Innovative approach of ECG recording by Micro-Electro-Mechanical Systems (MEMS)

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Human Computer Interaction

Wearable Computing

Seismocardiography

Machine Learning

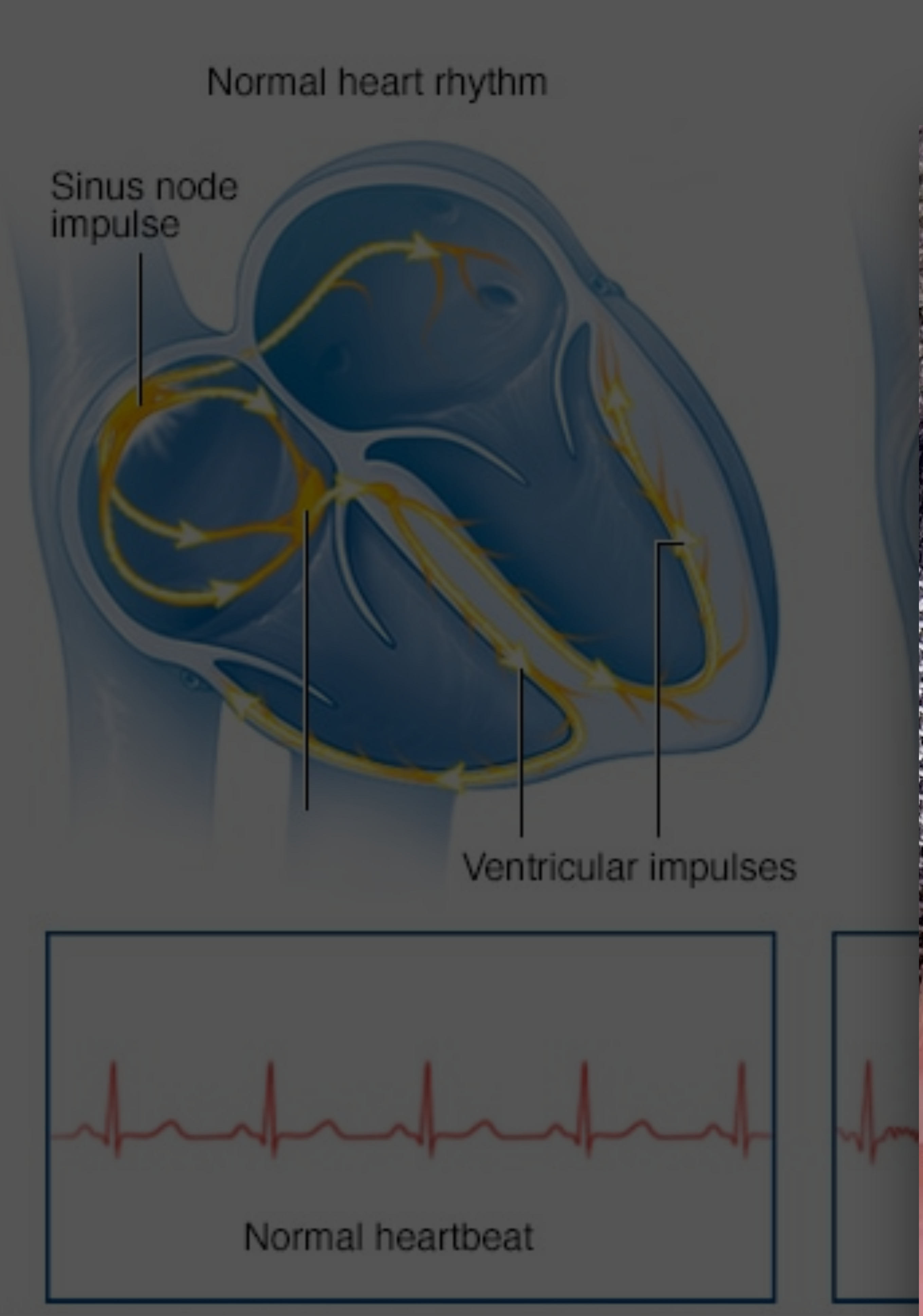
Pattern Recognition

Artificial Intelligence

Fraunhofer IGD

Visual Computing RESEARCH AND INNOVATION CENTER

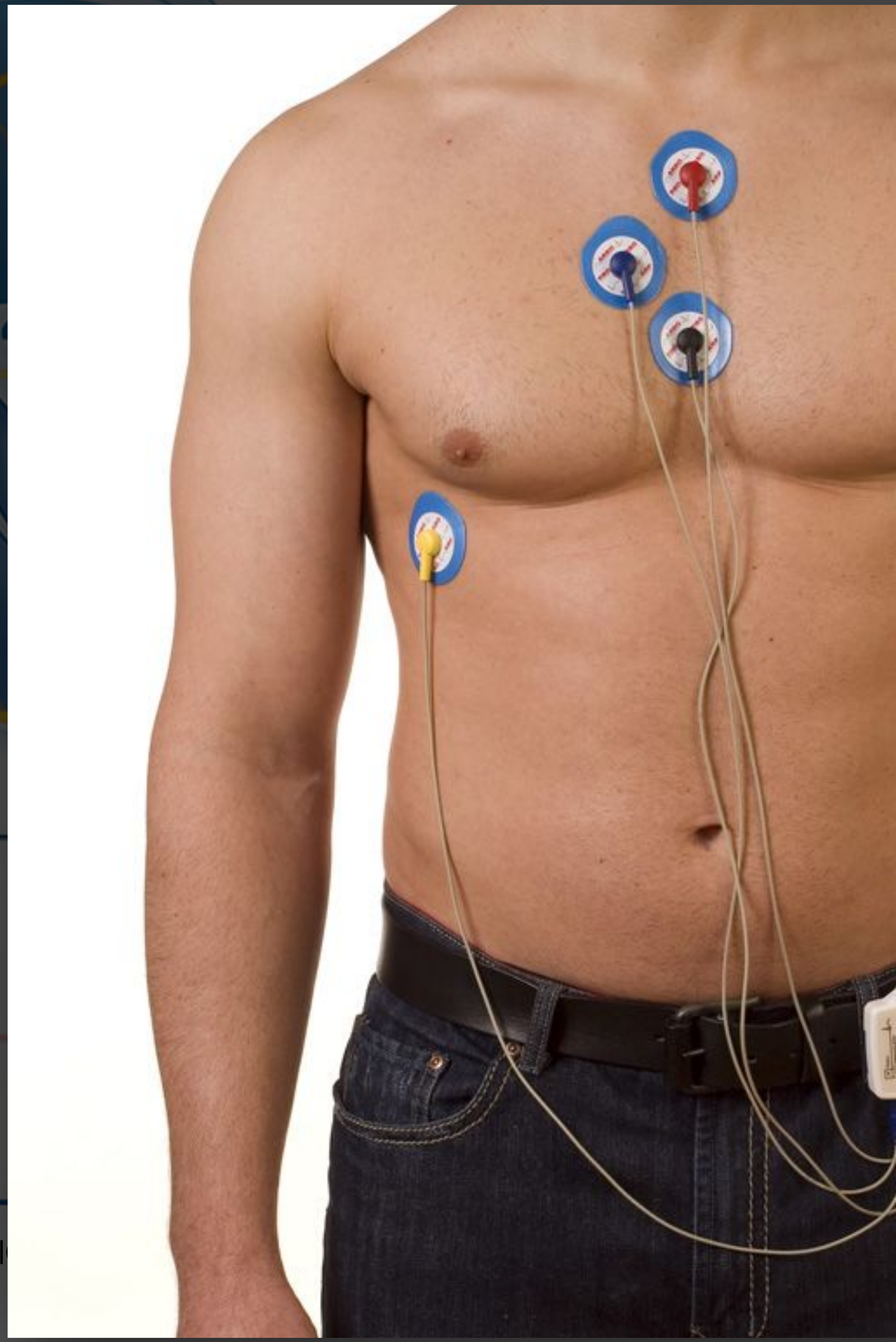
EMB



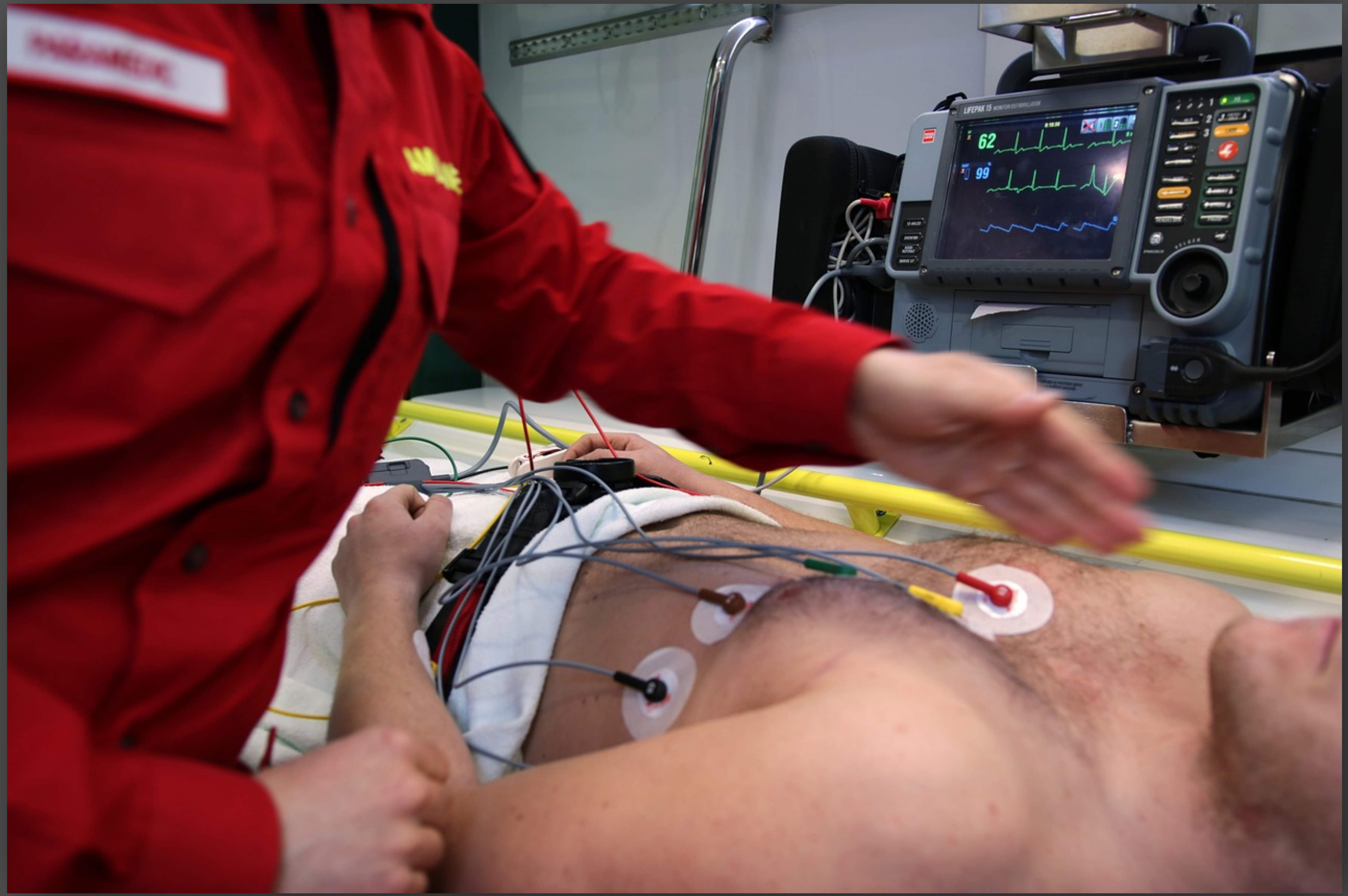
(C) MAYO FOUNDATION FOR MEDICAL EDUCATION AND RE ... UCATI

Normal heart rhythm

Atrial fibrillation (AFib)



Normal heart rhythm
Atrial fibrillation (AFib)
Abnormal impulse
VT
EARC
ICAL EDUCATION AND RESEARCH. ALL RIGHTS RESERVED.
9:41
'm feeling...



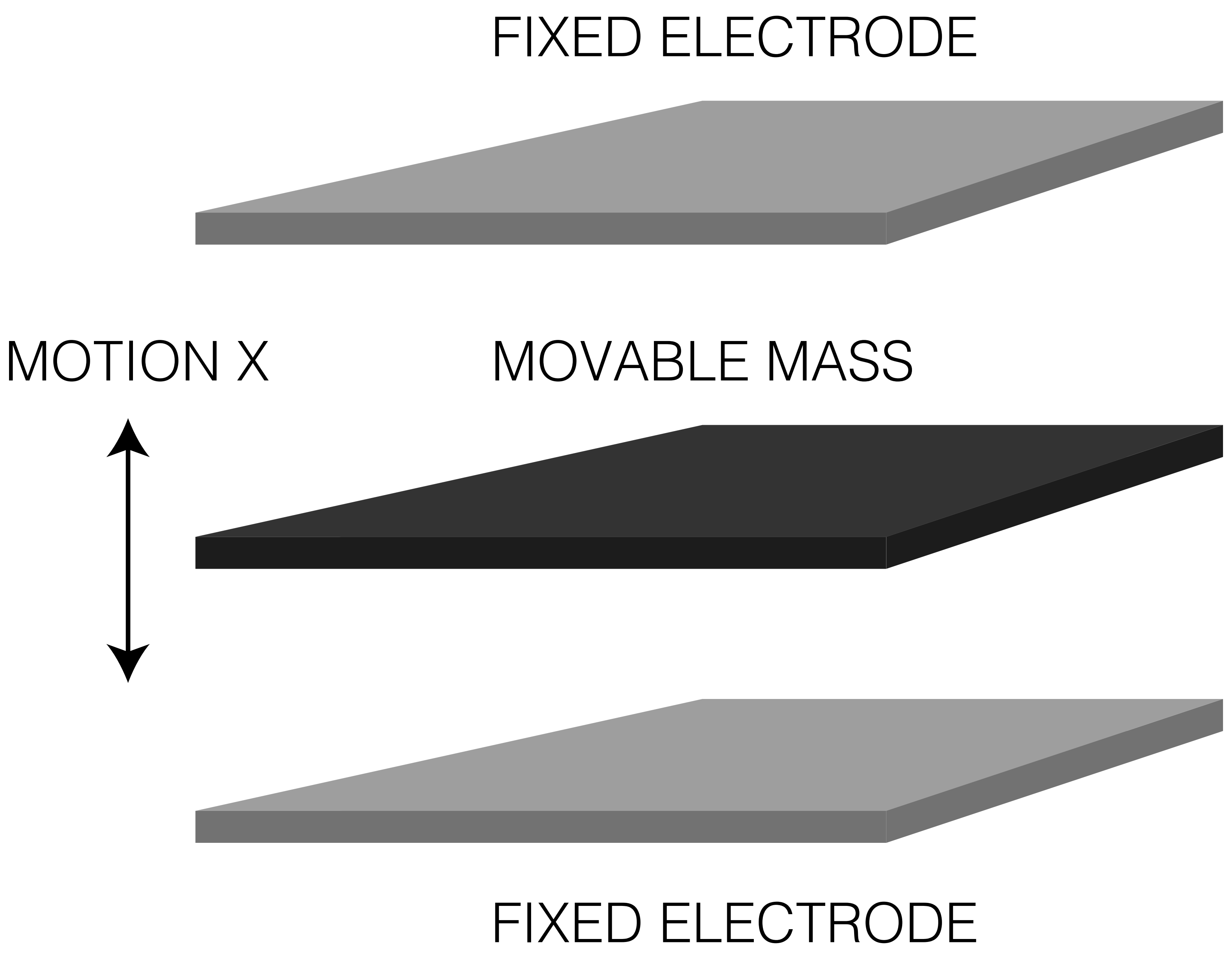


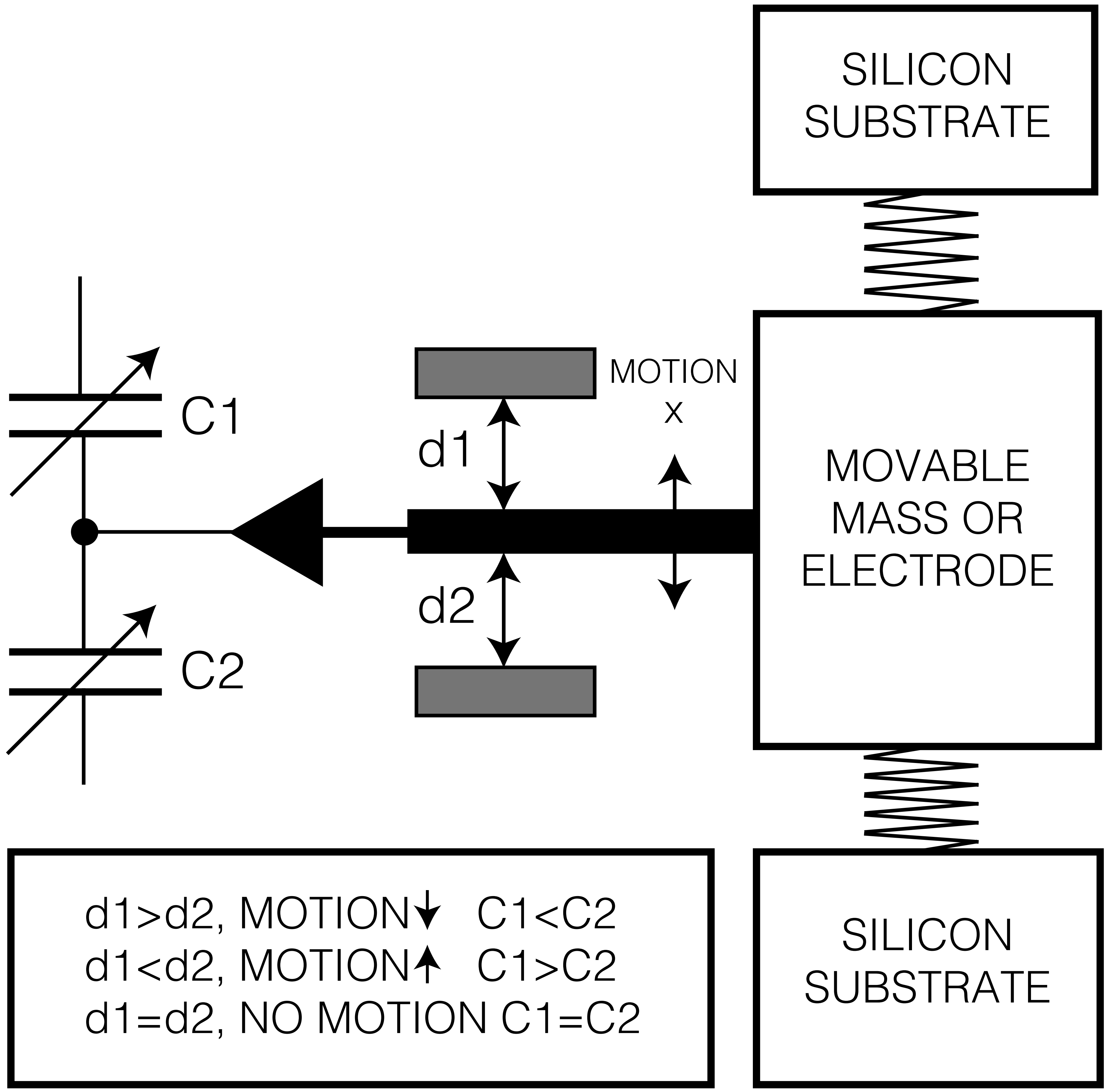
FÖR
CARL XV
USTAF
SVE


Portrait

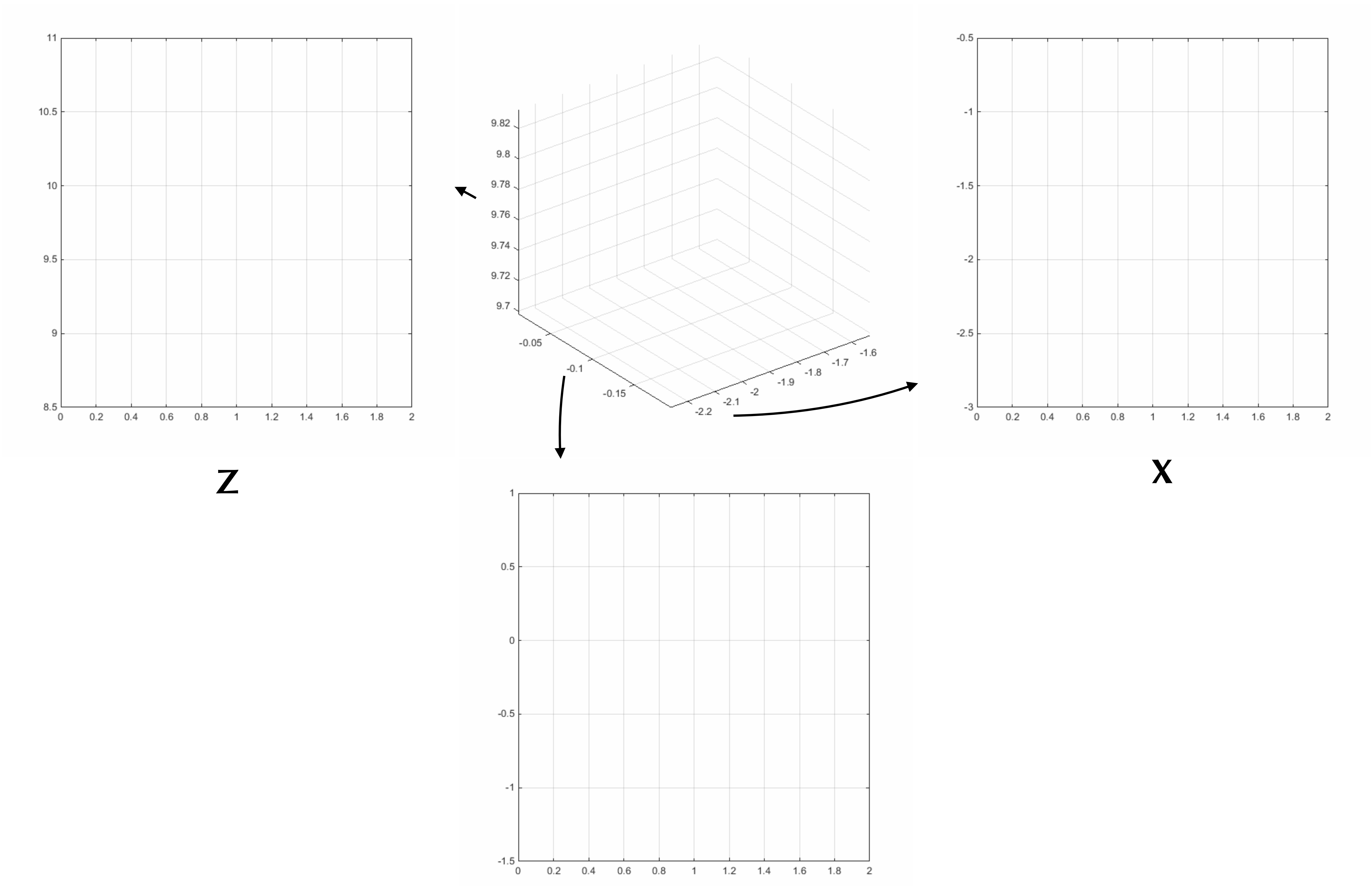

Landscape

Motivation


FIXED ELECTRODE
MOTION X
MOVABLE MASS
FIXED ELECTRODE


SILICON SUBSTRATE
C1
MOTION X
d1
MOVABLE MASS OR ELECTRODE
d2
C2
d1>d2, MOTION↓ C1<C2
d1<d2, MOTION↑ C1>C2
d1=d2, NO MOTION C1=C2
SILICON SUBSTRATE

Motivation

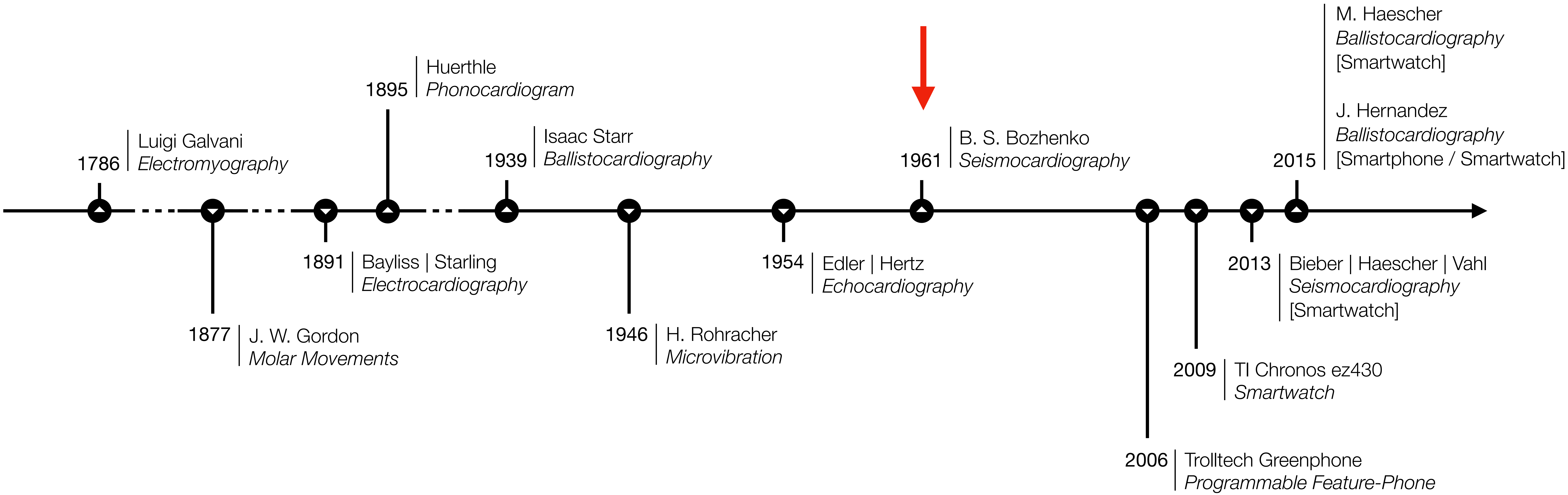


Z

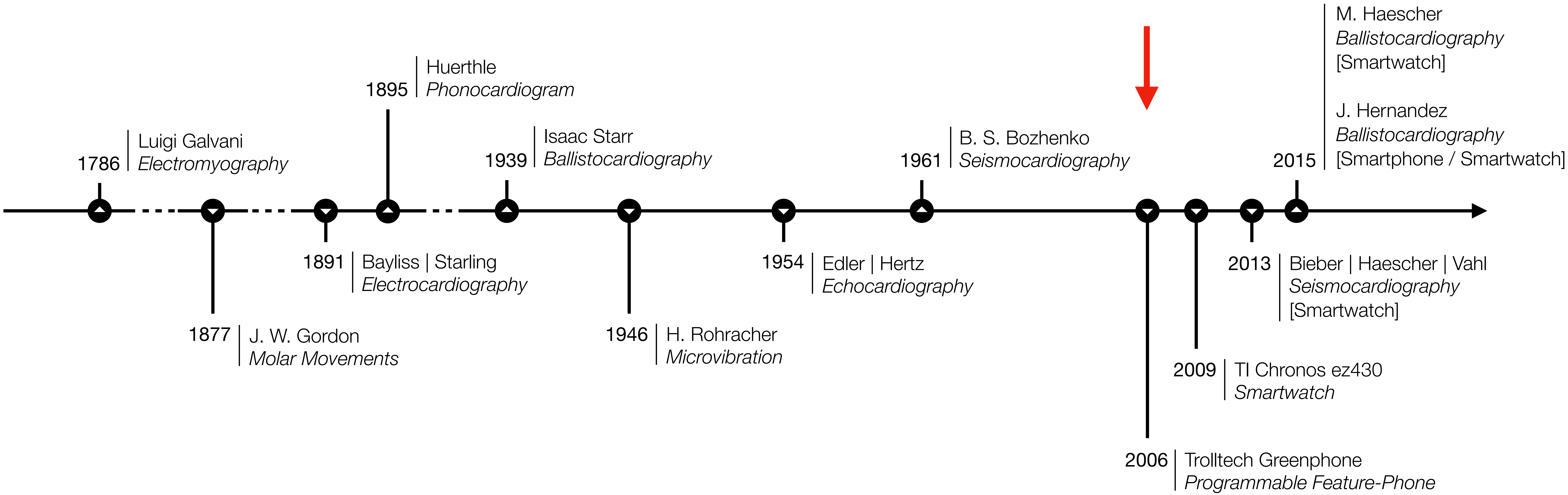
X

Y

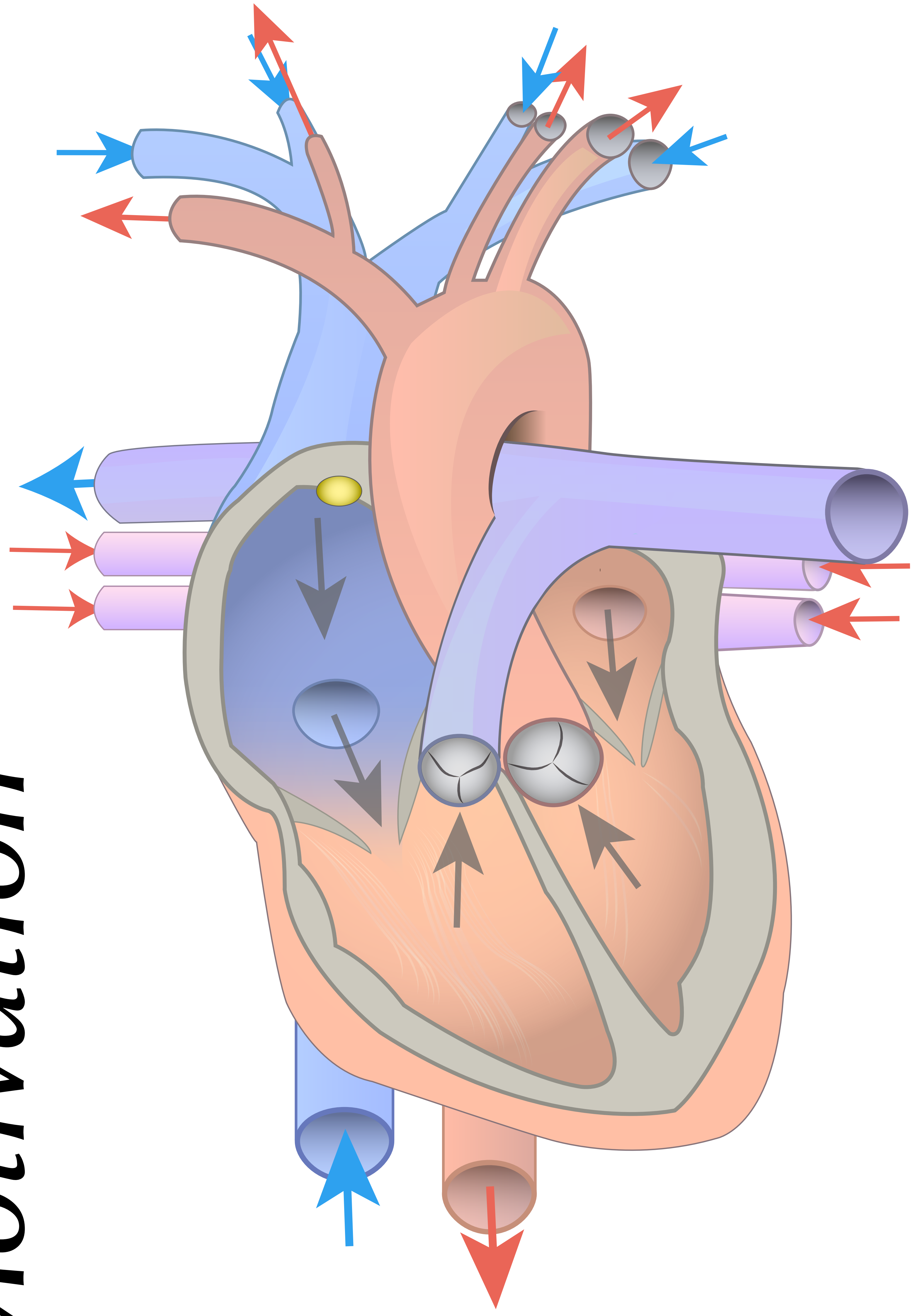
History of Diagnostic Tools

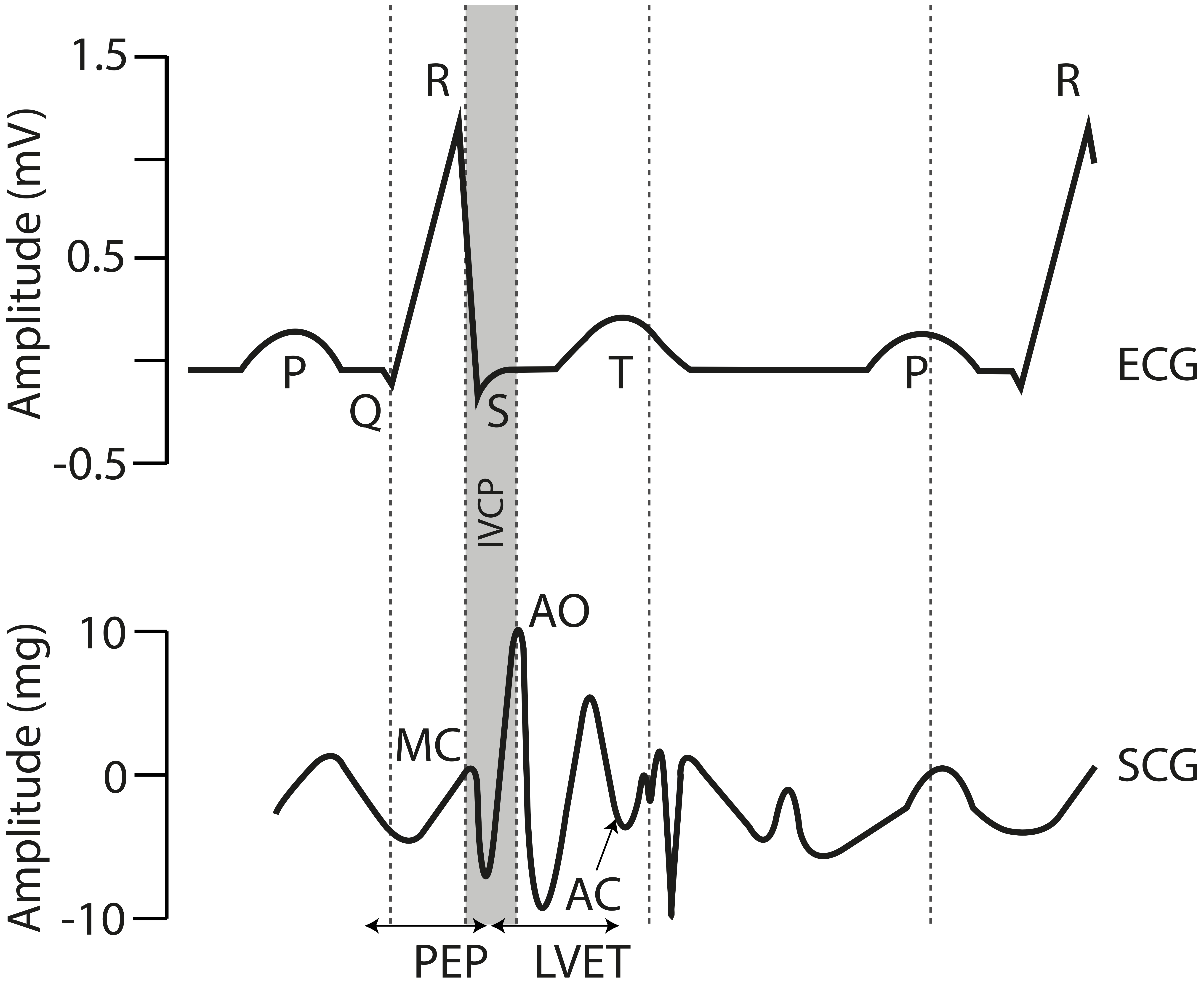


History of Diagnostic Tools

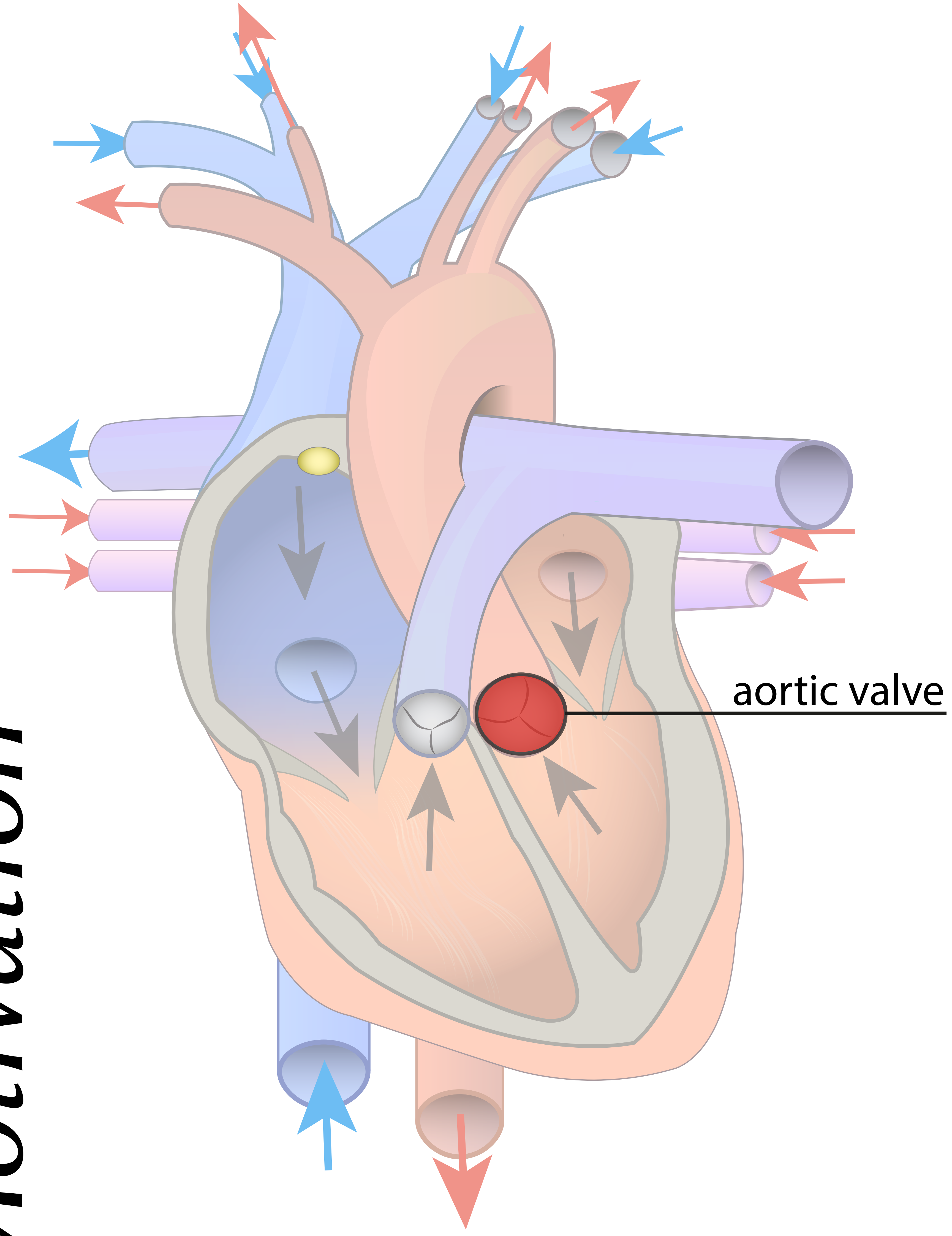


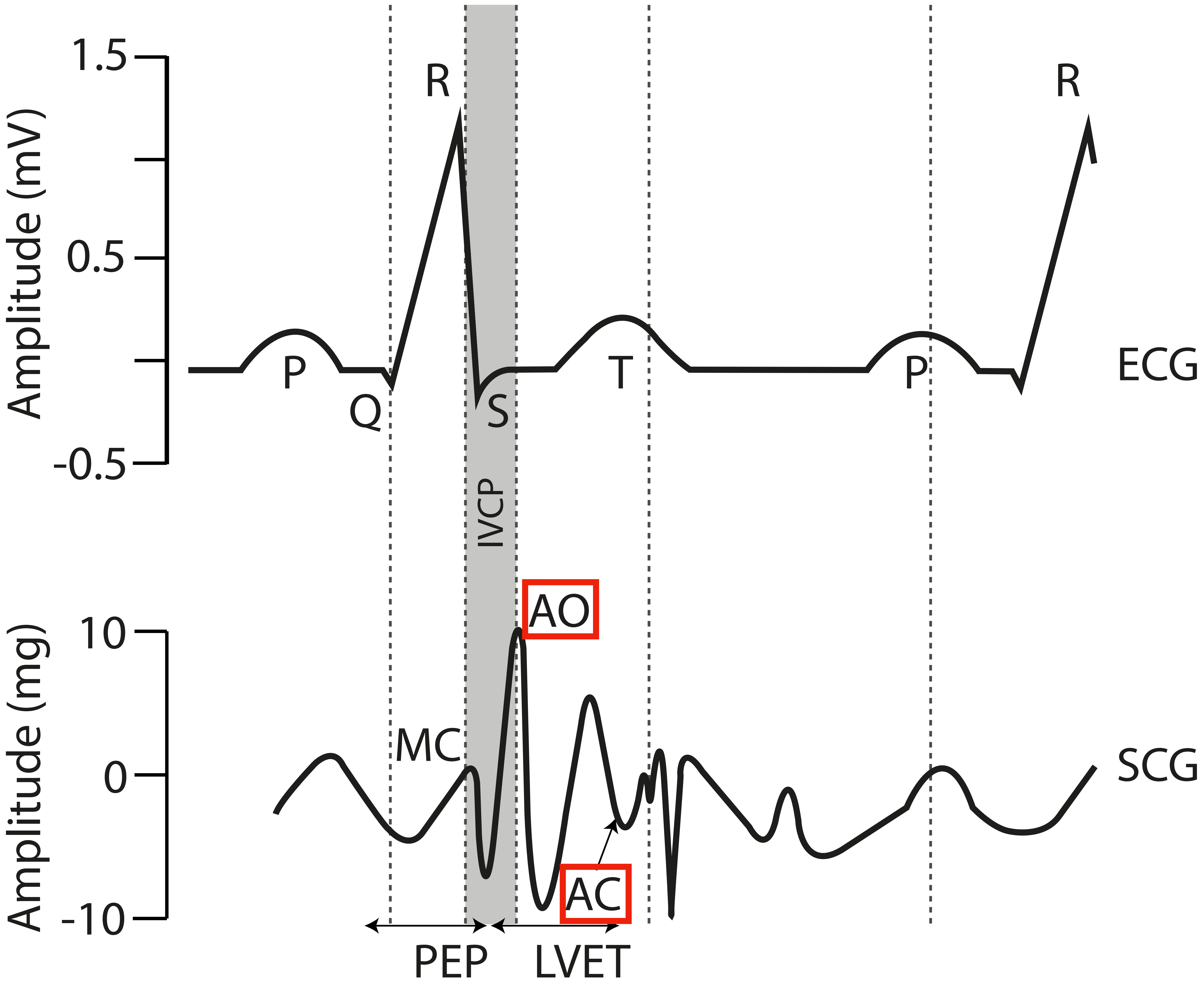
Motivation




1.5
0.5
-0.5
Amplitude (mV)
R
P
Q
S
T
P
R
ECG
IVCP
10
0
-10
Amplitude (mg)
AO
MC
AC
SCG
PEP
LVET

Motivation





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Initial Hypothesis

ECG and SCG share information on the cardiac cycle and allow for inference on the same pathologies

Related Work

According to the overview article of Taebi et al., SCG signatures include various important feature points of the cardiac cycle, including:

peak of atrial systole (AS),
mitral valve closure (MC),
peak of rapid systolic ejection (RE),
peak of rapid diastolic filling (RF),
isovolumetric contraction (IC),
mitral valve opening (MO),
aortic valve closure (AC),
aortic valve opening (AO),
isovolumetric movement (IM),
rapid diastolic filling time,
isotonic contraction (IC),
isovolumetric relaxation time (IVRT),
left ventricular ejection time (LVET),
maximum acceleration in aorta (MA),
total electromechanical systole period (QS2),
pre-ejection period (PEP),
maximum blood injection (MI),
isovolumetric contraction time (IVCT),
left ventricular lateral wall contraction peak velocity (LVC),
septal wall contraction peak velocity (SVC),
trans-aortic peak flow (AF),
trans-pulmonary peak flow (PF),
trans-mitral ventricular relaxation flow (MF_E),
and atrial contraction flow (MF_A).

Amirtahà Taebi, Brian Solar, Andrew Bomar, Richard Sandler, and Hansen Mansy. 2019. Recent Advances in Seismocardiography. *Vibration*. https://doi.org/10.3390/vibration2010005

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Related Work

This hypothesis is supported by various observations described in related work:

- changes in ECG and SCG signals due to ectopic events [1]
- changes in ECG and SCG signals associated with changes in coronary blood flow [2]
- changes in the signature of ECG and SCG due to AFib [3]
  - Koivisto et al. report an accuracy of 100% in separating positive atrial fibrillation (AFib) samples from negative AFib samples via SCG signals

[1] Marco Di Rienzo, Paolo Meriggi, Francesco Rizzo, Emanuele Vaini, Andrea Faini, Giampiero Merati, Gianfranco Parati, and Paolo Castiglioni. 2011. A wearable system for the seismocardiogram assessment in daily life conditions. In *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*. https://doi.org/10.1109/IEMBS.2011.6091058

[2] D M Salerno, J M Zanetti, L A Green, M R Mooney, J D Madison, and R A Van Tassel. 1991. Seismocardiographic changes associated with obstruction of coronary blood flow during balloon angioplasty. *The American Journal of Cardiology* 68, 2: 201–207.

[3] Tero Koivisto, Mikko Pänkäälä, Tero Hurnanen, Tuija Vasankari, Tuomas Kiviniemi, Antti Saraste, and Juhani Airaksinen. 2015. Automatic detection of atrial fibrillation using MEMS accelerometer. In *Computing in Cardiology*. https://doi.org/10.1109/CIC.2015.7411039

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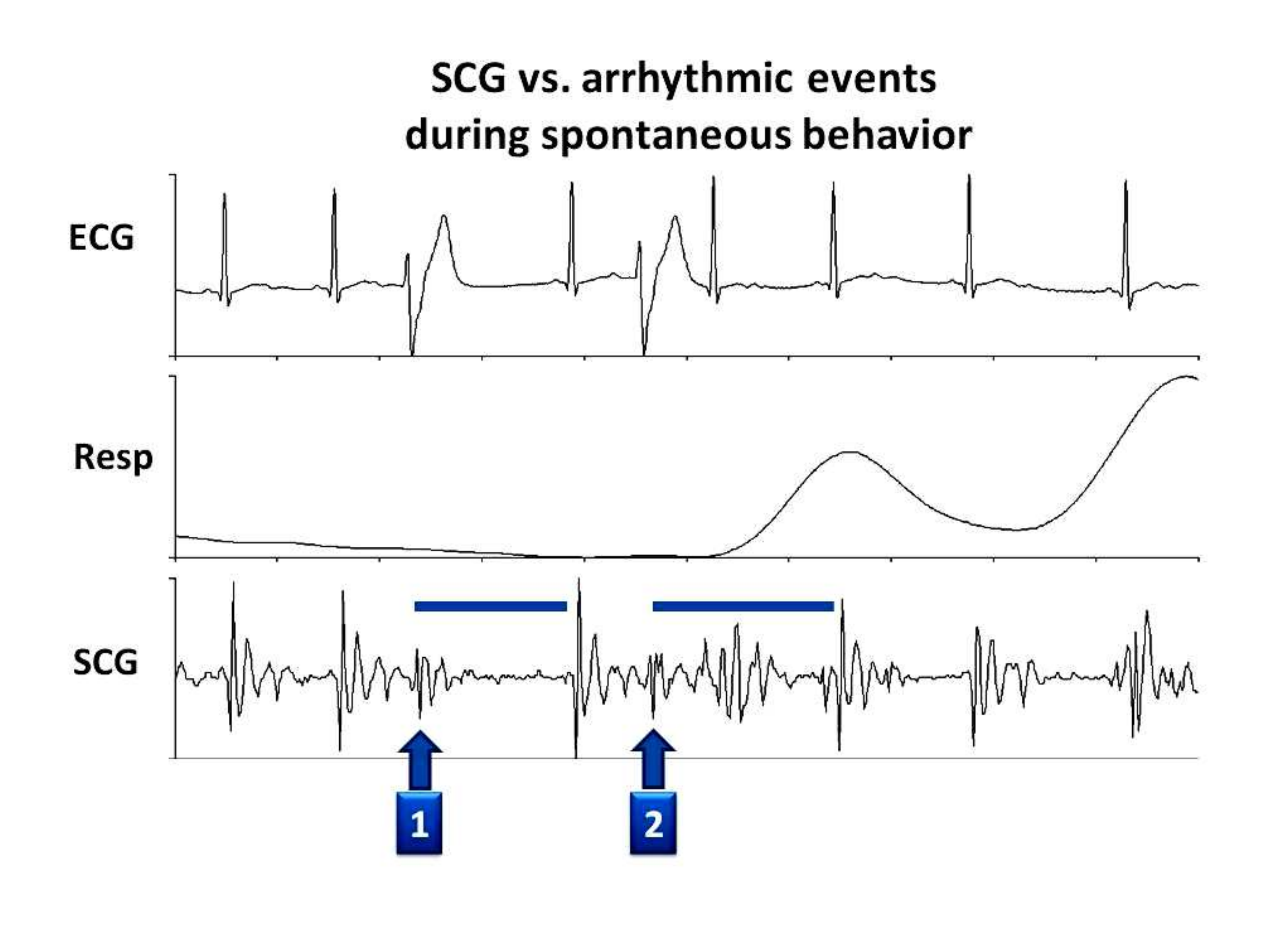

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Concept Idea

Transform SCGs into ECGs by applying Artificial Intelligence (Deep Convolutional Autoencoder Network)

Dataset

CEBS Dataset:

Participants

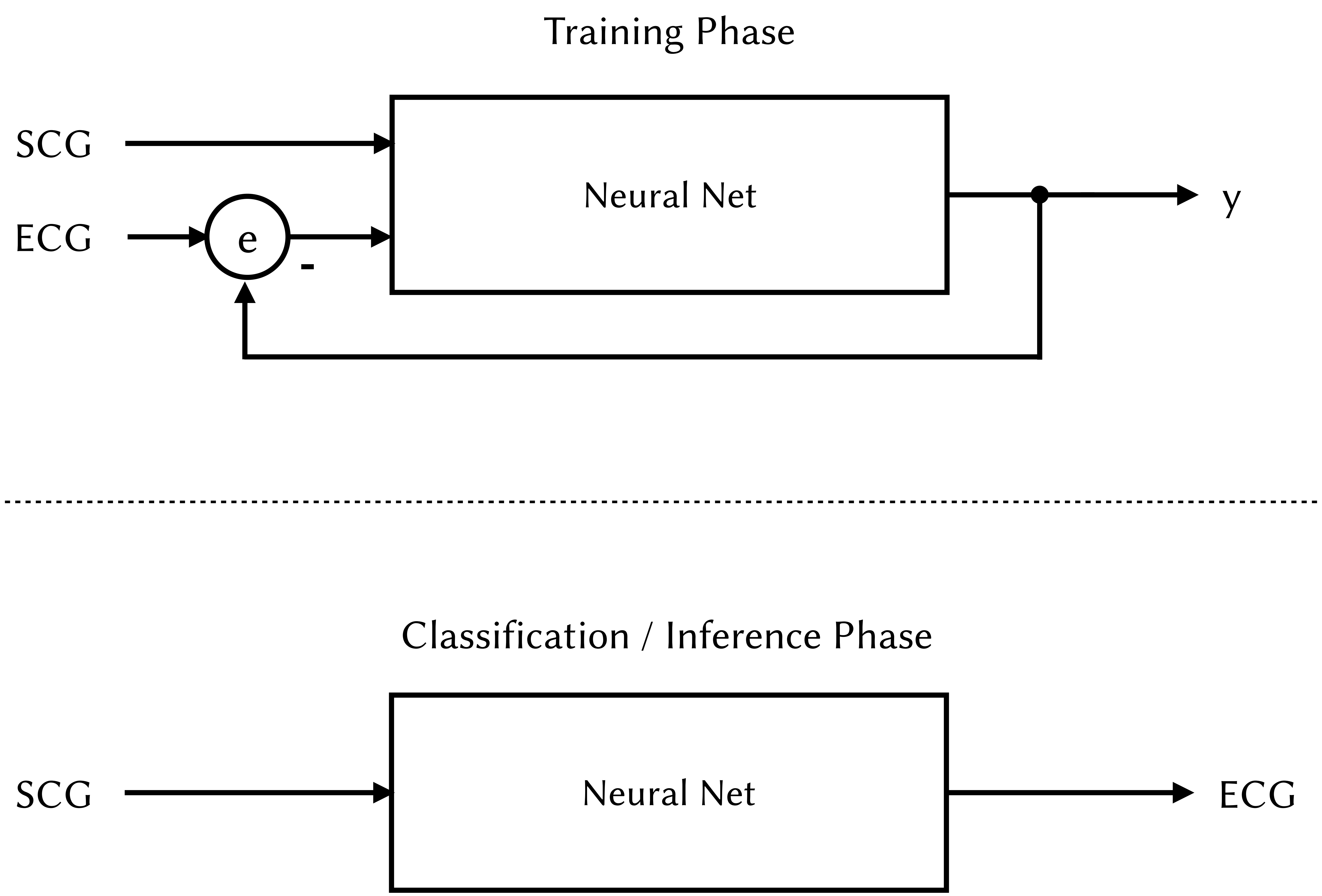
The mean age of the **sample (n=20)** is given with *M: 24.4, SD: ±3.10* years. The sample consists of **12 male subjects and 8 female subjects** of Caucasian ethnicity. The tested subjects are referred to as presumably healthy.

IEEE Dataset:

Participants

A group of **29 healthy volunteers (all male)**. Demographics are given as follows: age of M: 29yrs, SD: ± 5yrs; height of M: 179cm, SD: ± 5cm; weight of M: 76kg, SD: ± 11kg; BMI of M: 24kg/m^2, SD: ± 3kg/m^2 [24].

Basic Concept



Results

Parameter	CEBS	IEEE 1	IEEE 6
xcorr	0.94 ± 0.05	0.88 ± 0.05	0.91 ± 0.06
MSE	0.01 ± 0.01	0.05 ± 0.05	0.04 ± 0.05
NMSE	0.79 ± 0.59	0.49 ± 0.42	0.40 ± 0.44
RMS	0.84 ± 0.30	0.22 ± 0.09	0.18 ± 0.10
NRMS	0.09 ± 0.05	0.65 ± 0.26	0.55 ± 0.31
PRDN1	84.4 ± 30.5	157.5 ± 76.2	121.5 ± 59.8

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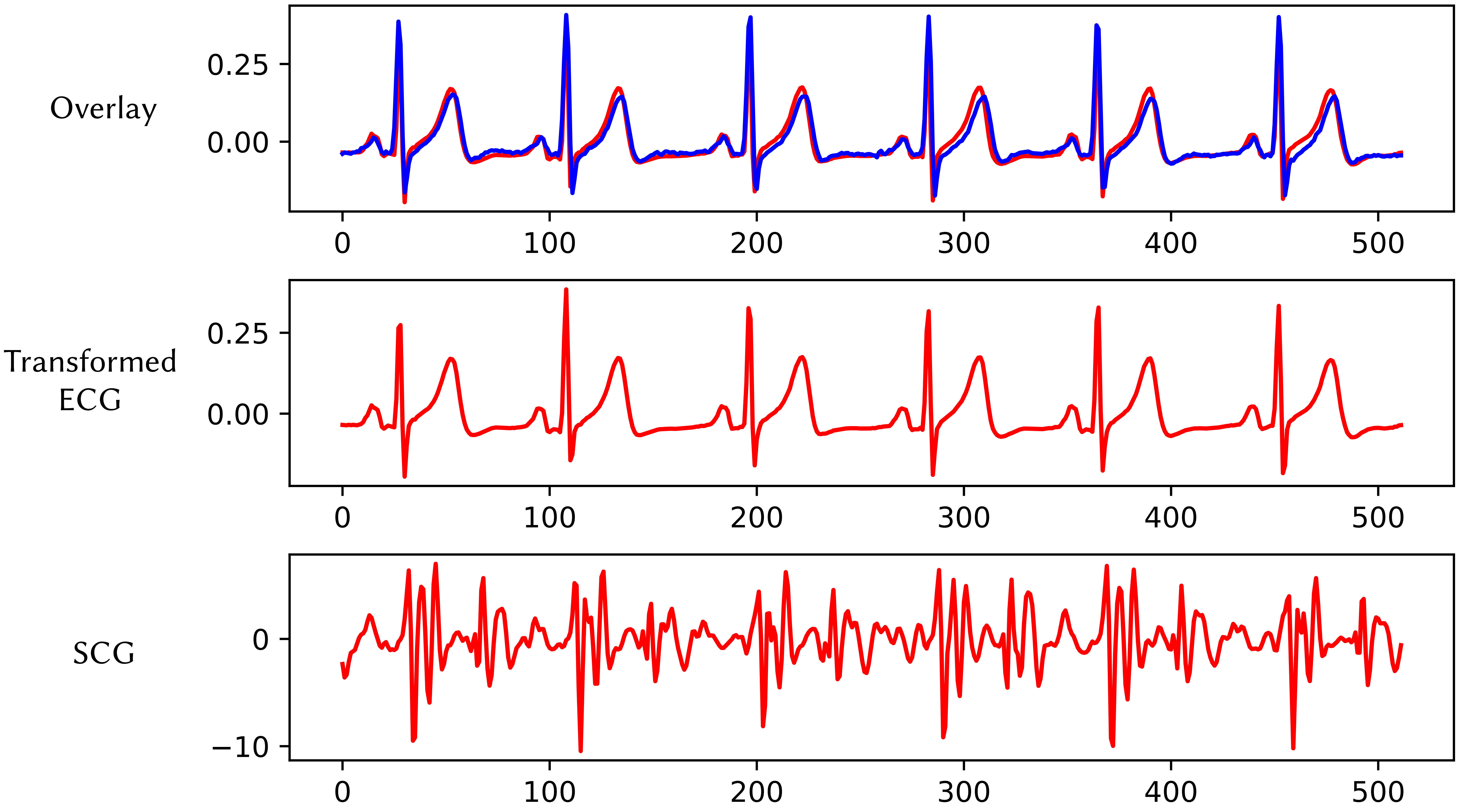
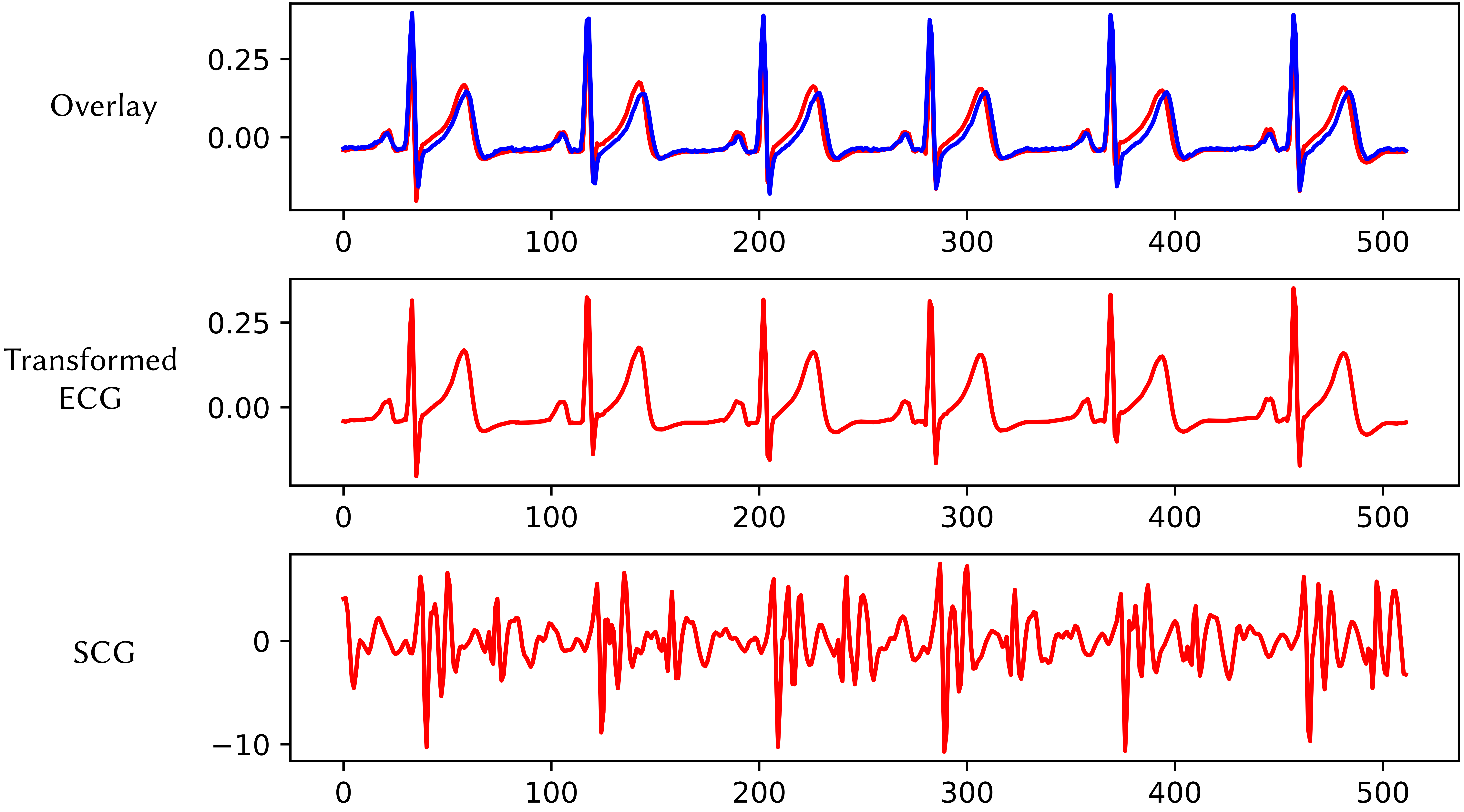


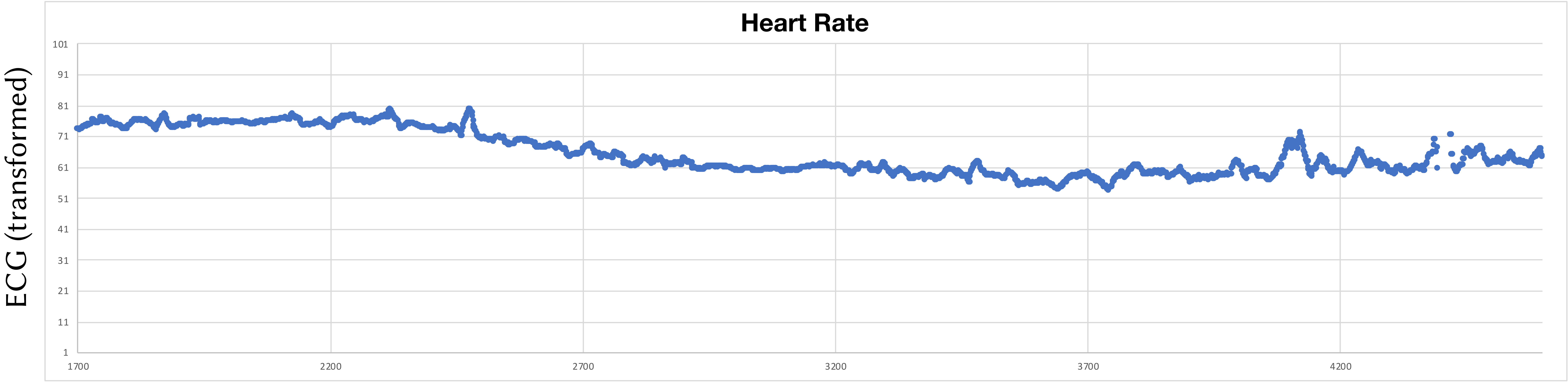
Overlay
0.25
0.00
0
100
200
300
400
500
Transformed ECG
0.25
0.00
0
100
200
300
400
500
SCG
0
−10
0
100
200
300
400
500

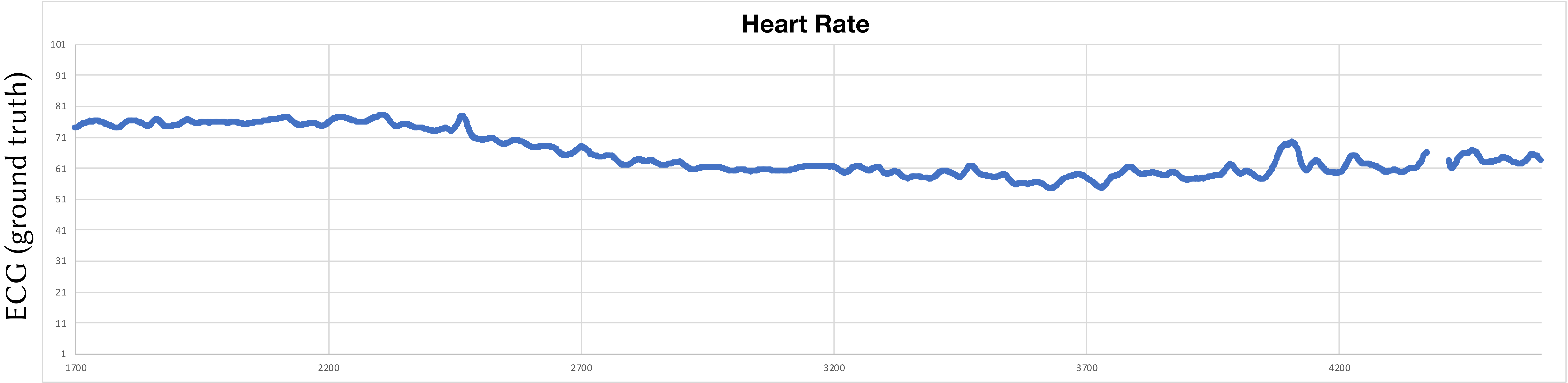
Results



Overlay
0.25
0.00
0
100
200
300
400
500
Transformed ECG
0.25
0.00
0
100
200
300
400
500
SCG
0
−10
0
100
200
300
400
500

Results


Heart Rate
ECG (transformed)
101
91
81
71
61
51
41
31
21
11
1
1700
2200
2700
3200
3700
4200


Heart Rate
ECG (ground truth)
101
91
81
71
61
51
41
31
21
11
1
1700
2200
2700
3200
3700
4200

Results

harmonic mean of precision and sensitivity:

$$F_1 = 2 \cdot \frac{PPV \cdot TPR}{PPV + TPR} = \frac{2TP}{2TP + FP + FN}$$

subject	F1 Score
s01	0,96
s02	0,94
s03	0,99
s04	0,97
s05	0,97
s06	0,99
s07	0,97
mean	0,97

Demo

Conclusion

- Record an ECG without electrodes (no rash or skin irritation, no faulty electrode placement)
- No specific device needed, since smartphones etc. are already widespread (inexpensive solution that can be rolled out via an app update)
- Ideal for rural areas and third world countries

Outlook

- Recording of pathologic SCG and ECG signals
- Integration of Machine Learning for identification of pathologies in transformed signals (e.g., AFib)
- Transformation of more than one ECG channel (e.g., 12-lead ECG)
- Investigation of alternative sensor technologies (e.g., radar)

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