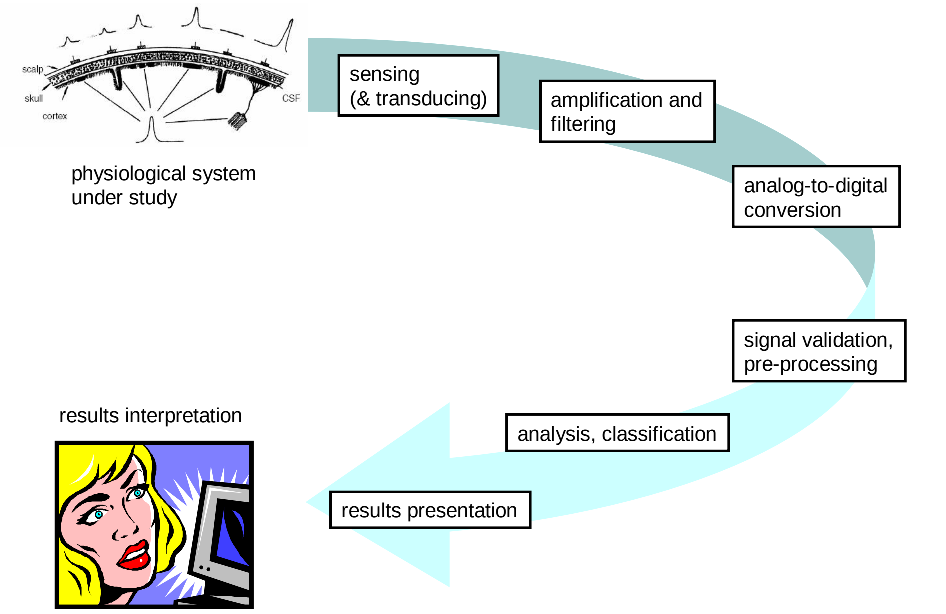
Tfy-99.275 lecture 6

Dealing with
Artefacts and Noise

Biomedical Signal Interpretation ”Chain”



Signal Validation / Preprocessing tasks

- noise attenuation or removal / feature enhancement
- artefact detection
- artefact rejection
- indication of 'validity' of data

- After this preprocessing stage, characteristic features are extracted from the data. They are then used to derive conclusions from or to perform pattern recognition tasks on.

Artefacts

- Artefacts are components in the measured signal that are not a result of the (physiological) process under study but come from an external source.
- There is a close relation to the concept of 'noise', and it is not always clear which of the terms artefact or 'noise' is most appropriate in a given application. Merriam-Webster:
  - noise: irrelevant or meaningless data or output occurring along with desired information
  - artefact: a product of artificial character (as in a scientific test) due usually to extraneous (as human) agency

- Artefacts can range from occasional nuisance to a vexing biosignal processing problem consuming lots of time and effort to deal with.

Sources of artefacts

- Physical – originating 'outside' the patient (e.g., mains interference, electrosurgical equipment)
- Biological – originating within the patient (e.g., ECG activity seen in EEG signal, spontaneous EEG in EP signal, muscle activity, eye movements (EOG), body movements,...)

Biological Artefacts

- Biological artefacts are not always a bad thing. They can have practical use and they may convey important information about the patient.
- For example:
  - EOG artefacts in an EEG can be used to as in-built calibration signal to check the recording set-up
  - consistent occurrence of EOG or muscle activity may indicate sub-clinical epileptic seizures
  - presence of artefacts in EEG may indicate emergence from coma or anaesthesia
  - phenomena that are artefacts in a routine EEG recording are an essential part of the data in a sleep recording
- One investigator's noise may be another investigator's signal!

Dealing with artefacts

- Be very conservative with 'cleaning up' recordings by removing artefacts from the data. Rather carefully annotate them instead.
- General philosophy:
  - minimise physical artefacts/noise by using a good recording set-up
  - use appropriate filters to further minimise external noise
  - identify, classify, annotate biological artefacts
    Preferably: 'DON'T REMOVE THEM!' (if you must, then at least make a good backup of your raw uncleaned data)

Some examples of sources of disturbances...

a) some electrical potentials generated in the body
b) movement of the subject, this results in movement of recording electrodes which in its turn causes a change in electrode impedance
c) electro-chemical effects; polarization effects due to ion-transport in electrode-electrolyte combinations
d) mains interference
e) other equipment (especially electrosurgical and X-ray equipment, mobile phones)
f) changes in the measurement set-up (either on purpose or not) by personnel

... that are better dealt with by using a good measurement set-up than by throwing a fancy signal processing method at them

a) good electrode placement, make sure a patient is relaxed and warm (shivering involves heavy muscle movements)

b) press or glue electrodes well to skin

c) use electrode material that minimises polarisation effects and try to minimise electrical current density

d) avoidance of loops in cables, shielding, use of Faraday cage

e) try to measure as far away as possible from potentially interfering equipment

f) make personnel well aware of the measurement set-up

Examples of artefacts

- Electromyographic (EMG) activity picked up during brain activity recordings: especially contraction of neck and jaw muscles will interfere with EEG recording at scalp electrodes.
- If we only want to study the EEG (up to 60 Hz max), we can easily filter this out since the EMG's frequency content lies in the range 100-300 Hz, if we want to study evoked potentials we run into problems because the frequencies overlap.

note: use of muscle relaxants (during anaesthesia) effectively eliminates this type of artefacts

Examples

- Eye movement during brain activity recordings: because the eye can be considered an electrical dipole, eye movements will change the electrical activity recorded at the scalp electrodes. Artefacts may be minimised by having subjects keep their eyes closed during recording.

- Electrosurgical equipment can generate very strong, high-frequency electrical fields that can be picked up by the ECG and EEG electrode leads. This type of interference is often so strong that the (high-gain) EEG amplifiers overload, resulting in a signal that is absolutely useless.

Eye movements

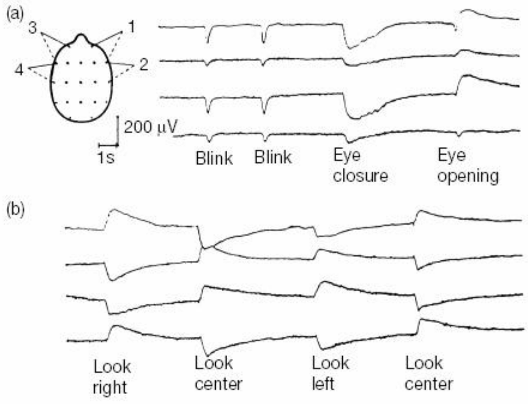
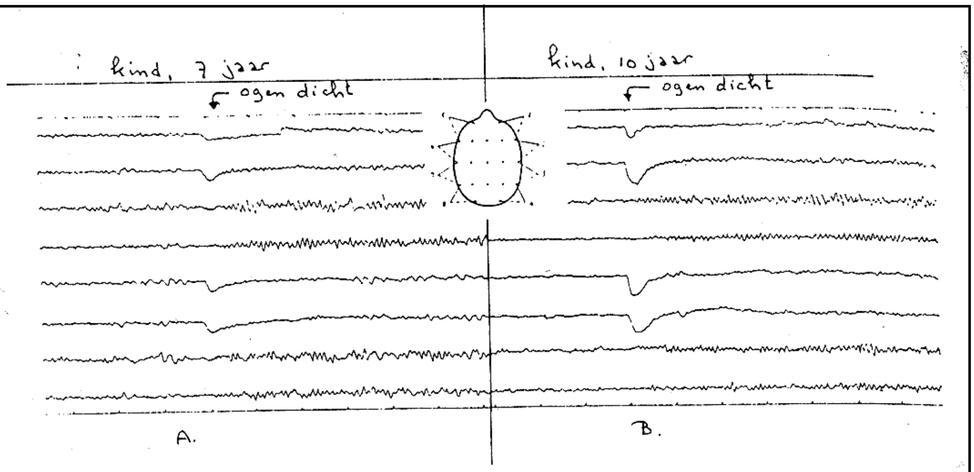
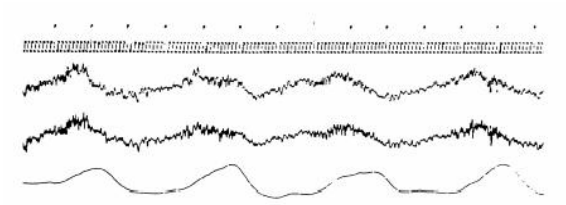


Fig. 6.66 Eye movement potentials: (a) vertical; (b) lateral. From Binnie *et al.* (2003), with permission.

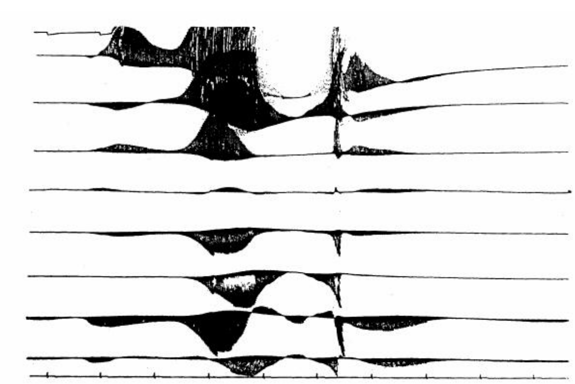


Eye movement artefacts in EEG recordings of a child of 7 years (left) and a child of 10 years old (right). The arrows ("ogen dicht") indicate closing of the eyes

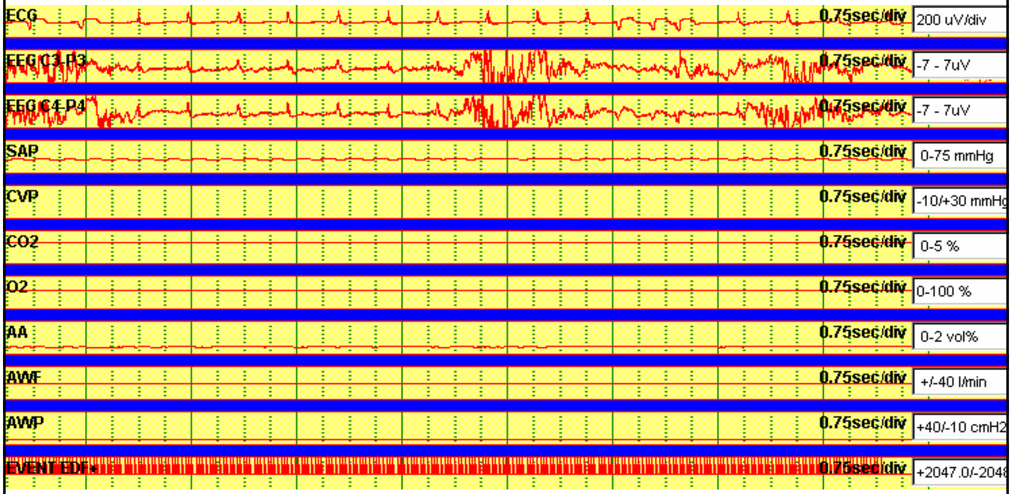


breathing artefacts on EEG

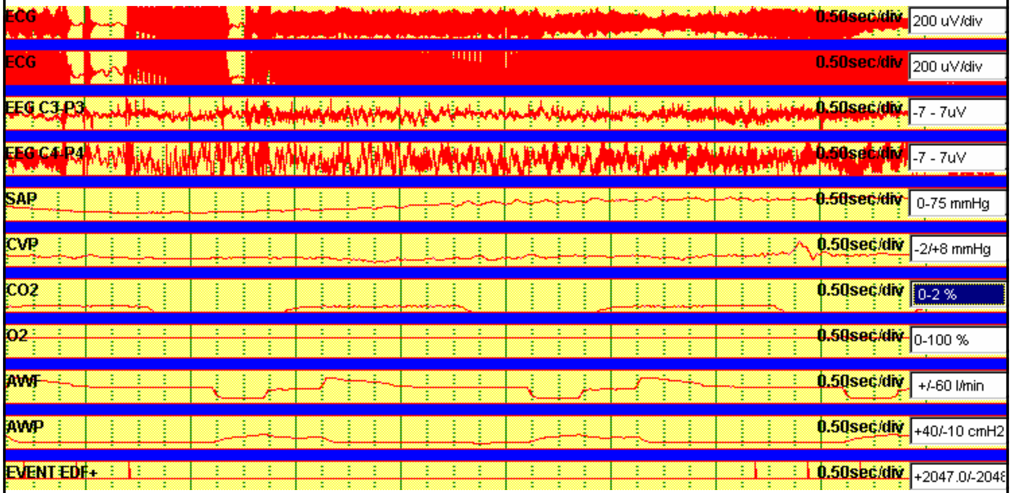
faulty X-ray equipment in proximity



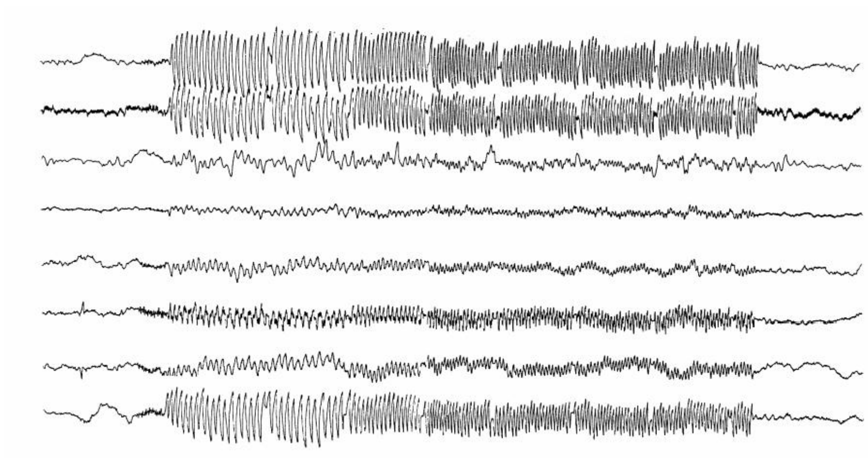
Artefact: ECG pick-up on EEG



Fibrillator switched on



left: artefacts in EEG produced by movement and/or poor contact
right: EEG after correcting montage of electrodes



interference from hospital call system

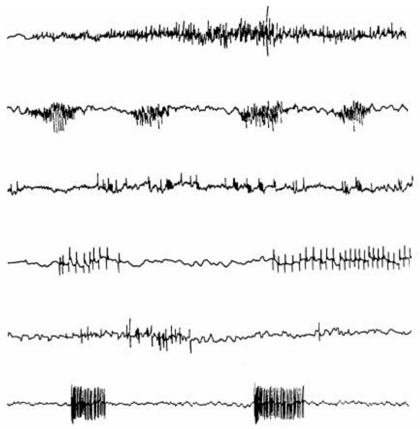
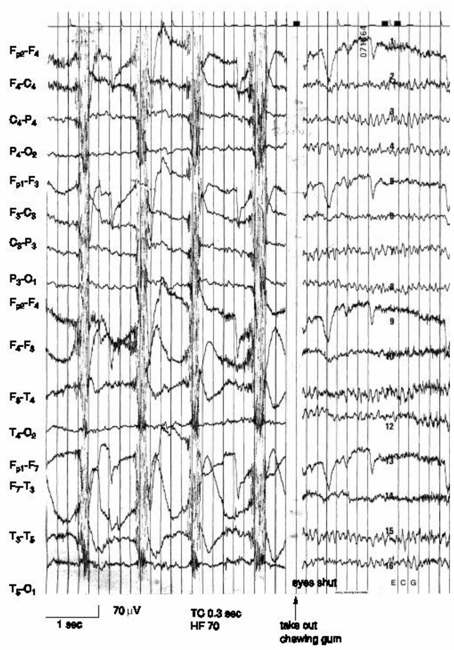
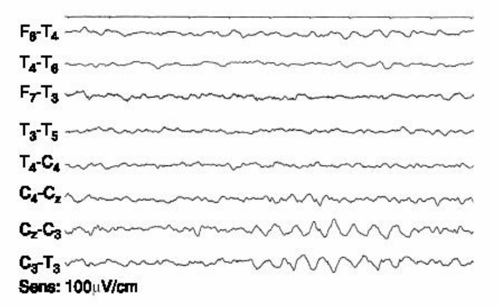


Fig. 4.2.87. A variety of myogenic potentials recorded from electrodes on the scalp. The 4th example shows repetitive unit potentials; the last is due to facial myokymia (see Section 2.4.4.1 of Volume 1).

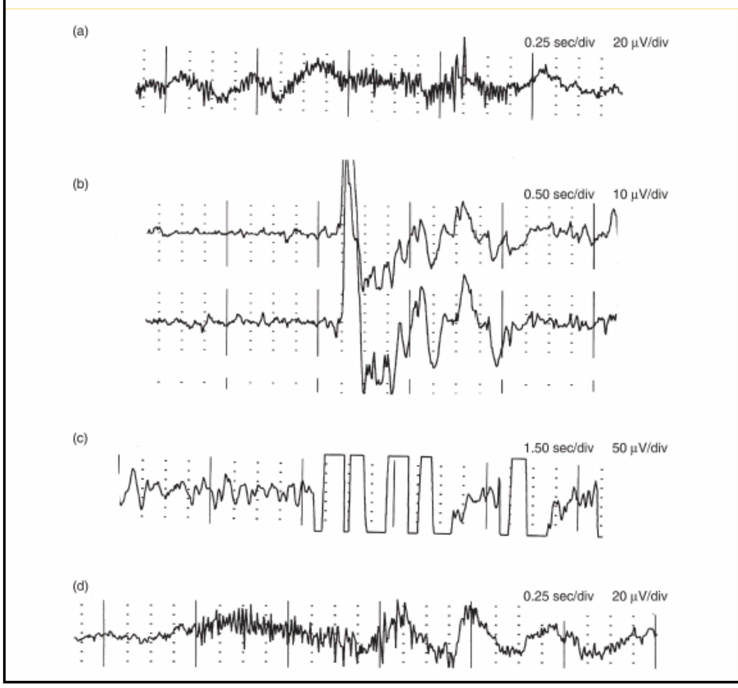
different types of muscle activity disturbing the EEG



effects of chewing (left half of picture)



rhythmical slow waves due to dummy-sucking in a 3-month old infant



Artefacts in a recording in the ICU:
(a) scalp muscle potentials (EMG);

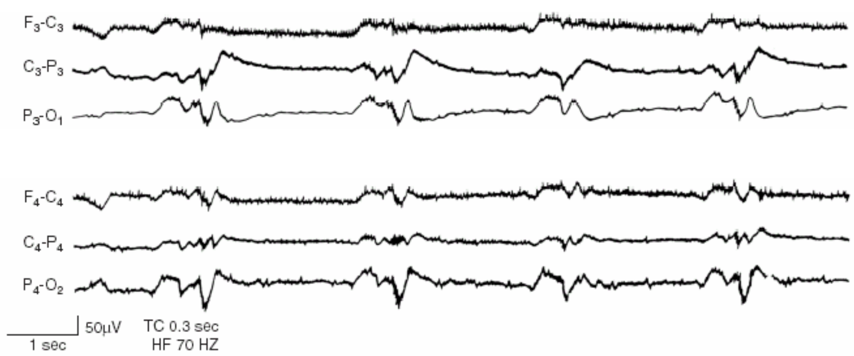
(b) patient coughing;

(c) coughing during airway suction;

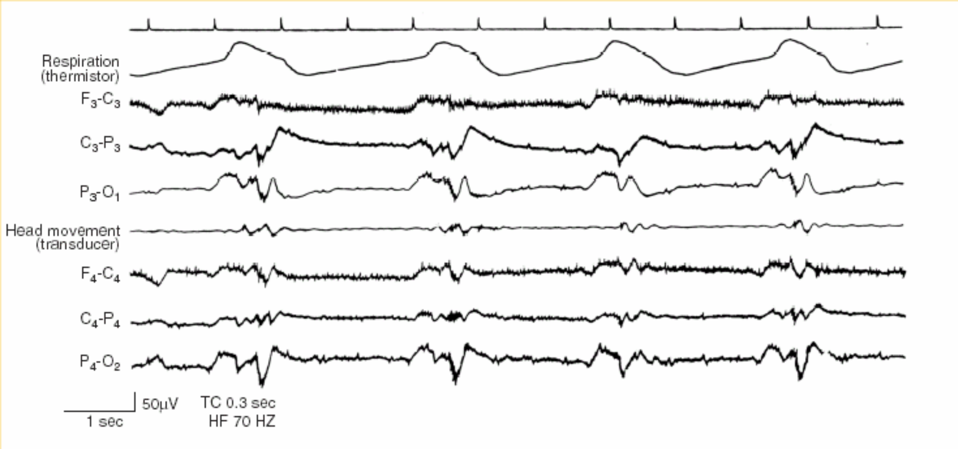
(d) mixed scalp muscle potentials and movement artefacts during physiotherapy.

- sometimes, what appears to be an interesting physiological phenomenon may turn out to be an artefact
- and sometimes what appears to be an artefact (to an engineer) may turn out to be be an interesting physiological phenomenon

Apparent rhythmical activity in EEG

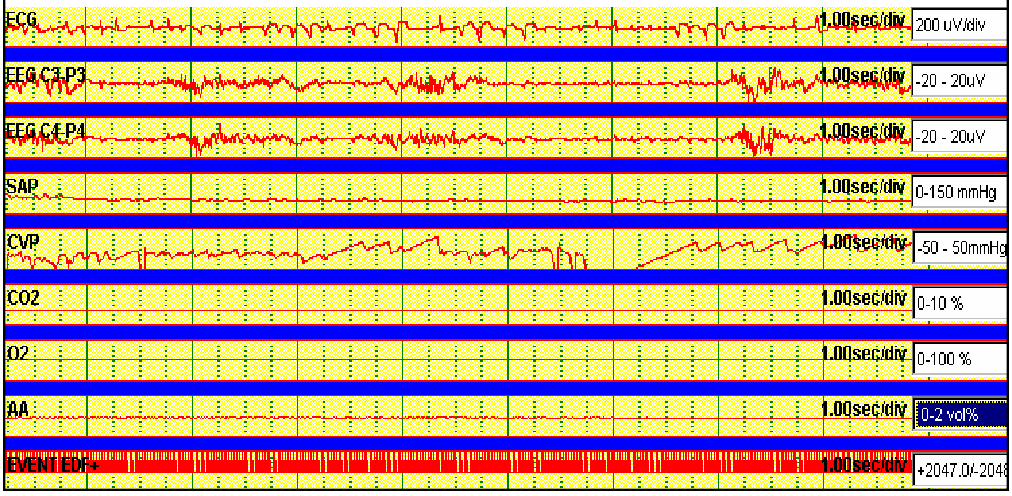


Origins revealed by monitoring breathing and head movement



Peculiar signal, but NOT an artefact: Burst suppression

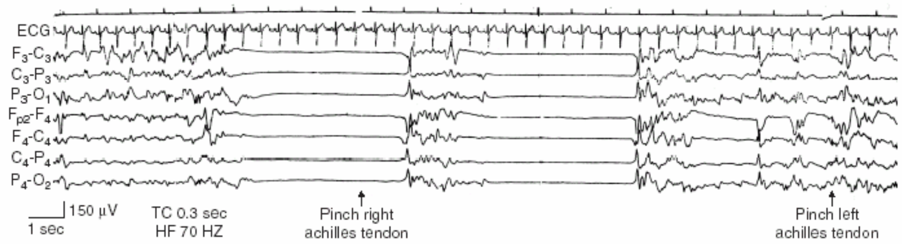
almost flat EEG combined with bursts of activity. May be indication of deep anaesthesia (in this picture) and is in that case harmless and reversable



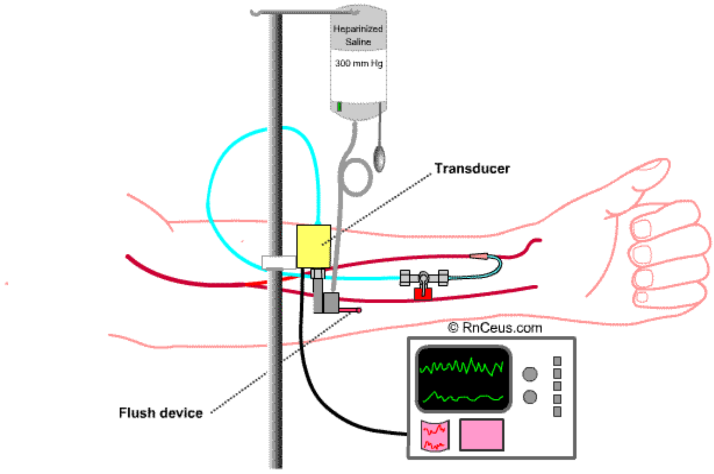
Burst suppression (2)

But it may also indicate reduced blood flow in the brain and then point to impending brain damage

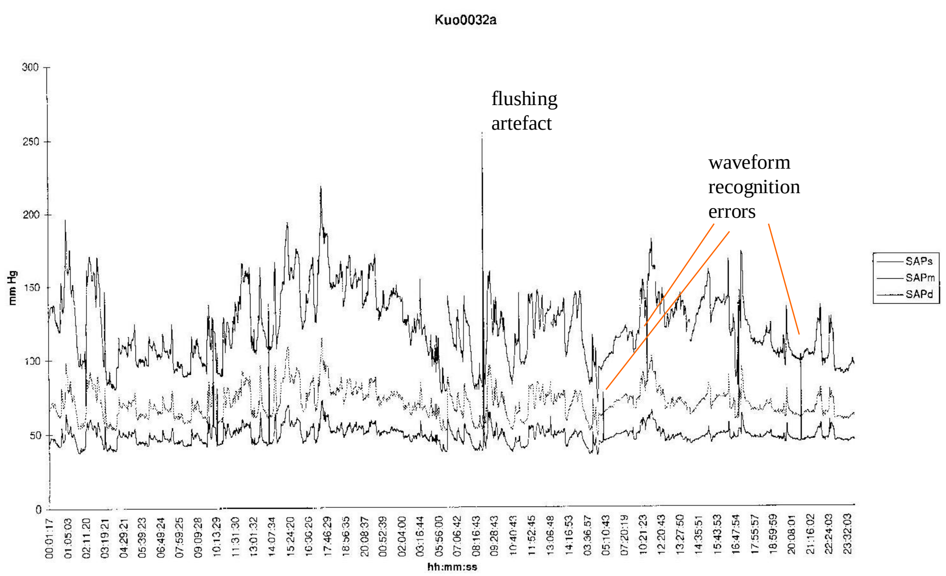
In this picture: burst-suppression, unaffected by painful stimuli, in a comatose 40-year-old man who had sustained an intra-operative cardiac arrest 16 h earlier.
He was ventilated but died 8 h later.



Intravenous Blood Pressure measurement device
Pulse wave travels through liquid-filled tube. The tube needs to be flushed regularly in order to remove occuring tiny air bubbles that deteriorate the signal quality.



Intravenous blood pressure trend data (1 sample/2 mins) in ICU



Artefact Detection

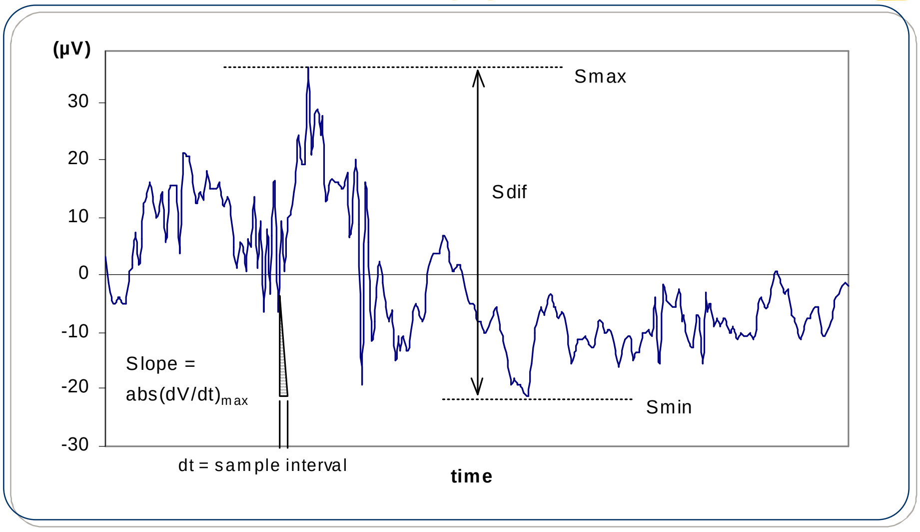
- Virtually all commercially available equipment has built-in artefact detection features that rejects data if the amplitude of the input signal exceeds a certain preset value, the artefact detection threshold.

- The idea is that many artefacts cause changes that are large in comparison with the biosignal under study.

- Problems:
  - how to set those thresholds? and
  - certainly not all artefacts cause high amplitude changes

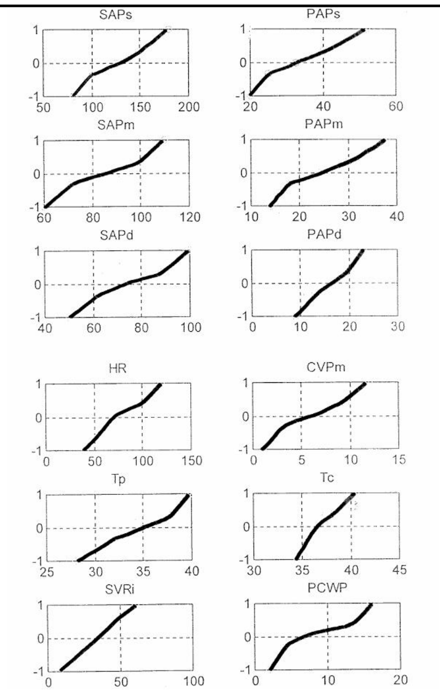
- other indicators (than large amplitudes) of artefacts
  - unusually small amplitudes
  - large slopes in the signal
  - presence of spikes (short periods in which a very high/low slope occurs, after which the signal returns to its original value)

- Parameters: Max, Min, Difference, Slope



Determination of thresholds

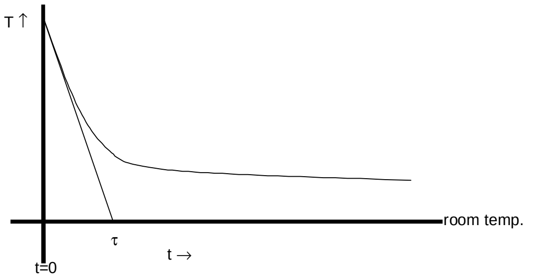
- A too tight threshold would result in rejection of data that has no serious artefacts, a too loose threshold would allow the acceptance of 'bad' data.
- Sometimes clinical knowledge of the 'limits' of physiological systems or use of physics to detect 'impossible' situations can be employed, but this often only gives an impression of the 'loose side' of the limits.
- Setting of thresholds can only be done after an evaluation of the range of values of reliable, normal signals (without serious artefacts).



clinicians' opinions of 'workable regions' of signals recorded in the ICU. On horizontal axes are the measured values, on the vertical axes are the clinicians opinions on whether that value is 'low', 'high' or 'normal'. 0 is normal, +1 is the highest possible 'sensible' value, -1 the lowest possible sensible value.
This provides us with some guidelines on where to put thresholds for artefact detection.
SAP (Systemic Arterial Pressure),
PAP (Pulmonary Arterial Pressure),
's','m','d' indicates systolic, mean, diastolic pressure.
HR (heart rate),
CVPm (Central Venous Pressure),
Tp (peripheral temperature),
Tc (core temperature),
SVRi (Systemic Vascular Resistance index),
PCWP (Pulmonary Capillary Wedge Pressure).

Thresholds

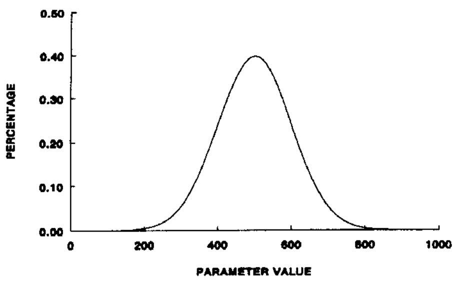
- An upper limit for a slope threshold;
  for example, a steep drop in body temperature



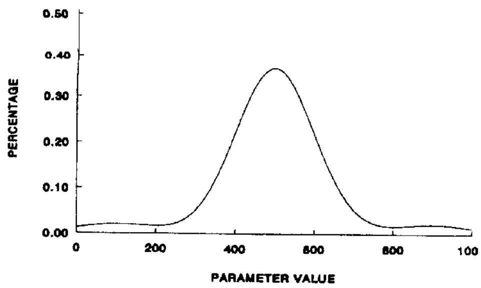
if, for an average person (representative for the studied population), the temperature drop after death would look like the above figure, data containing much larger slopes (smaller t) would indicate there is something wrong in the measurement

Thresholds

- Often, the measured signal is regarded as a stochastic signal and amplitudes and slopes are stochastic variables with a certain statistical distribution.
- Knowledge of the characteristics of these distributions can help to set the thresholds at the correct levels.
- In the case where parameters have a Gaussian distribution and where artefacts cause strongly deviating values, setting thresholds may be quite straightforward.



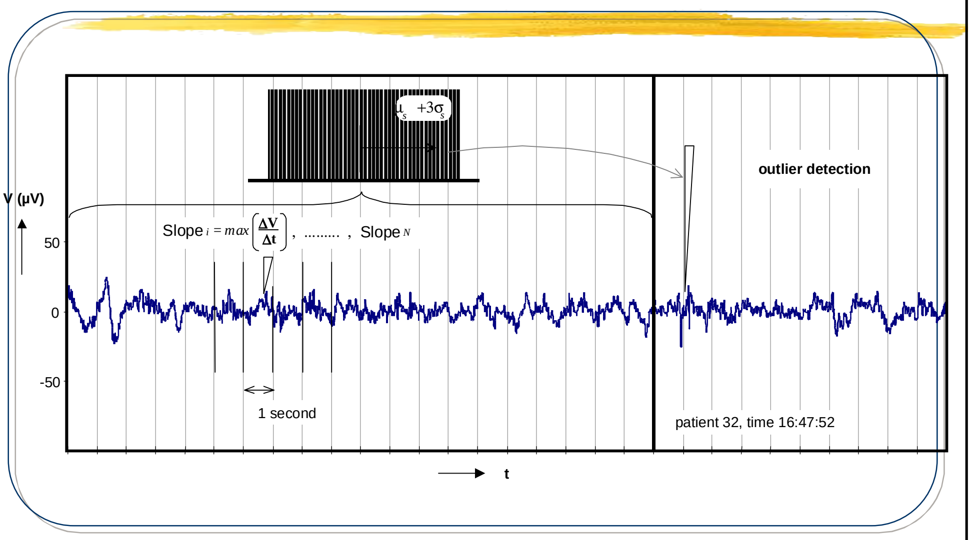
Gaussian distribution



distribution disturbed by artifacts

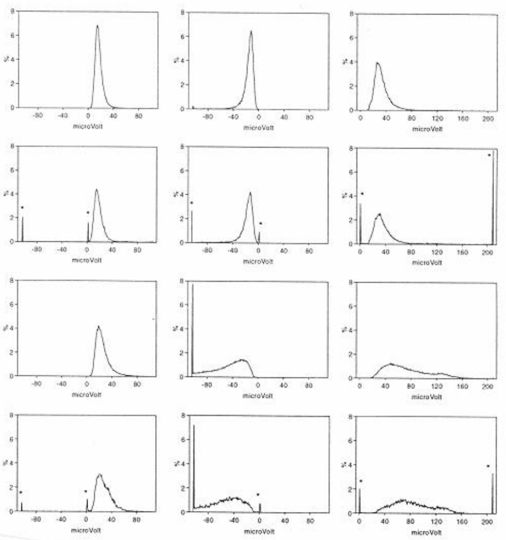
- By estimating the mean, μ, and standard deviation, σ, of the slopes and amplitudes in a set of (artefact free) control data one can get an idea of the distribution.
- In a Gaussian distribution 99.7% of the samples are supposed to be situated between μ - 3 σ and μ + 3 σ, so one can hypothesise that in situations without artefacts, taking these values as threshold, nearly all 'good' data will be accepted.
- In this approach, still one has to choose the width of the interval with acceptable values.
  (μ - 3 σ, μ + 3 σ) or (μ - 4 σ, μ + 4 σ) are chosen most often in practice.

slope detection on the basis of statistical outliers



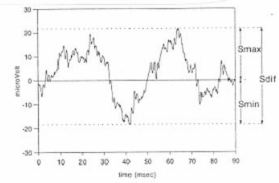
Note:

- The conditions under which some signal is measured can change with the application (laboratory study vs. measurement during operations vs. measurements for sport physiology vs. ...), this requires a separate definition of the threshold for each application and equipment setup.
- This method works on the assumption that we have Gaussian distributions, this assumption may not be (is probably not) valid (and one should verify this!).
- It is assumed that deviations occur only due to artefacts, but the signal may deviate from normal for other reasons also, in that case a redefinition of 'normal' should be made.



Histograms for the different recording categories. (Left column) Histograms of Smax; (middle column) histograms of Smin; (right column) histograms of Sdif. (Upper row) Recordings without artifacts, recorded before or after CPB; (second row) recordings containing artifacts from electrosurgery, recorded before or after CPB; (third row) recordings without artifacts, recorded during CPB; (last row) recordings containing artifacts from electrosurgery, recorded during CPB. Asterisk (*) denotes changes in histogram caused by artifacts.

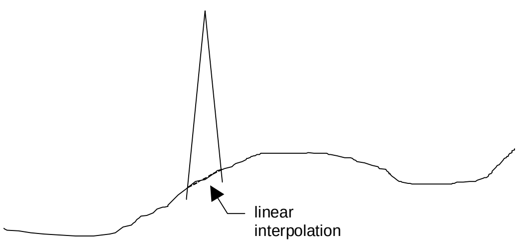
histograms of AEP amplitudes during different stages of surgery



Definition of Smax, the maximum amplitude occurring in a sweep; Smin, the minimum amplitude occurring in a sweep; Sdif, the difference between the maximum and minimum amplitude occurring in a sweep.

Spike removal

- removal of spikes may be done by using a linear interpolation between the samples where the large slopes occur instead of the actually measured data
- one has to be careful with this though (the size of the interpolation part should not become too large)



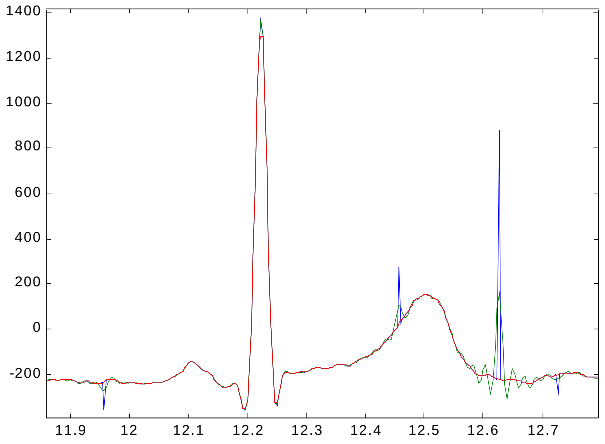
Spike removal using non-linear filtering: Median filter

- input sequence N samples
- reorder so that samples are arranged in ascending order of magnitude, $x(1) \leq x(2) \leq x(3) \ldots \leq x(N)$
- output of a median filter is the centre sample in the ordered sequence,

$$med(x) = \begin{cases} x(k+1) & \text{if } N = 2k+1 \\ \frac{1}{2}(x(k)+x(k+1)) & \text{if } N = 2k \end{cases}$$

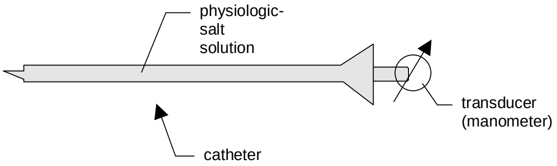
- Properties
  - good at removing sharp short-lasting artefacts ('shot noise')
  - good at restoring step changes / edges
  - 'problem': response in frequency domain depends on input (non-linearity)
  - gets computationially heavy for large N

'Best application' for median filtering: shot noise



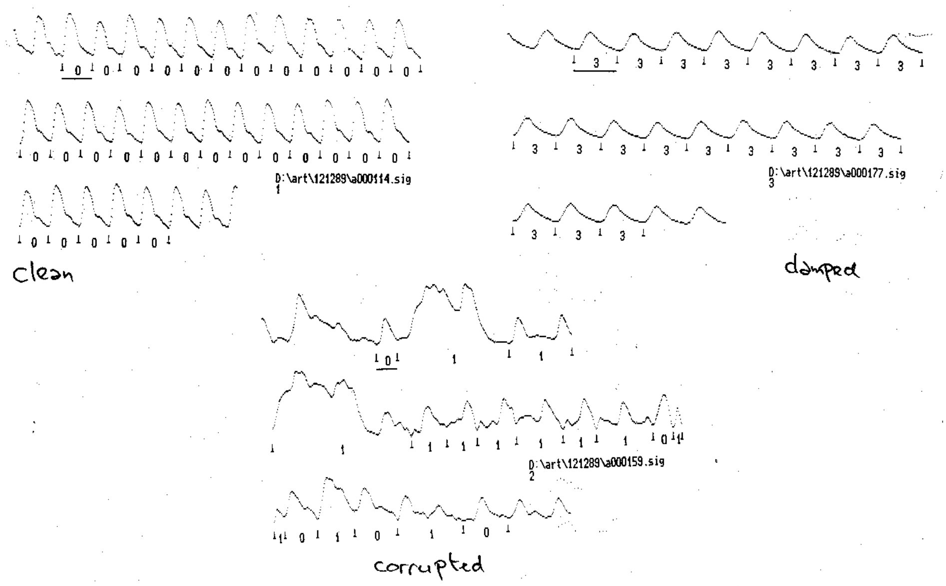
Blue: original EKG with shot-noise
Green: FIR (N=151) filtered EKG
Red: median (N=3) filtered EKG

catheter-manometer systems



- the pressure wave is propagated through the liquid-filled catheter (this acts as a filter)

- This limited dynamic performance of such a system alters the waveforms.
- Tiny air bubbles developing gradually over time or kinking of connected tubes may affect the signal.
- This can cause either resonance in the system, causing oscillations and systolic overshoot, or damping, causing slower rising pulsations with systolic underestimation and sometimes diastolic over-estimation
- Resonance can usually be detected easily, damping however is quite difficult

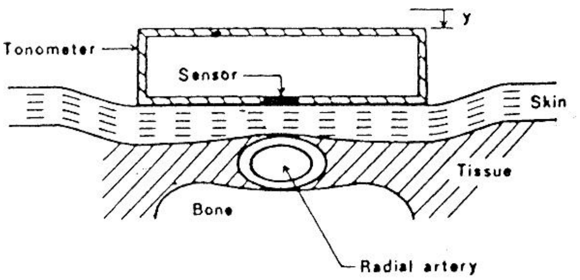


examples of clean, damped and corrupted waveforms

use of neural net

- Detection of damped waveforms cannot be done by a mere glance at the curves, it requires experience. Moreover, this detection should not require continuous attention from the staff, so it should be done automatically
- Neural networks (using the backpropagation algorithm) were trained to distinguish between 'acceptable' and damped waveforms successfully.

Motion artefacts in non-invasive pulse blood pressure measurements



- The sensor reacts to stress due to arterial pressure to be transmitted through the skin, force is measured in contact with the skin.

Motion artefacts in non-invasive pulse blood pressure measurements

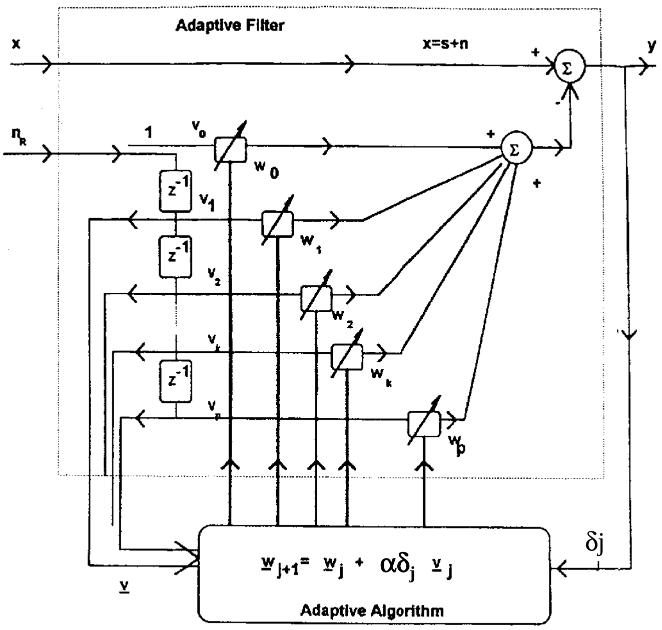
- Normally, these measurements are performed while the subject is stationary and does not move the pulse location. But, it has become of increased interest to use this type of measurements for moving subjects.
- However, the movement of the hand or even a finger can appear in the recordings. Also, the positioning and application force can alter, resulting in another type of artefact.
- The magnitude of those artefacts is typically in the order of the actual pulse pressure signal, making ambulatory recordings impractical if those artefacts cannot be removed.

use of adaptive filter

- Motion artefacts can be removed if the artefact is common to the entire sensor contact surface.
- A second sensor can be used to record the signal away from the artery (but still quite near the original sensor), it records the tissue compression force.
- The original sensor records the pulse plus tissue compression force.
- Identical to the adaptive noise cancellation technique that was discussed earlier, an adaptive algorithm can be used to cancel the motion artefacts successfully

s=pulse signal
n=tissue compression force

nr='related to' tissue compression force



Adaptive line enhancement of diastolic heart sounds

- noninvasive assessment of coronary occlusions by recording heart sounds. (detection of coronary artery disease [CAD])
- these measurements are heavily corrupted by background noise.
- ALE filtering effectively eliminated the background noise

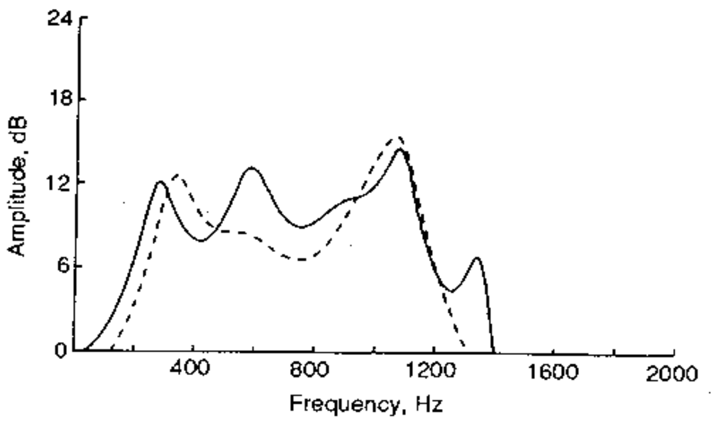


Fig. 8.10. PSD function obtained from the ARMA model applied to the diastolic heart sounds of a CAD patient. Solid line, after ALE; broken line, before ALE. [From Akay *et al.* [18]].

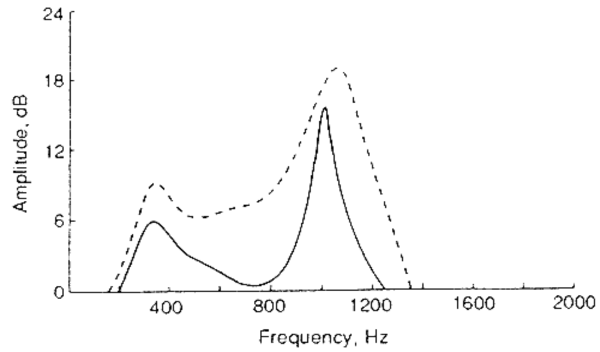


Fig. 8.11. PSD function obtained from the ARMA model applied to the isolated heart sounds of a normal patient. Solid line, after ALE; broken line, before ALE. [From Akay *et al.* [18]].