Biosignal processing I
(Biosignaalien käsittely I)
521273S, Autumn 2019

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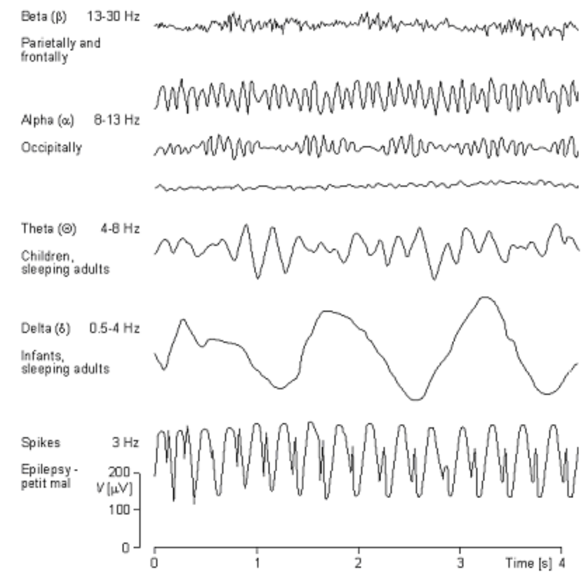
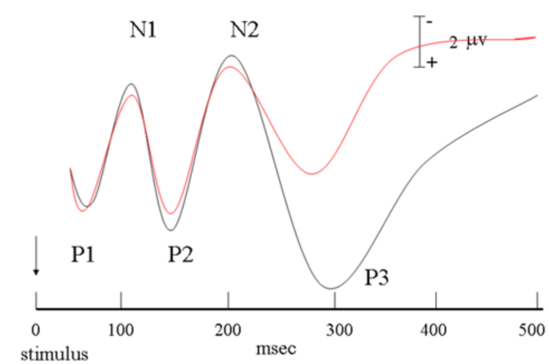
Professor of biomedical engineering

Biosignals

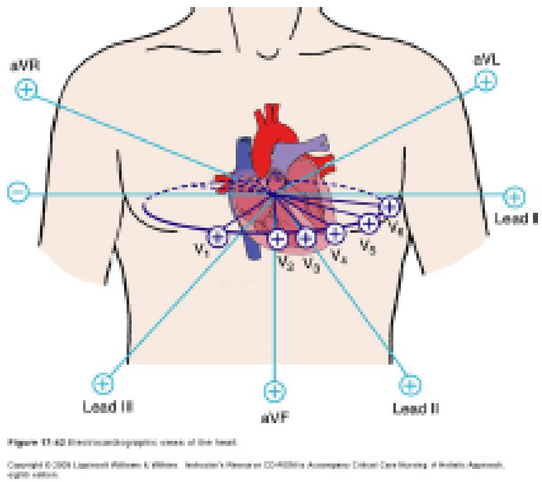
• Biosignal is a summarizing term for all kinds of signals that can be (continually) measured from biological beings
• The term biosignal is often used to mean bio-electrical signal but in fact, biosignal refers to both electrical and non-electrical signals. Examples:

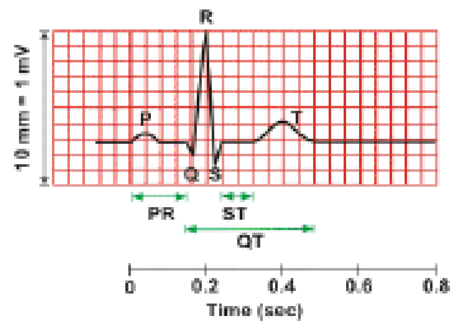
- **Bio-electrical signals**: Electrocardiogram (ECG), electromyogram (EMG), electroenkefalogram (EEG), electro-okulogram (EOG), electroneurogram (ENG)
- **Bio-magnetic signals**: magnetocardiogram (MCG), magnetoencephalogram (MEG)
- **Bio-acoustic signals**: phonocardiogram (PCG)
- **Bio-mechanical signals**: blood pressure, uterus contraction, respiratory signal
- **Bio-impedance signals**: impedance cardiography (ICG)
- **Ultrasound signals**





ECG Electrocardiogram



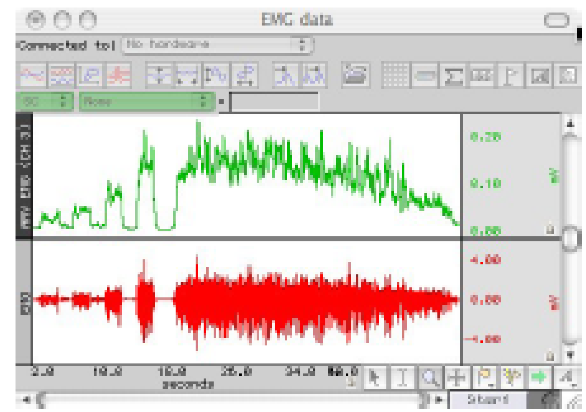


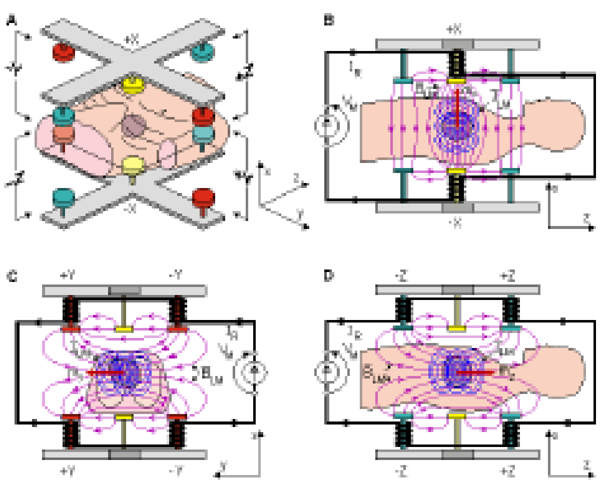
P wave (0.08 - 0.10 s) QRS (0.06 - 0.10 s)

P-R interval (0.12 - 0.20 s) Q-T_c interval ($\leq$ 0.44 s)*

$*QT_c = QT/\sqrt{RR}$

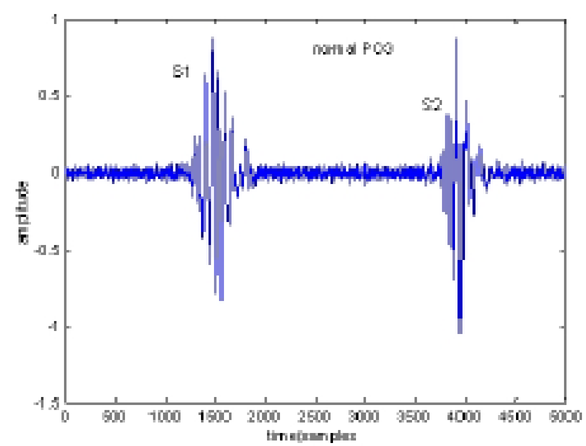
EMG Electromyogram



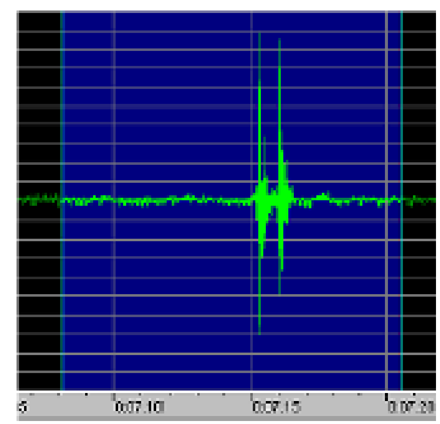


MCG

Magnetocardiogram

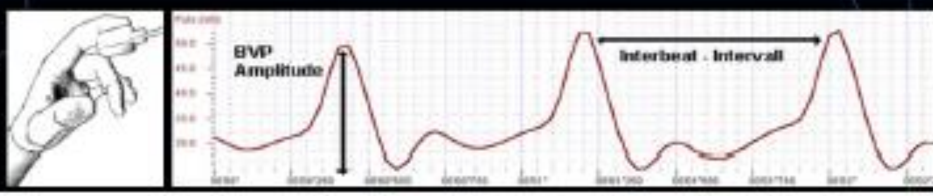


PCG Phonocardiogram

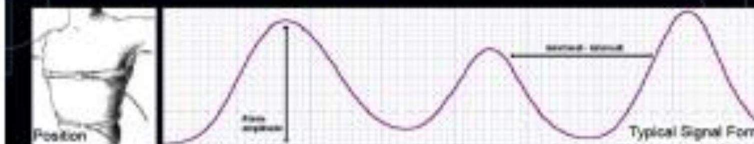


US Ultra sound

BVP (Blood Volume Pulse)



RESP (Respiration)



- Relative measure of chest expansion
- On the chest or abdomen
- Respiration rate (RF) and relative breath amplitude (RA)

SC (Skin Conductivity)

- Measure of skin's ability to conduct electricity
- Linear correlated with arousal
- Represents changes in sympathetic nervous system and reflects emotional responses and cognitive activity

Example application areas

- Medical technology
  - Patient monitoring, diagnostics, prognostics
  - On-line monitoring of nomadic patients
- Wellness technology
  - Measurement of healthiness
  - Fitness measurement

Signal Analysis Objectives

- Information gathering for signal analysis
    - Measurement of biomedical phenomena
        - Determination of system state
    - Invasive vs. non-invasive
    - Active vs. passive
  - Measurement quality -> limit of information
- Diagnosis
    - Comparison to reference/normal values
    - Detection of pathology or abnormality
        - Computer-aided diagnosis using quantitative analysis

Signal Analysis Objectives

- Monitoring
  - Obtaining continuous or periodic information
  - Relative changes or trends in the state of the system
- Therapy and control
  - Medication or intervention based on measurements
- Evaluation
  - Quantify the effect of treatment
  - Quality control of treatment

Aims of the course

- Course presents digital signal processing methods that are often applied in biosignal processing (EEG, ECG,…) applications
- Basic principles are presented in lectures, while practical experimentation is performed in the laboratory exercises

Learning outcomes

After completing the course, a student:

1. knows special characteristics of the biosignals and typical signal processing methods

2. can solve small-scale problems related to biosignal analysis

3. implement small-scale software for signal processing algorithms

Course implementation

- 5 credit units
- Lectures, laboratory works, written examination
- Web pages: in Moodle system: check the messages! Automatic e-mails to the students.
- Lectures and labworks are time synchronized by content

- Lectures:
  - On every Tuesday at 9.15-10.00 in PR101, starts at 29.10.2019 and ends at 3.12.2019
- Laboratory works: independent working with Matlab and biosignal data
  - Processing and analysis of real biosignals; programming tasks in Matlab language
  - All programming tasks are done on the Matlab Grader system (online system): automatic checking of results. User account needed
  - 6 tasks; it is compulsory to do each one and assignments must be approved by the Matlab Grader!
  - The next labwork will be announced on the preceding Friday on the course website in Noppa
  - Extra points for early birds: return the submission by the next Tuesday night to earn 1 point to be added on the exam points (next 3 exams). Otherwise, the deadline is on the next Friday
  - Consulting assistants: on every Tuesday at 10.15-12.00 in MA336 + MA337 + MA343. On every Friday at 8.15-10.00 in MA336 + MA337 + MA343. Starts at 29.10.2019 and ends at 10.12.2019
  - Plagiarism is strictly prohibited and the submissions will be checked by the assistants!

- Material:
  - Primary source: *RM. Rangayyan, Biomedical signal analysis – a case-study approach. 2002 or 2015. Chapters 1-6, part of Chapter 8 (8.1, 8.2, 8.4, 8.5*). E-book available in the university library
  - Selected articles from literature
  - (Lecture slides)
- Exam: 12.12.2019 (2 retakes in the Spring: 30.1.2020, 12.03.2020)
- Grading is based on the exam results and 'early bird' extra points (max 6). Grading scale 1-5. Zero stands for a fail.

Contact information

- Lecturer: Prof. Tapio Seppänen,
  Center for Machine Vision and Signal Analysis, TS309

- Primary assistant: Mr. Zalán Rajna,
  Center for Machine Vision and Signal Analysis

- Labwork consulting assistants: Youssef Hosni, Ahmed Elabasy
  Center for Machine Vision and Signal Analysis

- e-mail: firstname.lastname@oulu.fi

Related courses at ITEE faculty

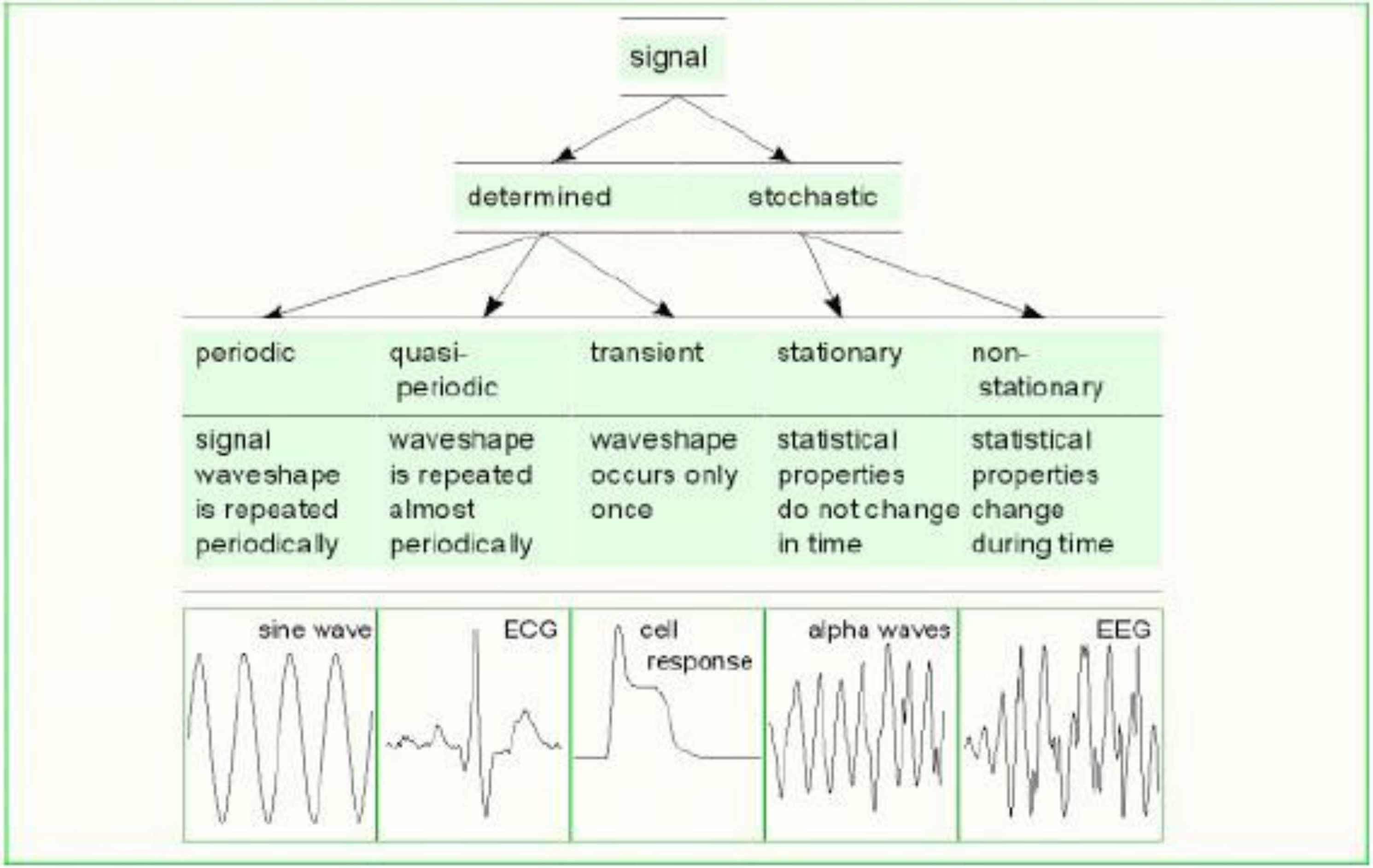
- Biosignal processing I (521273S)
- Biosignal processing II (521282S)
- Machine learning (521289S)
- Deep learning (521153S)
- Biomedical engineering project (521284S)
- Affective computing (521285S)
- Function and analysis of cardiovasccular system (521149S)
- Introduction to computer vision method for biomedical images (521149S)

Degree programme in biomedical engineering (2 years, MSc, DI/TtM)

- Joint-programme between:
  - The faculty of information technology and electrical engineering (DI)
    - Signal and image processing
  - The faculty of medicine (TtM)
    - Biomechanics and medical imaging
- About eligibility of applicants:
  - Bachelor's (or higher) degree in biomedical engineering, computer science, information technology, electrical engineering, control engineering, biophysics, or other relevant fields.
- Read more at: https://studyinfo.fi/wp2/en/

Introduction

Biosignals – Classification



Signal acquisition and analysis

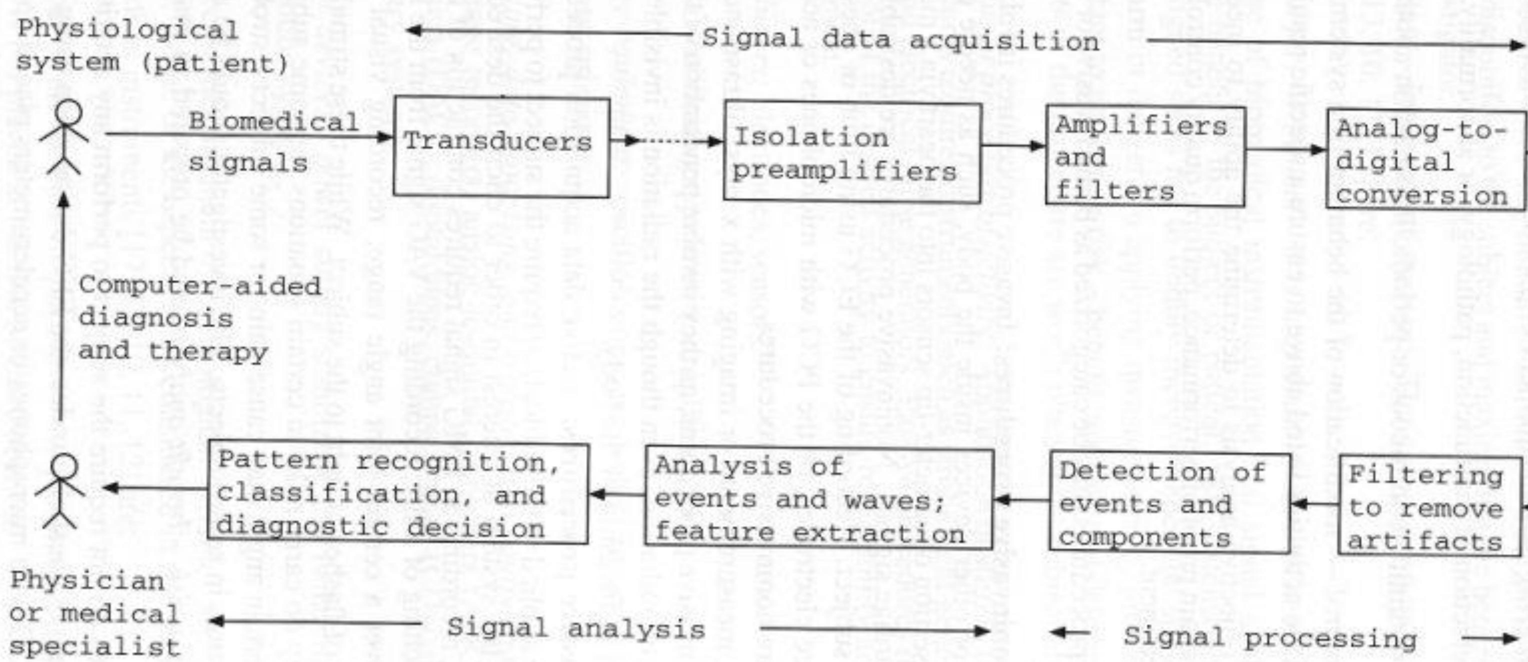


Figure 1.32 Computer-aided diagnosis and therapy based upon biomedical signal analysis.

Biosignals – Some specific properties

- signal is often feeble
  => AMPLIFICATION
- signal contains noise
  => filtering, decompositions
- signal contains artifacts (e.g. unwanted transients) among interesting events
  => Event detection, segmentation, filtering
- each biosignal has a specific frequency-domain characteristics
  - may contain information also in slow changes (min, h)
    -> analysis of low frequencies
  - typical : 1/f –form spectrum, wide frequency bands
- signal is unstable or unstationary
  - due to physiological and measurement environment

Signal analysis difficulties

- Inter-relationships and interactions among physiological systems
  - Can make interpretation of signals difficult
- Effect of instrumentation/procedure on the system
  - Spurious variations may result
  - Is this artefactual or is this result true?
- Physiological artifacts and interference
  - E.g., patient movements disturb measurements
  - Mother and fetus ECG get mixed

ECG:Electrocardiogram

- Electrical potential changes due to contractile activity of the heart
- Measured usually by standard 12-lead system
  - With four limb electrodes and six chest electrodes
- Common ECG-applications are
  - stationary ECG
  - Holter-monitoring
  - stress-ECG (exercise testing)
  - telemedicine applications
  - heart rate monitors
- Invasive intrumentation:
  - heart pacemakers
  - arrhythmia-pacemakers

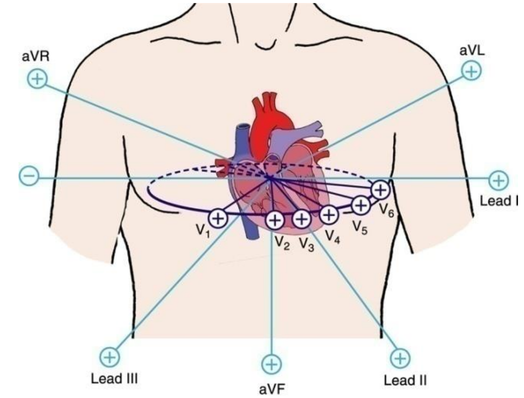
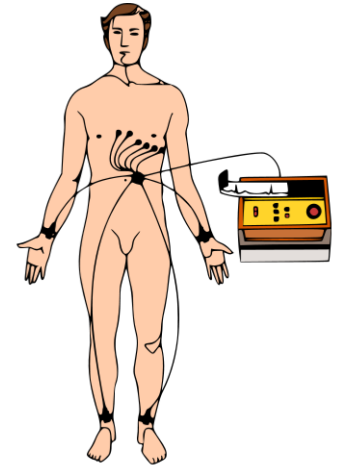


Figure 17-42 Electrocardiographic views of the heart.

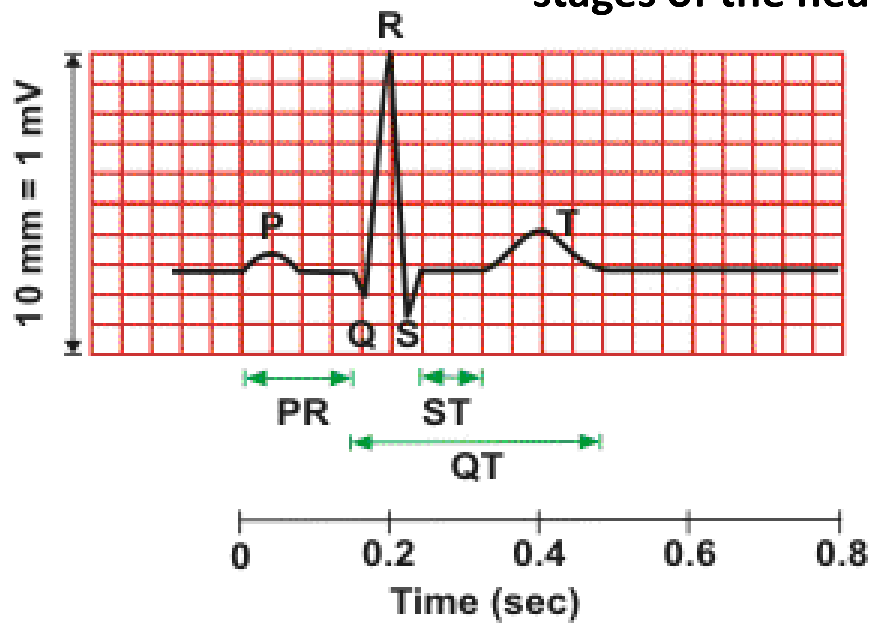


ECG structure

Contraction and relaxation stages of the heart

E.g. Feature analysis

Automatic detection of different segments and waves (amplitudes, intervals)



P wave (0.08 - 0.10 s)

P-R interval (0.12 - 0.20 s)

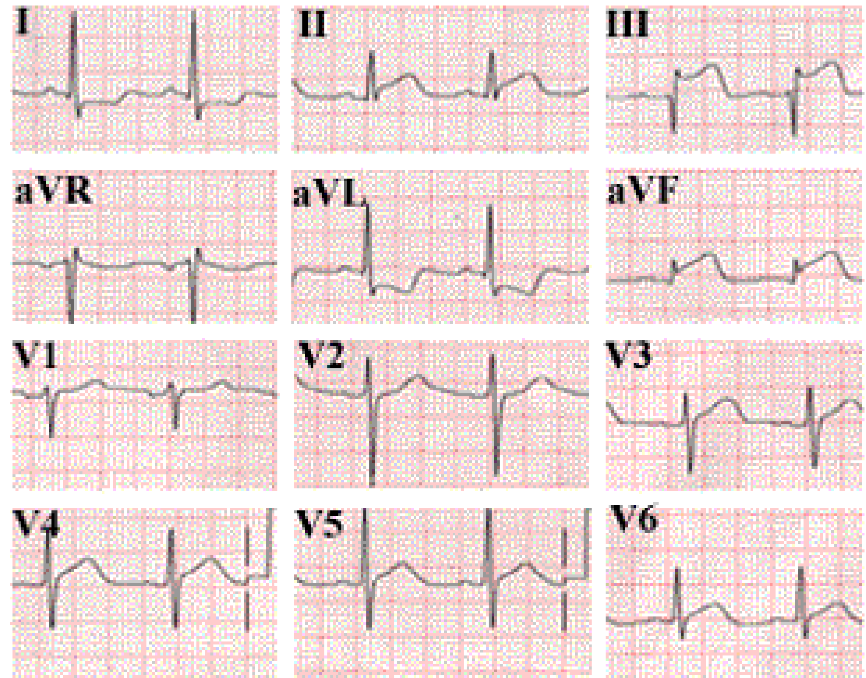
QRS (0.06 - 0.10 s)

Q-T_C interval ($\leq$ 0.44 s)*

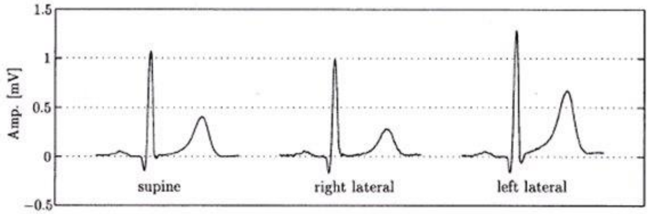
$*QT_C = QT/\sqrt{RR}$

ECG:Electrocardiogram

- ECG analysis focus:
  - QRS complex detection
  - feature analysis
  - classification of arrhythmias
  - ECG signal compression
  - Heart rate variability (HRV) analysis

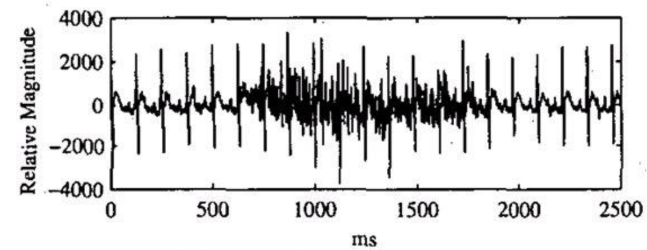


Effect of body position on ECG:



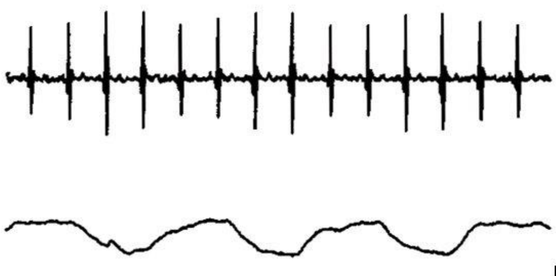
Beat morphologies for three different body positions.

Distortion caused by electromyogram:

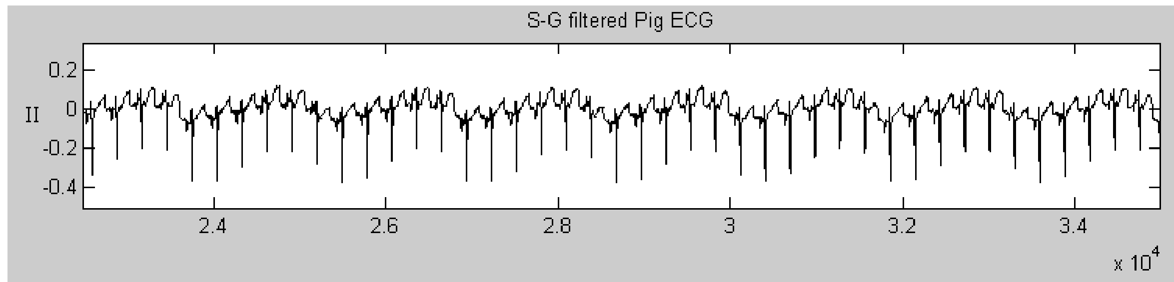


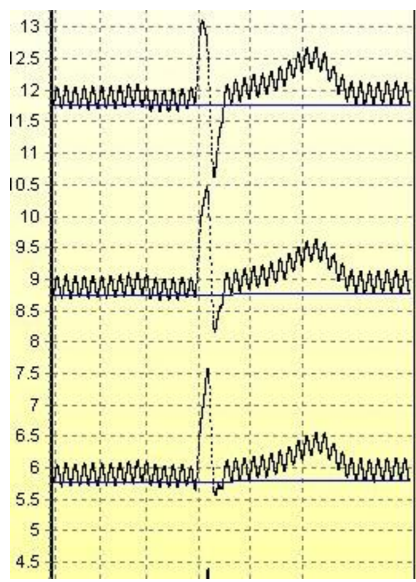
Recorded ECG corrupted by EMG noise.

Respiration-induced ECG modulation:

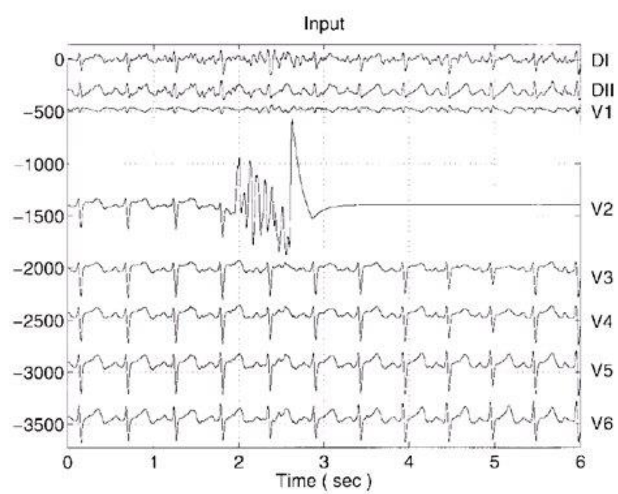


ECG (upper trace) and respiration measured by a pneumatic respiration transducer placed around chest (lower trace).





Channel loss:



Complete loss of channel V_2 during recording.

ECG: extra beats (PVC)

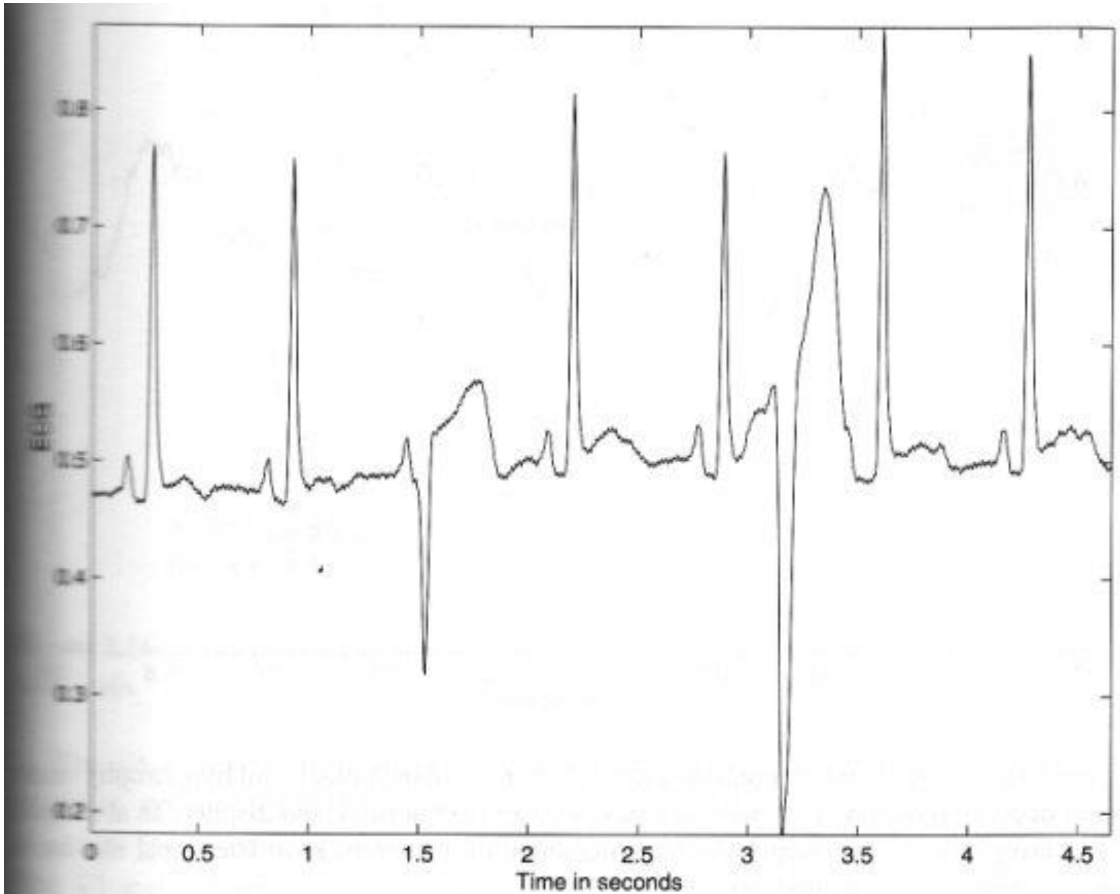


Figure 1.14 ECG signal with PVCs. The third and sixth beats are PVCs. The first PVC has blocked the normal beat that would have appeared at about the same time instant, but the second PVC has not blocked any normal beat triggered by the SA node. Data courtesy of G. Groves and J. Tyberg, Department of Physiology and Biophysics, University of Calgary.

ECG: bundle-branch block

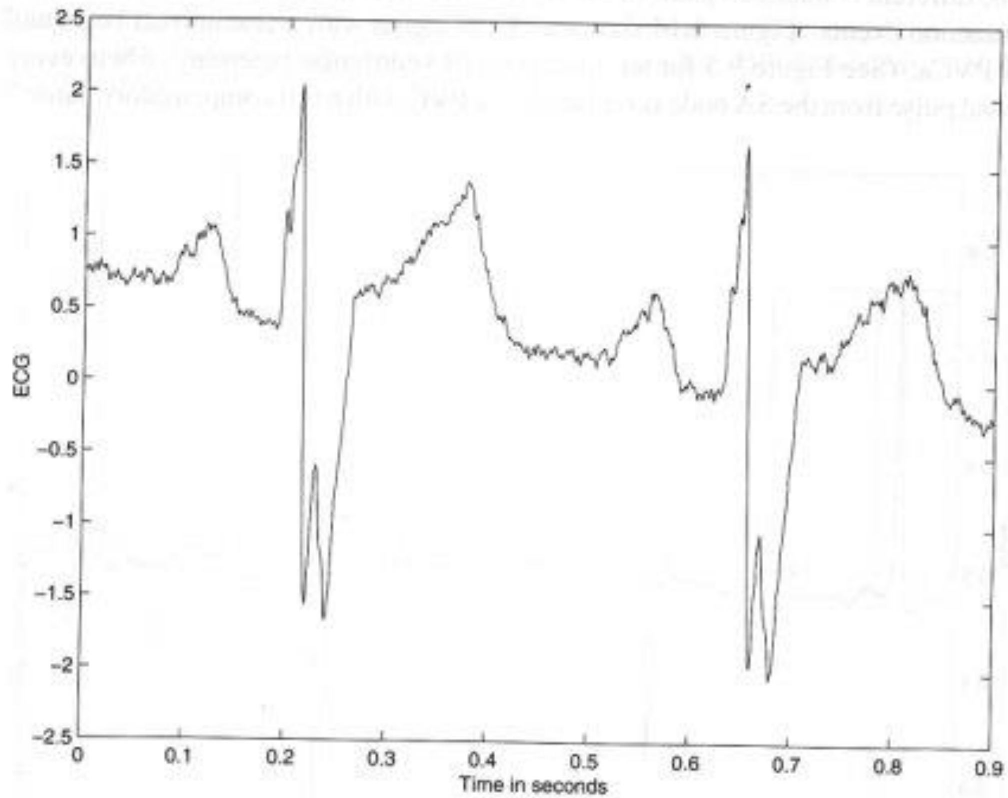
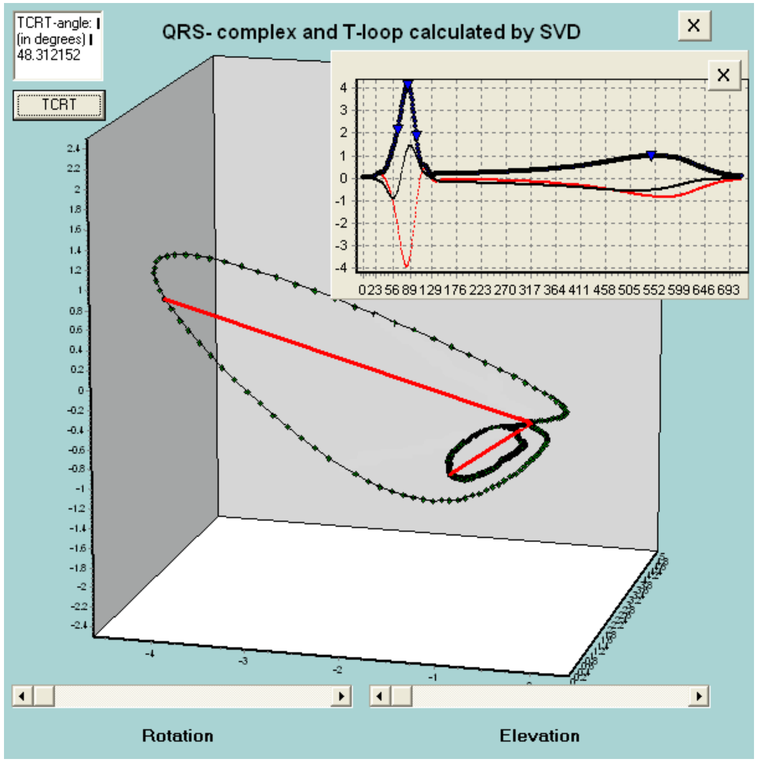
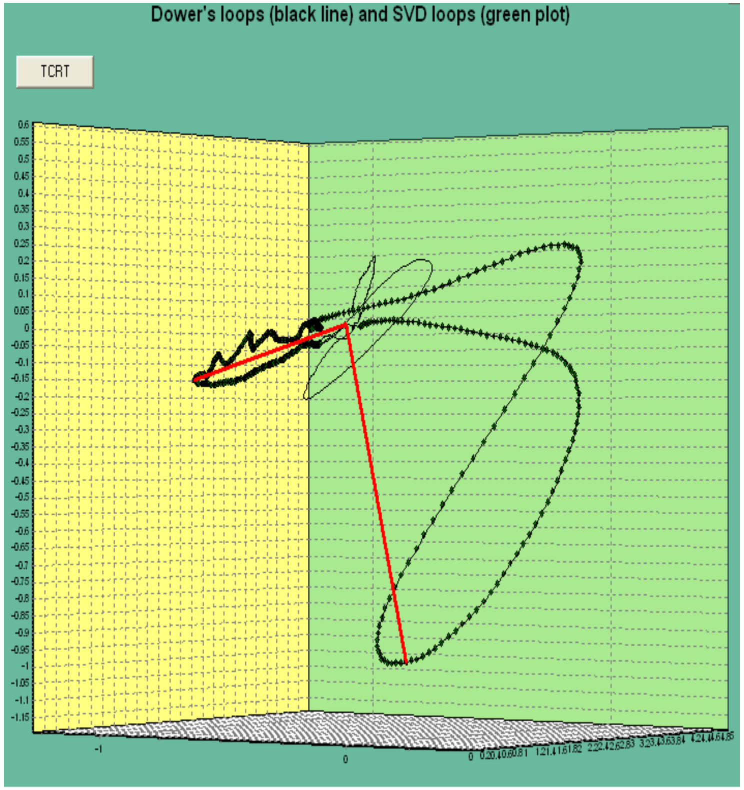


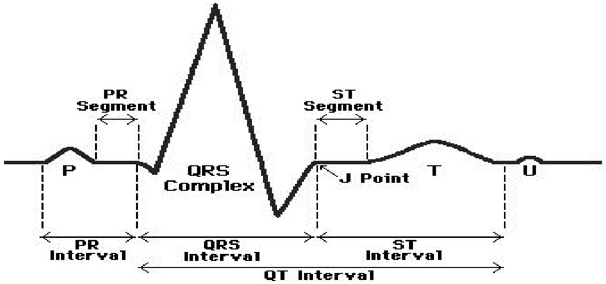
Figure 1.15 ECG signal of a patient with right bundle-branch block and hypertrophy (male patient of age 3 months). The QRS complex is wider than normal, and displays an abnormal, jagged waveform due to desynchronized contraction of the ventricles. (The signal also has a base-line drift, which has not been corrected for.)

SVD-based VCG-loop analysis



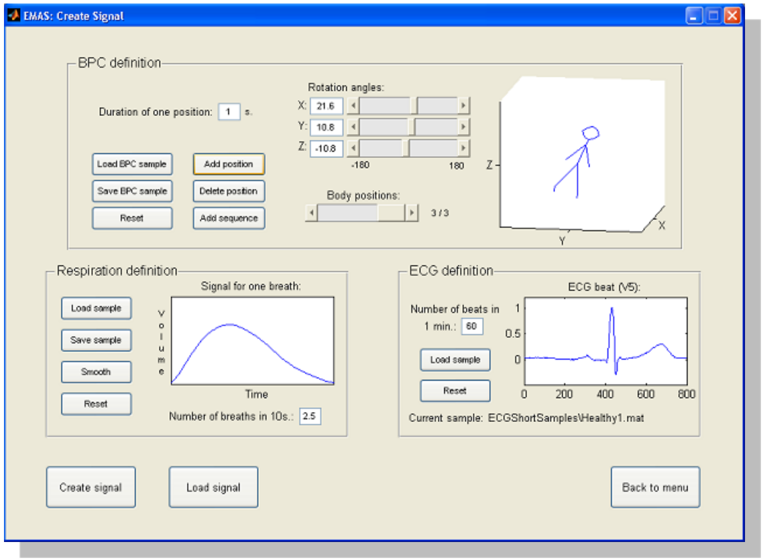


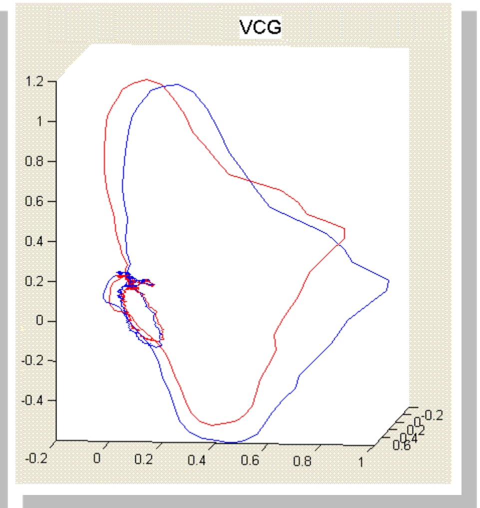
HEALTHY SUBJECT

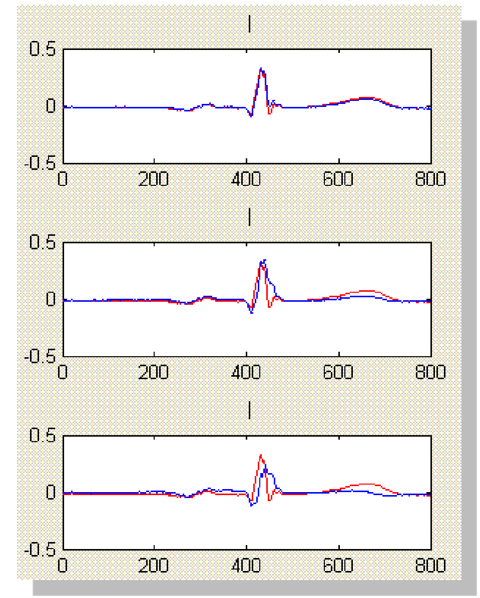


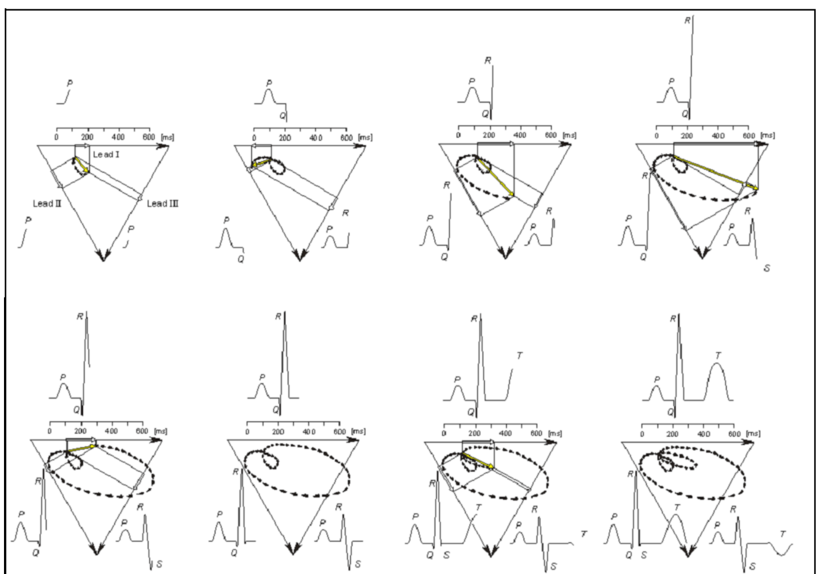
INFARCT PATIENT

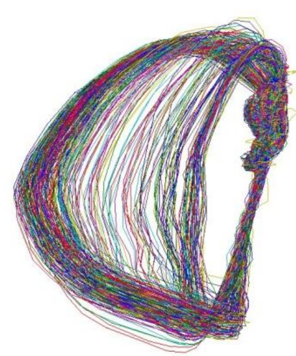
Dynamic VCG normalization for motion artifact removal



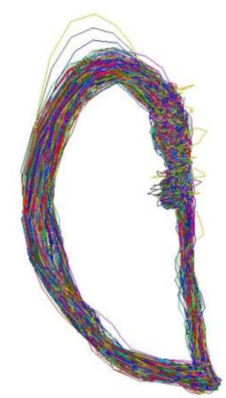




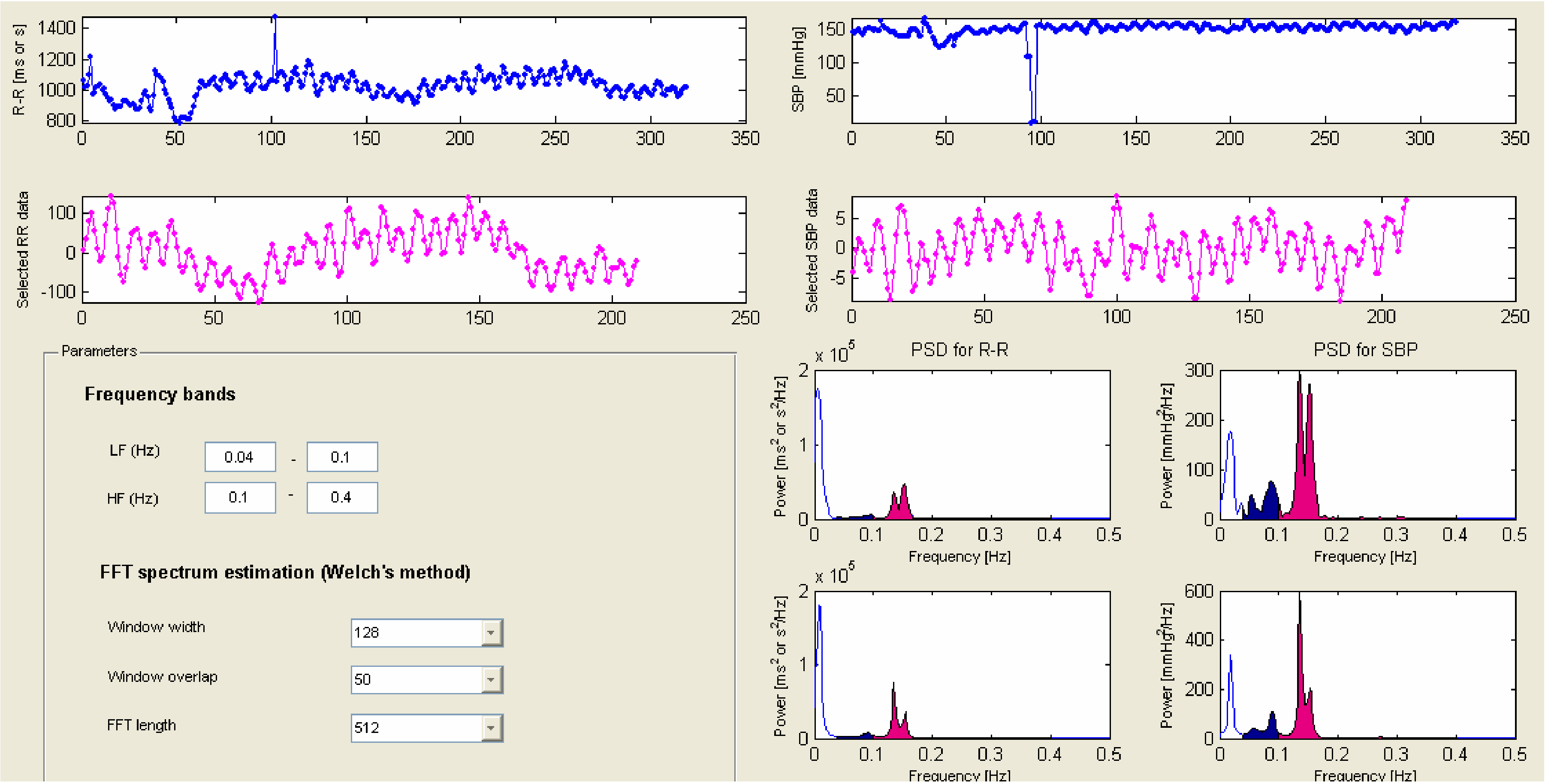




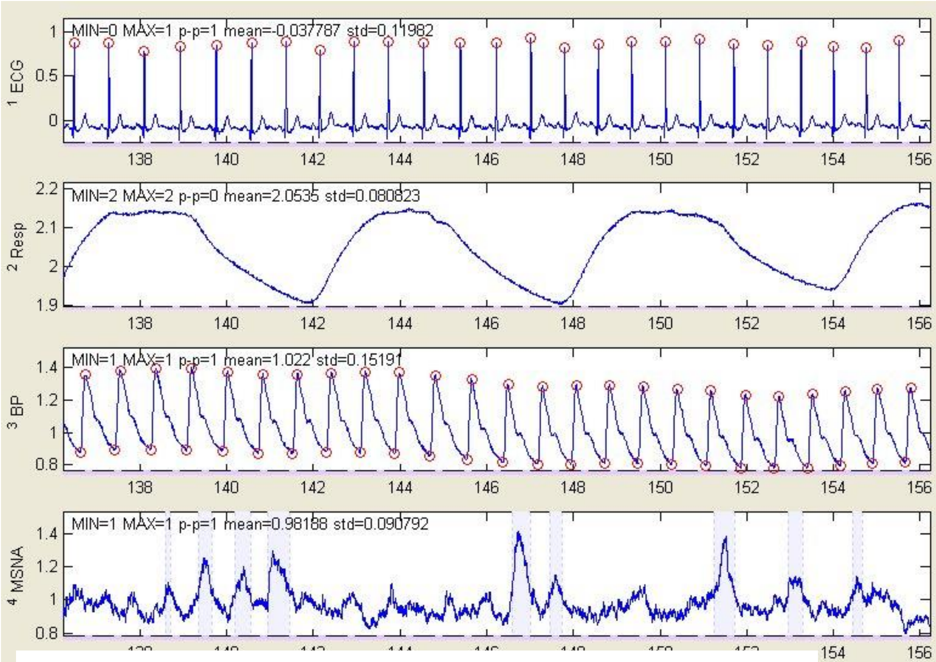
VCG loop structure normalization

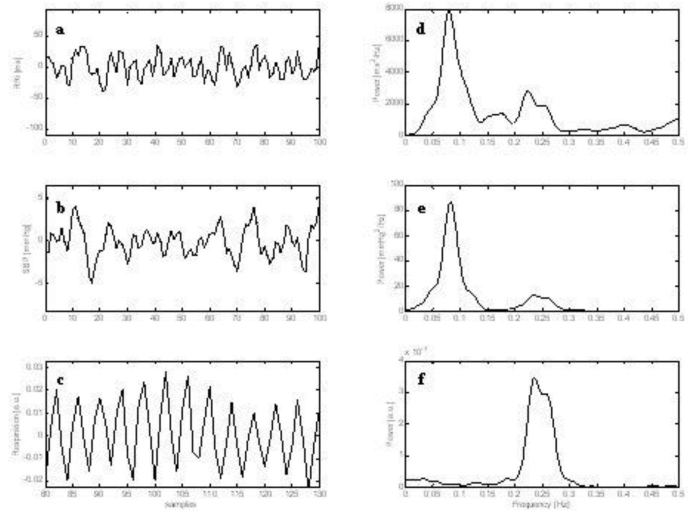


Heart rate variability (HRV) analysis

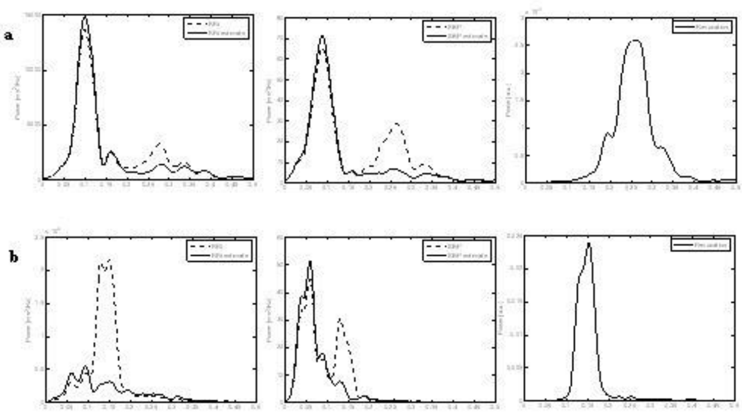


Cardiovascular signal processing: respiration component in ECG





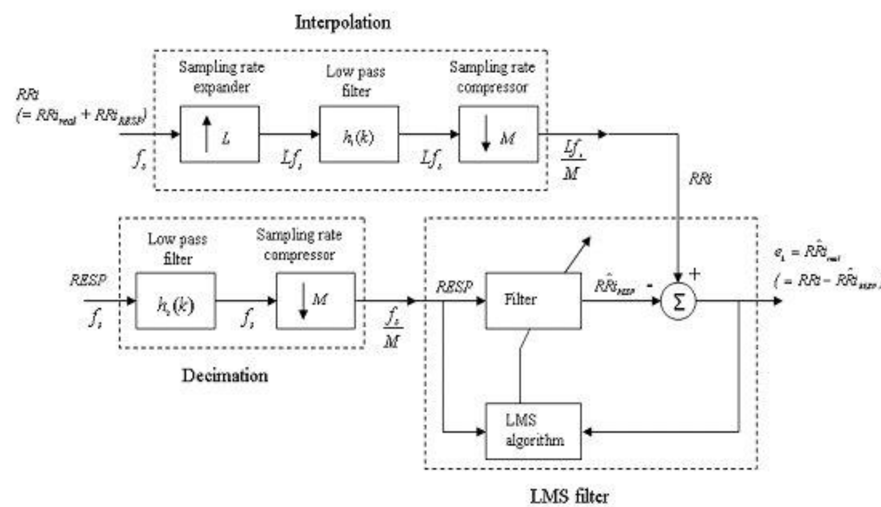
a) tachogram, b) systogram, c) respiration, and d)-e) their PSD, respectively.



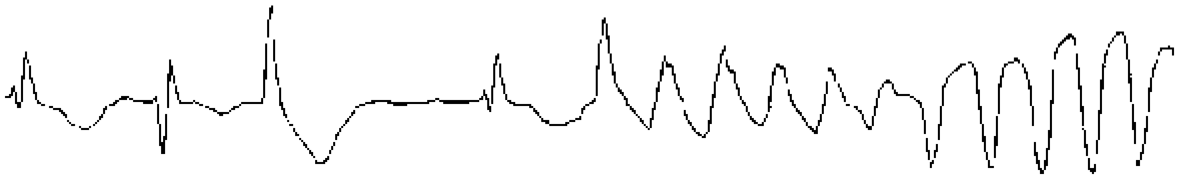
Filtered/nonfiltered tachogram and systogram and respiration signal.

a) Respiration rate within the HF band,

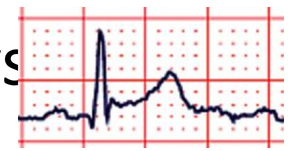
b) Respiration rate within the LF band.

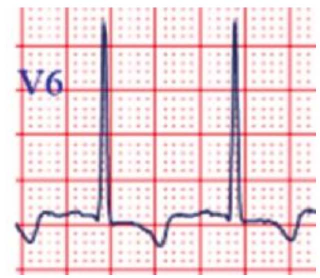


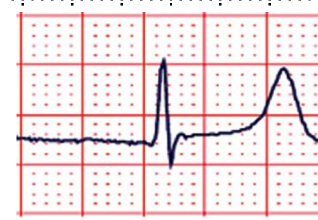
Block diagram of signal preprocessing and LMS adaptive filter.

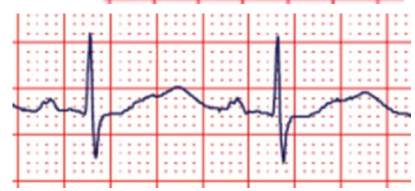


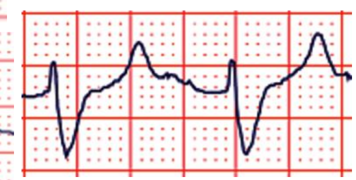
Morphological variation in ECG complicates automatic analysis

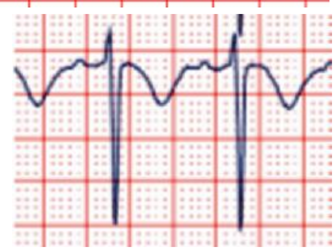


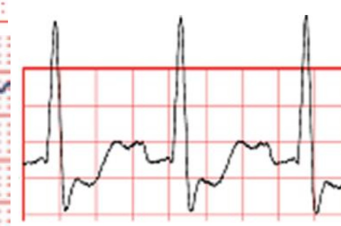






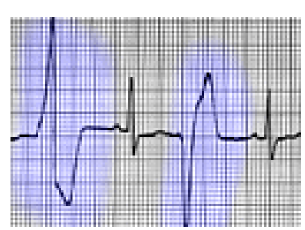


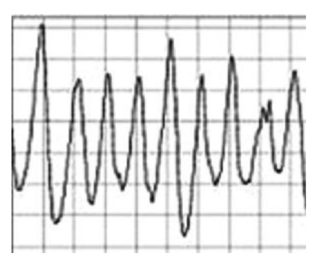




- Intersubject variability
  - Body size and shape
  - Differences in health
- Intrasubject variability
  - Electrolyte balance
  - Onsets of diseases
  - Effects of medications

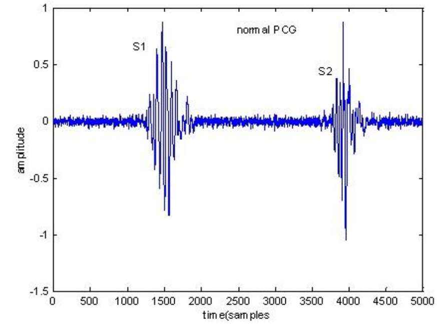
- Personalized profiles of baseline morphology and it’s variation

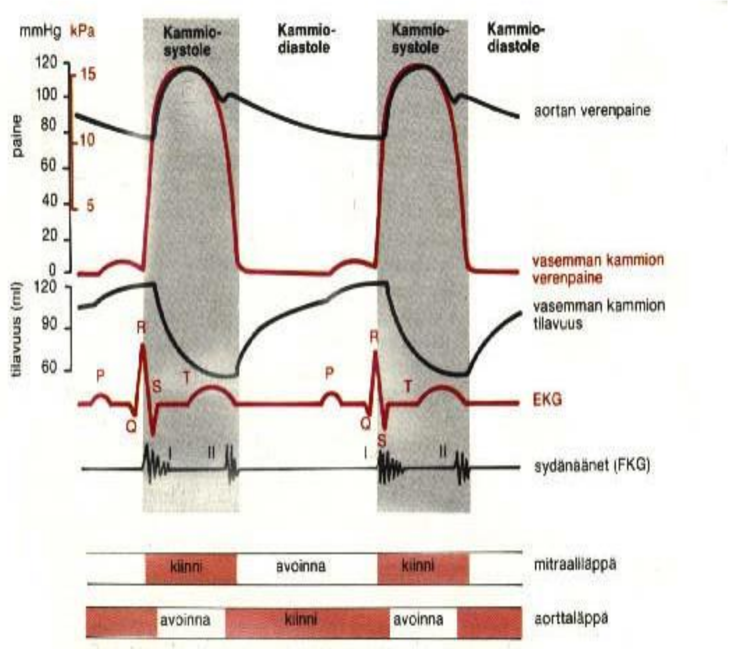




PCG: Phonocardiogram

- Mechanical vibration is the origin of this bio-acoustic signal. Physiologically, vibration is caused by blood flow through heart valves, heart chambers and vascular system.
- PCG can be split to two parts:
  - First heart sound is related to closing of atrioventricular (AV-) valves (beginning of systole)
  - Second heart sound is related to closing of semilunar valves (end of systole)
- Conventionally, it has been listened by a doctor utilizing a stethoscope, i.e. auscultation. Also, the sounds can be recorded (electric stethoscope) for further analysis in time and frequency domain.





PCG genesis

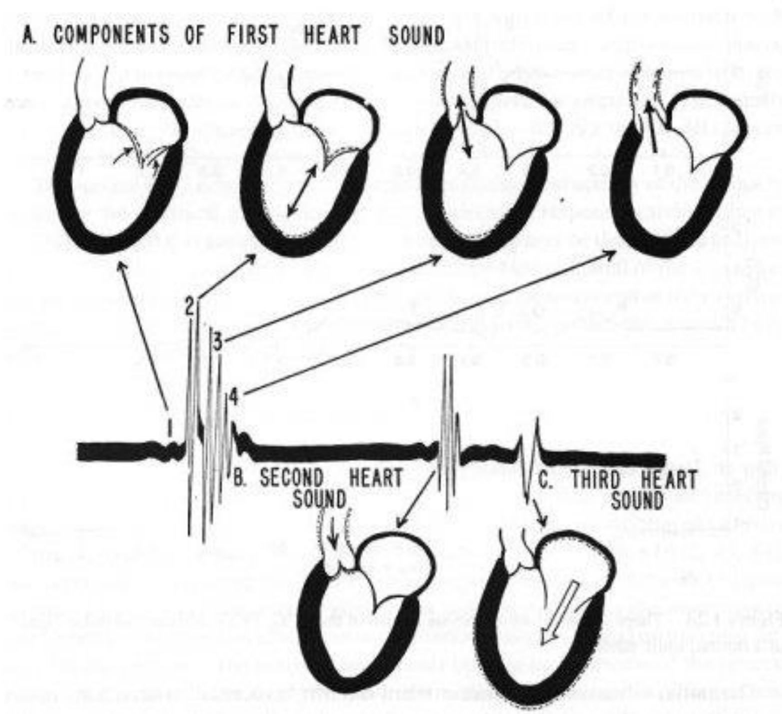
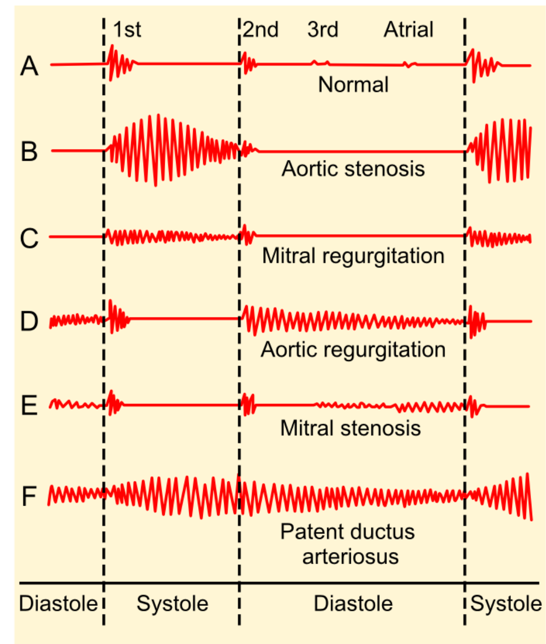


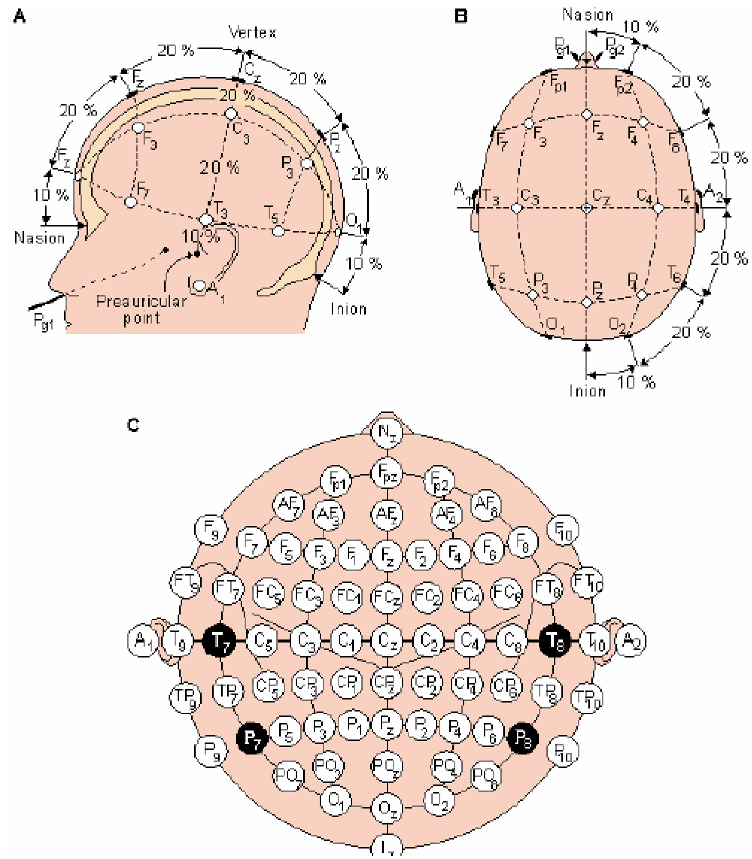
Figure 1.25 Schematic representation of the genesis of heart sounds. Only the left portion of the heart is illustrated as it is the major source of the heart sounds. The corresponding events in the right portion also contribute to the sounds. The atria do not contribute much to the heart sounds. Reproduced with permission from R.F. Rushmer, *Cardiovascular Dynamics*, 4th edition, ©W.B. Saunders, Philadelphia, PA, 1976.



Phonocardiograms from normal and abnormal heart sounds

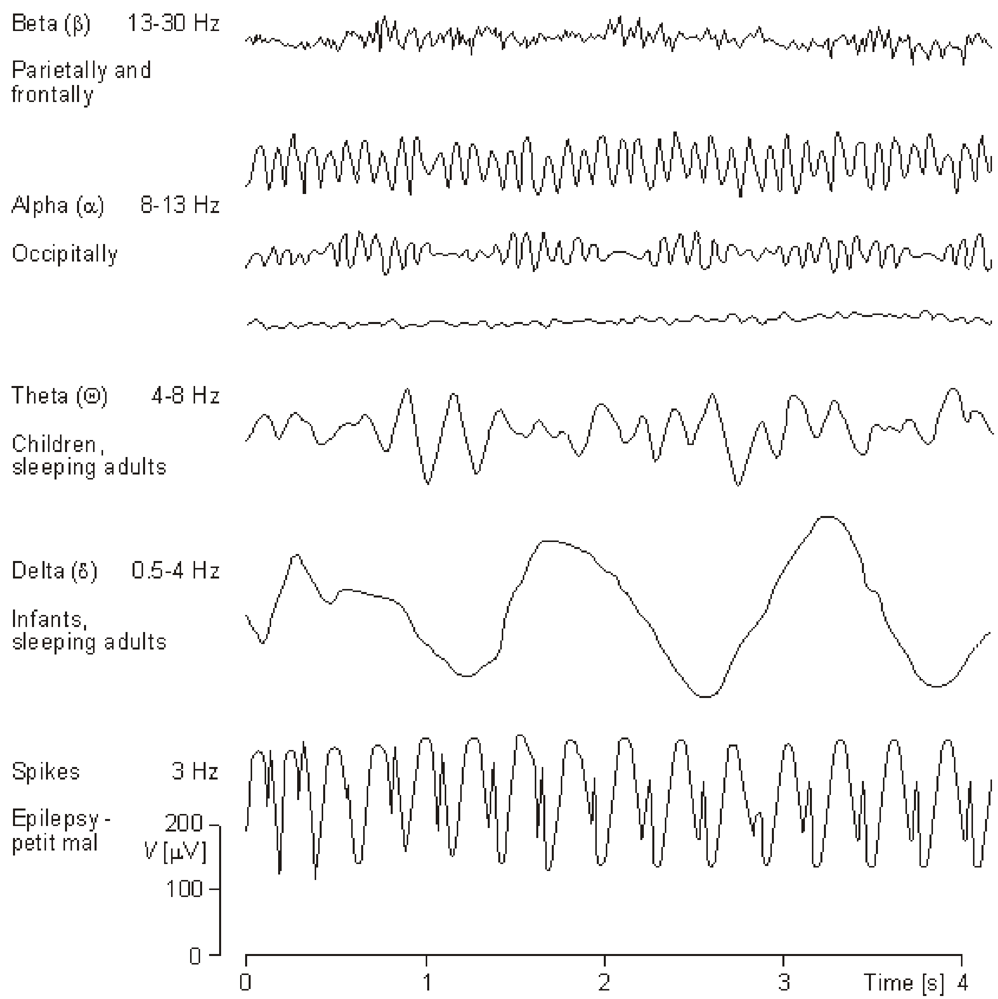
EEG: Electroencephalogram

- EEG measures electrical potential changes in function of time (microV) from scalp
  - Induced by post-synaptic potentials in apical dentrites of pyramidal cells
- ECoG: electrocorticogram from surface of brain
- Measurement with standard electrode locations



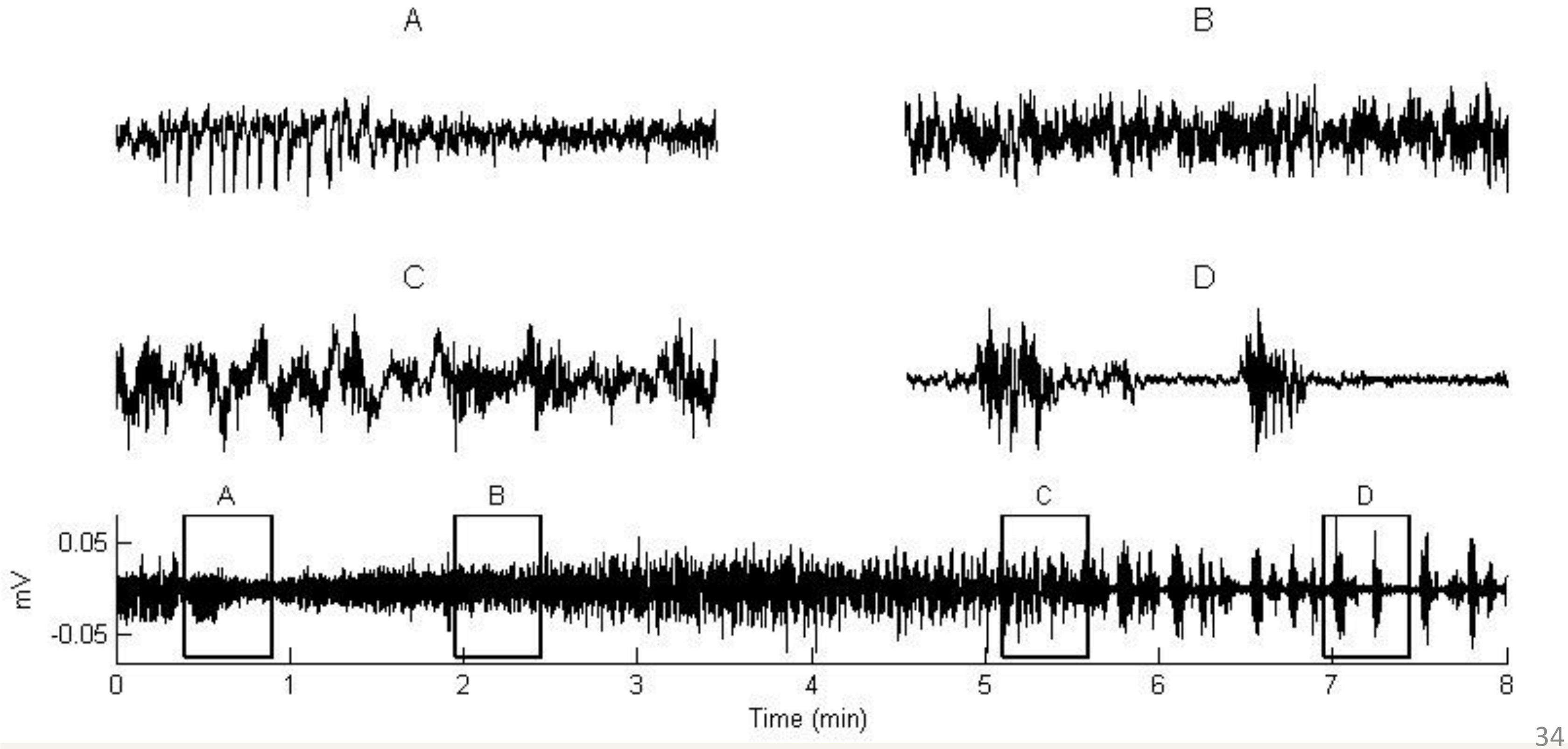
10-20- system =
Standard of EEG electrode locations

EEG signal frequency bands, ’rythms’

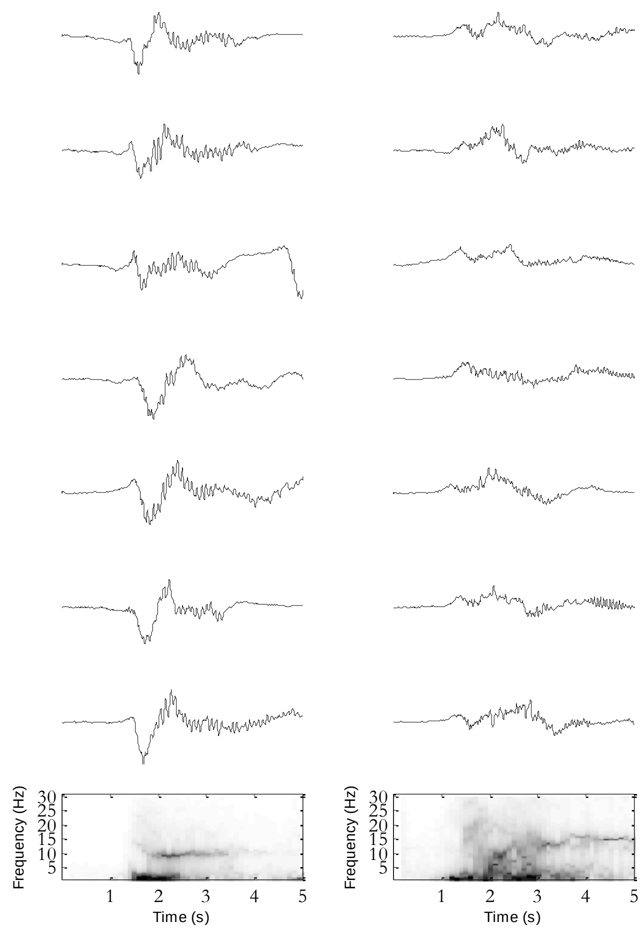


EEG during Anesthesia

- EEG during induction of propofol anesthesia
  - Infusion with a fixed rate

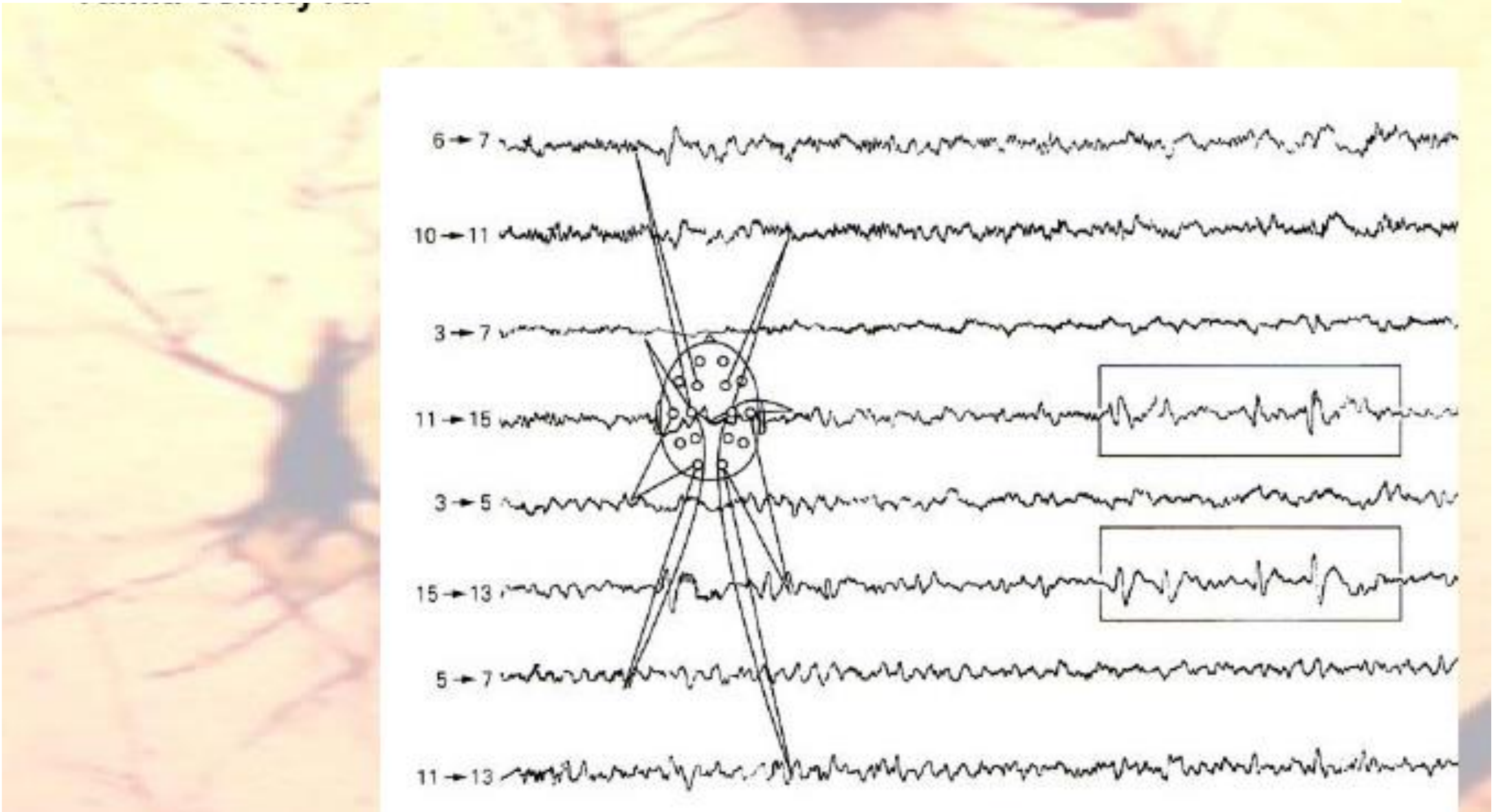


Spectrogram of EEG burst suppression



Epileptic event detection using EEG

Local epileptic event in EEG:
Interictal (between seizures) waveform recognition



EEG artefacts

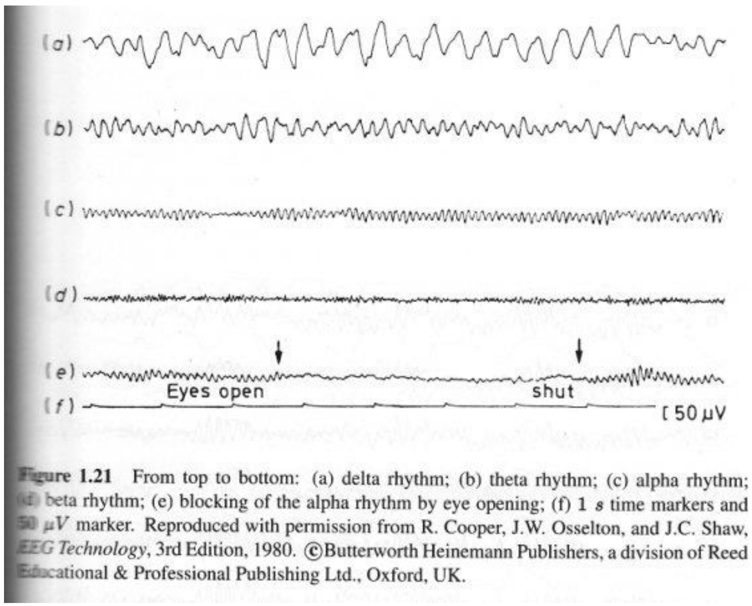
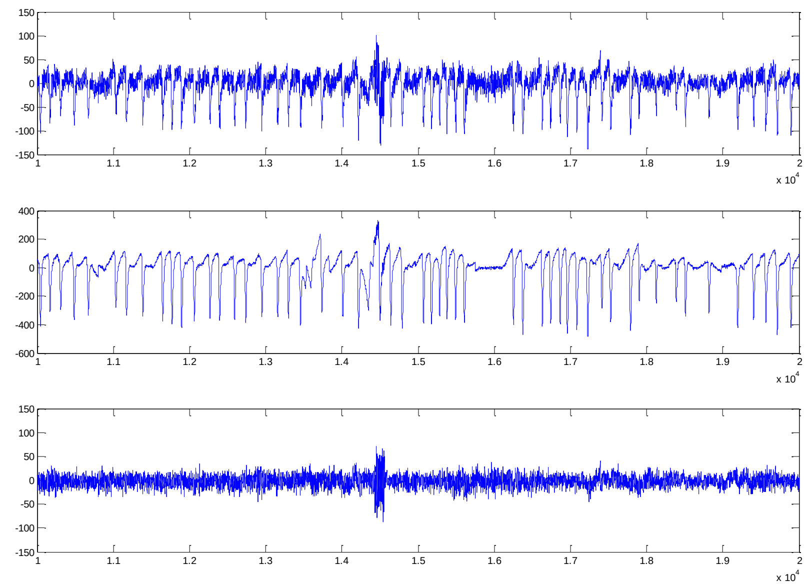


Figure 1.21 From top to bottom: (a) delta rhythm; (b) theta rhythm; (c) alpha rhythm; (d) beta rhythm; (e) blocking of the alpha rhythm by eye opening; (f) 1 s time markers and 50 μV marker. Reproduced with permission from R. Cooper, J.W. Osselton, and J.C. Shaw, *EEG Technology*, 3rd Edition, 1980. ©Butterworth Heinemann Publishers, a division of Reed Educational & Professional Publishing Ltd., Oxford, UK.

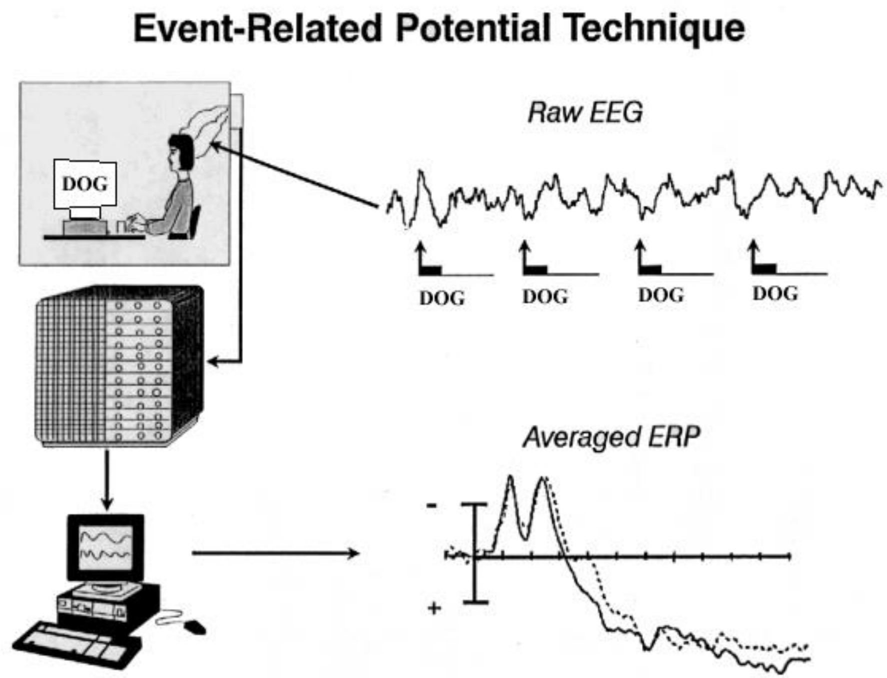


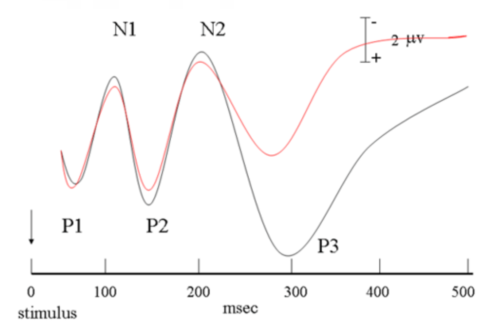
Blocking of alpha rhythm by eye opening

EOG artifact (eye blinks) filtering:
- Top: Noisy EEG
- Middle: Reference EOG signal
- Bottom: Filtered EEG

ERPs: Event Related Potentials

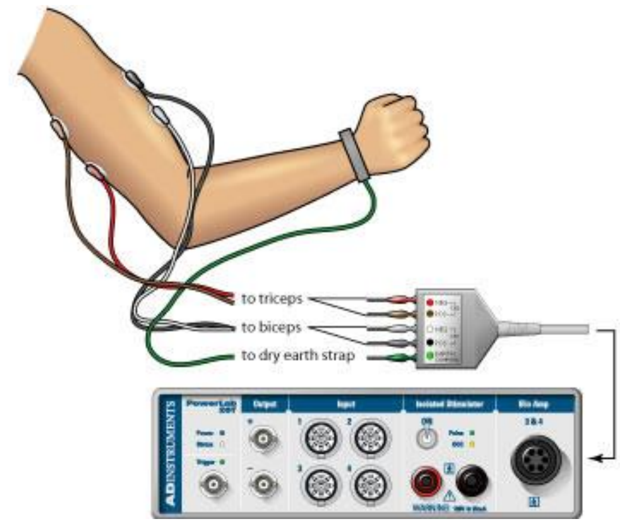
- Event or stimulus
  - Sensory (Evoked Potential)
  - Cognitive (Event Related Potential)
- Repetitions
  - 100-2000 vs. Signal to noise ratio
- Averaging
  - Waveform
    - Amplitudes, latencies

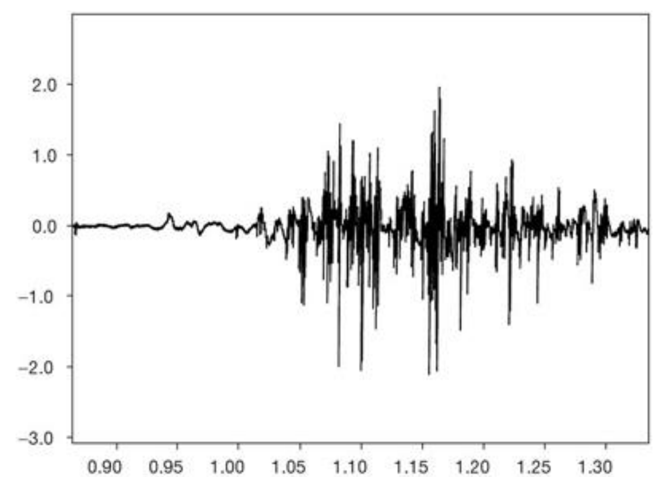




EMG: Electromyography

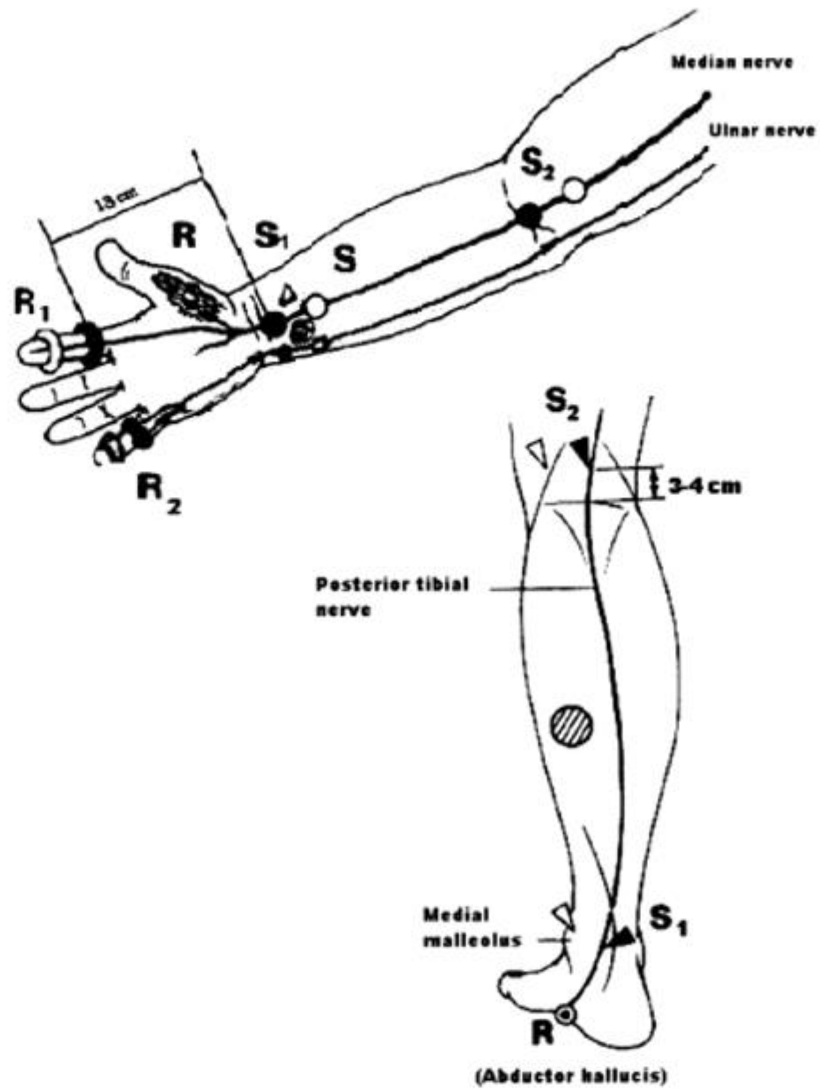
- Measurement of the electrical potential generated by muscle cells a) spontaneously, b) in light and c) strong contraction
- Motor unit potentials, complex patterns of cell recruitment





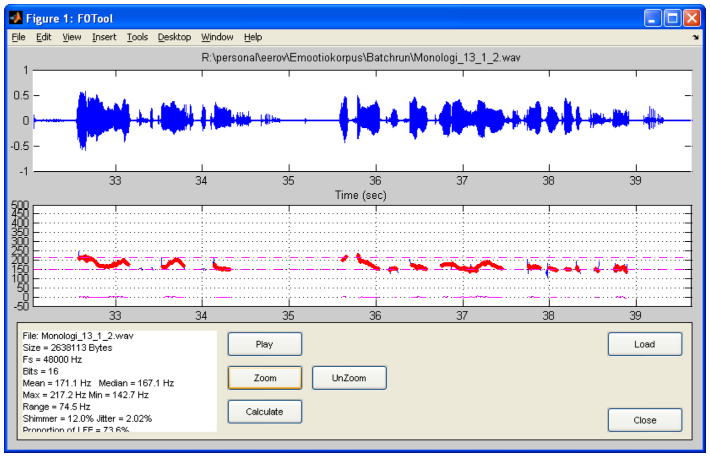
ENG: Electroneurography

- Nerve conduction velocity
  - Motor or sensory nerve
  - Thick myelinated axons
- Stimulation (S)
- Response measured (R)
- Latency and amplitude determined

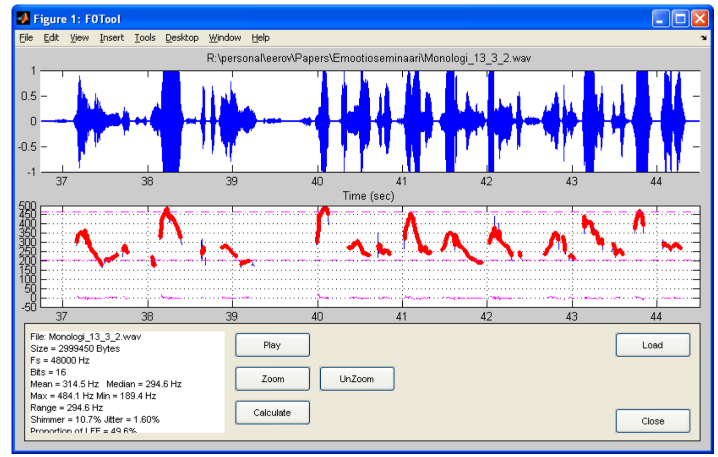


Speech signal

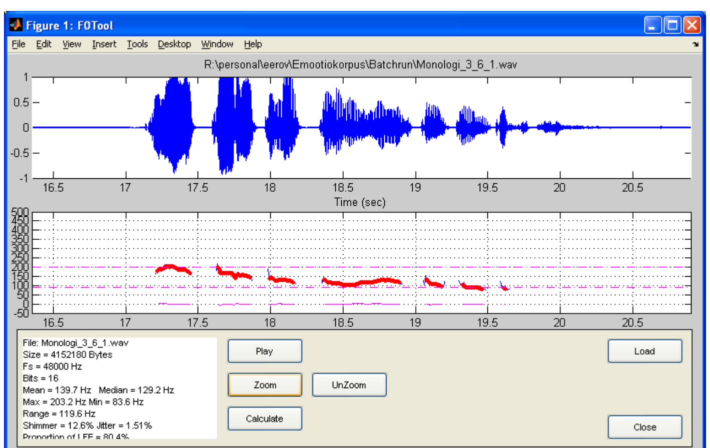
Neutral



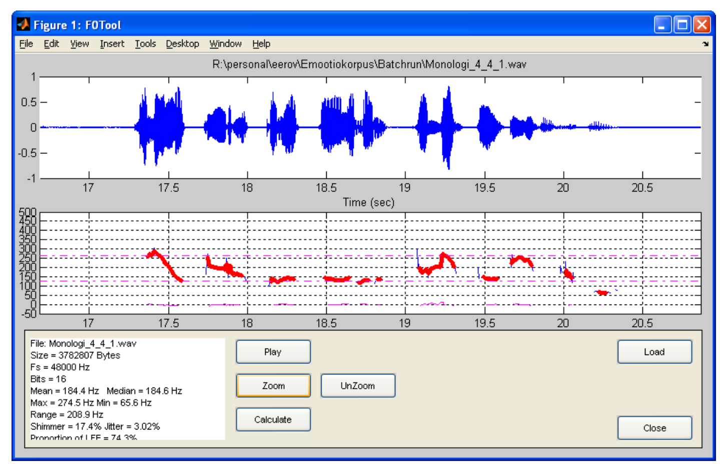
Angry



Bored



Happy



Automatic emotion recognition from voice: feature selection and classification

TABLE 1
Confusion matrices for the best embedding classifications

S-Isomap	Neutral	Sad	Angry	Happy
Neutral	82.9%	4.3%	1.4%	11.4%
Sad	8.6%	81.4%	2.9%	7.1%
Angry	8.6%	0.0%	71.4%	20.0%
Happy	14.3%	5.7%	11.4%	68.6%
average precision: 76.1%				

W-Isomap	Neutral	Sad	Angry	Happy
Neutral	88.6%	5.7%	2.9%	2.8%
Sad	18.6%	77.1%	1.4%	2.9%
Angry	11.4%	0.0%	62.9%	25.7%
Happy	18.6%	1.4%	7.1%	72.9%
average precision: 75.4%				

PCA	Neutral	Sad	Angry	Happy
Neutral	84.3%	4.3%	4.3%	7.1%
Sad	14.3%	78.6%	2.8%	4.3%
Angry	4.3%	0.0%	68.6%	27.1%
Happy	14.3%	7.1%	17.1%	61.5%
average precision: 73.2%				

kNN	Neutral	Sad	Angry	Happy
Neutral	82.9%	5.7%	4.3%	7.1%
Sad	14.3%	72.8%	4.3%	8.6%
Angry	10.0%	1.4%	64.3%	24.3%
Happy	14.3%	4.3%	15.7%	65.7%
average precision: 71.4%				

TABLE 3
Confusion matrix of human listeners

	Neutral	Sad	Angry	Happy
Neutral	78.4%	16.9%	2.6%	2.1%
Sad	12.9%	85.3%	1.0%	0.8%
Angry	14.9%	2.9%	76.9%	5.3%
Happy	24.3%	5.4%	3.3%	67.0%
average precision: 76.9%				

TABLE 4
Validation of "angry" manifold emotional topology

#(true)	M1	M2	M3	M4	M5	F1	F2	F3	F4
1(-)	-	-	-	-	-	-	-	-	-
2(+)	-	-	+	-	+	-	+	+	+
3(-)	-	-	-	-	-	-	-	-	-
4(+)	+	+	+	+	+	+	-	+	+
5(+)	+	+	+	+	+	-	+	+	-
6(-)	-	-	-	-	-	-	-	-	-
7(+)	+	+	+	+	+	+	+	+	+
8(+)	+	+	+	+	+	+	-	+	+
9(-)	+	-	-	-	-	-	+	+	-
10(-)	-	-	-	-	-	+	+	-	-

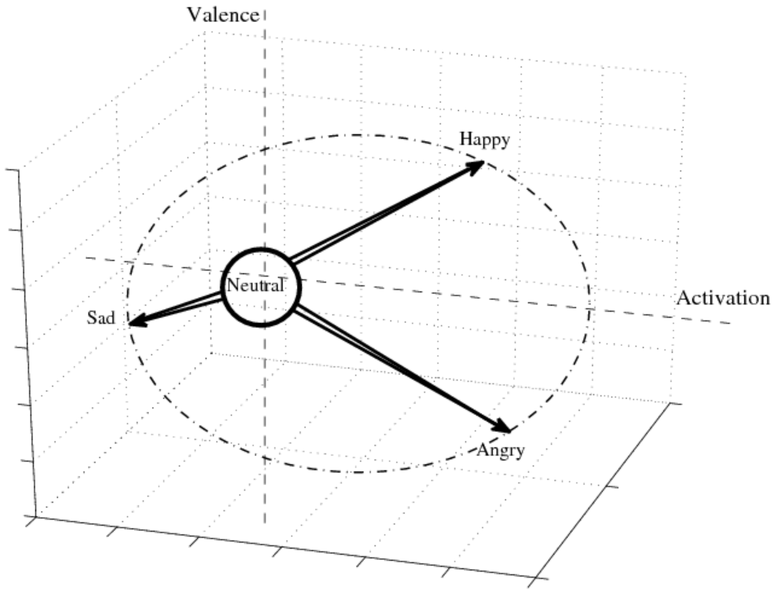
[7]. The visualization (Figure 3a) also clearly shows a class structure that can be viewed as matching both discrete [4] and dimensional circumplex [5] models.

Some 50 prosodic features are utilized for utterance classification

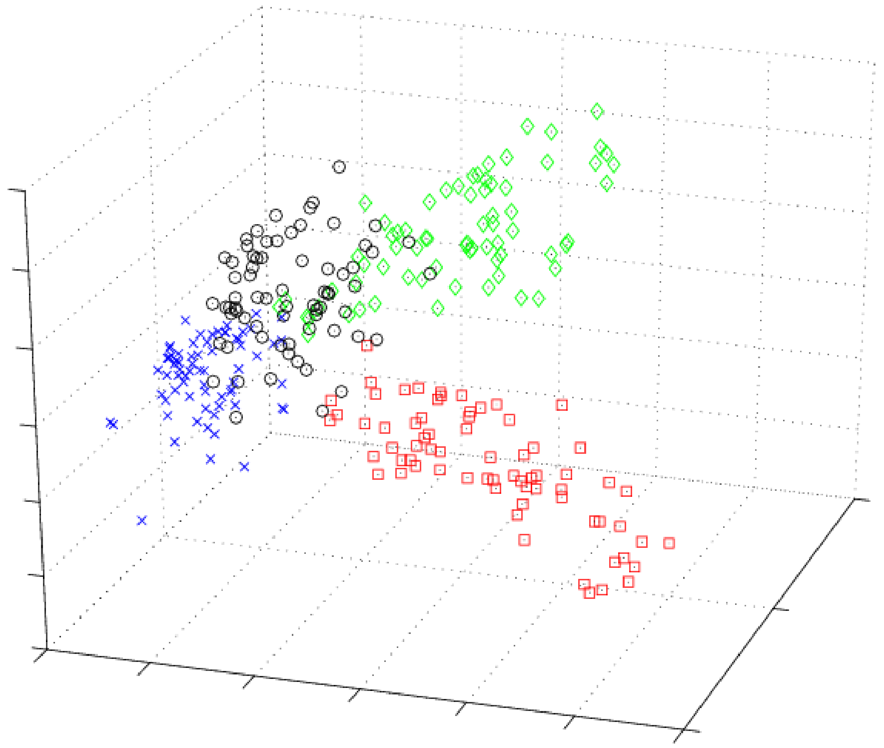
Material from actors

Classifier-based learning of nonlinear feature manifold: Visualization of emotional speech prosody

Isomap-based manifold reconstruction
Optimization via classifier design
Intensity of emotions can be estimated

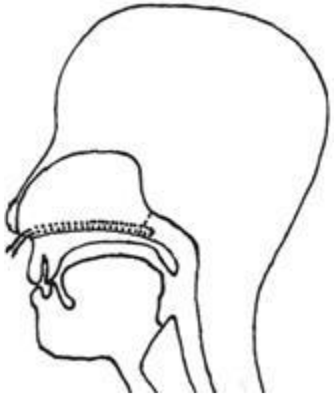


Activation, valence, potency/intensity/control



Neutral, sad, angry, happy

Measurement of dynamic resistance in upper airways



catheter inserted transnasally into the nasopharynx

Continous resistance via adaptive Broms model

Broms model

$v_r = v_0 + cr$

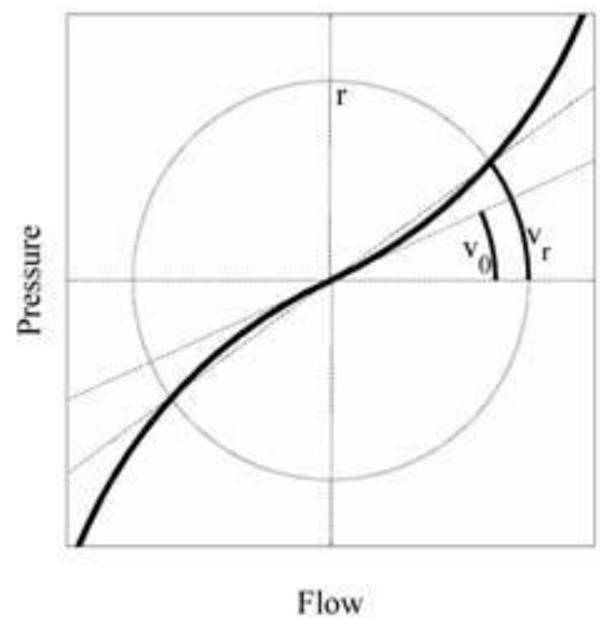
v_r = angle with radius r from the origin

v_0 = angle in the origin
c = curvature parameter

Resistance in radius r:

$R_r = x \tan v_r$

x = normalization factor



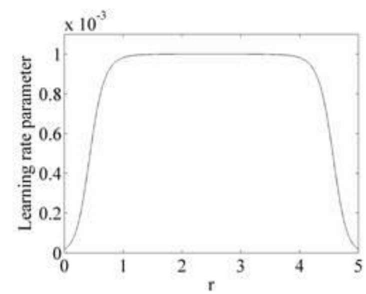
Adaptation through LMS filtering

$$\hat{\mathbf{w}}(k+1) = \hat{\mathbf{w}}(k) + \mu(k)\mathbf{u}(k)\left[v_r(k) - \mathbf{u}^T(k)\hat{\mathbf{w}}(k)\right]$$

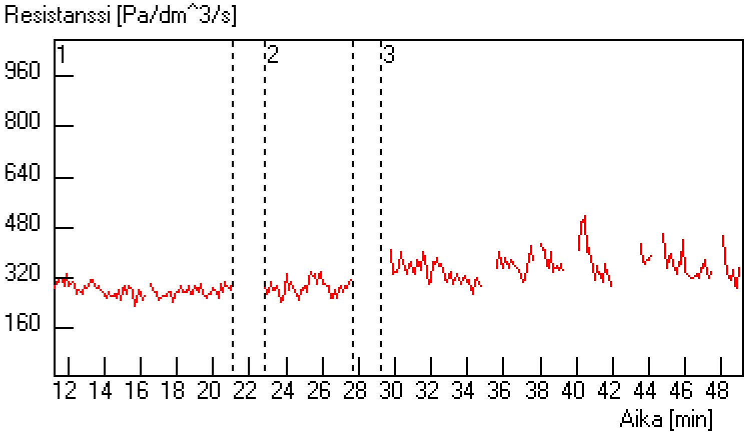
$$\hat{\mathbf{w}}(k) = \begin{bmatrix} v_0(k) \\ c(k) \end{bmatrix}$$

$$\mathbf{u}^T(k) = \begin{bmatrix} 1 & r(k) \end{bmatrix} = \begin{bmatrix} 1 & \sqrt{P'^2(k) + \dot{V}'^2(k)} \end{bmatrix}$$

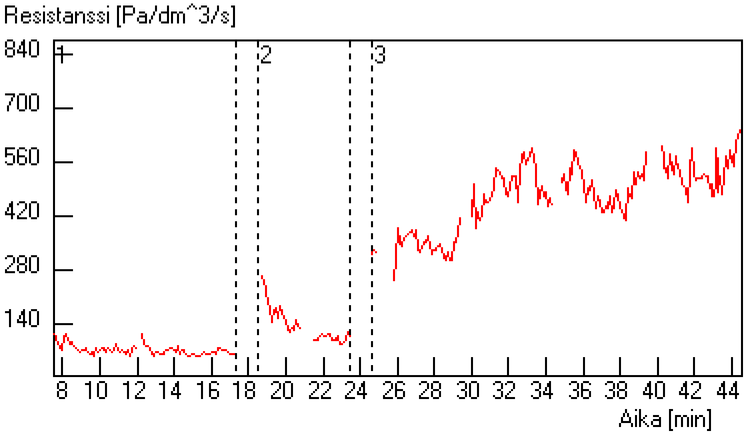
$$v_r(k) = \tan^{-1}\frac{P'(k)}{\dot{V}'(k)}$$



Allergic responses to birch nasal challenge test: preliminary results



Negative response



Positive response