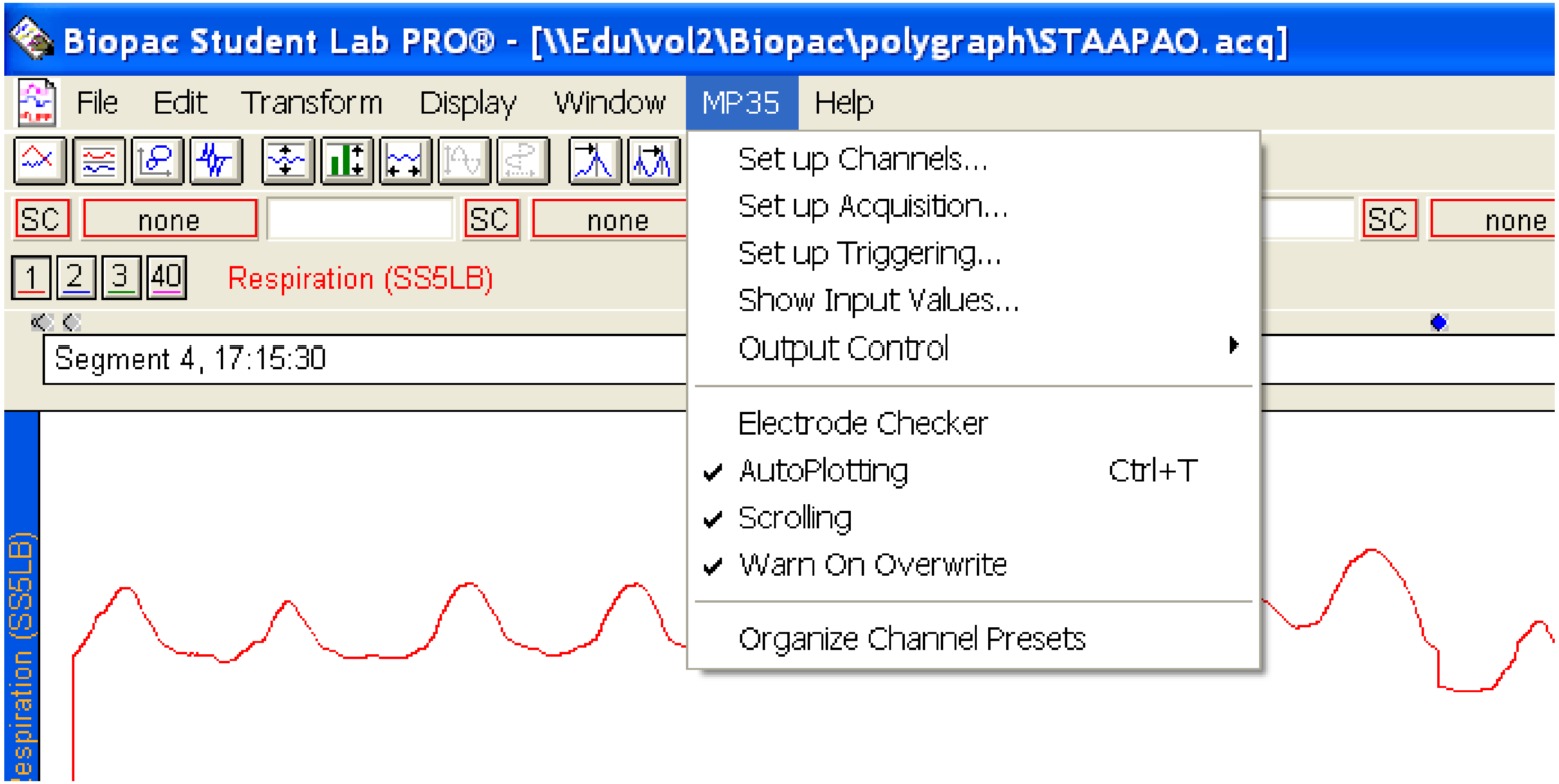
BIOPAC STUDENT LAB SYSTEM



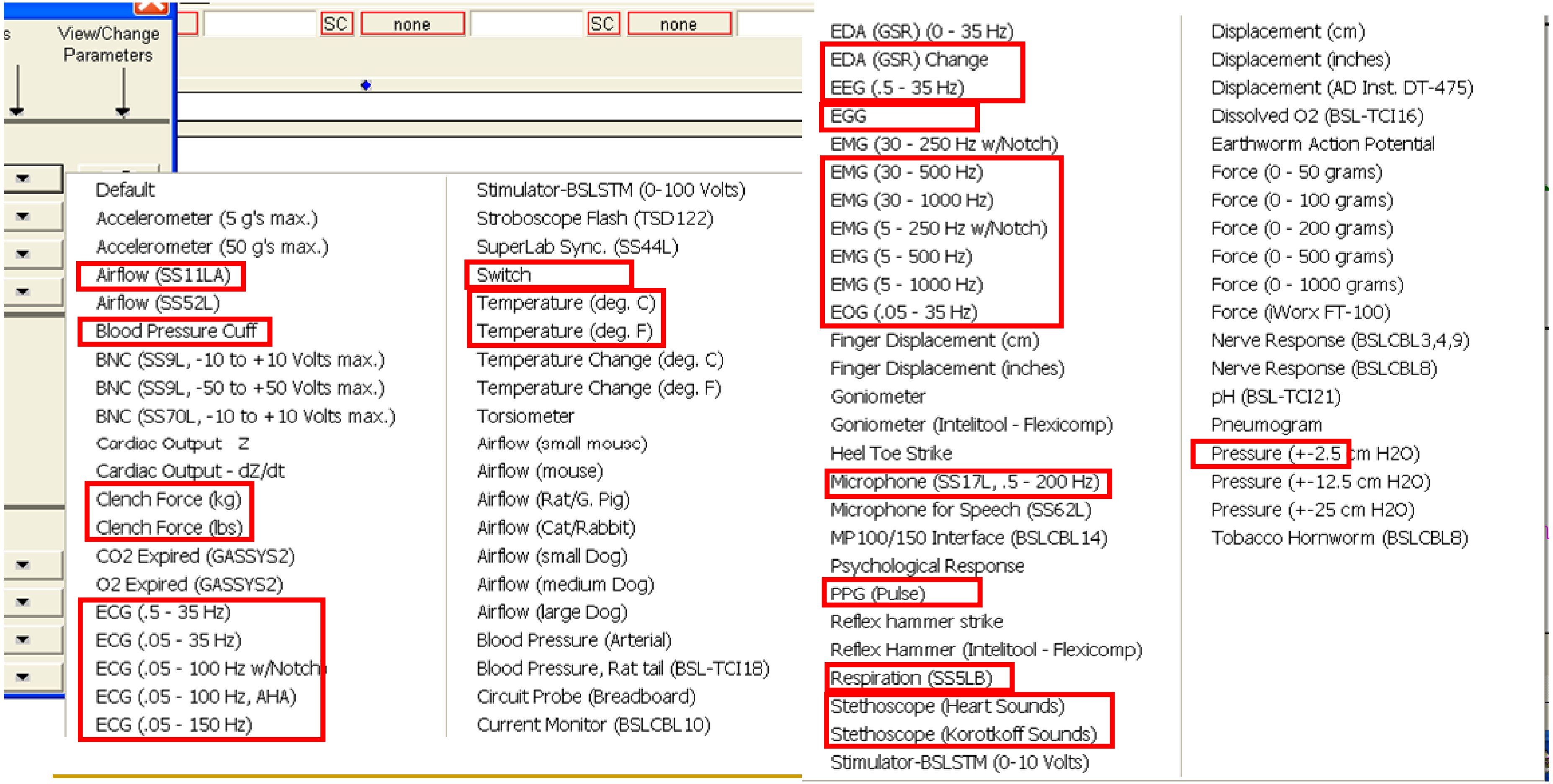
sensors:
- electrodes
- pressure transducers
- switches
- .
- .
- etc.

evaluation:
- pre-processing
- time intervals
- frequency content
- correlation
- .
- .
- etc.

setting-up

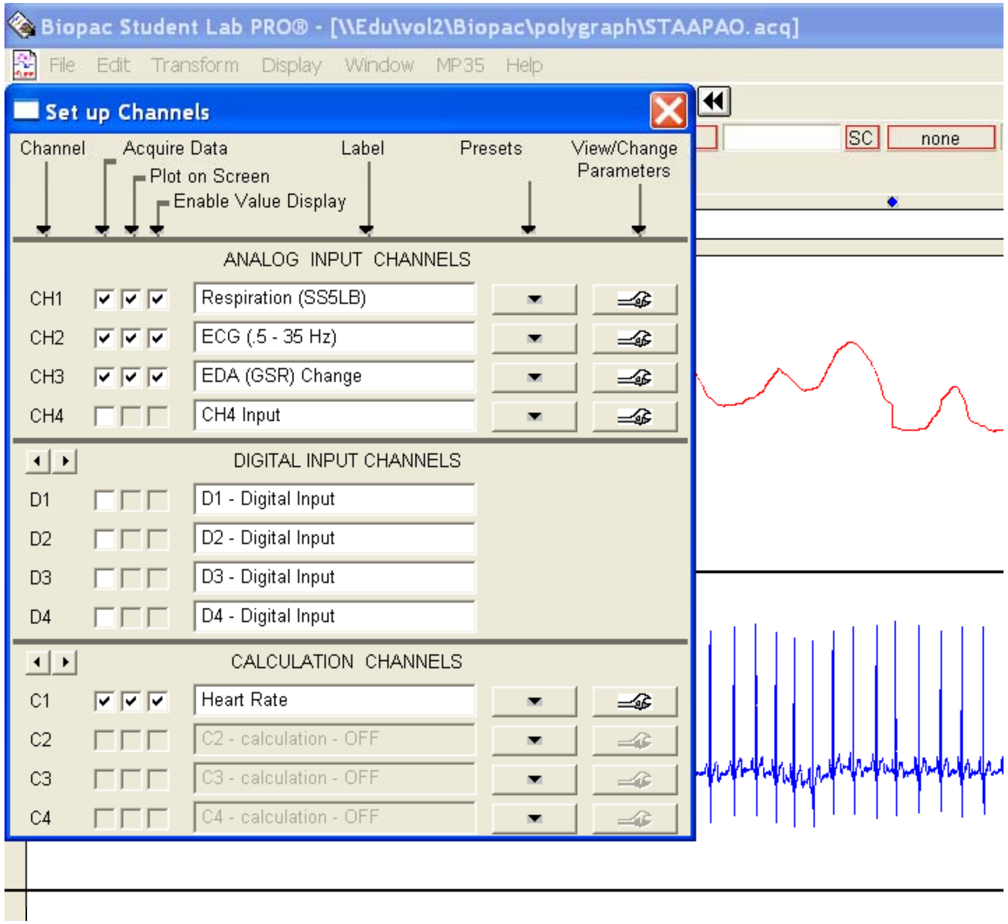

Biopac Student Lab PRO® - [\\Edu\vol2\Biopac\polygraph\STAAPAO.acq]
File
Edit
Transform
Display
Window
MP35
Help
SC
none
SC
none
SC
none
1
2
3
40
Respiration (SS5LB)
Segment 4, 17:15:30
Set up Channels...
Set up Acquisition...
Set up Triggering...
Show Input Values...
Output Control
Electrode Checker
AutoPlotting
Ctrl+T
Scrolling
Warn On Overwrite
Organize Channel Presets
Respiration (SS5LB)

setting-up: sensors



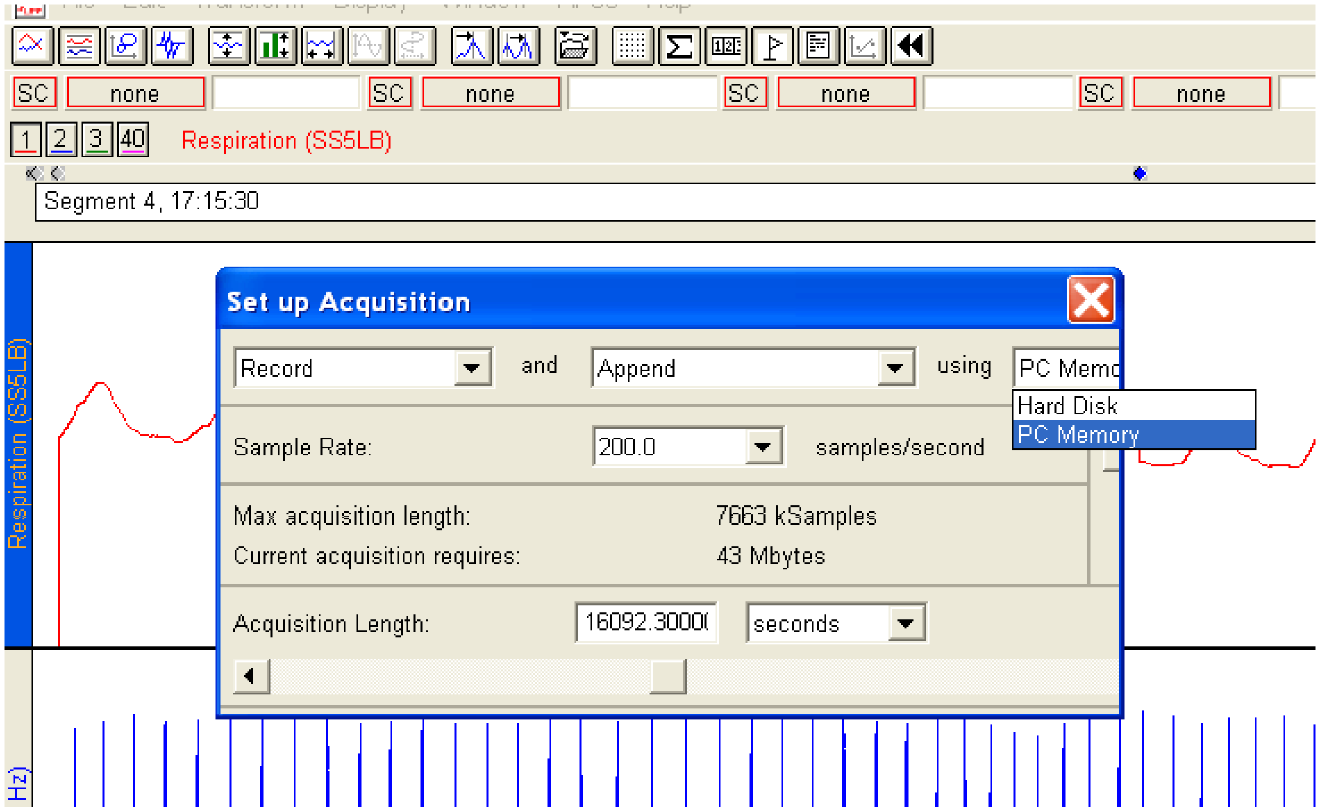
BIOPAC STUDENT LAB SYSTEM

setting-up: channels

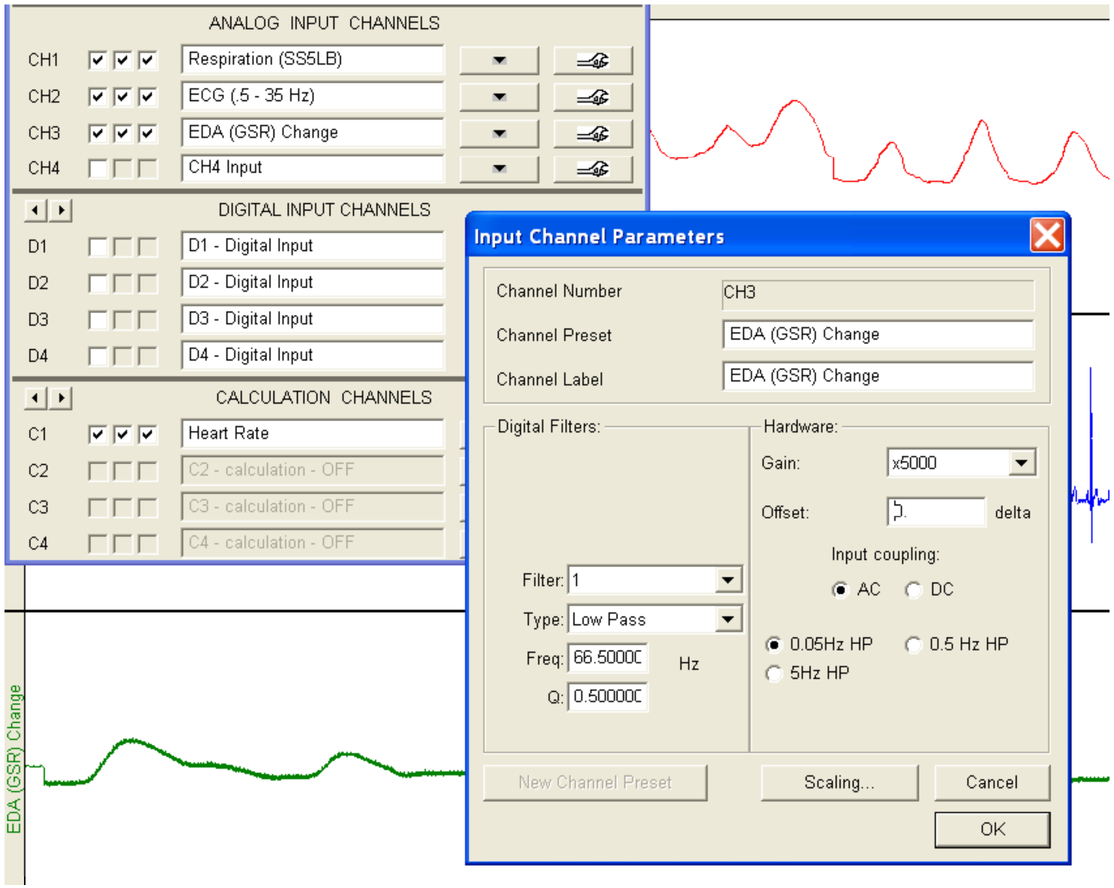


BIOPAC STUDENT LAB SYSTEM

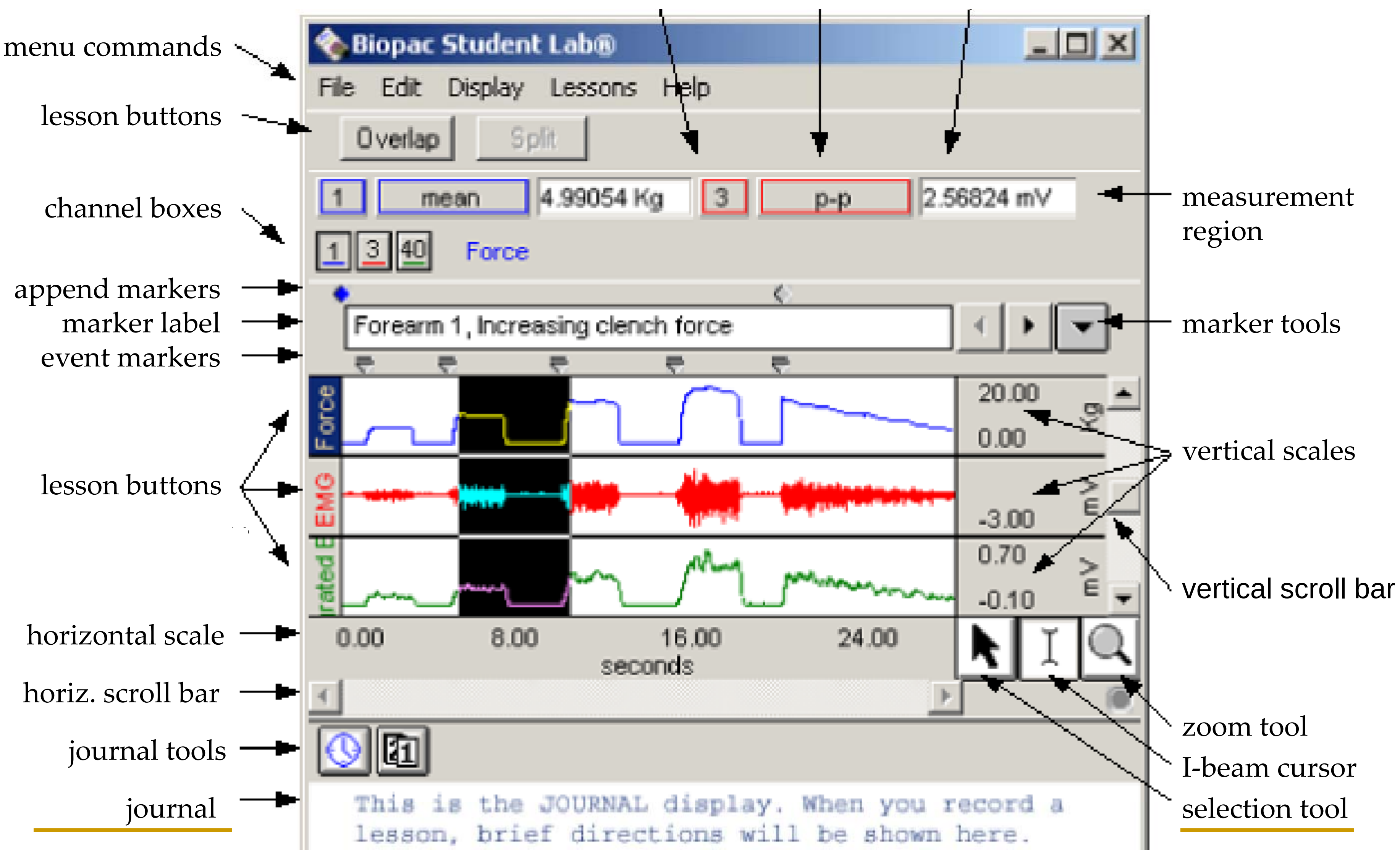
setting-up: recording length & sampling



setting-up: channel parameters



Biopac SL SYSTEM screen

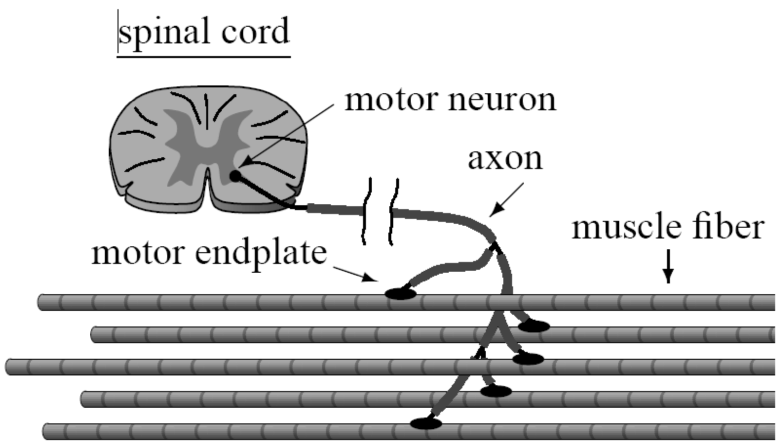


electromyography

basics

background

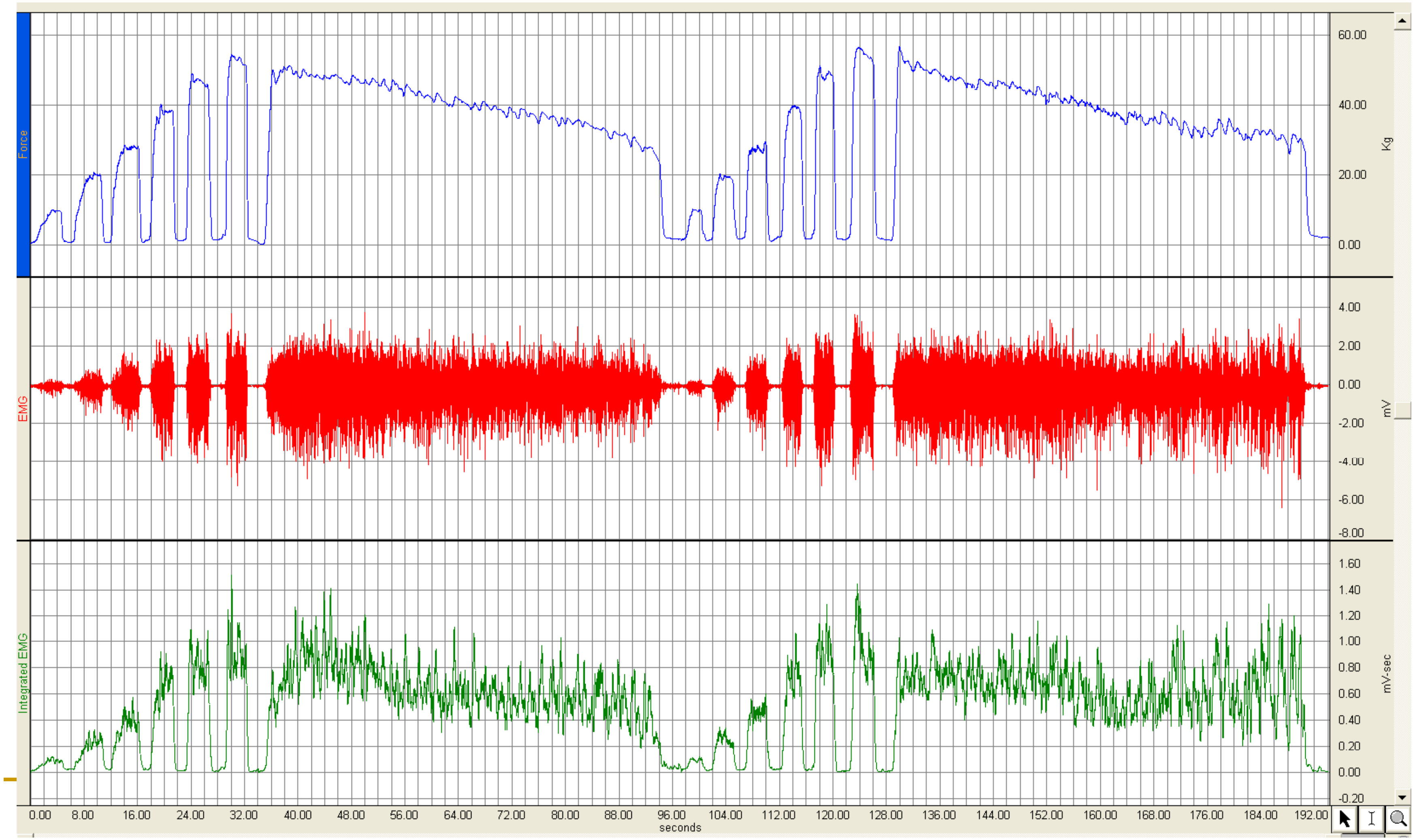
- Skeletal muscle performs mechanical work.
- It is stimulated to contract when the brain or spinal cord activates motor units.
- An action potential in the motoneuron causes activation of muscle fibers.
- The activation of motor units by action potentials generates a stochastic voltage signal in the muscle.
- The amount of work is proportional to the number of activated motor units.
- Surface electromyography is measures total muscle electrical activity via skin electrodes



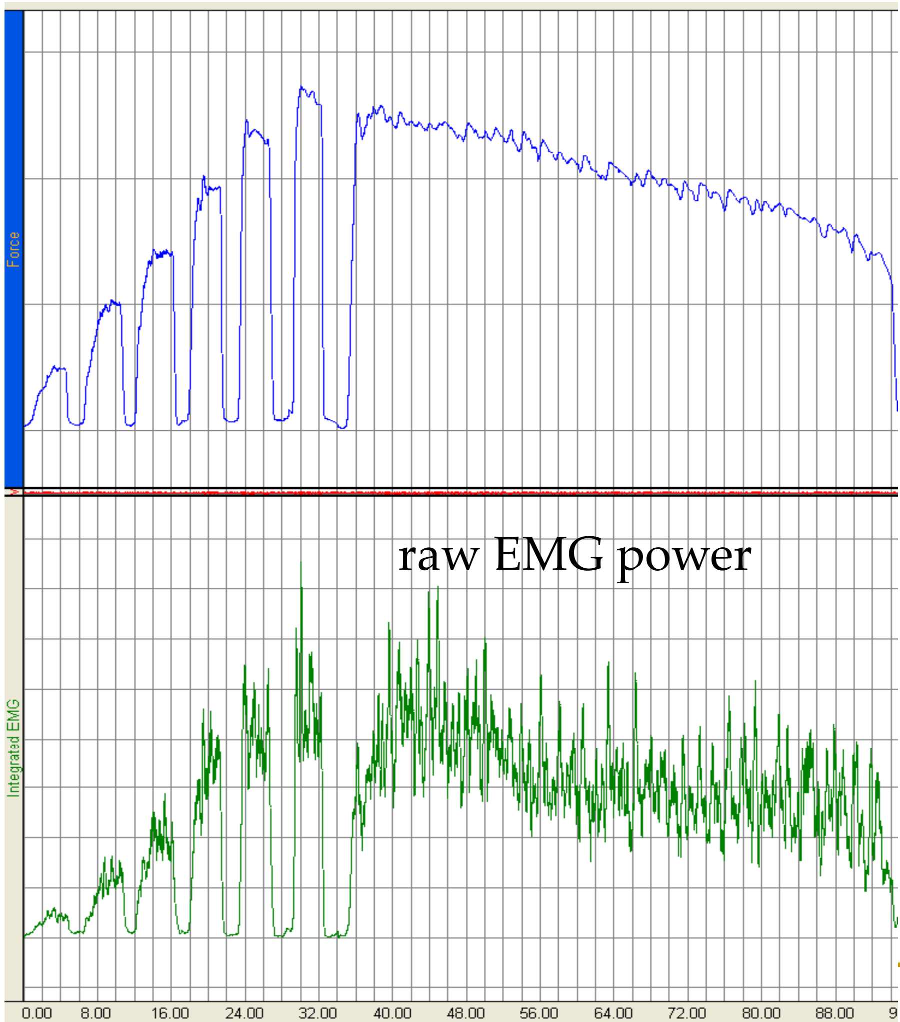
measurement tasks

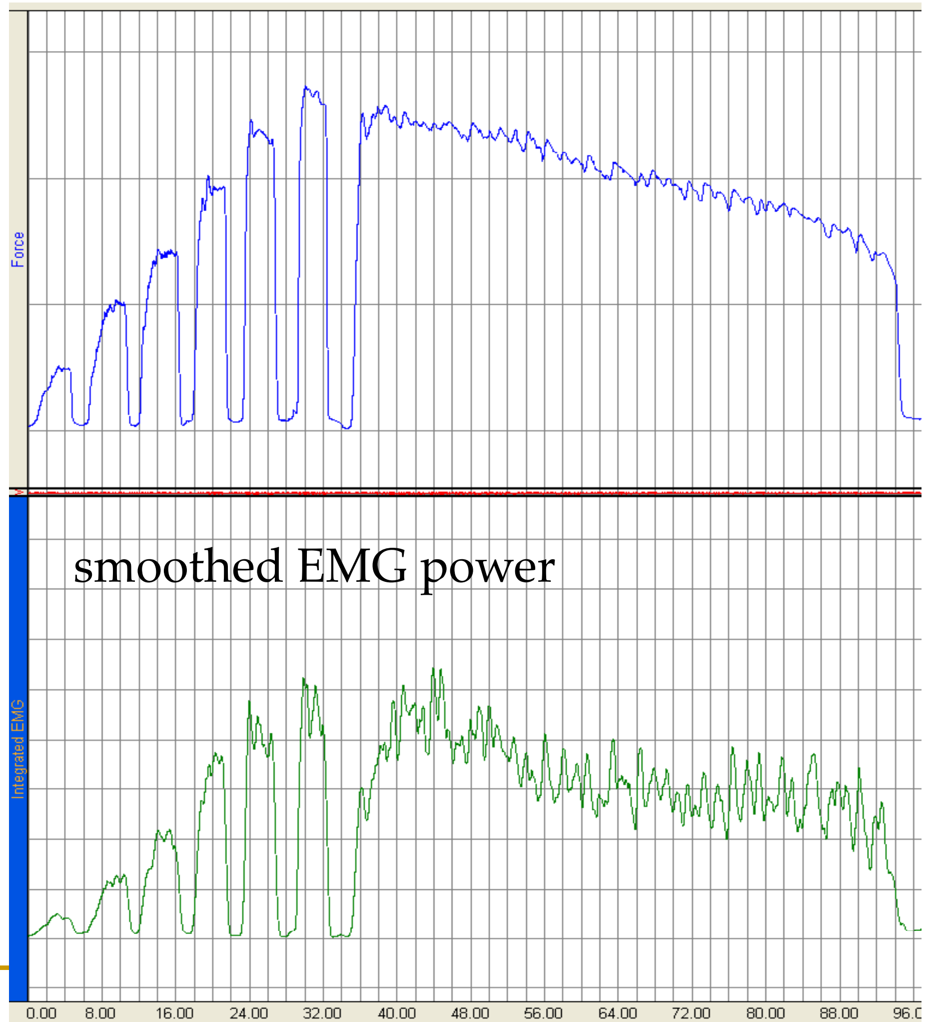
- measurement of EMG during stepwise changes in grip force
- computation of EMG intensity
- correlation analysis between grip force and EMG activity
- relationship between grip force and EMG intensity during maximum effort

measurement protocol

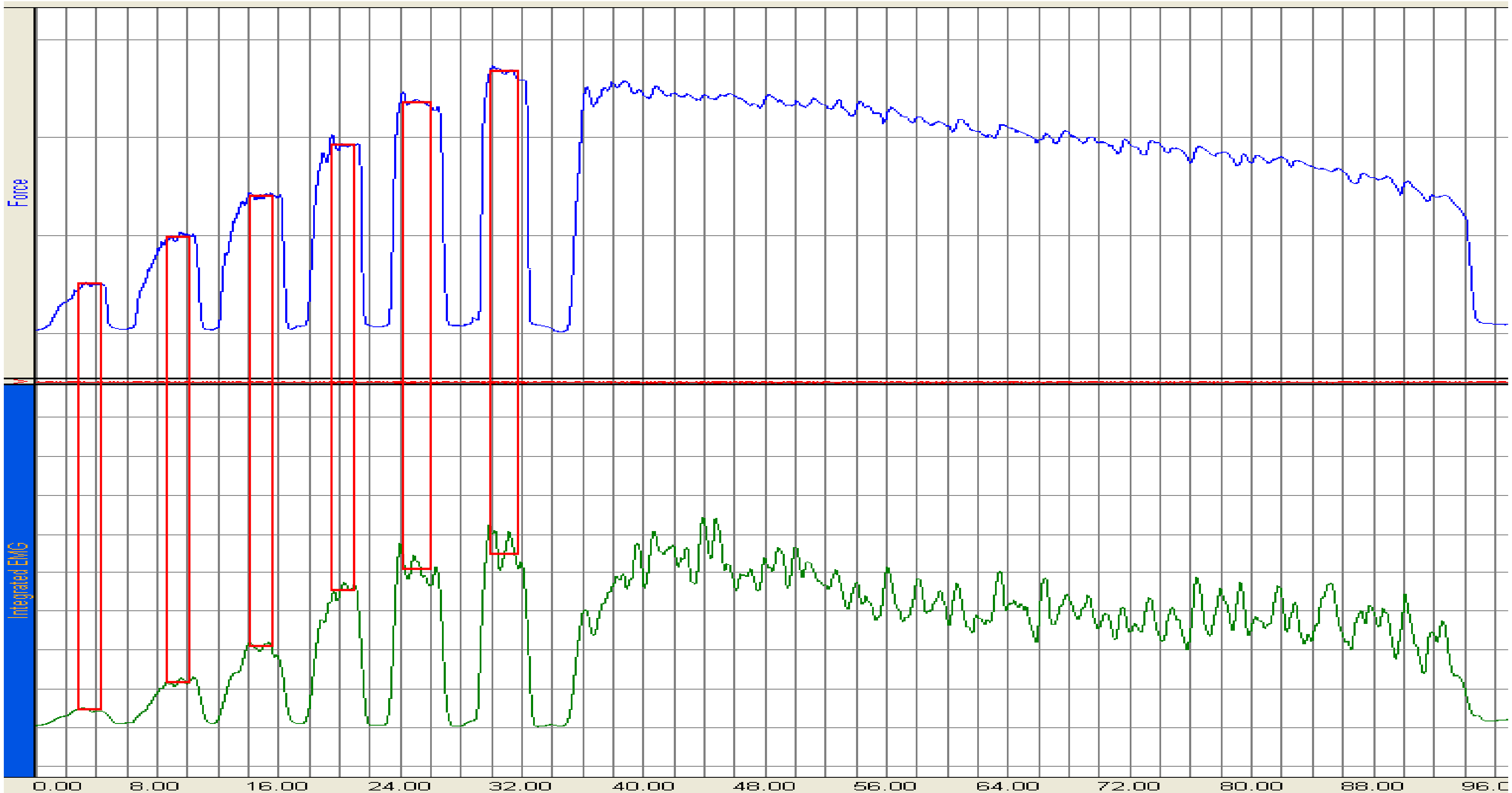


preprocessing

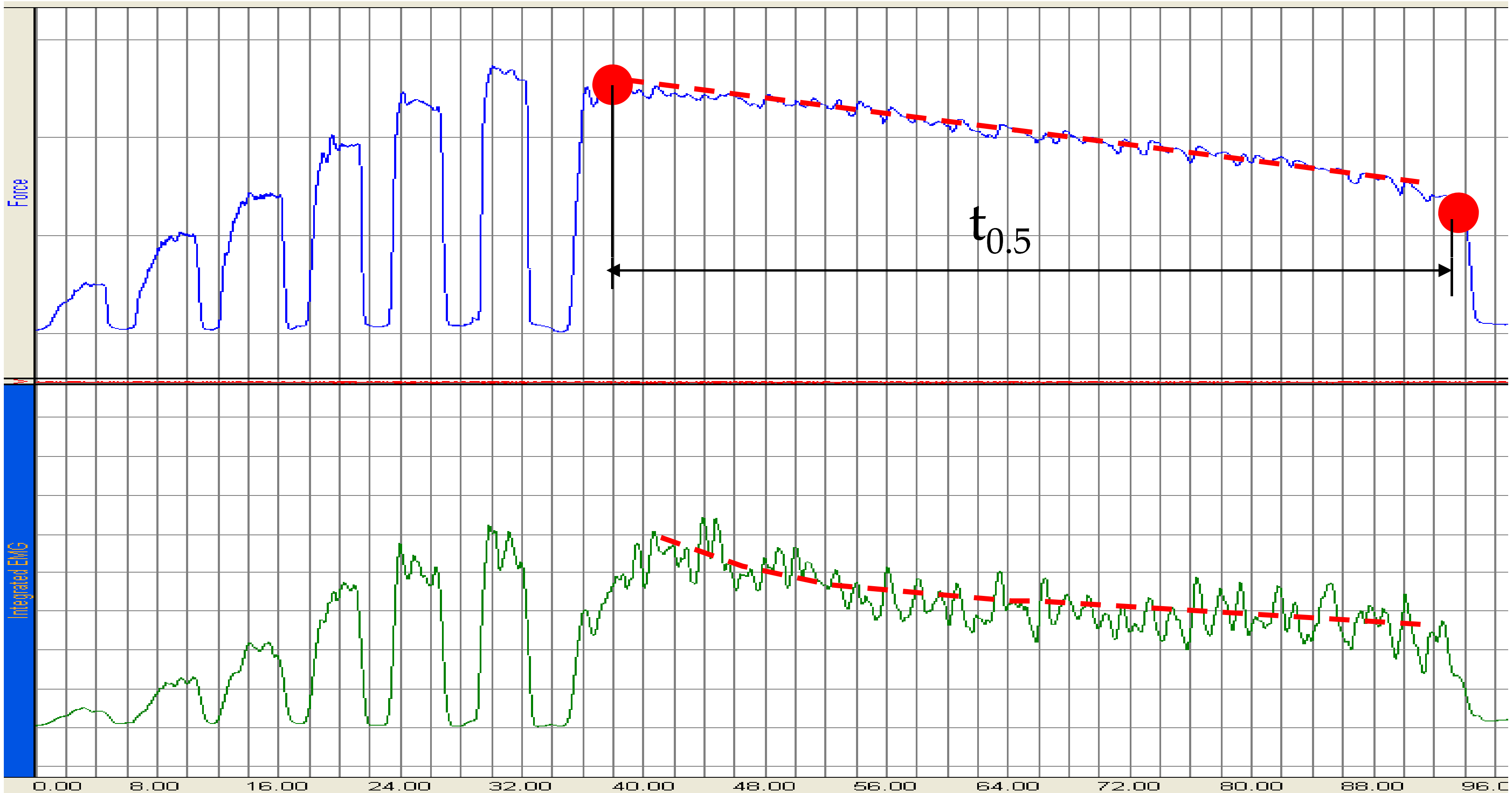


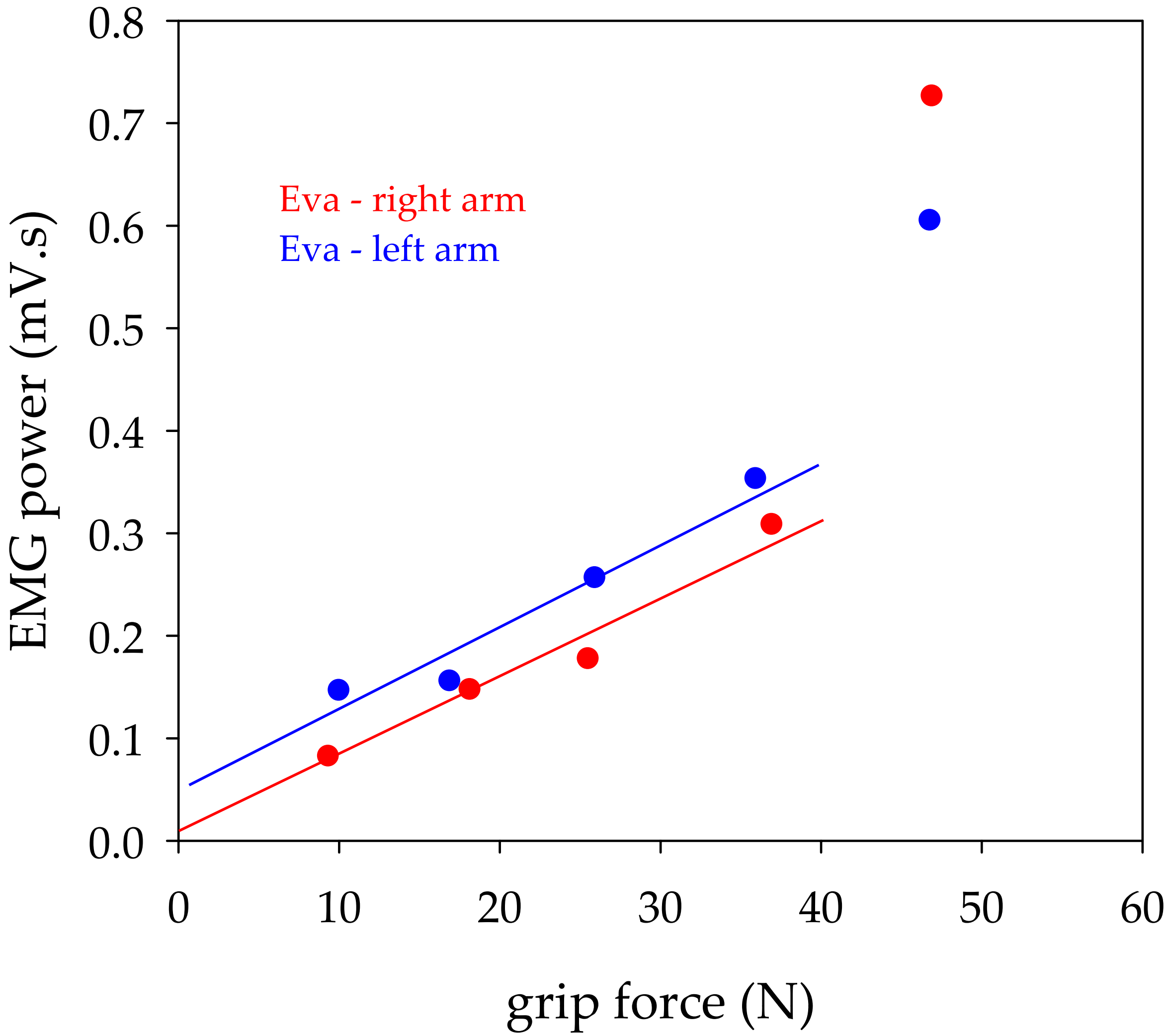


evaluation: plateau responses



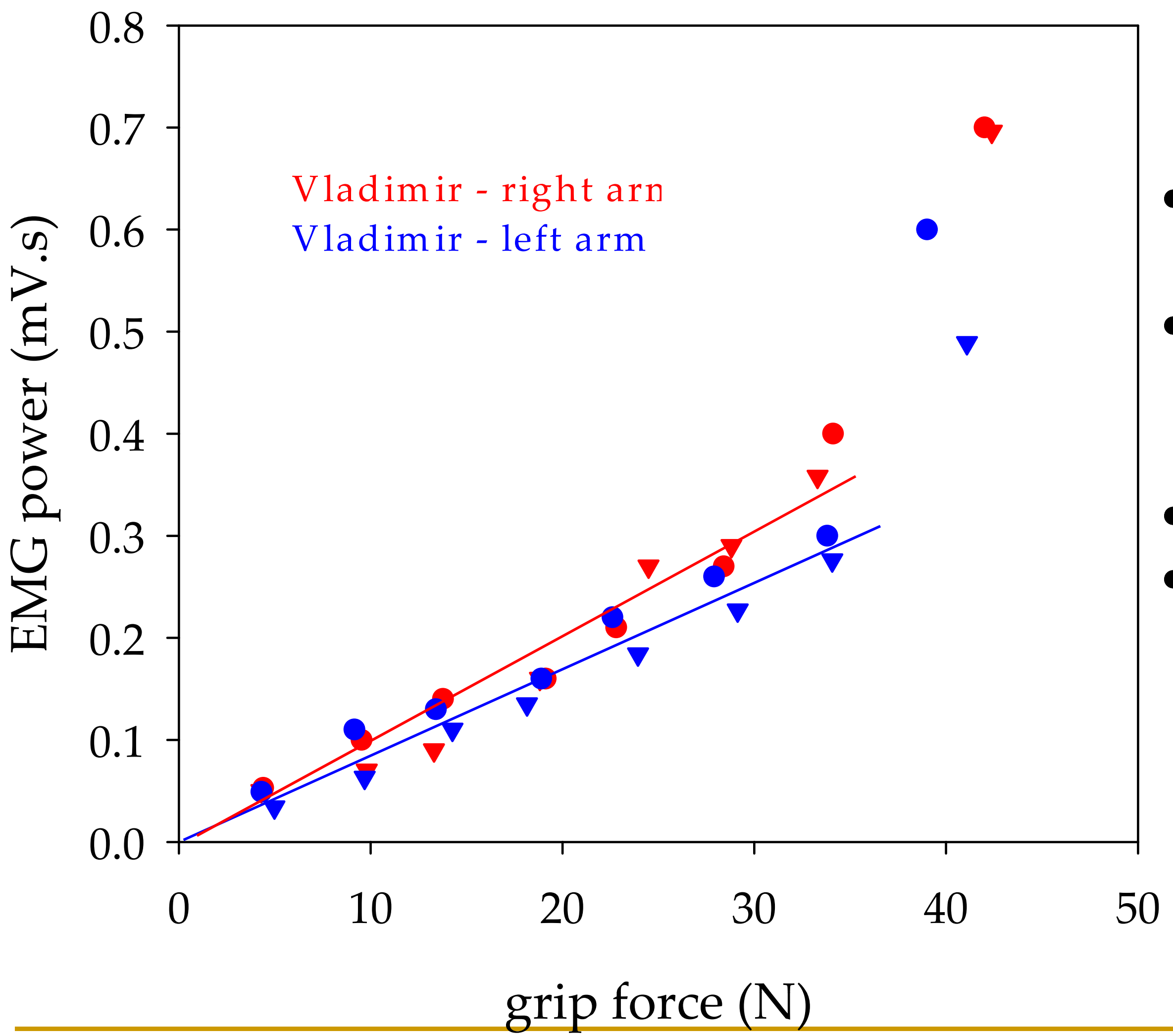
evaluation: muscle fatigue





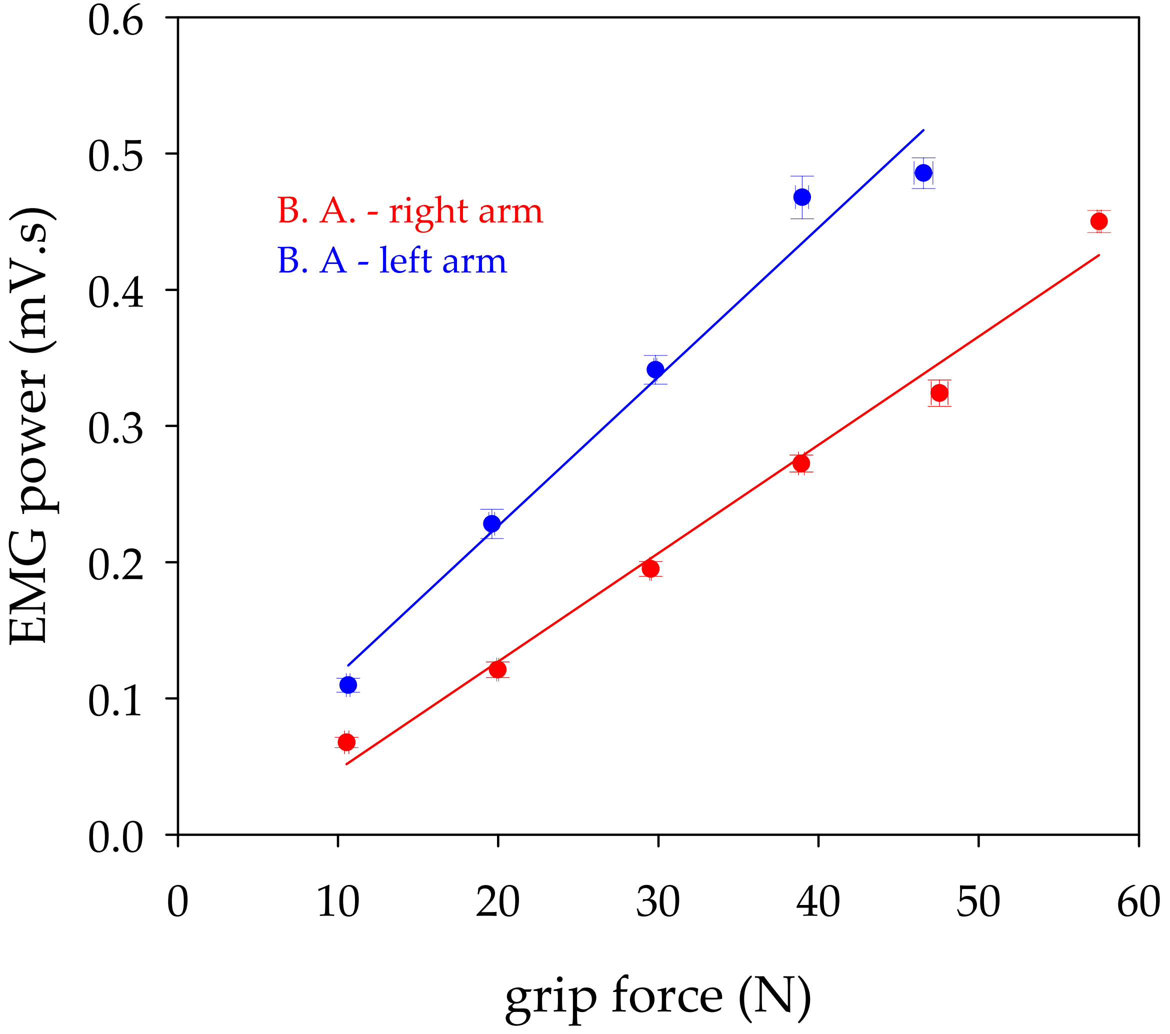
points of discussion

- submaximal effort: linear relationships
- maximal effort: dysproportional EMG power
- asymmetry
- shifted relationships



points of discussion

- submaximal effort: linear relationships
- maximal effort: dysproportional EMG power
- asymmetry
- different slopes



points of discussion

- nearly linear relationships
- marked asymmetry
- small inter-observer variability

electrocardiography

basics

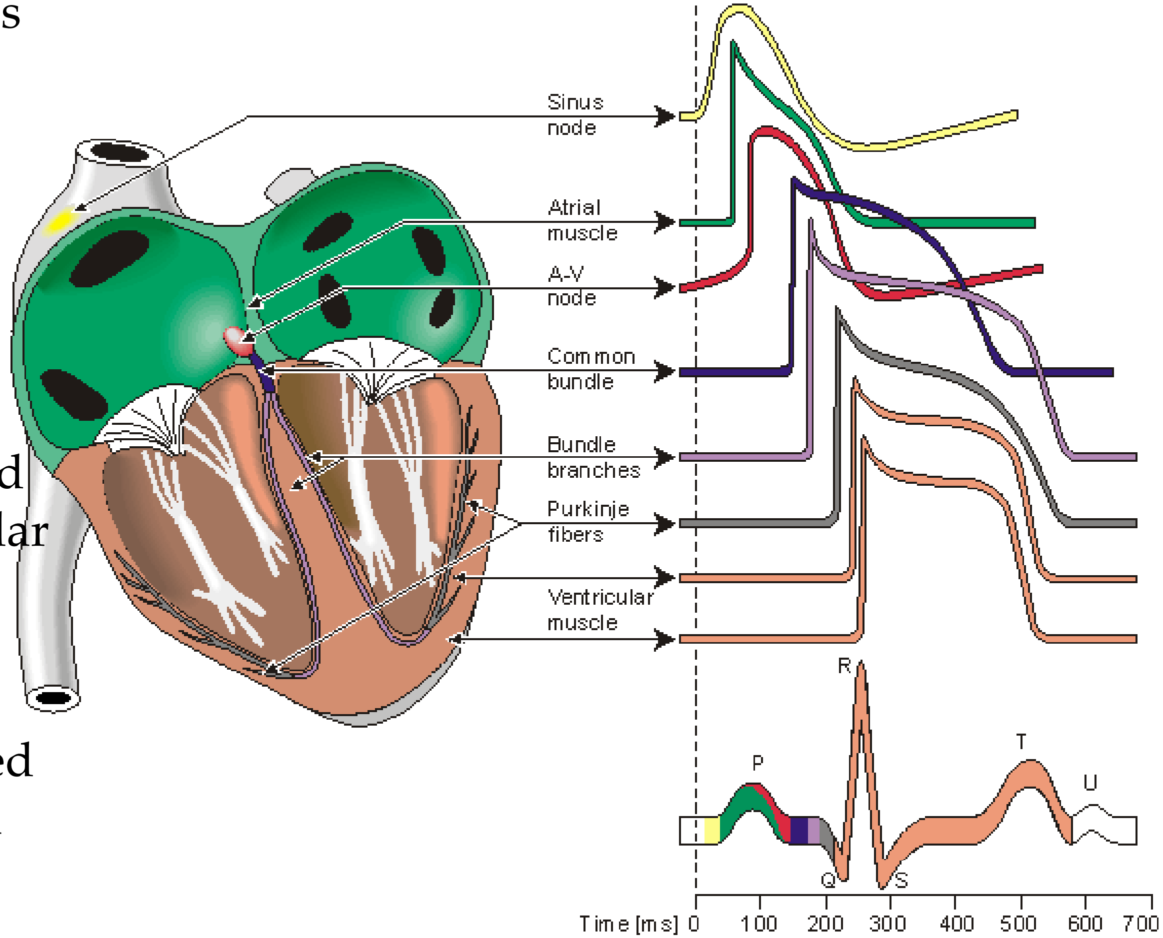
Background

Specialized pacemaker cells start the **electrical sequence** of depolarization and repolarization

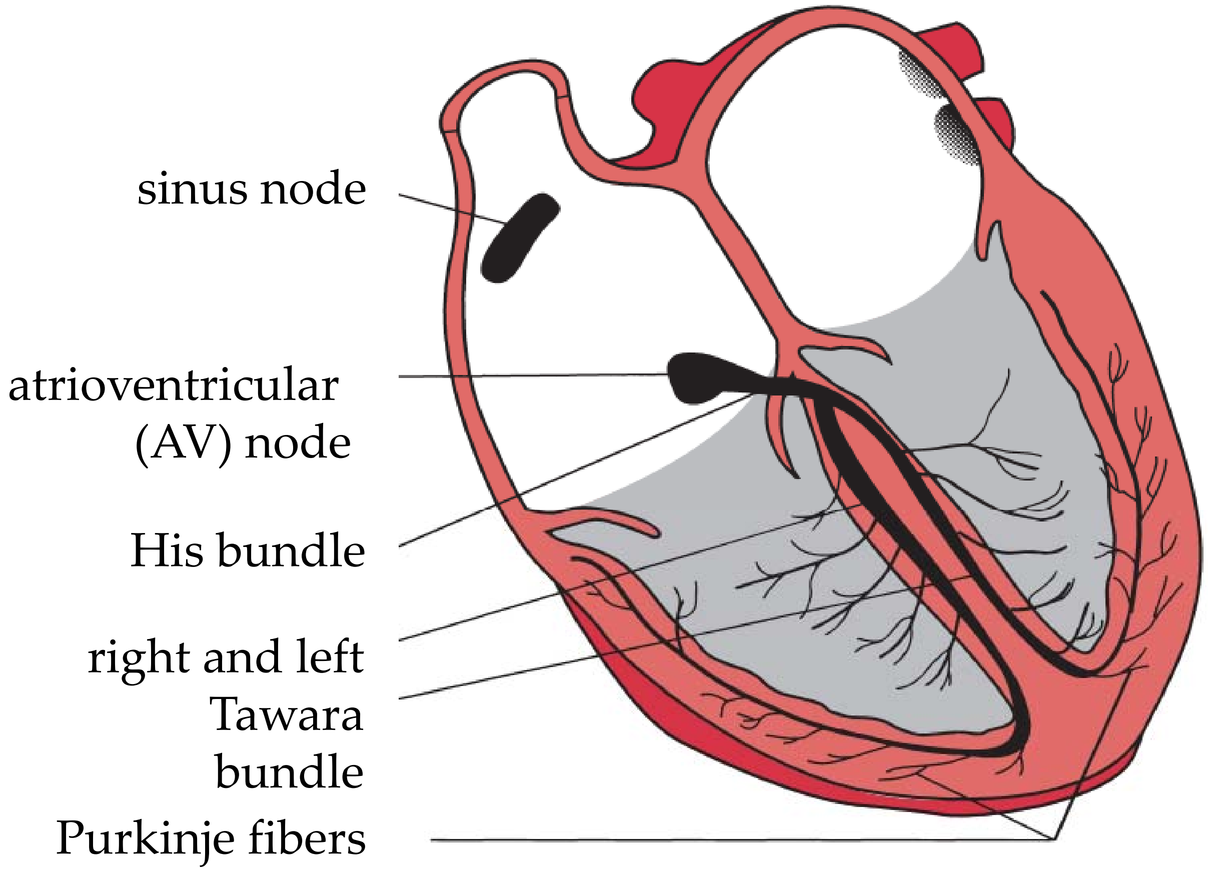
The **electrical signal** is generated by the sinoatrial (SA) node and spreads to the ventricular muscle

The **electrical activities** of the heart can be detected on the body surface via surface electrodes

Action potentials



Background:



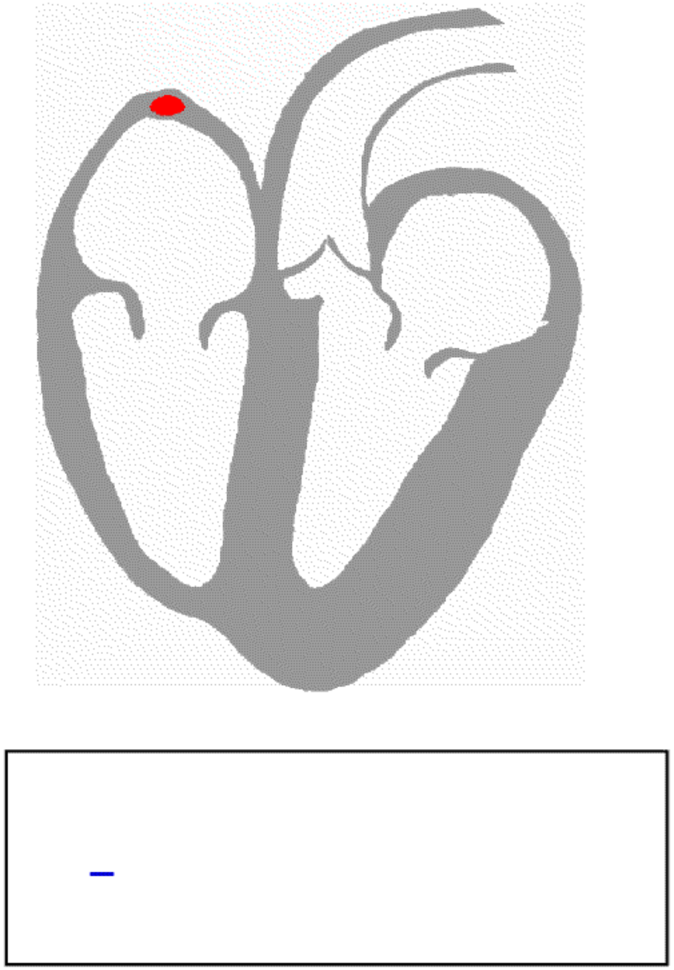
rhythm generator: polarisation - depolarisation

↓

conducting system

↓

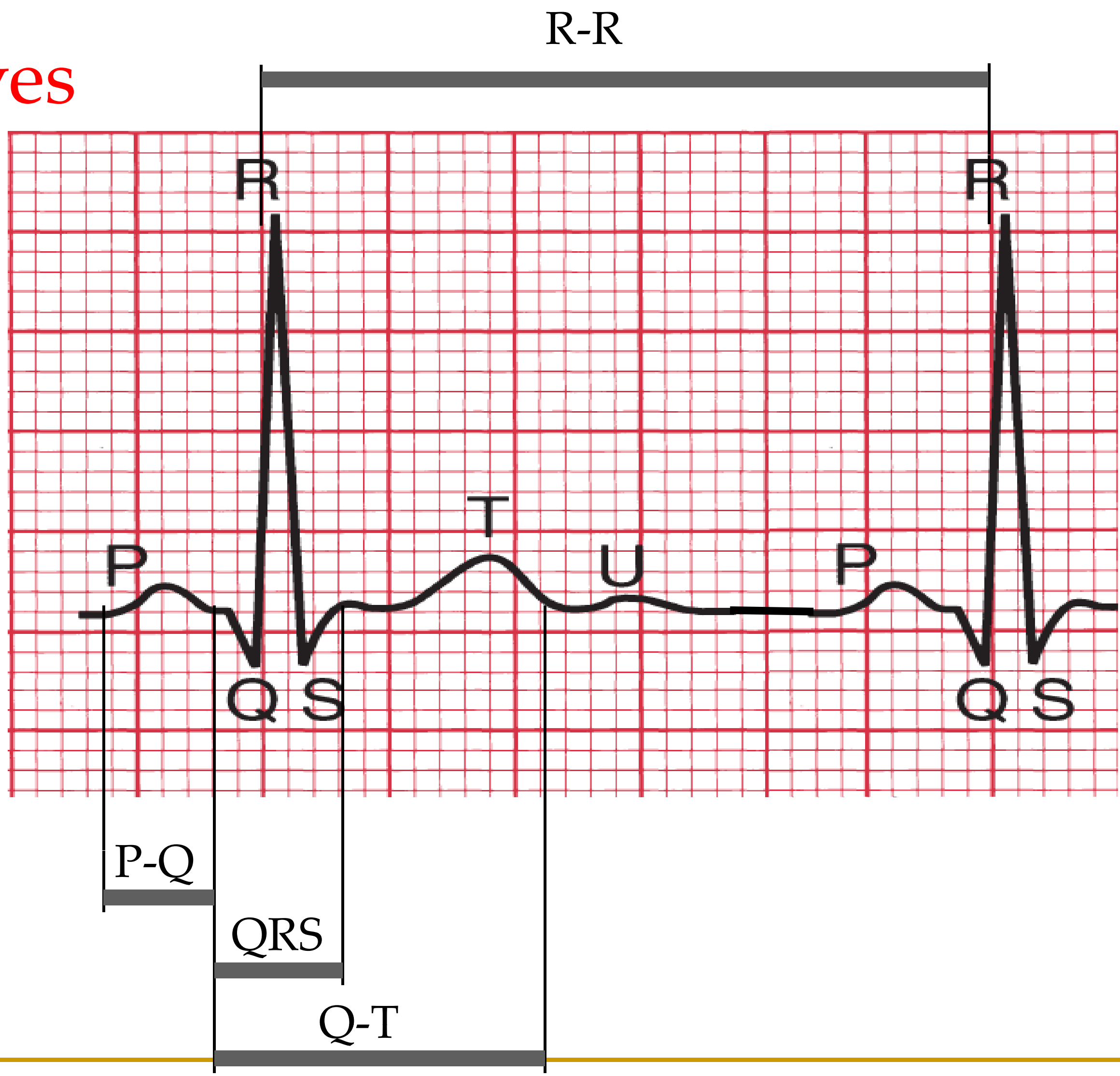
contractile cells



<ECG_principle_slow.gif>

the ECG waves

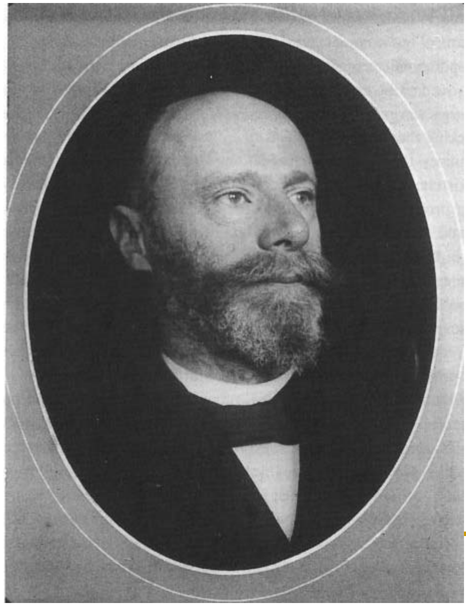
1. baseline
2. P: atrial repolarisation
3. QRS: ventricular depolarisation
4. S-T: ventricular contraction
5. T: ventricular repolarisation

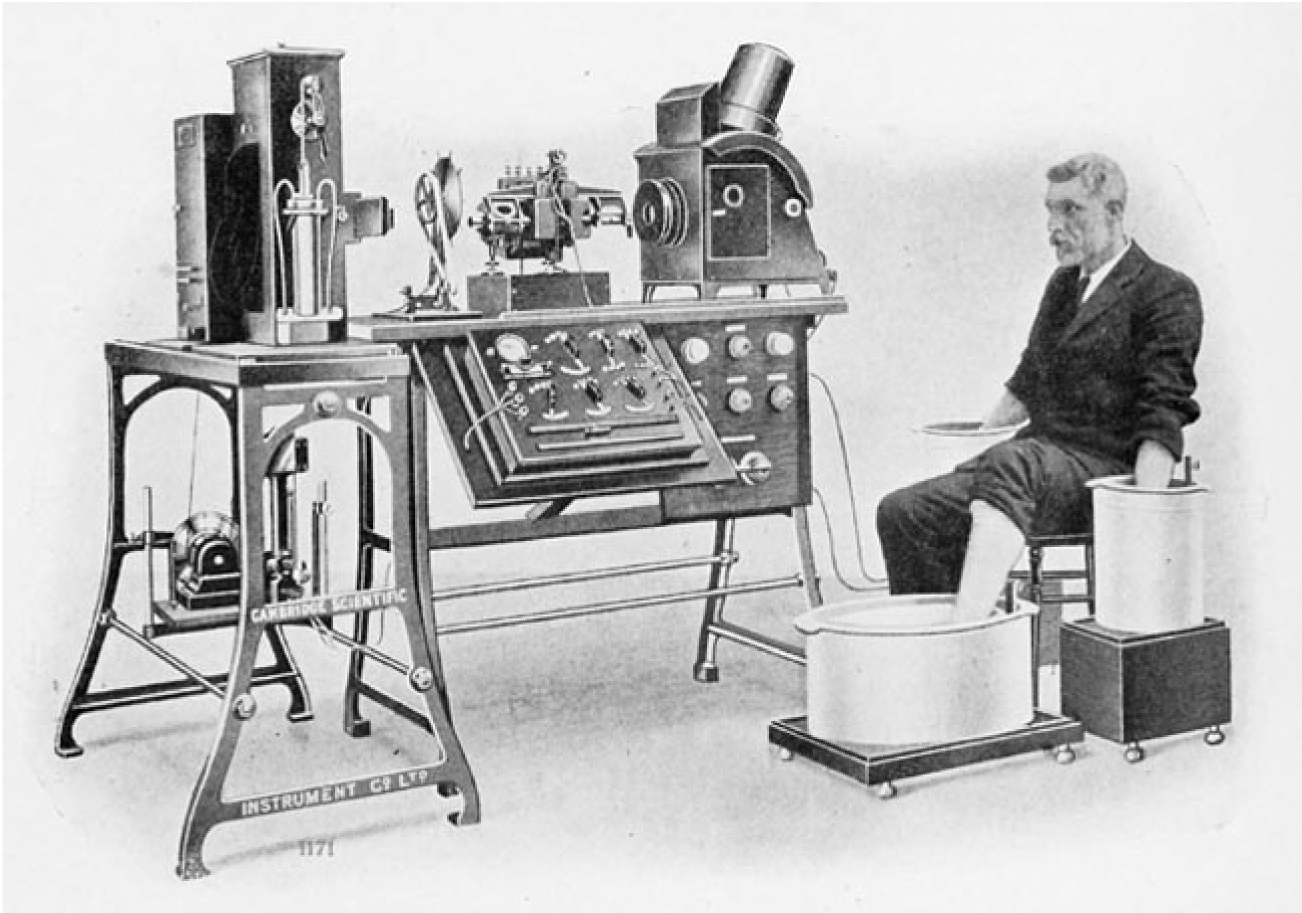


Willem Einthoven
(1860 –1927)

Professor, University of Leiden (1886)

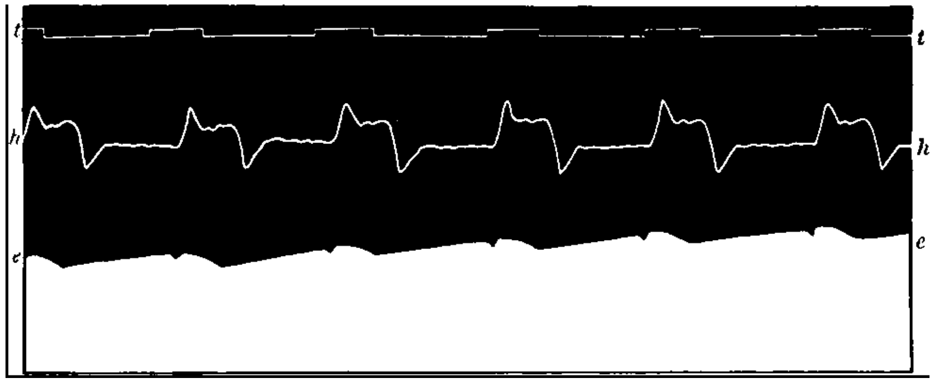
Nobel Prize in Medicine (1924)



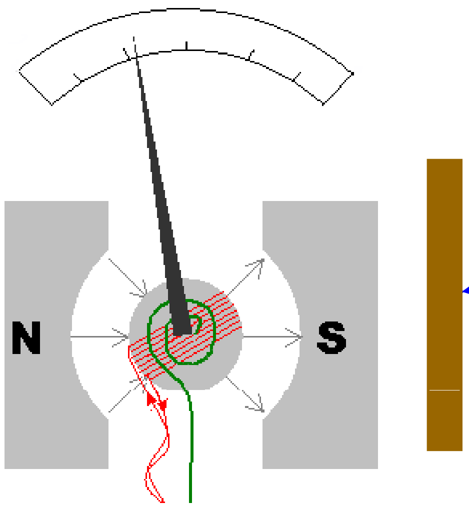


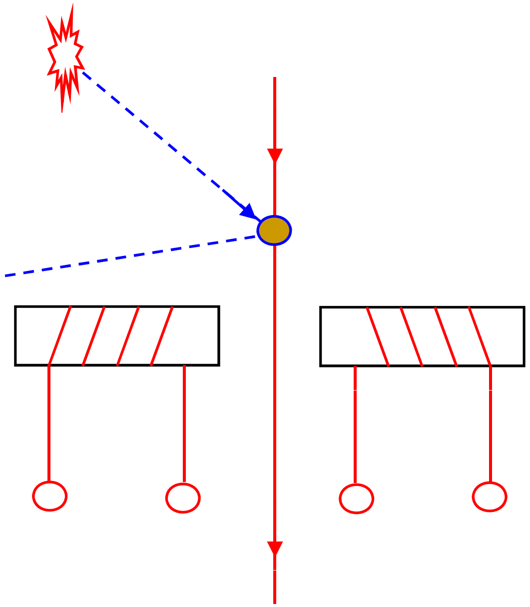
Photograph of a Complete Electrocardiograph, Showing the Manner in which the Electrodes are Attached to the Patient, In this Case the Hands and One Foot Being Immersed in Jars of Salt Solution

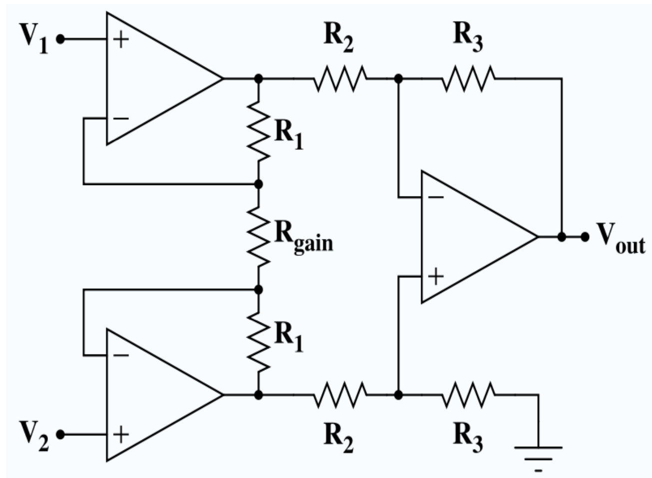
Augustus Desiré Waller (1856–1922)



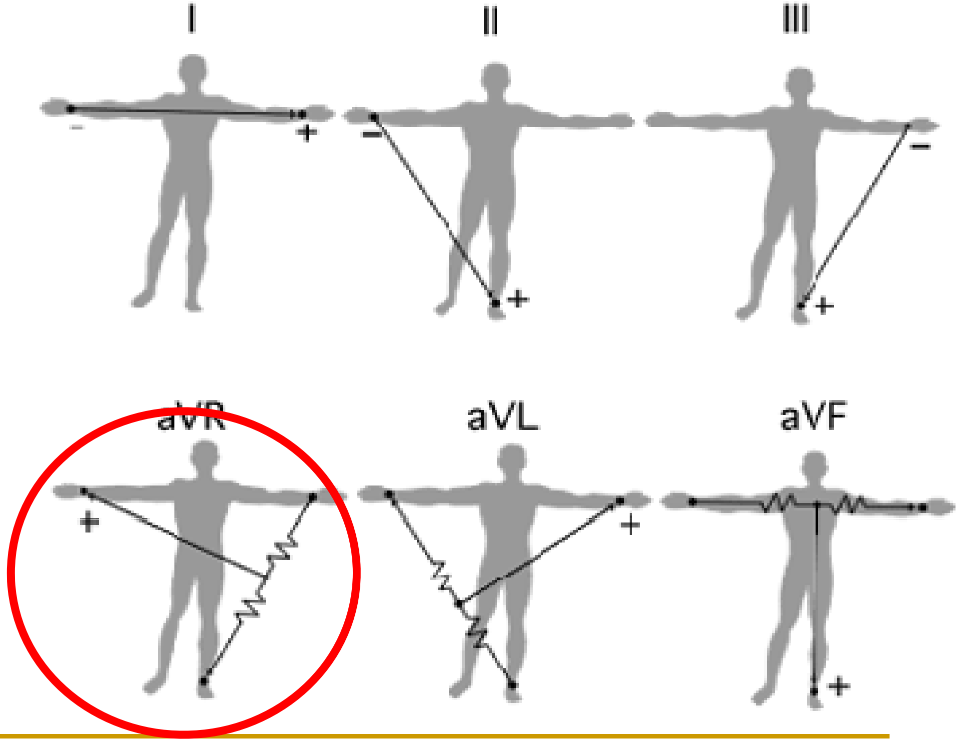
Measurement tools







Electrode leads



Bipolar (Einthoven)

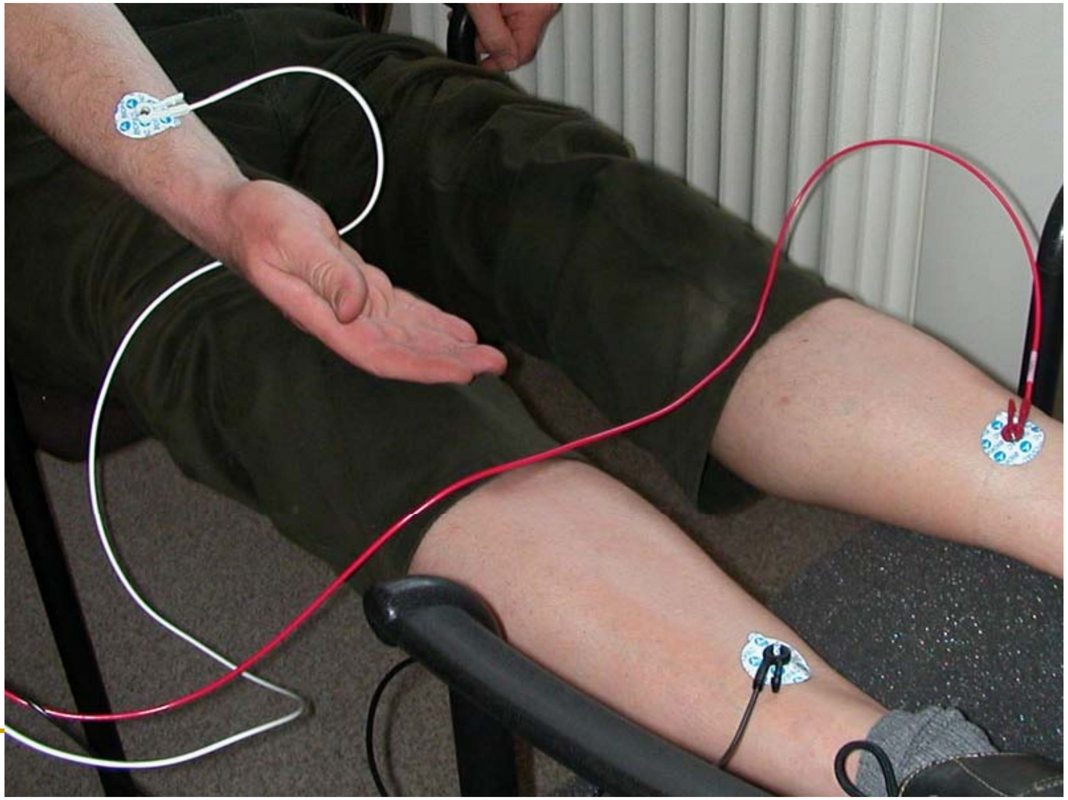
The standard leads I, II and III form a triangle, from which the electrical axis of the heart can be established

Unipolar

- aVR: right hand
- aVL: left hand
- aVF: left leg

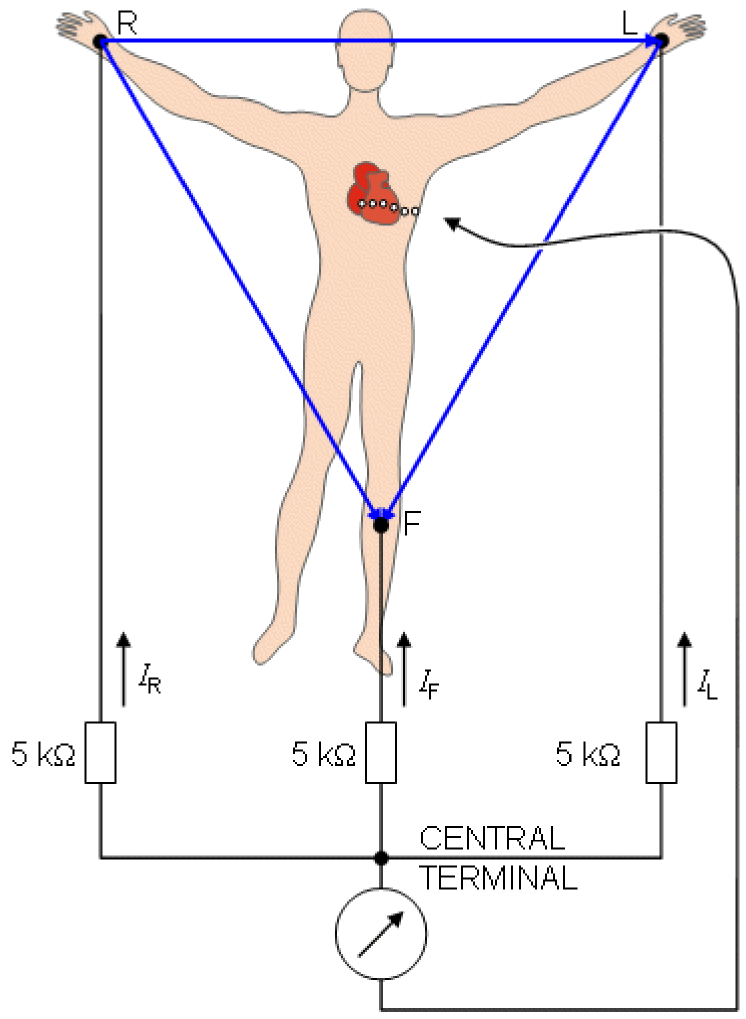
Measurement tools

- non-reusable electrodes
- cable
- amplifier
- anti-aliasing filter
- AD converter

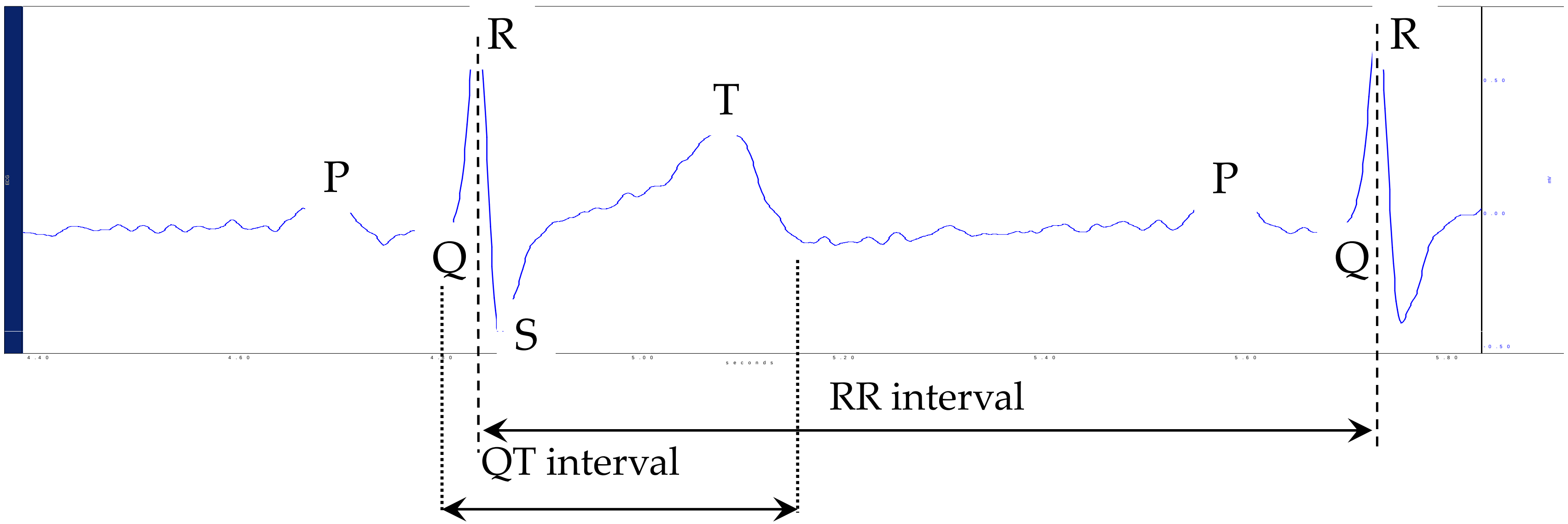


Measurement tools

The virtual ground:
the central terminal



signal analysis

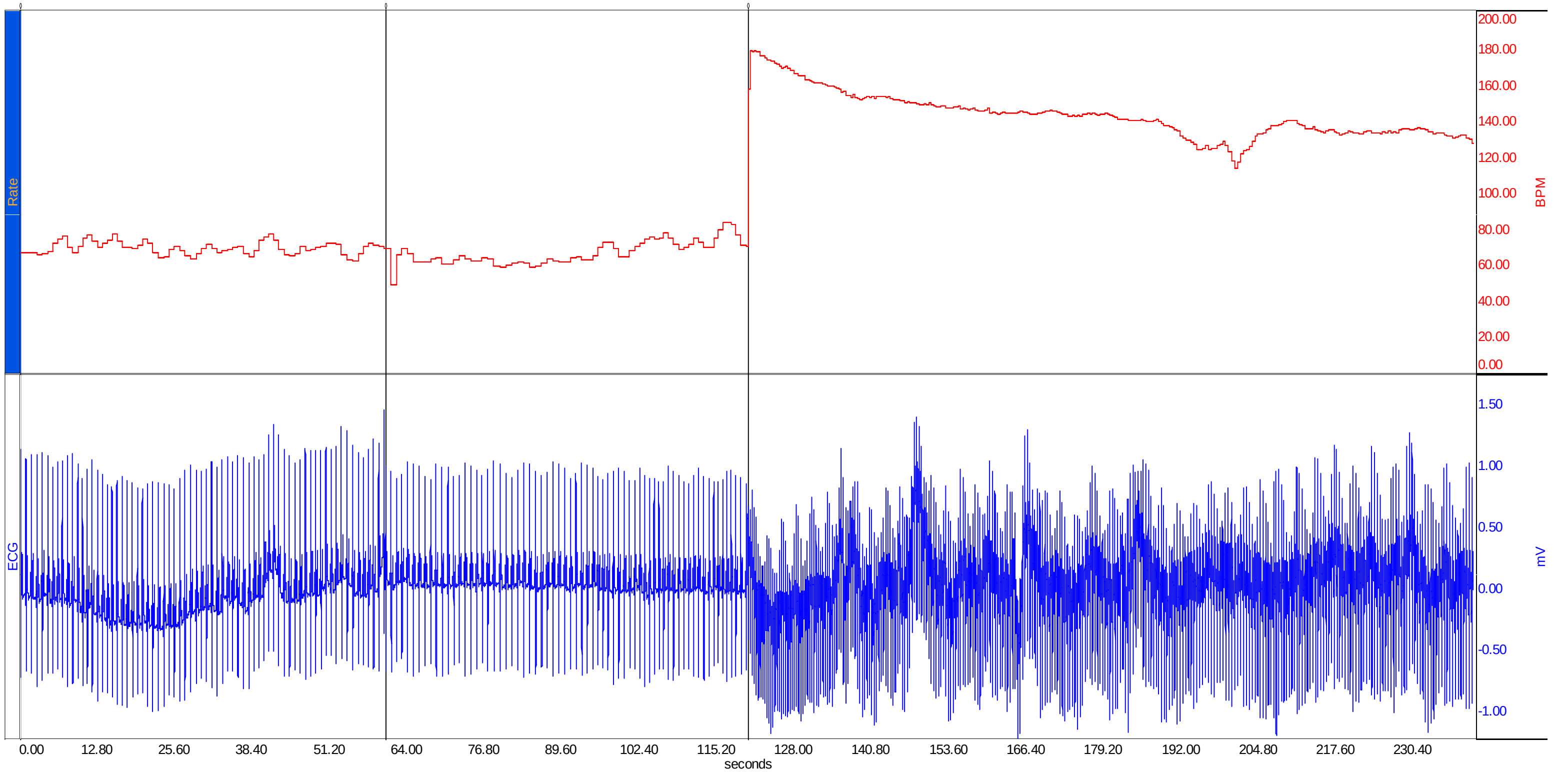


- display of the ECG signal at different time scales
- determination of the characteristic time intervals (RR and QT) és and their ratio (QT/RR)
- tracking of the instantaneous heart rate

heart rate dynamics

mean heart rates are similar in supine and sitting positions

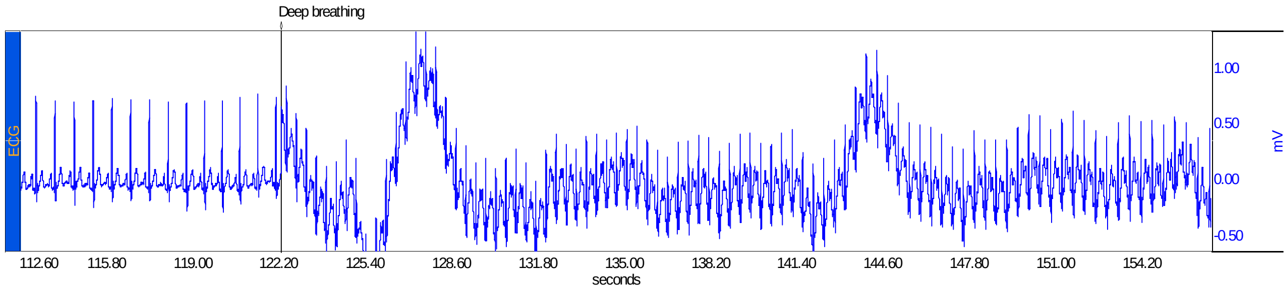
post-exercise heart rate decreases fast initially but does not normalise in 2 min



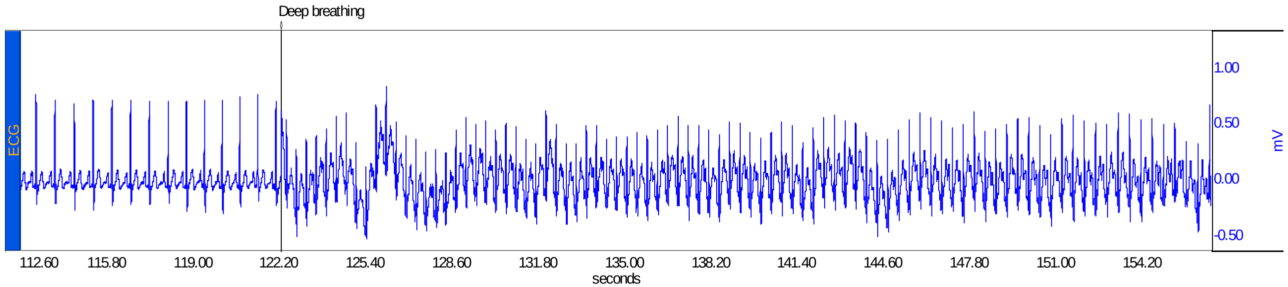
Pre-processing: high-pass filtering

steady periods unaffected, baseline stability recovered

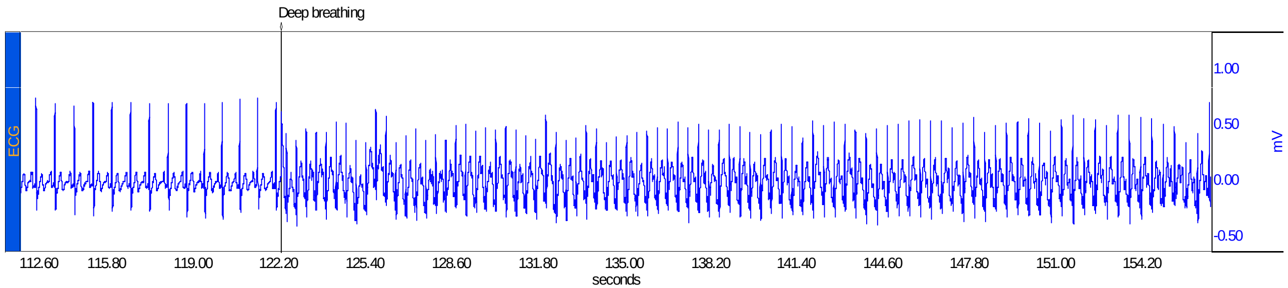
unfiltered



f > 0.5 Hz



f > 1 Hz

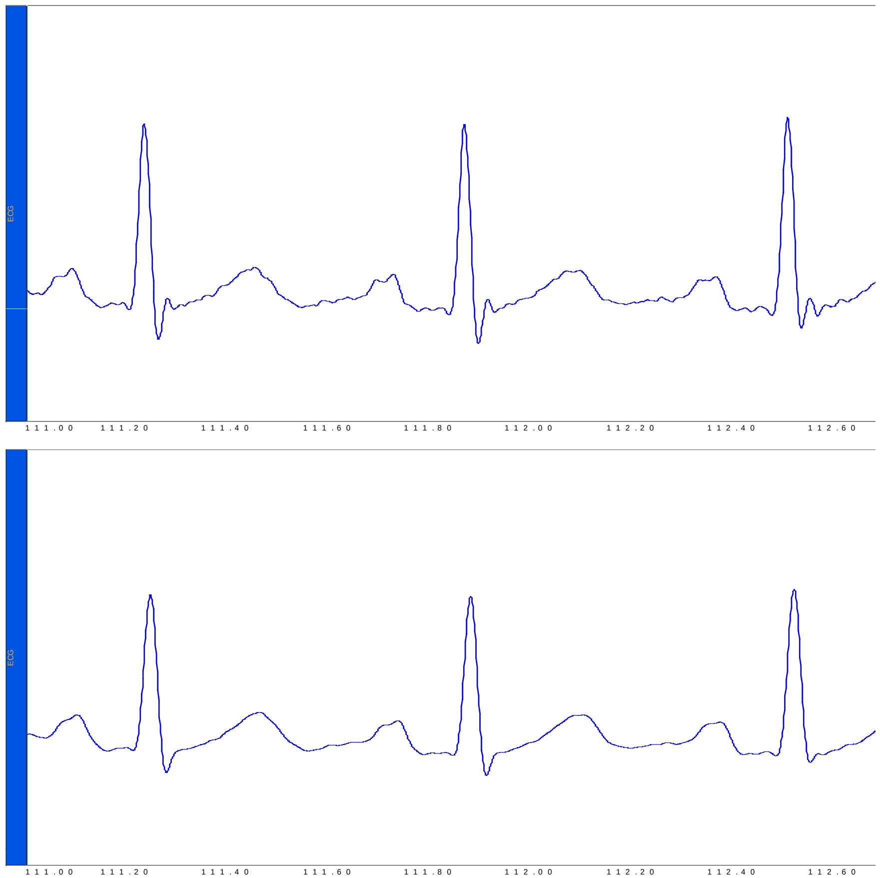


Effect of low-pass filtering

smoothing without shape distortion

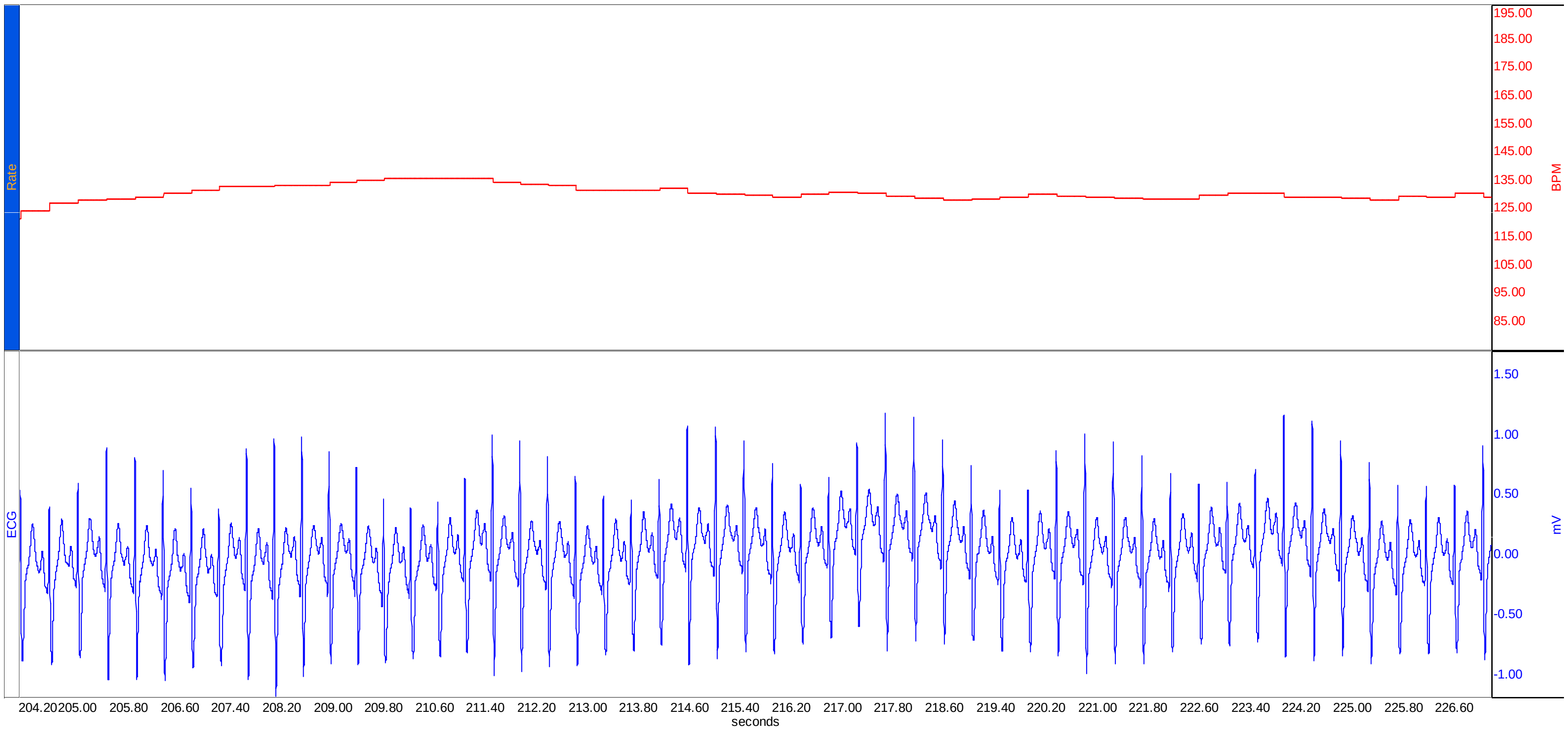
unfiltered

f < 20 Hz



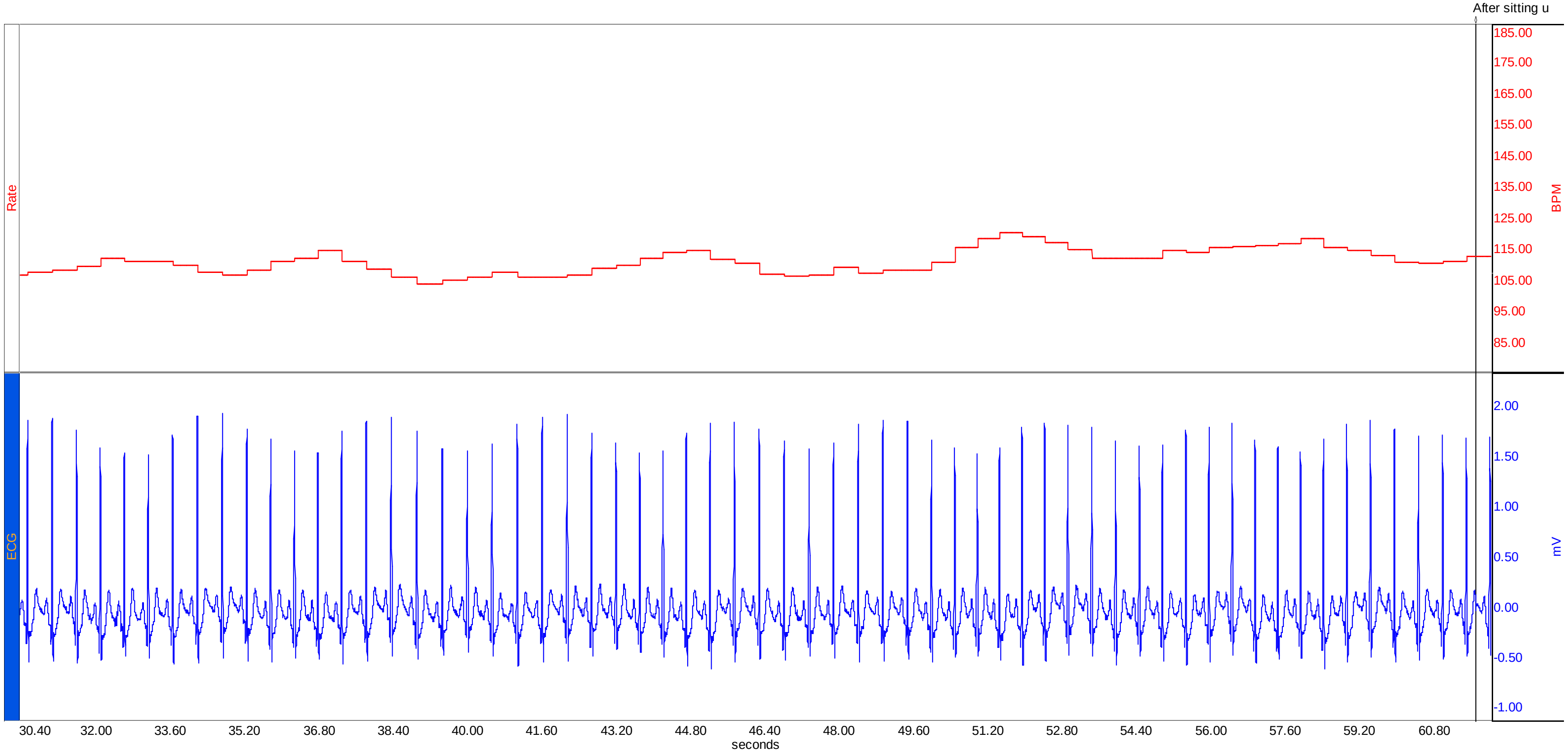
Heart rate dynamics

ECG amplitude is modulated by respiration



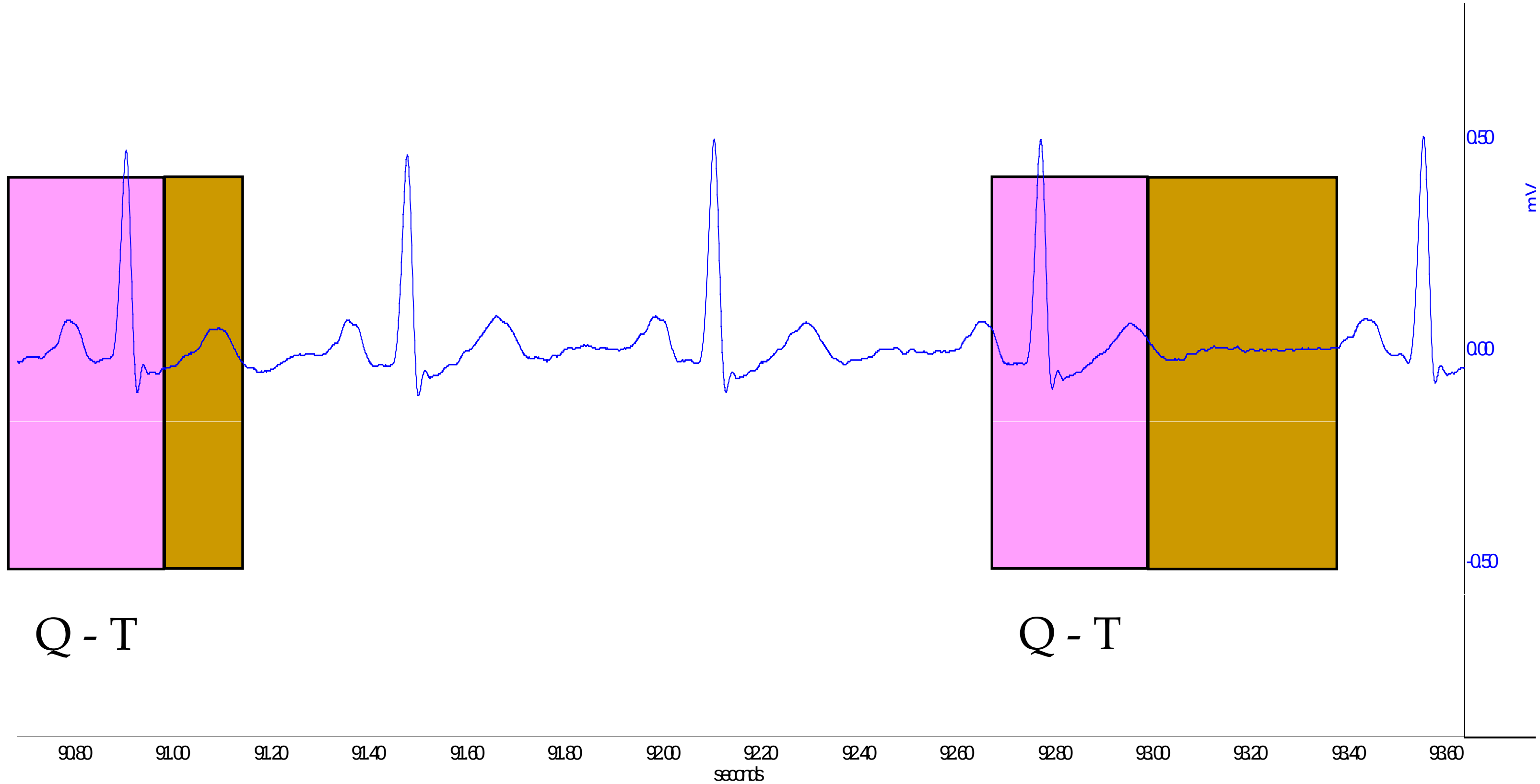
Heart rate dynamics

both ECG amplitude and heart rate are modulated by breathing



ECG: heart rate dynamics

respiration changes the length of the isoelectic interval



Heart rate dynamics

Q-T shortening and recovery

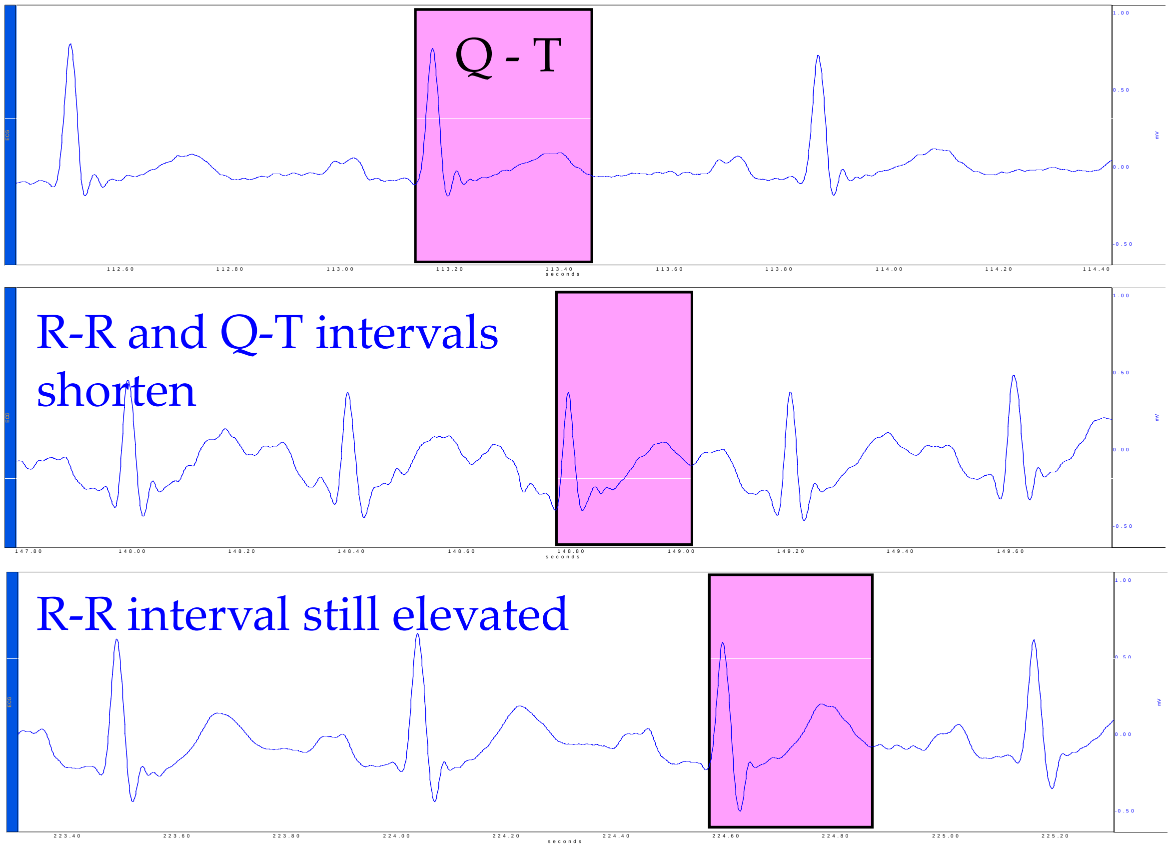
rest

10 s

post-exercise

100 s

post-exercise



Points of discussion:

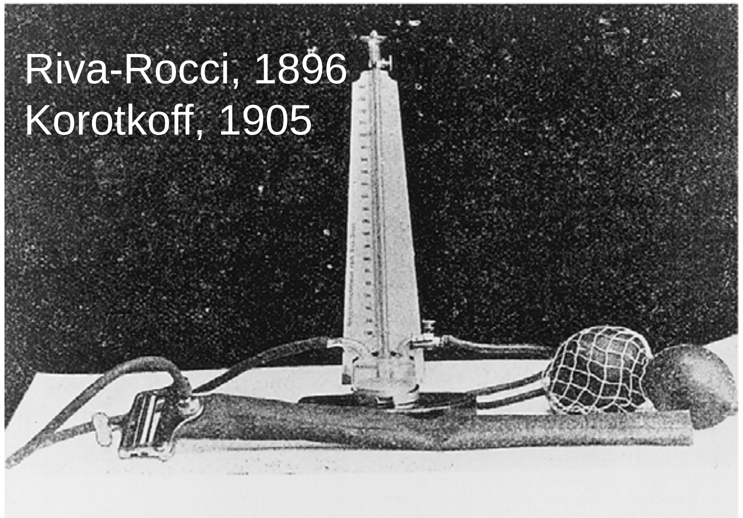
- Why was the ECG baseline less stable after the exercise than before?
- Heart rate did not return to the resting level in 2 min after the exercise. How long time do you think would be needed for a complete recovery?
- High-pass filtering can restore the baseline stability of a recording that includes low-frequency fluctuations, but it must not change the ECG waveform. What (high-pass) corner frequency (in Hz) would you set if the minimum heart rate in the recording is 70/min?

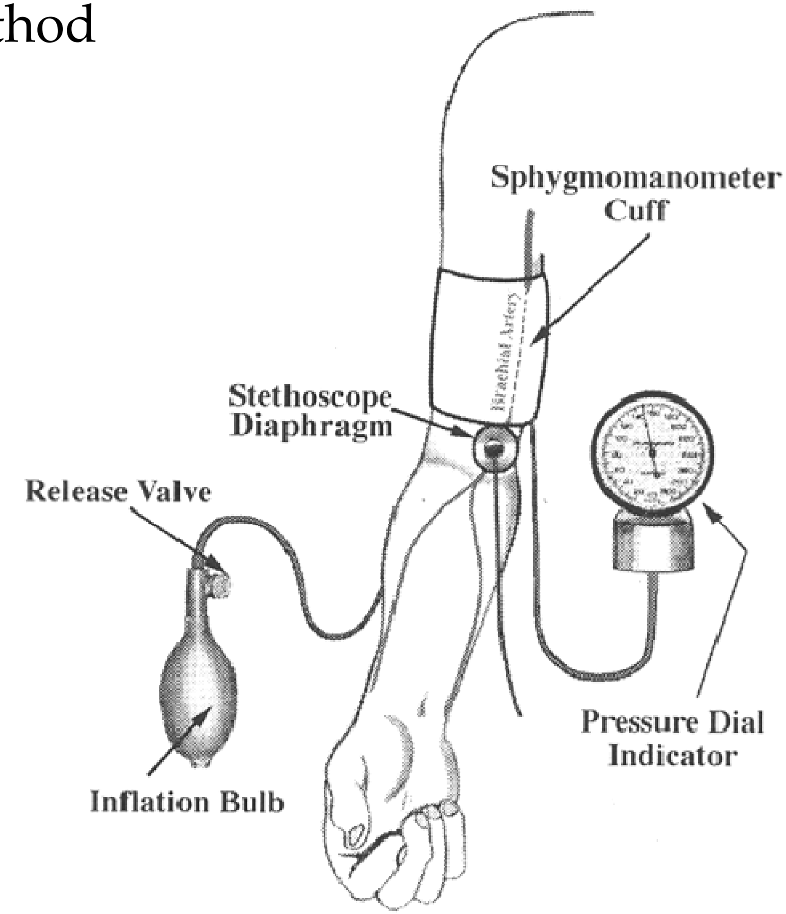
non-invasive measurement of blood pressure

basics

INDIRECT MEASUREMENT OF SYSTEMIC BLOOD PRESSURE

arrangement of the auscultation method

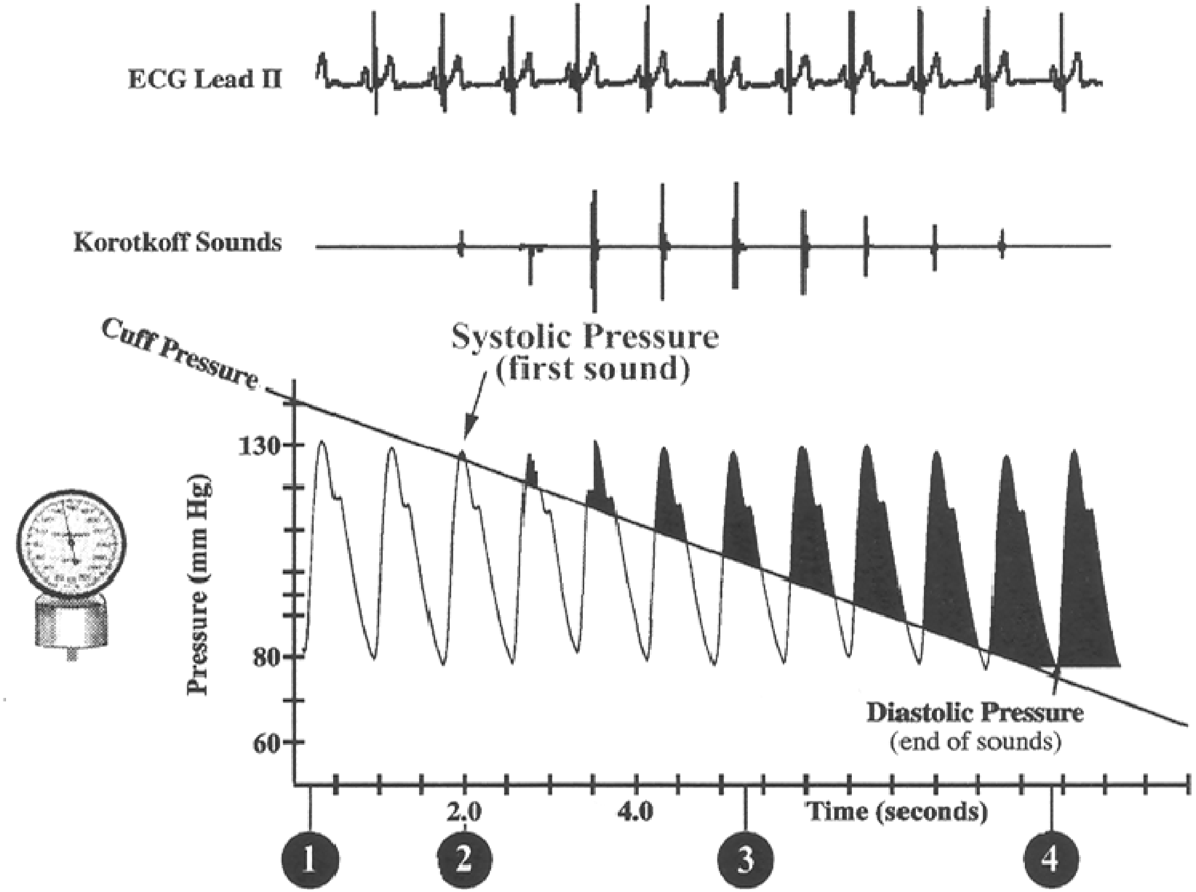




INDIRECT MEASUREMENT OF SYSTEMIC BLOOD PRESSURE

PRINCIPLE: comparison of cuff pressure, Korotkoff sounds and ECG

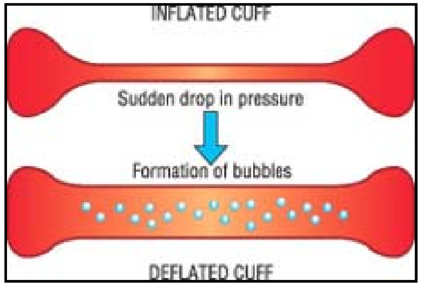
Nikolai Sergeievich Korotkoff



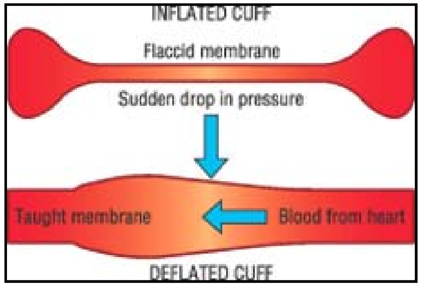
Computer-aided measurement techniques

mechanisms of the Korotkoff sounds

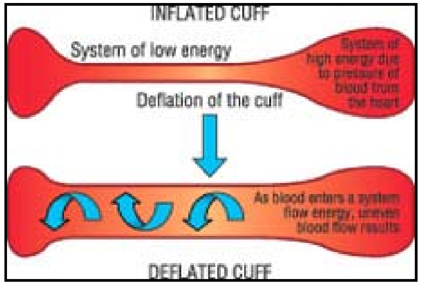
cavitation theory



vessel wall stretch theory

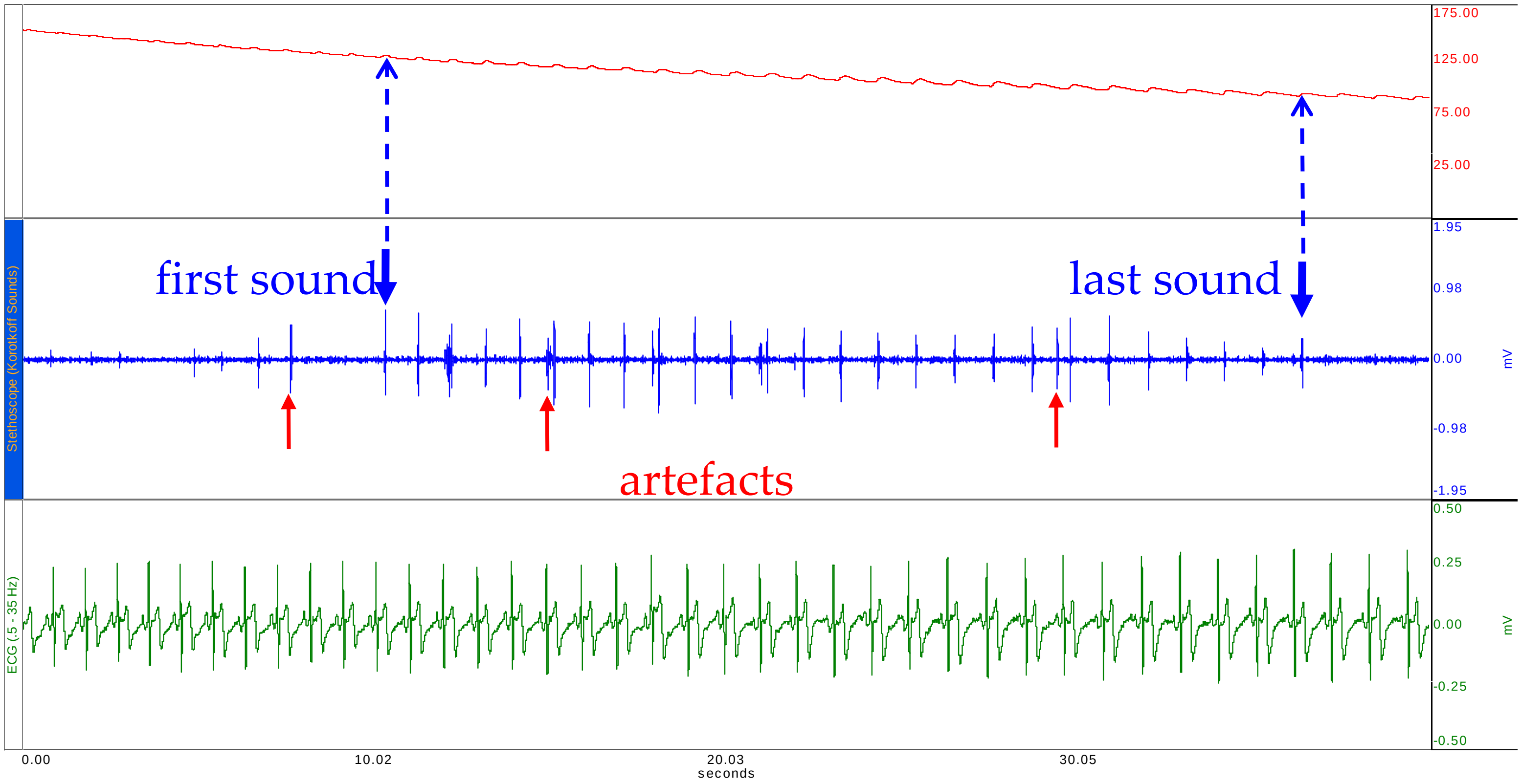


turbulence

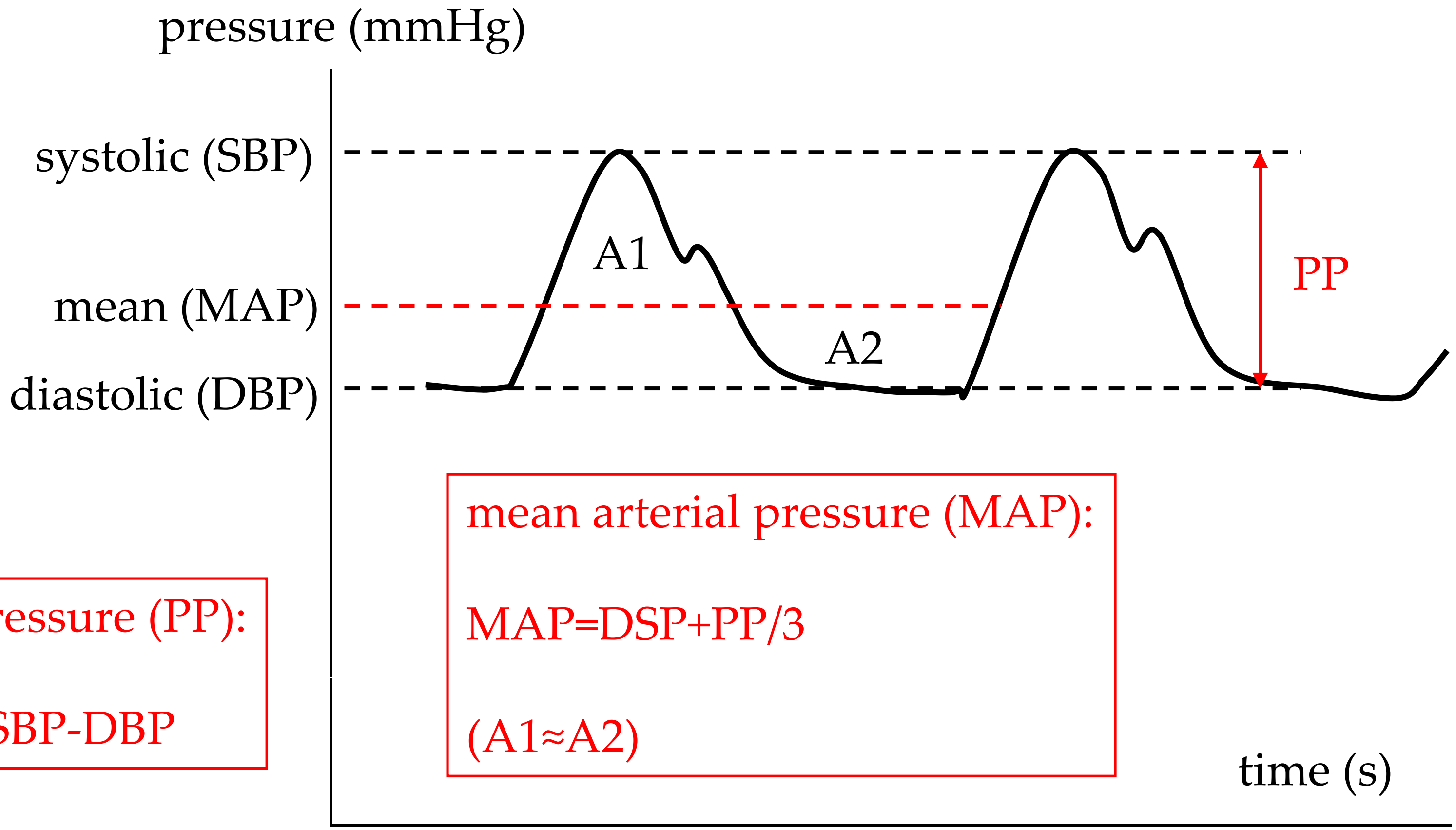


other theories
combinations

IDENTIFICATION OF THE KOROTKOFF SOUNDS



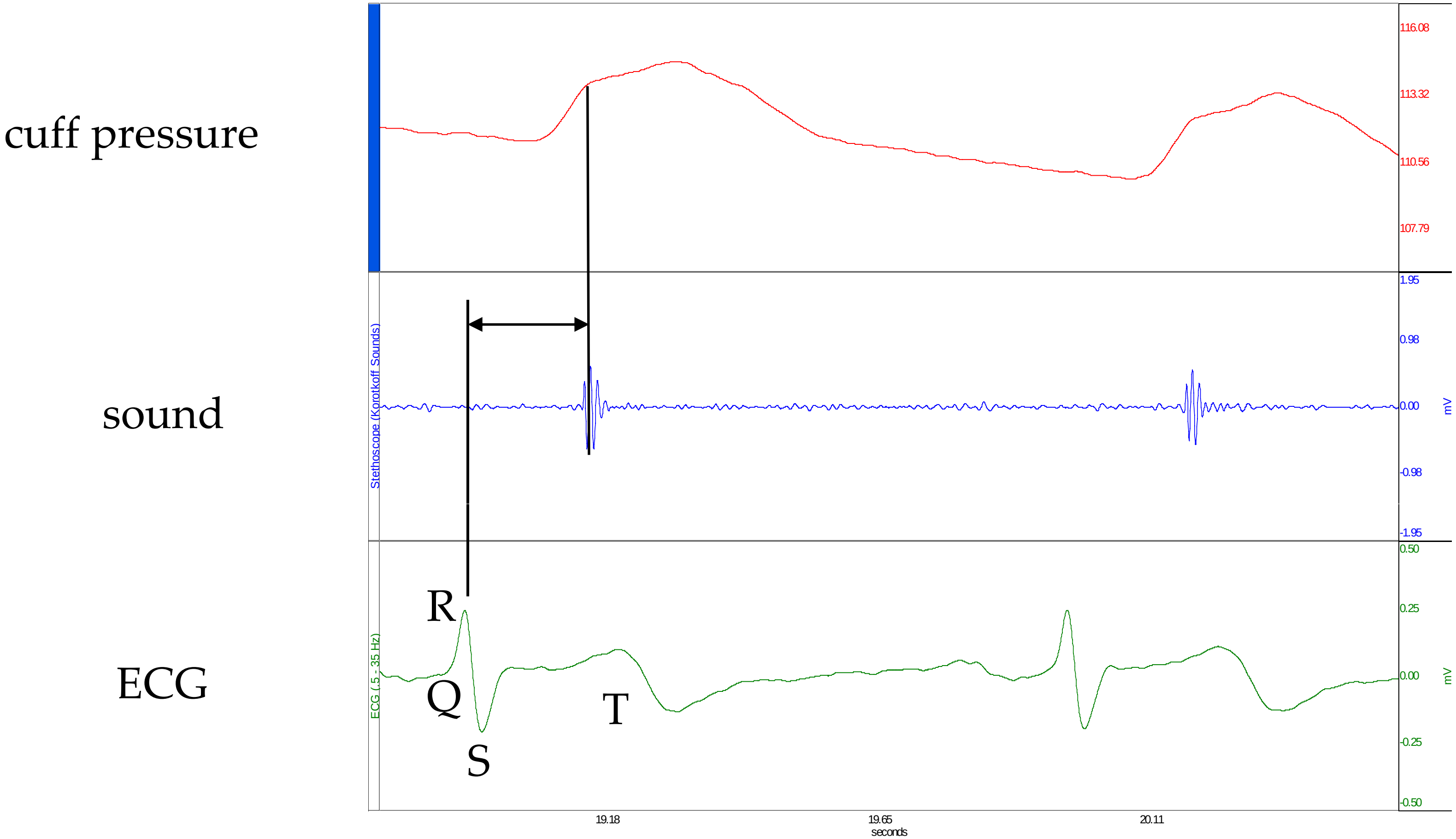
SYSTOLIC, MEAN AND DIASTOLIC PRESSURES



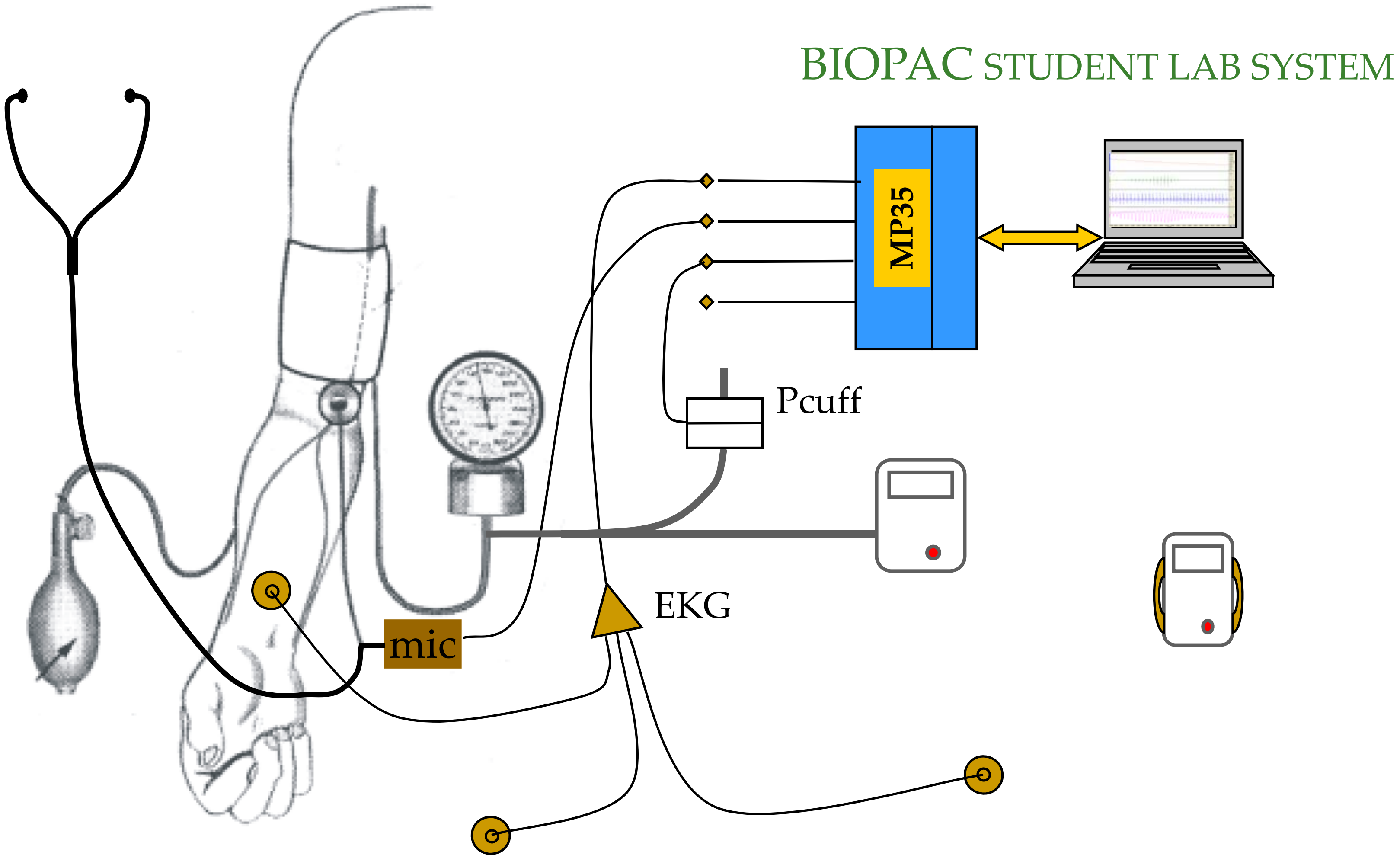
pulse pressure (PP):

PP=SBP-DBP

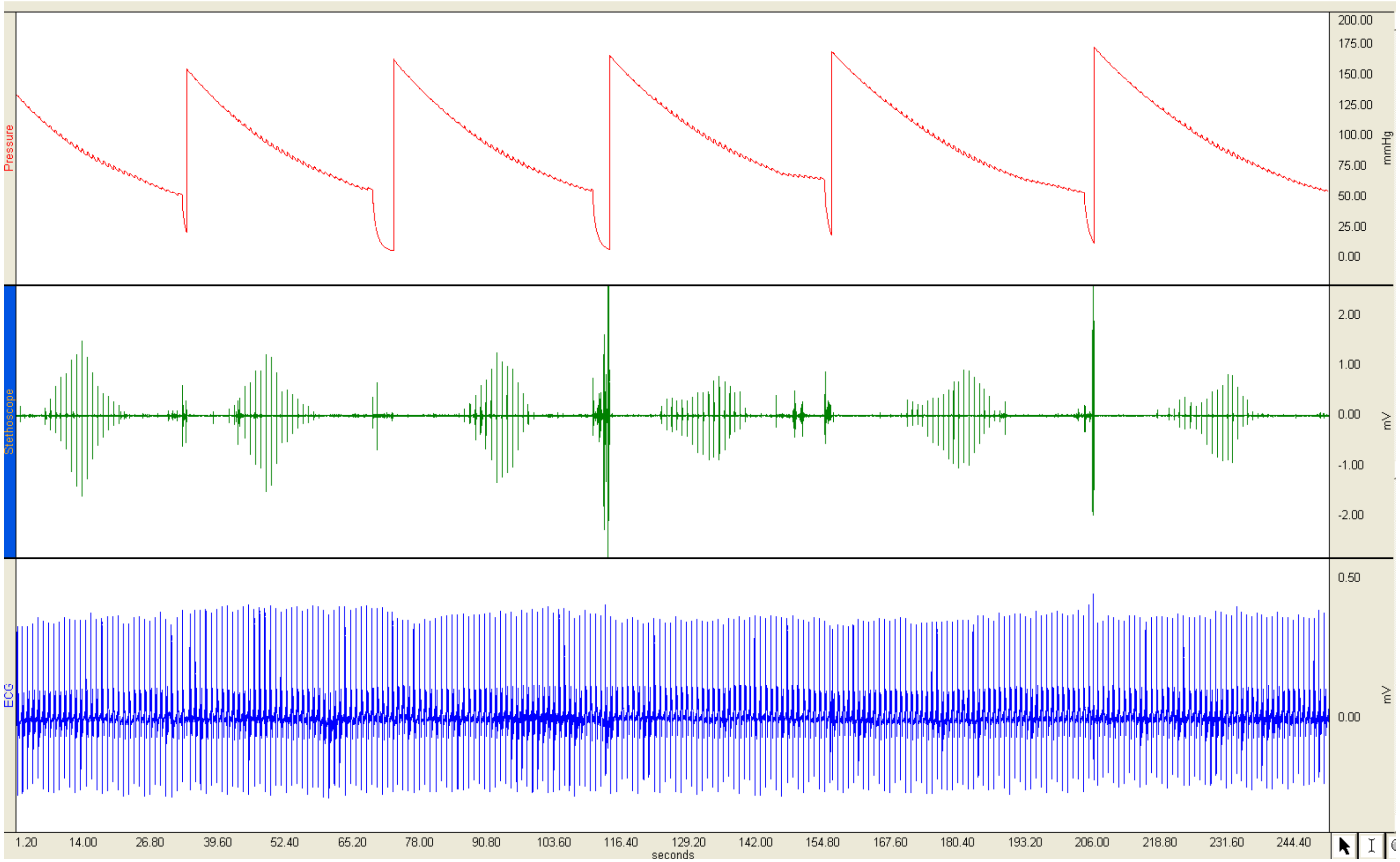
KOROTKOFF SOUNDS AND THE ECG CYCLE



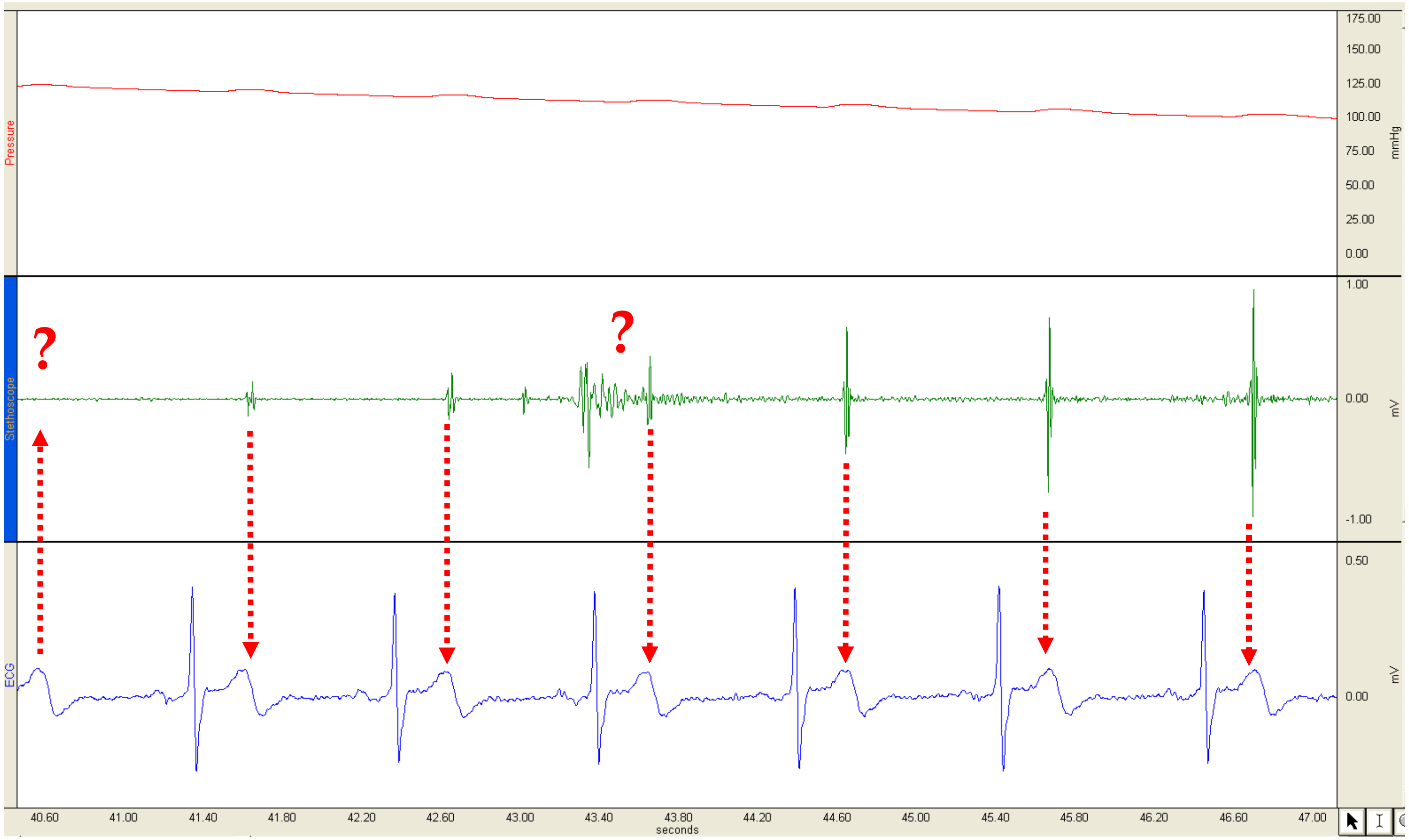
study arrangement



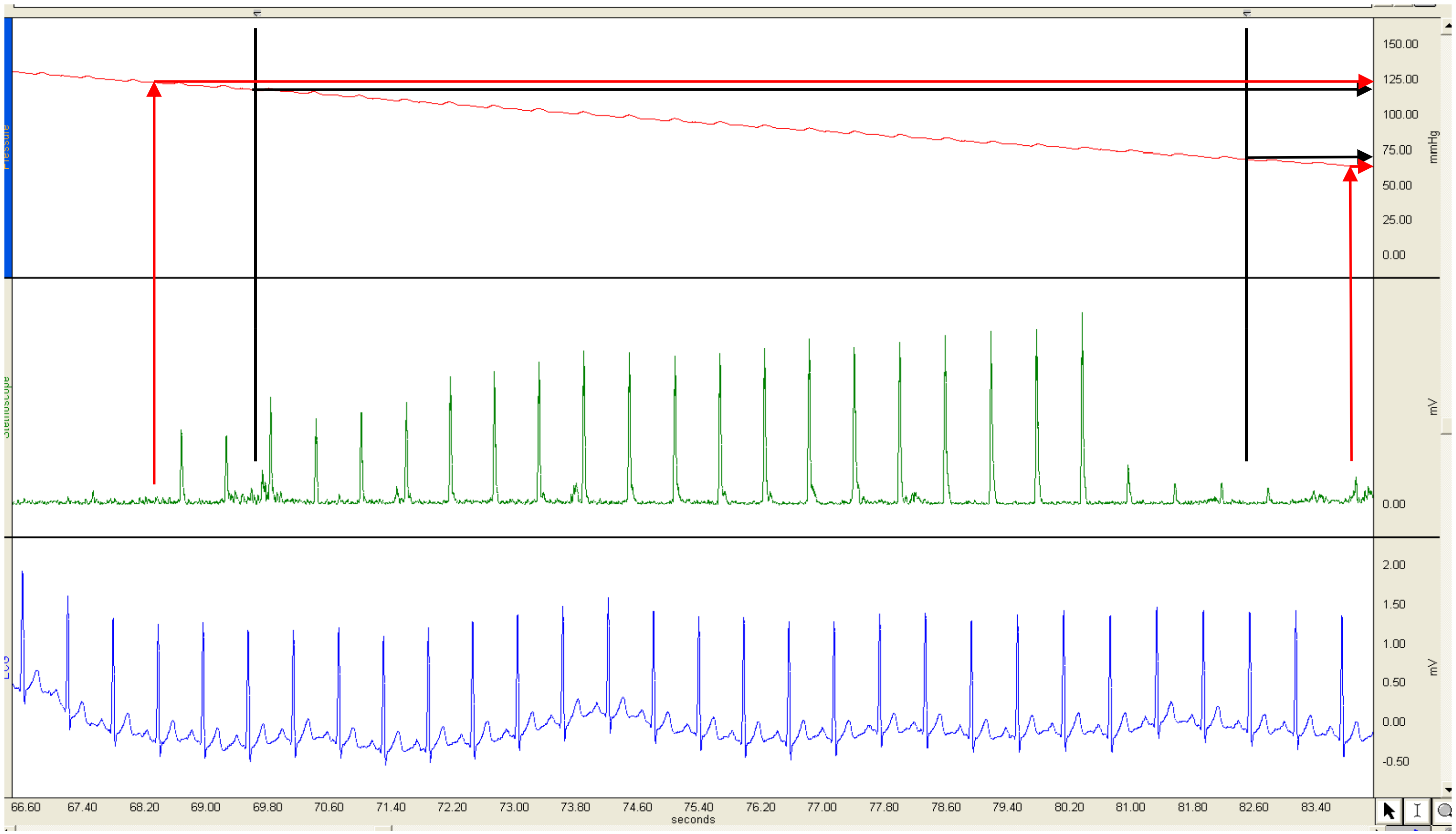
recordings: cuff pressure – stethoscope sound - ECG



identification of the Korokoff sounds and artifacts



auditory vs visual identification of the Korokoff sounds



the oscillometric principle

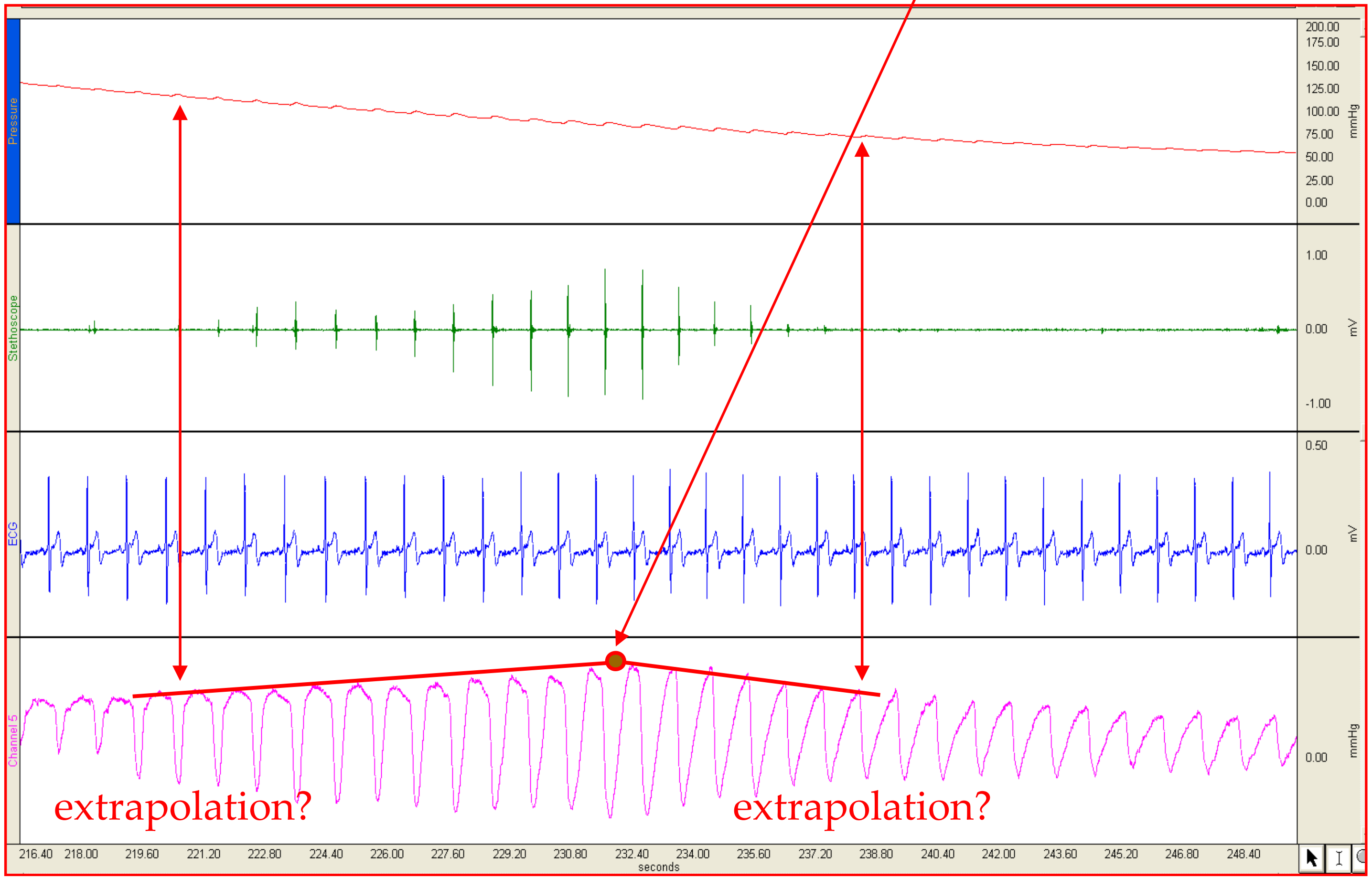
maximum pulse pressure=mean arterial pressure

cuff pressure

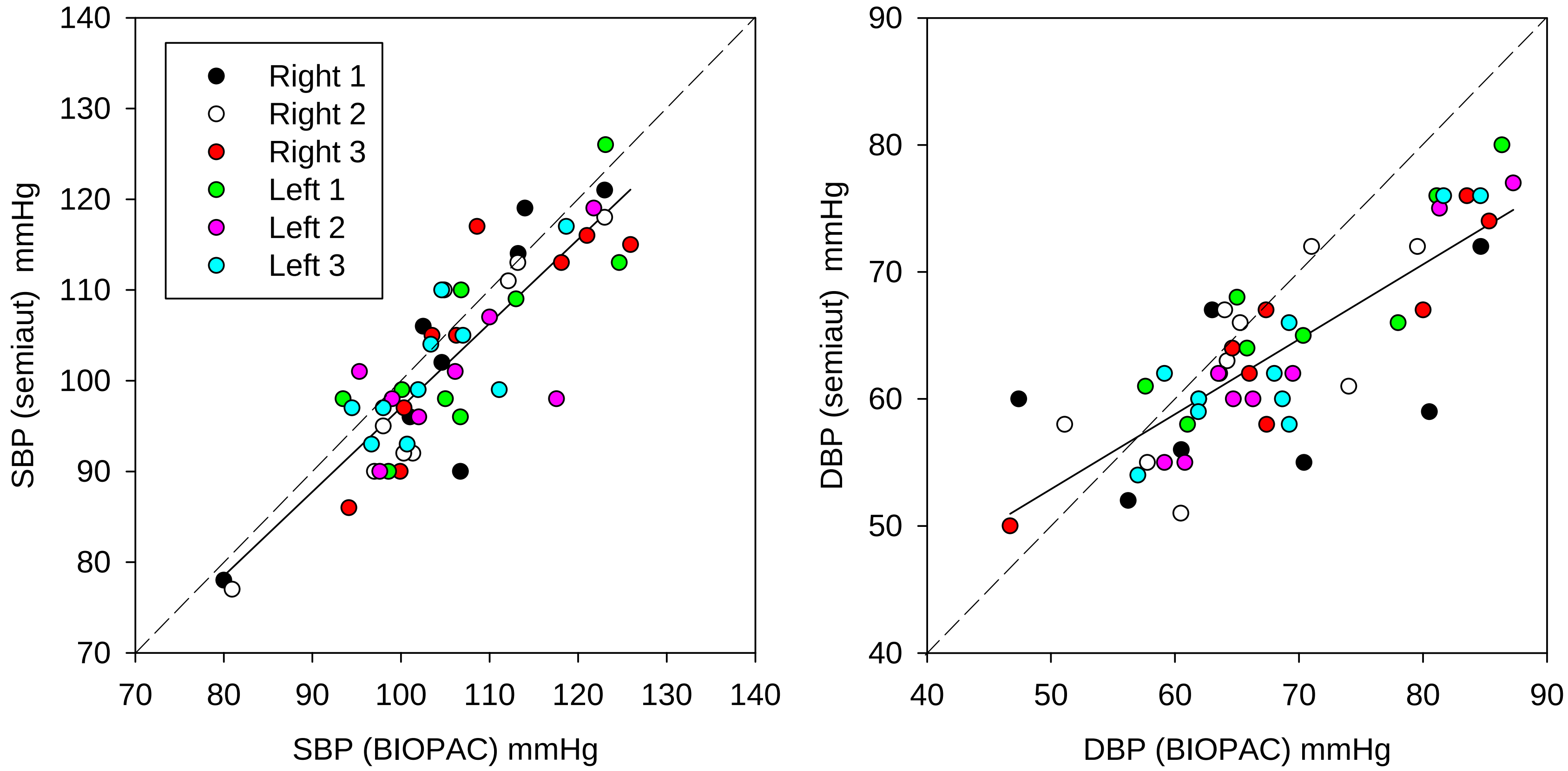
stethoscope sound

ECG

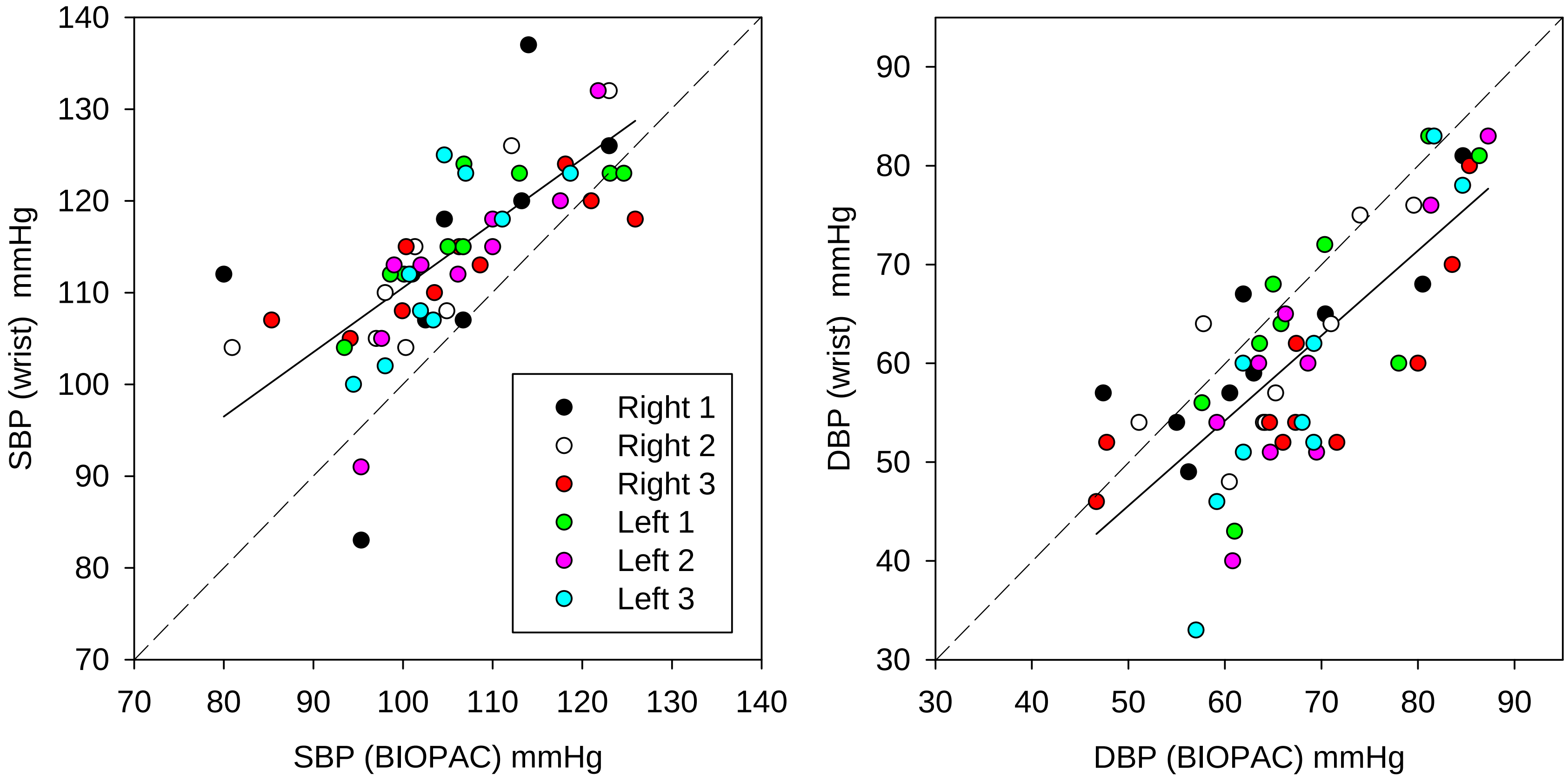
pulse pressure



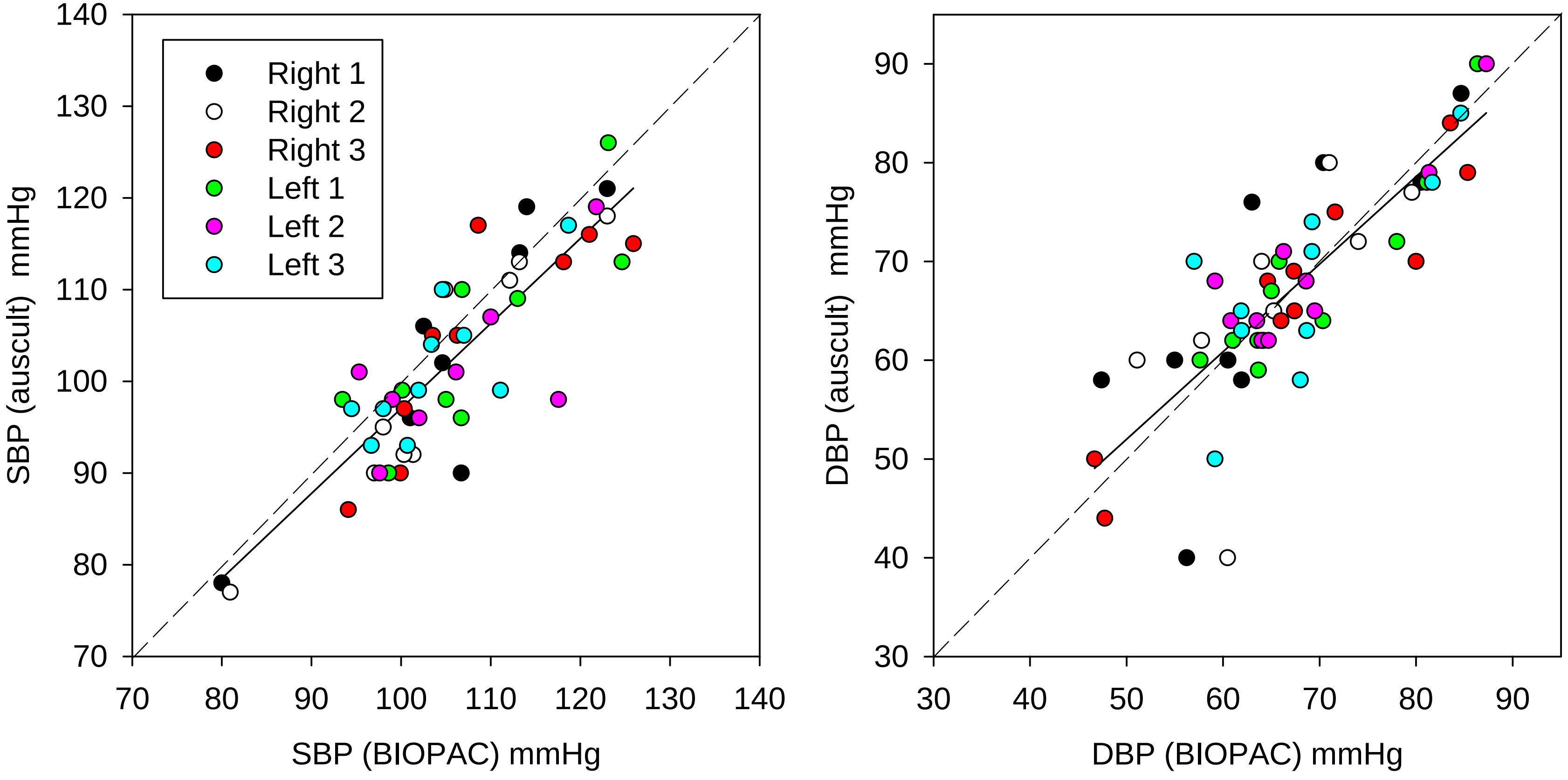
comparison of the routine measurements with the computer evaluations: semiautomatic vs BIOPAC



comparison of the routine measurements with the computer evaluations: wrist vs BIOPAC



comparison of the routine measurements with the computer evaluations: auscultation vs BIOPAC



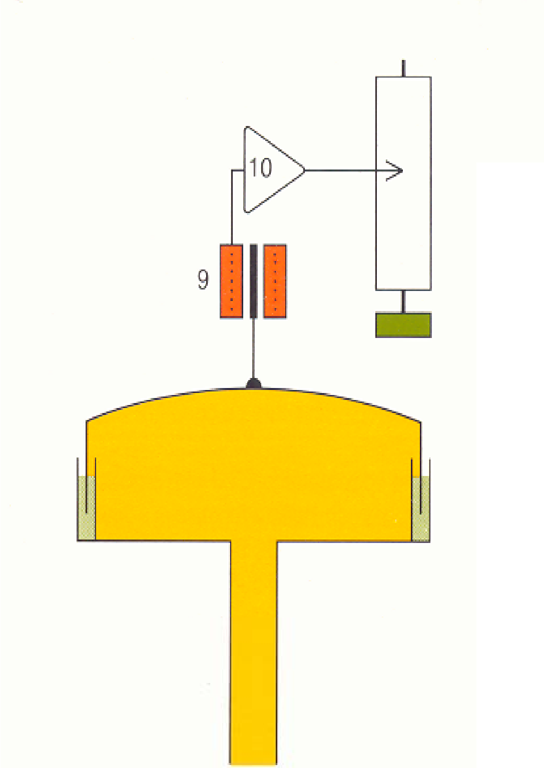
points of discussion:

- effects of atherosclerosis
- persistence of sounds below DBP
- the mercury column
- aneroid barometers
- finger photoplethysmography
- upper arm – wrist - finger
- oscillometry

spirometry and oscillation mechanics

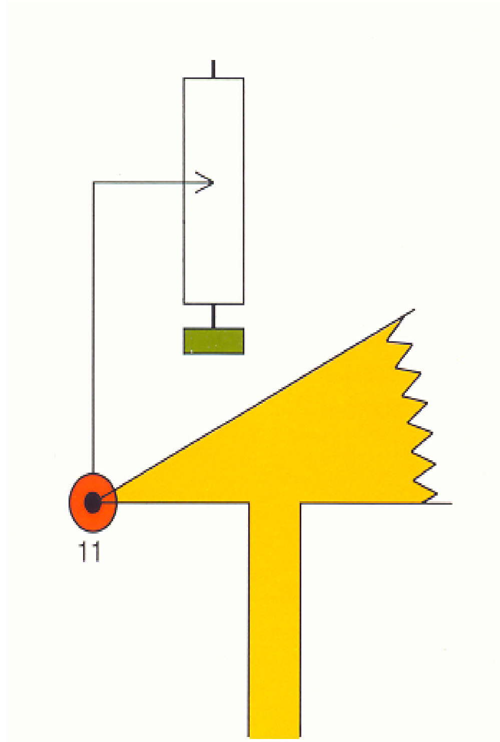
basics

Spirometer types



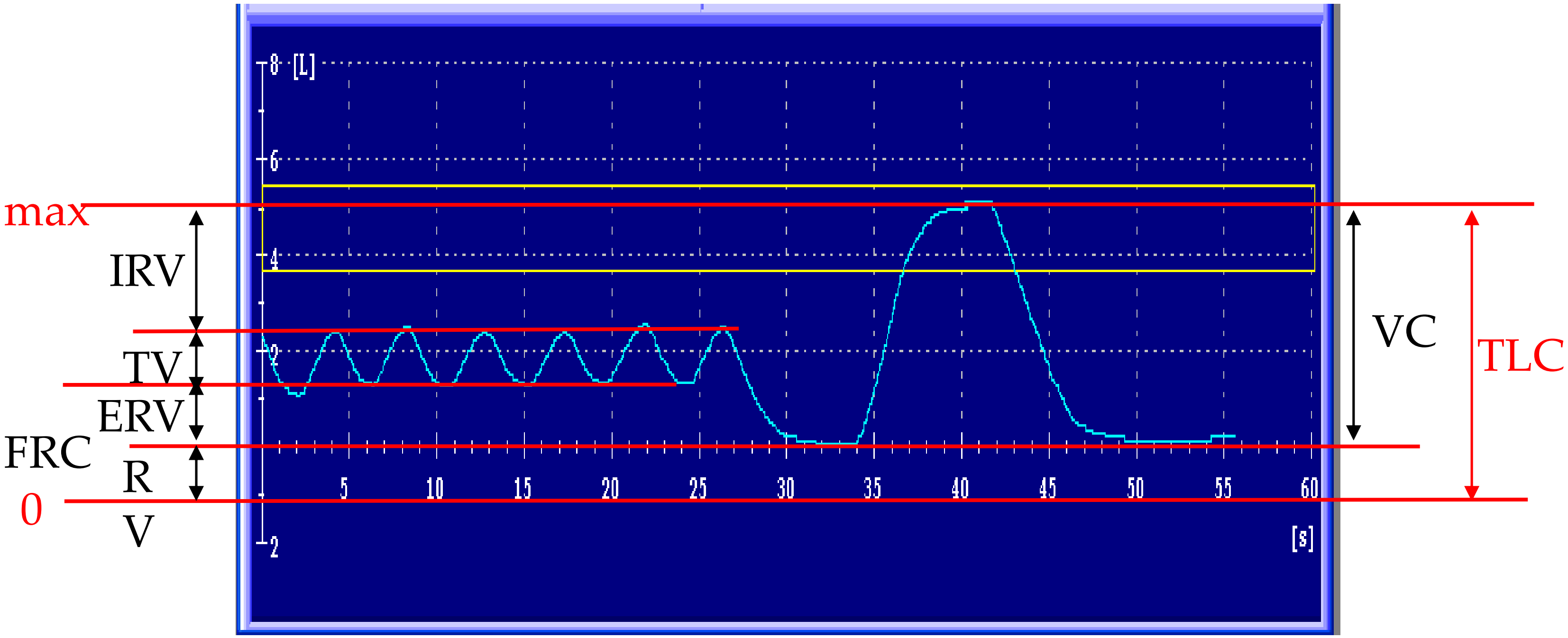
Water seal cylinder spirometer

Menzies spirometer (1790)



Bellows spirometer

quasistatic lung volumes

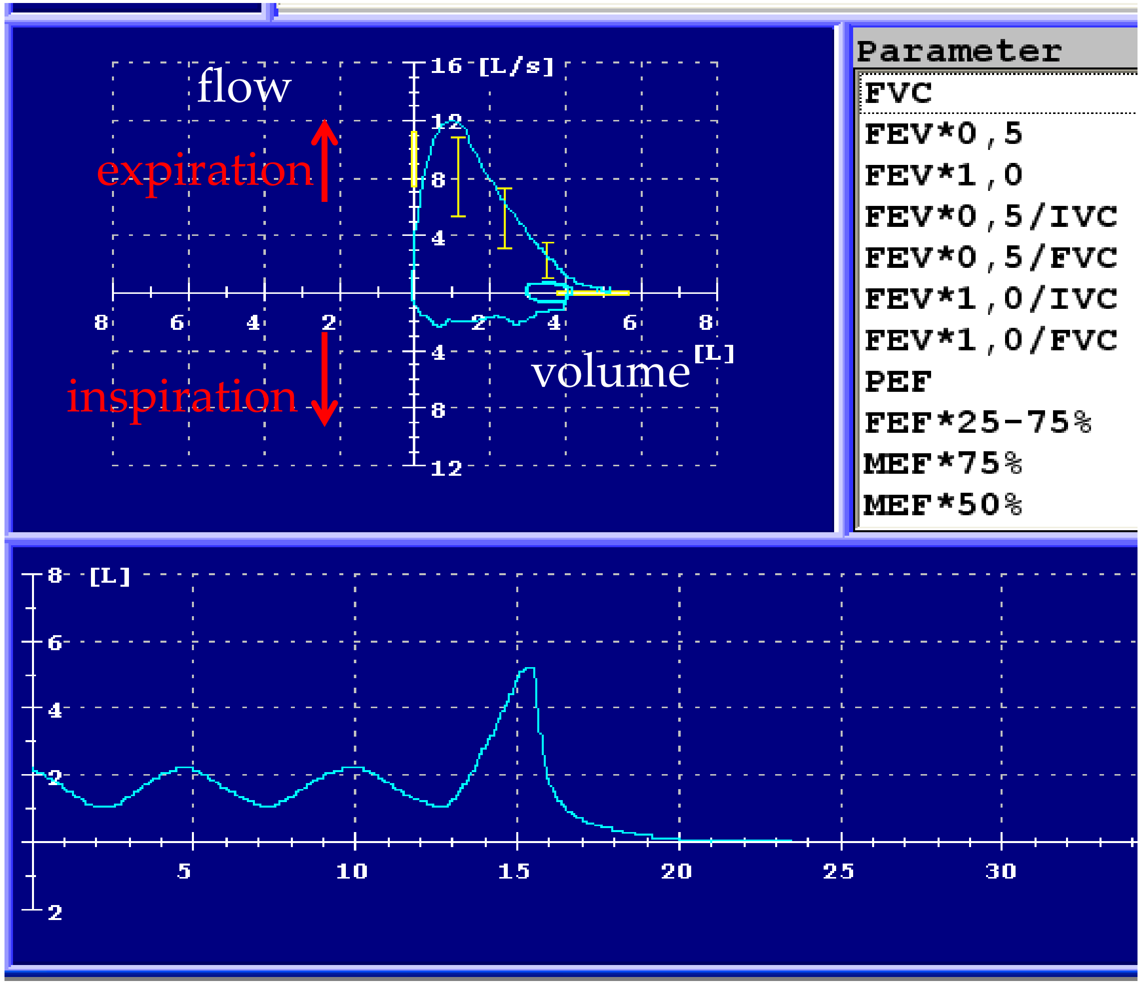


TV: tidal volume
IRV: inspiratory reserve volume
ERV: expiratory reserve volume
RV: residual volume

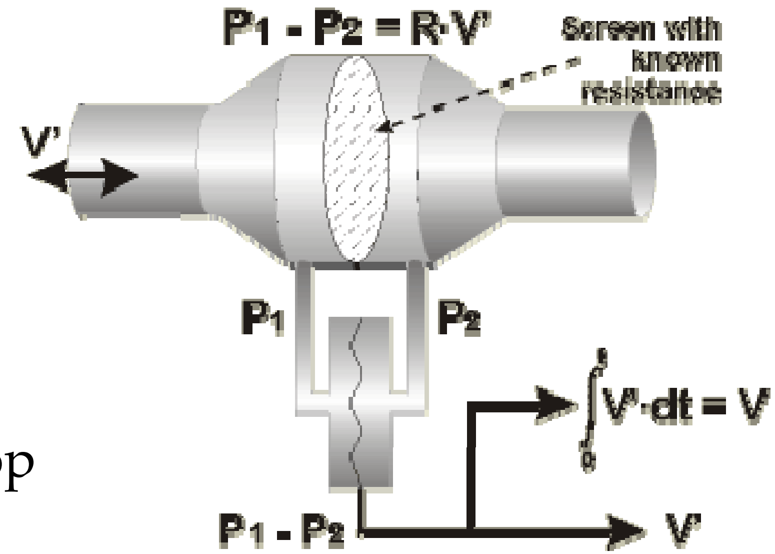
FRC: functional residual capacity
VC: vital capacity
TLC: total lung capacity

forced expiratory flow-volume loop

<u>task</u>: expiration of the maximum possible volume of the forced expiratory vital capacity (FVC) in the 1st second (FEV1)

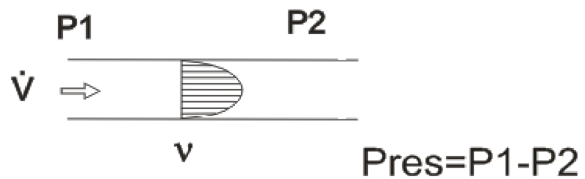


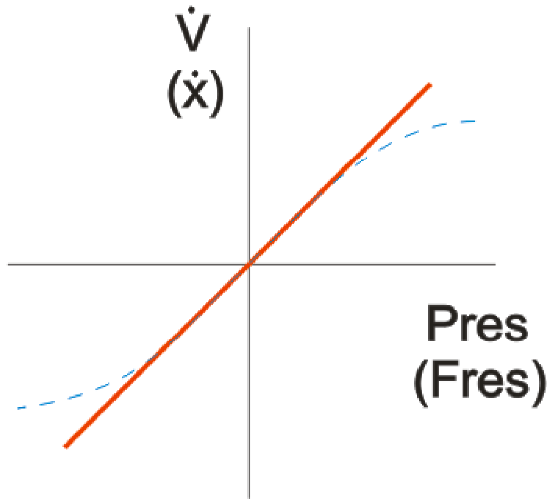
the pneumotachograph



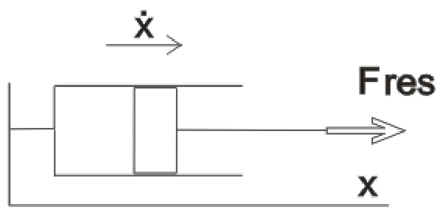
- Flow (V') is measured as the pressure drop across a fine metal or plastic screen
- In the laminar regime, the pressure drop is proportional to flow (*Hagen-Poiseuille law*)
- Volume is obtained via integration of the flow signal

the simple model of respiratory mechanics – the resistance

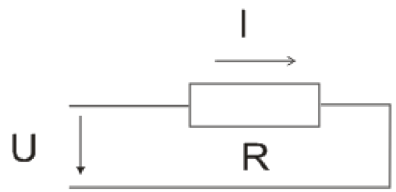




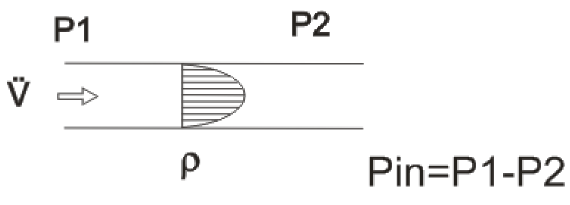
mechanical analogue

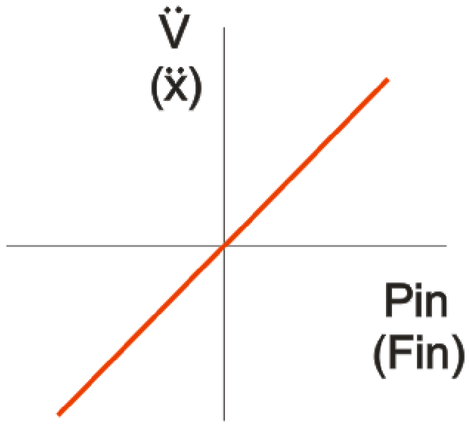


electrical analogue

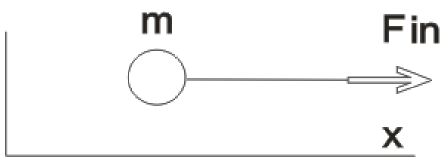


the simple model of respiratory mechanics – the inertance

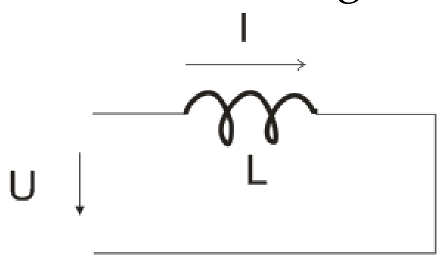


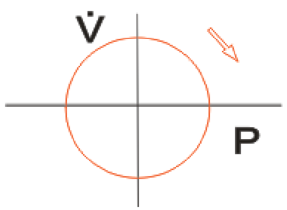


mechanical analogue

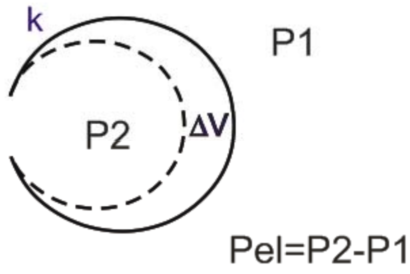


electrical analogue

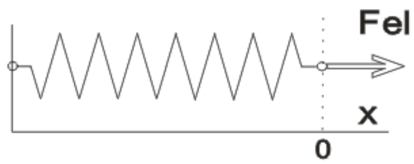




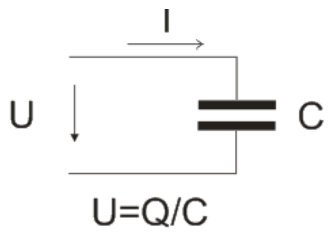
the simple model of respiratory mechanics – the elastance

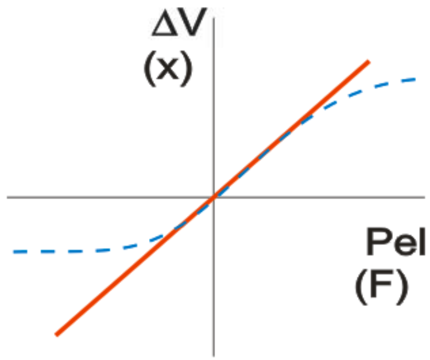


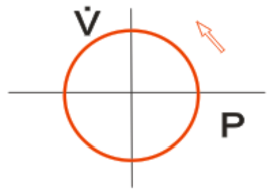
mechanical analogue



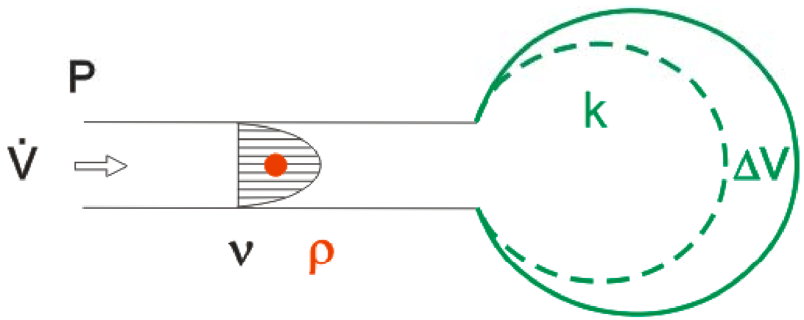
electrical analogue

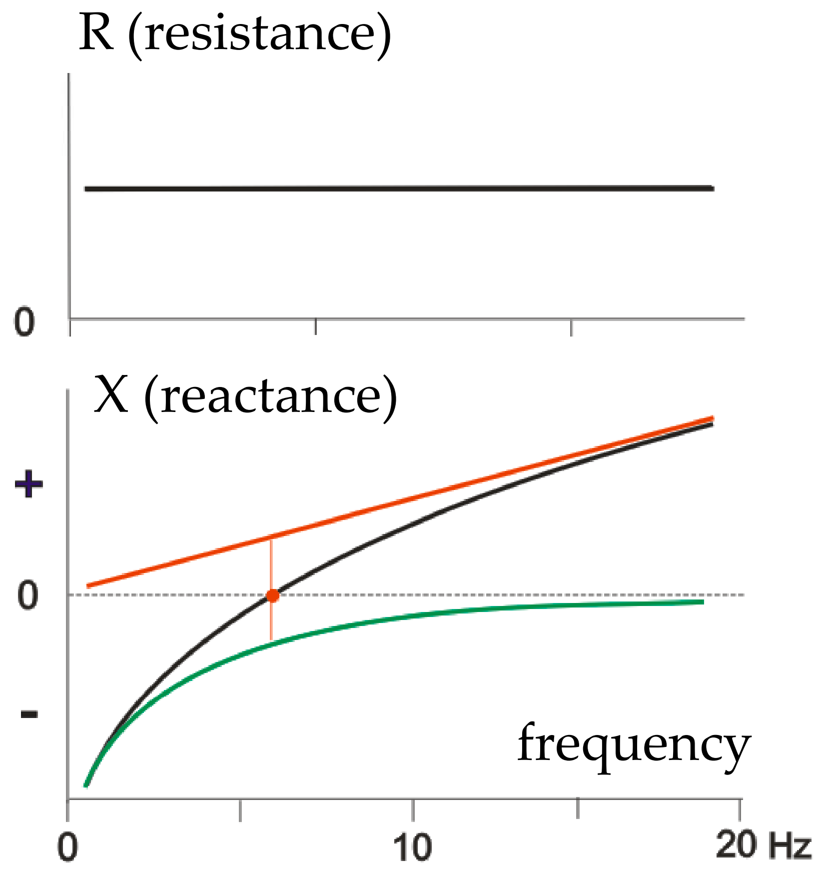






the simple 3-parameter model of respiratory mechanics

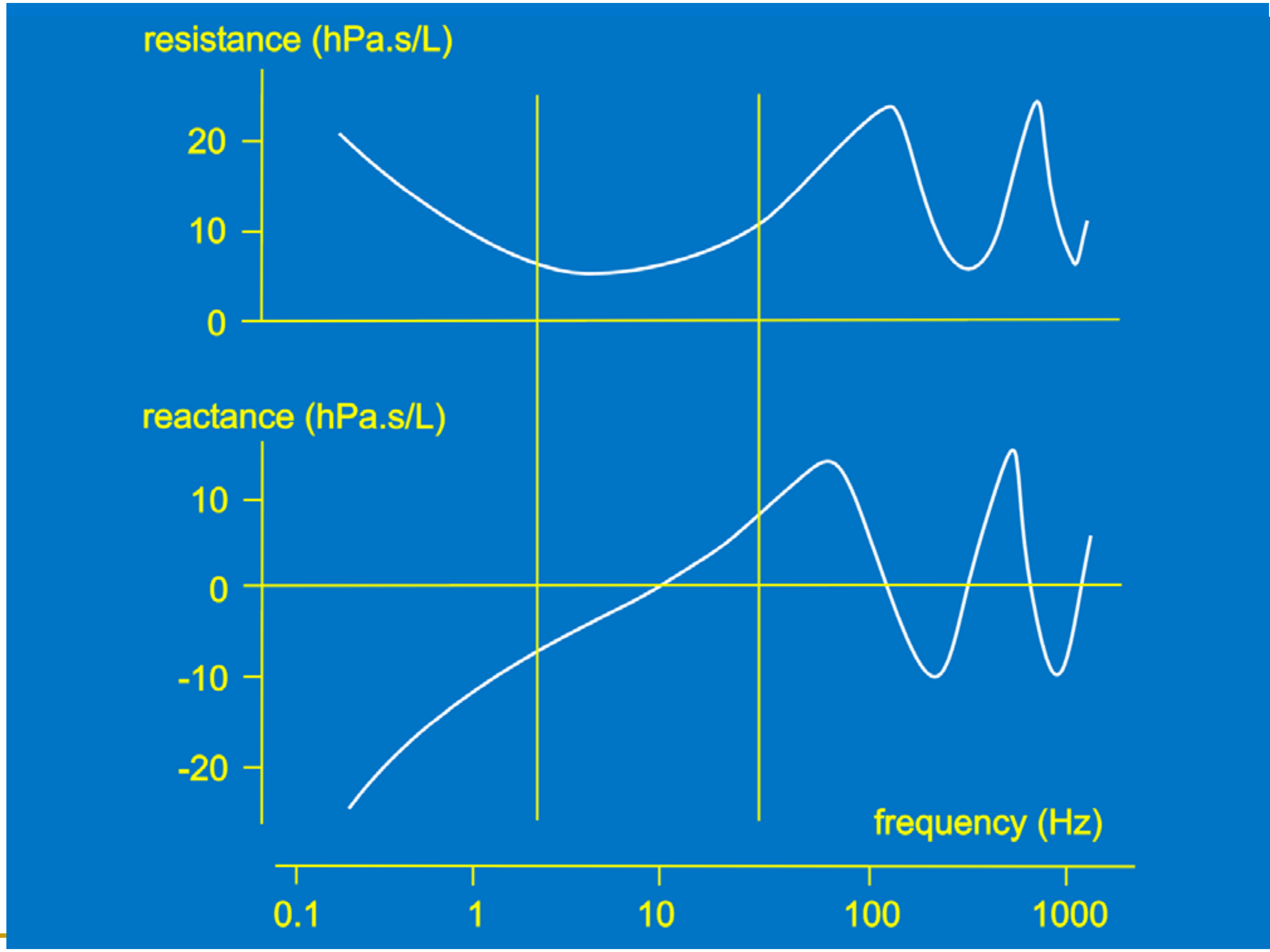




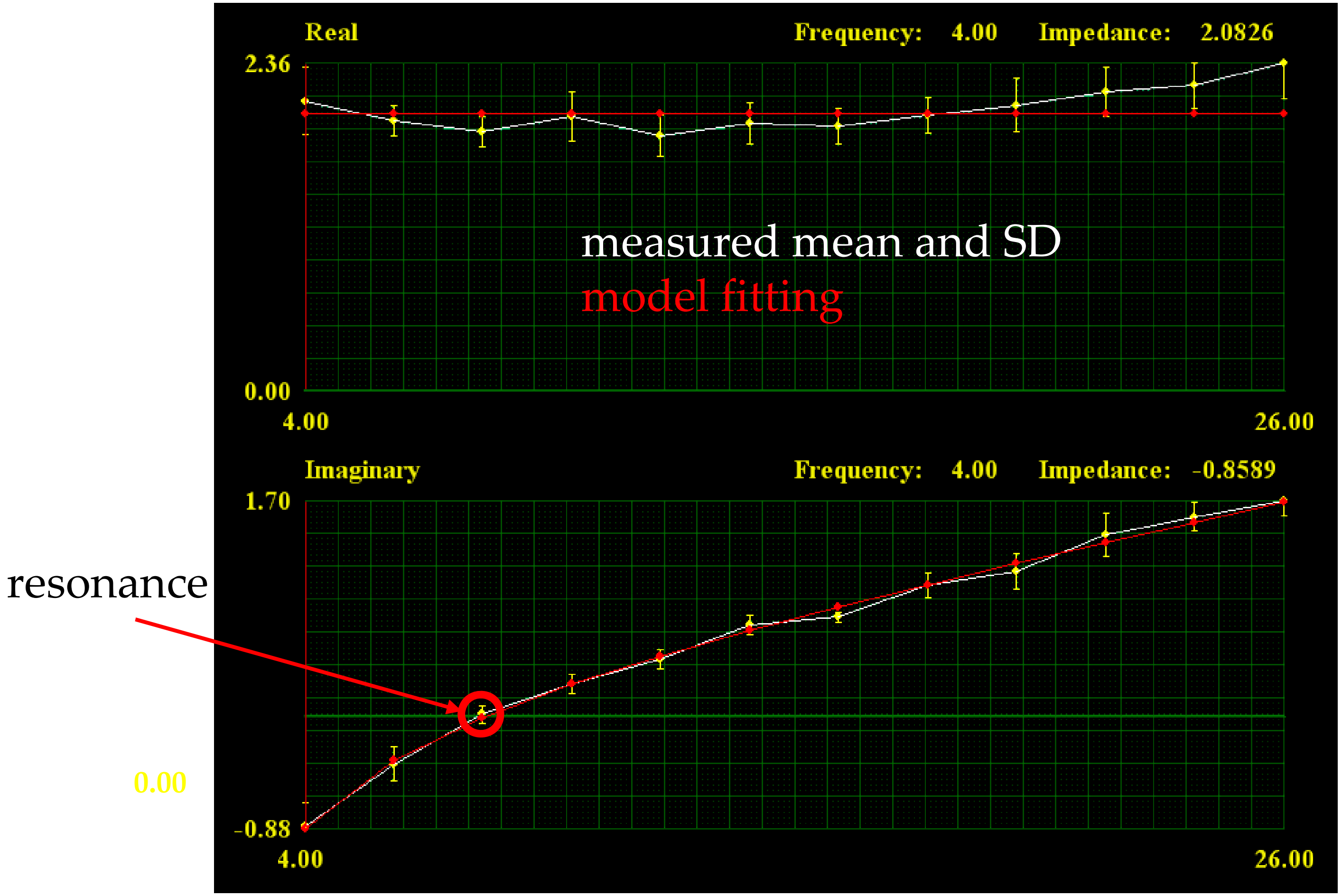
energy dissipation
resistance

energy storage
inertance
elastance

broad-band impedance of the respiratory system



3-parameter evaluation of respiratory impedance

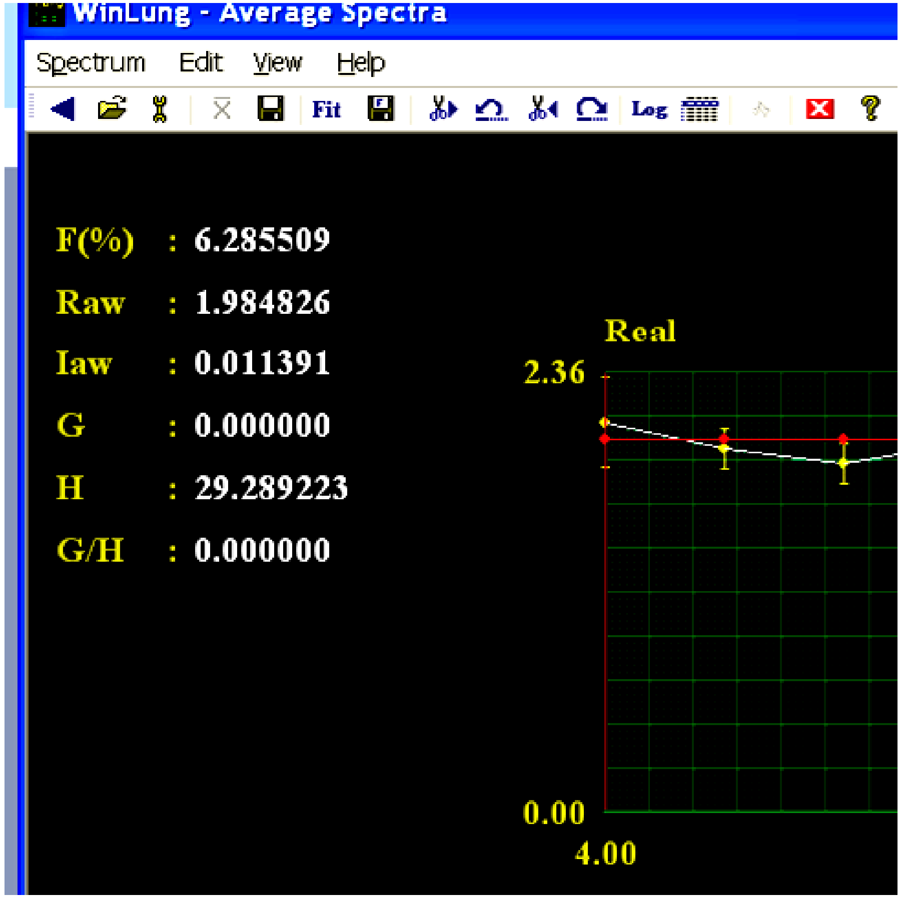


3-parameter evaluation of respiratory impedance

F%: mean fitting error
Raw: airway resistance (hPa.s/l)
Iaw: inertance ($hPa.s^2/l$)
H: elastance (hPa/l)

resonance frequency:

$f_{RES} = (1/2\pi)\sqrt{(H/Iaw)}$



use of reference values for spirometry and mechanics

normal values established in a large population

statistical relationships describing the dependence on height (H), age (A) and body weight (W), for both genders

e.g. the predicted value of Raw (Raw*) for females:

$Raw^*_{[hPa.s/l]} = 9{,}051 - 0{,}0542 \cdot H_{[cm]} + 0{,}0105 \cdot A_{[yr]} + 0{,}0369 \cdot W_{[kg]}$

if H=160 cm, A=20 yr and W=55 kg, Raw*=2,62 hPa.s/l

Points of discussion:

- relationship between quasi-static and forced expiratory vital capacity
- measures of reproducibility
- errors in model fitting
- interdependence of lung volumes and mechanical parameters

spirometry and oscillation mechanics

basics