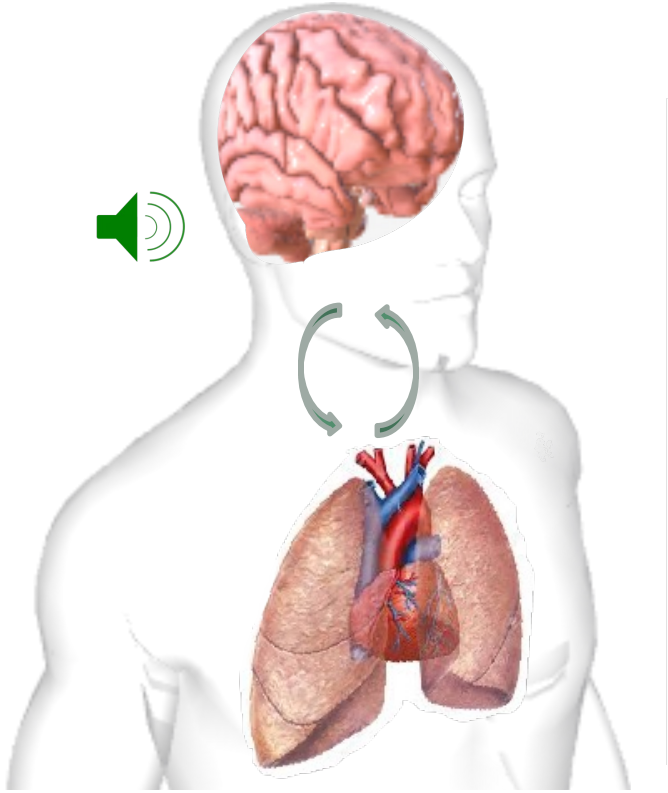
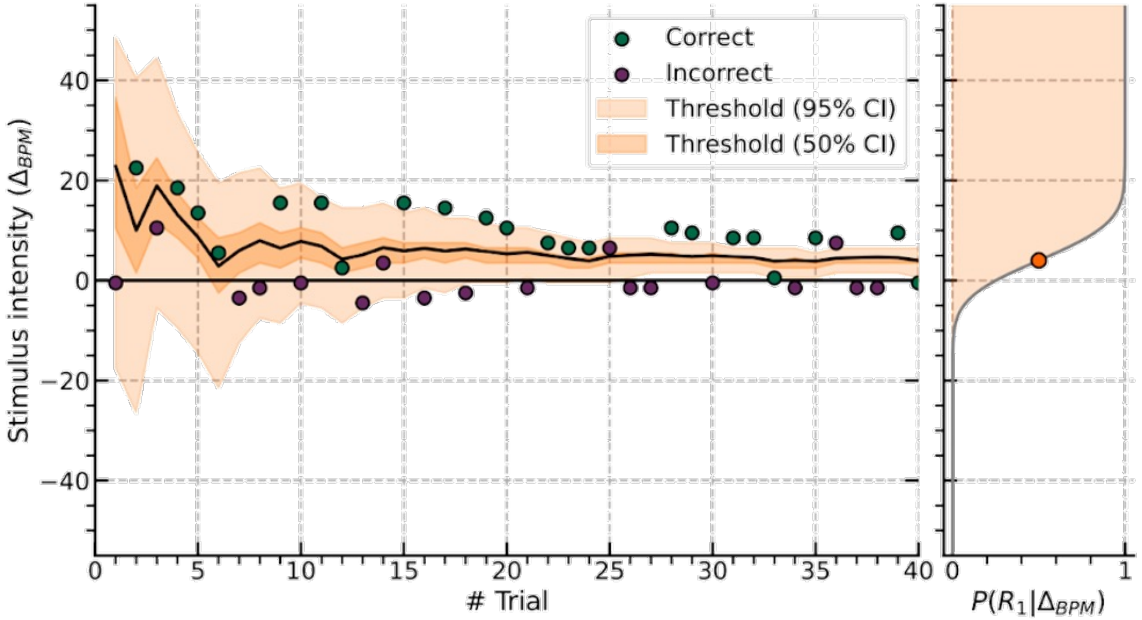
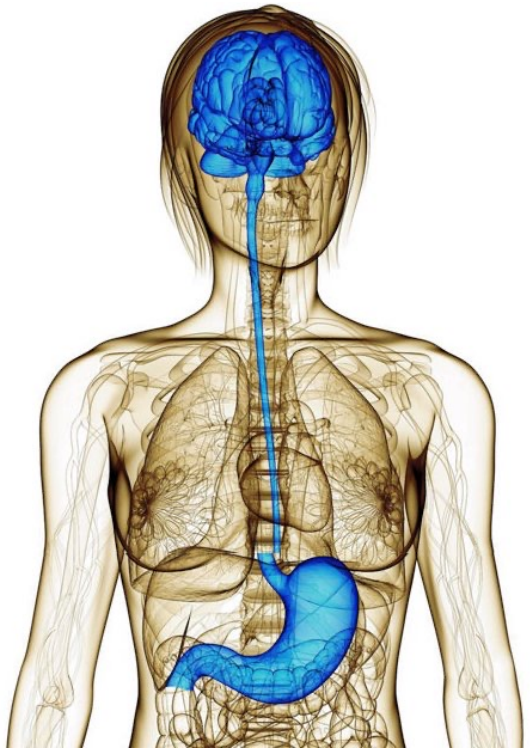
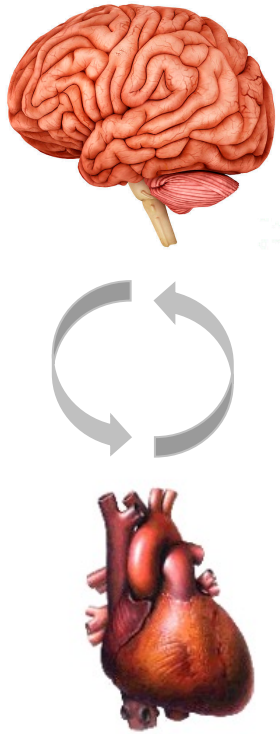
Analyzing Body-Brain Interactions

Esra Al, Leah Banellis, Ignacio Rebollo









How To Analyze Heart-Brain Interactions and Their Link to Behavior

Part I

Esra Al

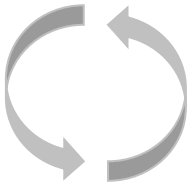
MAX-PLANCK-GESELLSCHAFT

MAX PLANCK INSTITUTE FOR HUMAN COGNITIVE AND BRAIN SCIENCES LEIPZIG

BERLIN SCHOOL OF MIND AND BRAIN

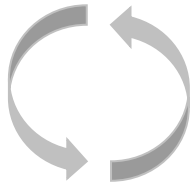
HUMBOLDT-UNIVERSITÄT ZU BERLIN

COLUMBIA UNIVERSITY



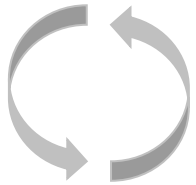
I - Cardiac Cycle

II - Heartbeat-Evoked Potentials



I - Cardiac Cycle

II - Heartbeat-Evoked Potentials

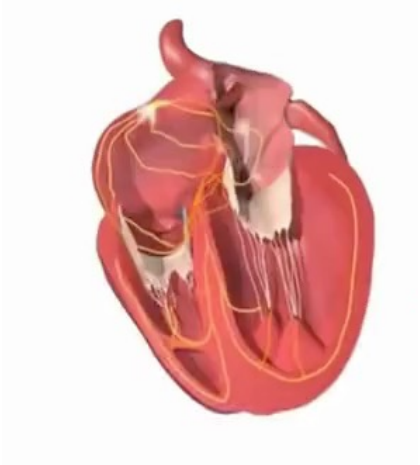


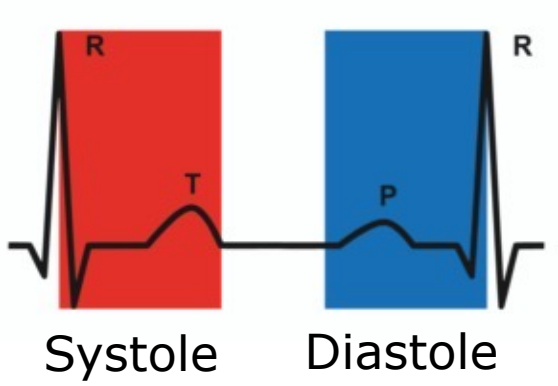
I - Cardiac Cycle

- Binary Analyses
- Circular Analyses

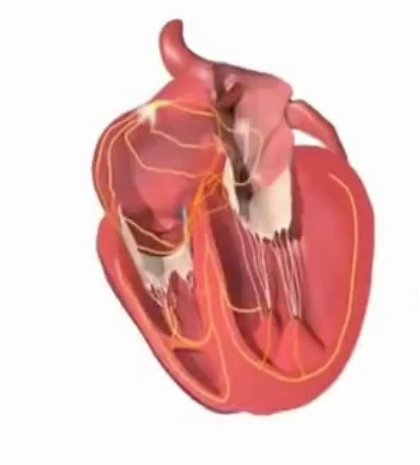
II - Heartbeat-Evoked Potentials

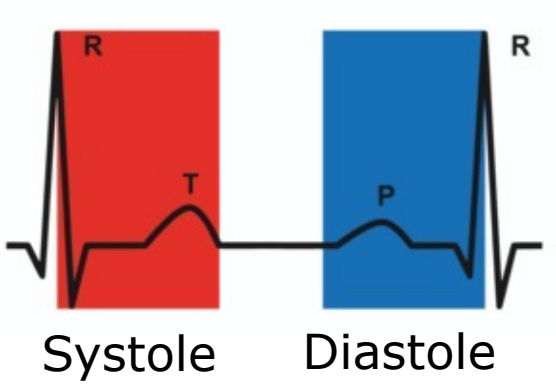
Cardiac Cycle – Binary Analyses

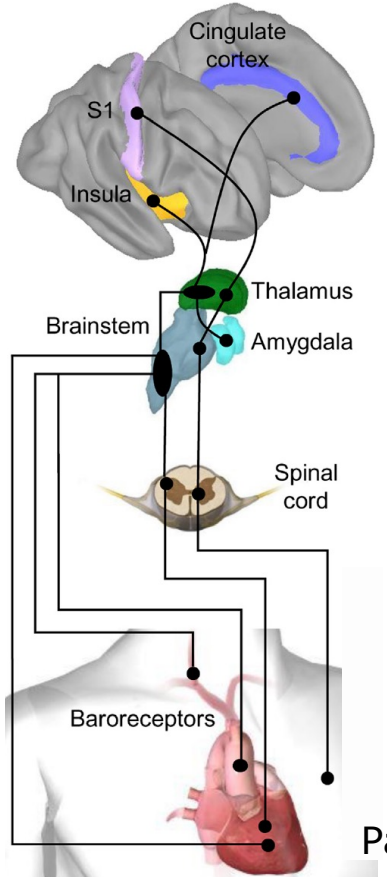




Cardiac Cycle – Binary Analyses

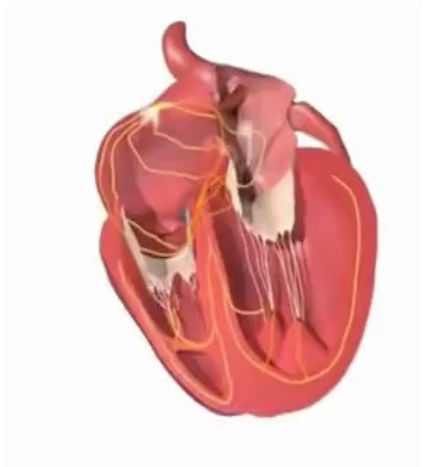


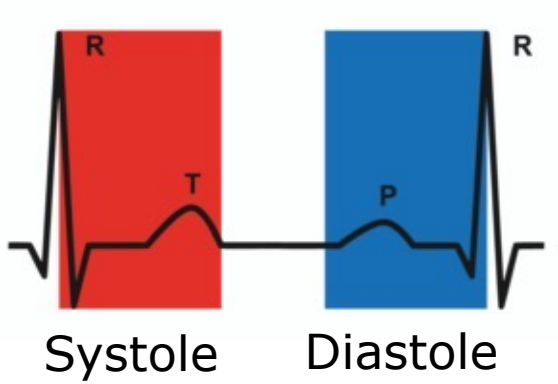


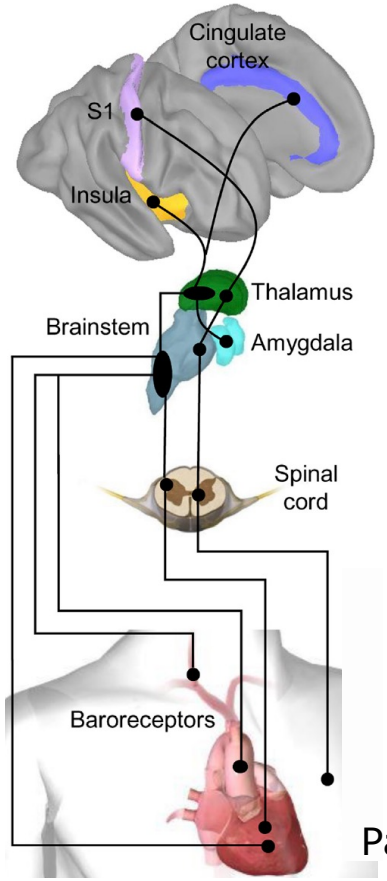


Park & Blanke, 2019

Cardiac Cycle – Binary Analyses







Park & Blanke, 2019

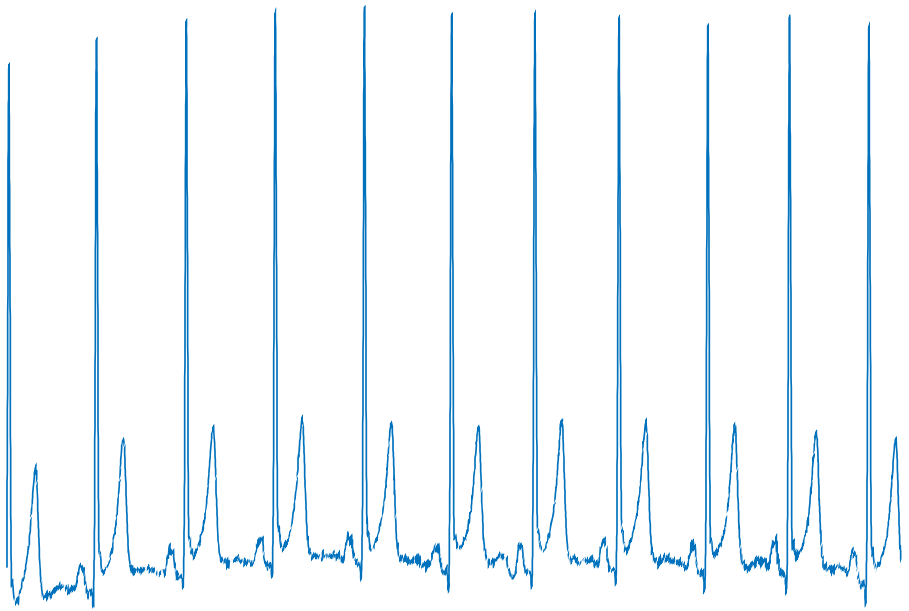
- Decreased auditory and visual perception during systole compared to diastole!

Saxon, 1970; Sandmann et al. 1977

How to Calculate the Systolic Window?

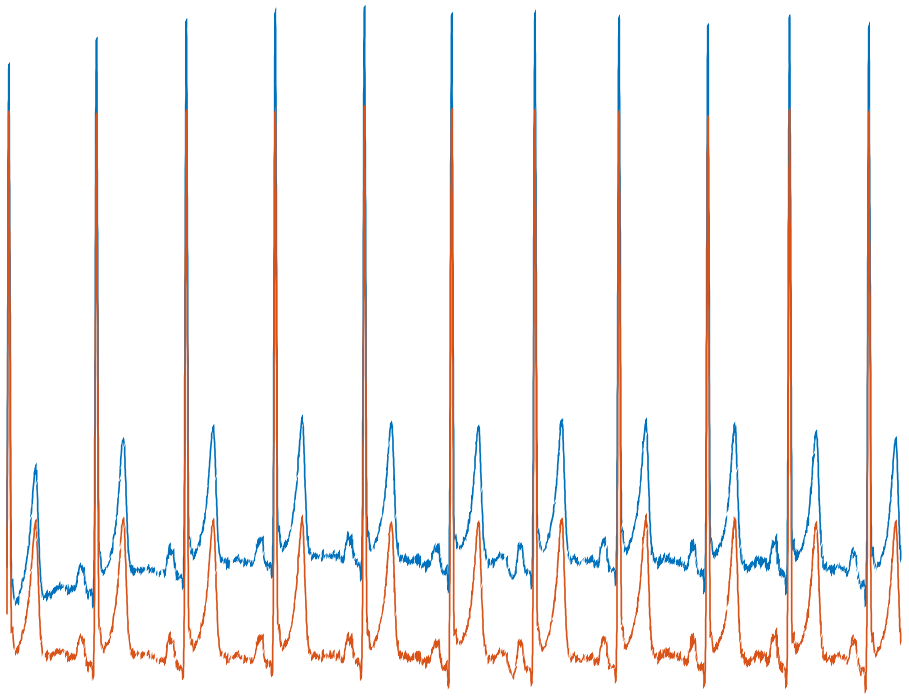
How to Calculate the Systolic Window?

Problem: ECG data has baseline drift and noise!



Filtering the ECG Signal

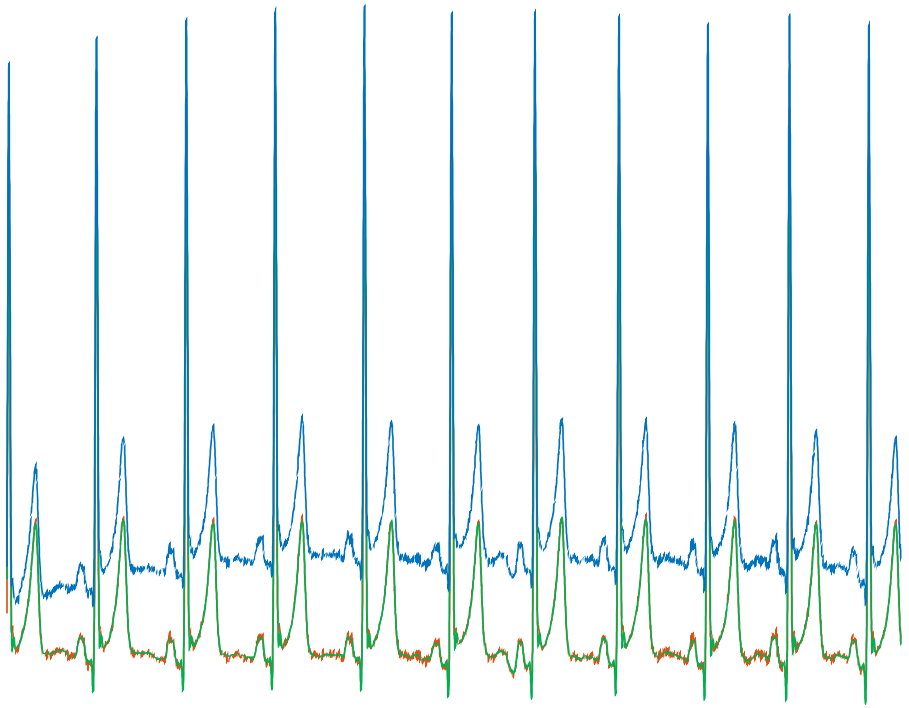
Solution 1) High-pass filtering of the ECG signal (0.5 Hz, Butterworth, 4th order) to reduce baseline drift.




```
[c,d]=butter(4,0.5/(EEG.srate/2),'high');
ECGdata=filtfilt(c,d,double(ECGdata));
```

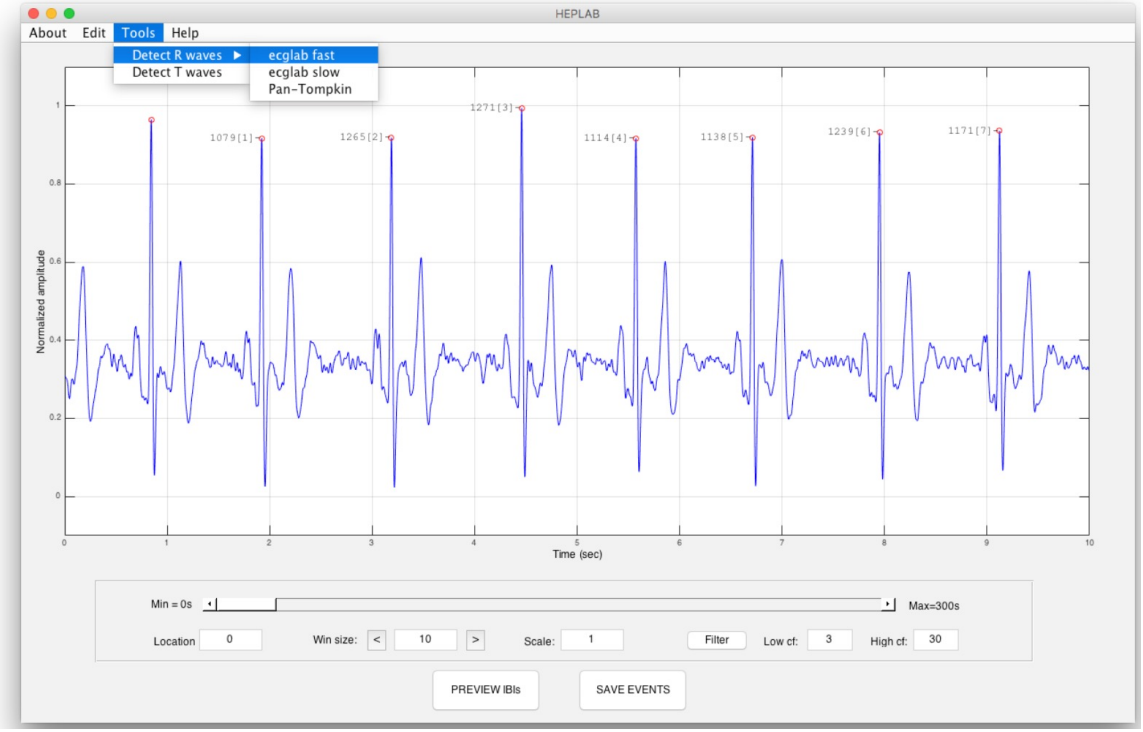
Filtering the ECG Signal

Solution 2) Low-pass filter (30 Hz, Butterworth, 4th order, cut-off frequency) to reduce noise.




```
[b,a]=butter(4,30/(EEG.srate/2));
ECGdata=filtfilt(b,a,double(ECGdata));
```

Determine R-peak Latencies



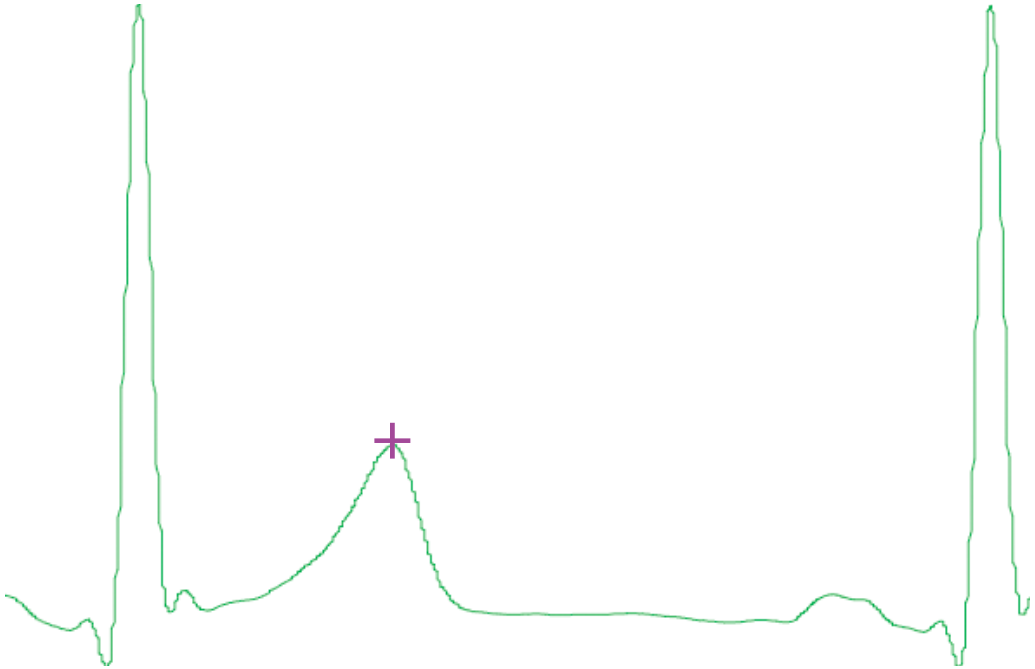
- Kubios software

- HEPLAB – EEGLAB extension

https://github.com/perakakis/HEPLAB

Determine T-peak positions

Use a local maxima function in a window starting from 140 ms after the R-peak until the 1/3 of the RR interval



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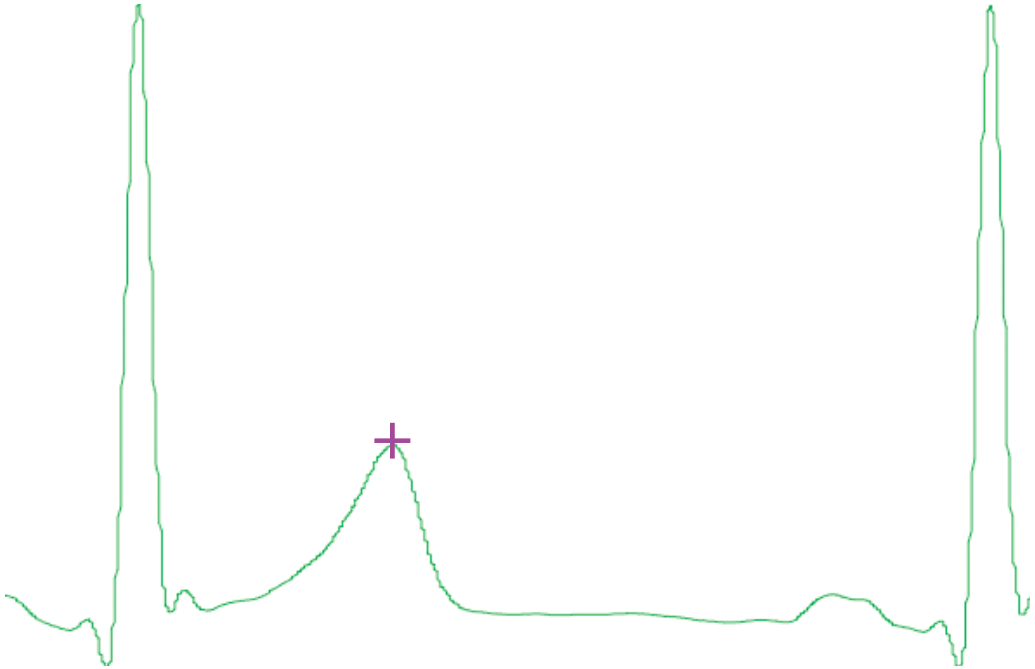
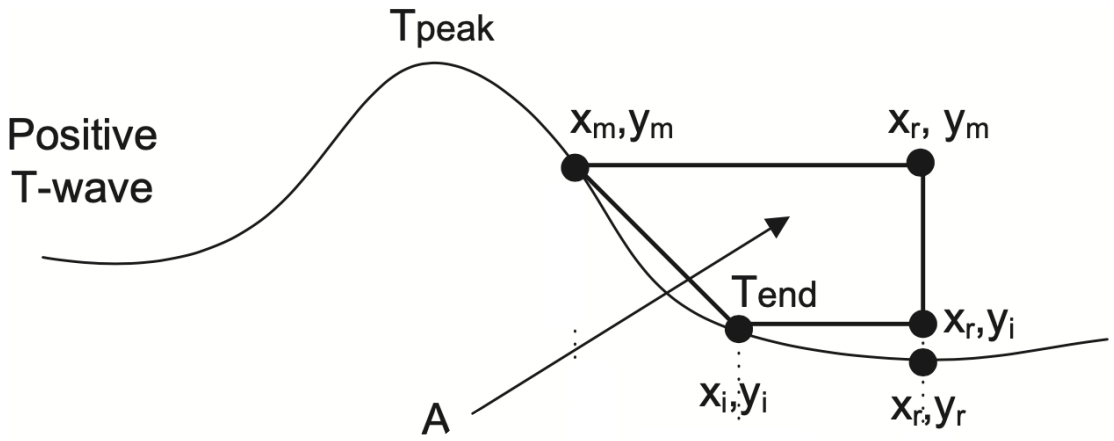


Code: https://github.com/Esra-Al/systole_detection

Finding the End of T-wave by Trapezium's Area Approach



$$A = 0.5\,(y_m - y_i)\,(2x_r - x_i - x_m)$$

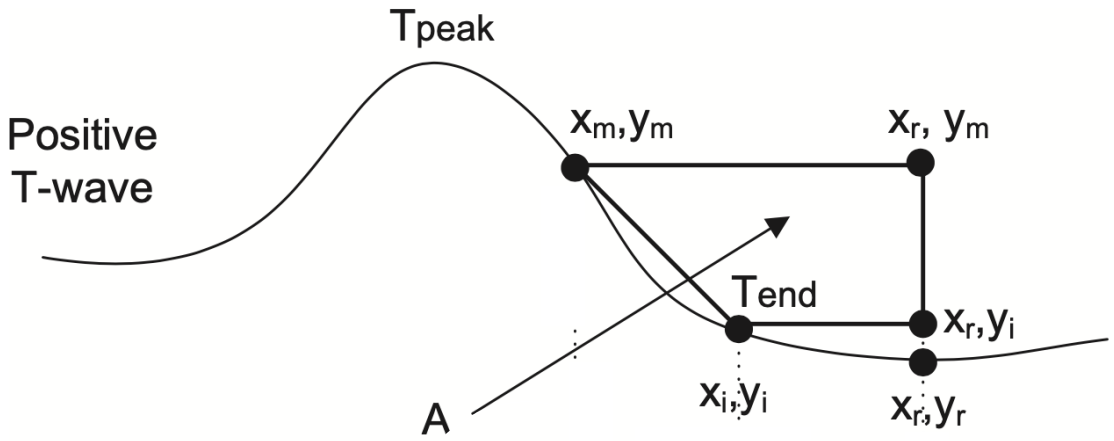
Trapezium's Area

1) Determination of the point ("x_m") after the T-peak, which has a minimum value in the first derivative

Code: https://github.com/Esra-Al/systole_detection

Vázquez-Seisdedos et al.,BioMedical Engineering, 2011

Finding the End of T-wave by Trapezium's Area Approach



$$A = 0.5\,(y_m - y_i)\,(2x_r - x_i - x_m)$$

Trapezium's Area

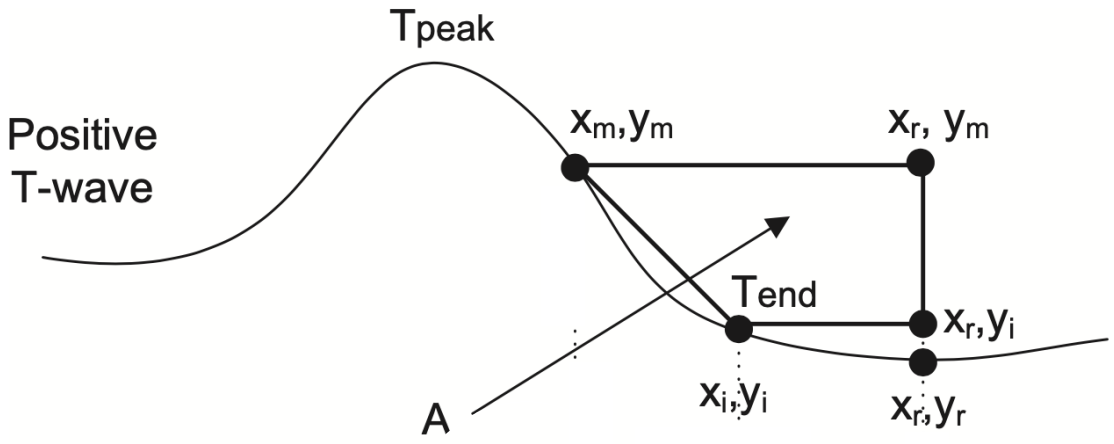
1) Determination of the point ("x_m") after the T-peak, which has a minimum value in the first derivative

2) Determine a point xr which is at least 80 ms after the T-peak

Code: https://github.com/Esra-Al/systole_detection

Vázquez-Seisdedos et al.,BioMedical Engineering, 2011

Finding the End of T-wave by Trapezium's Area Approach



$$A = 0.5\,(y_m - y_i)\,(2x_r - x_i - x_m)$$

Trapezium's Area

1) Determination of the point ("x_m") after the T-peak, which has a minimum value in the first derivative

2) Determine a point xr which is at least 80 ms after the T-peak

3) Find Tend by finding (xi, yi) that maximizes trapezium's area

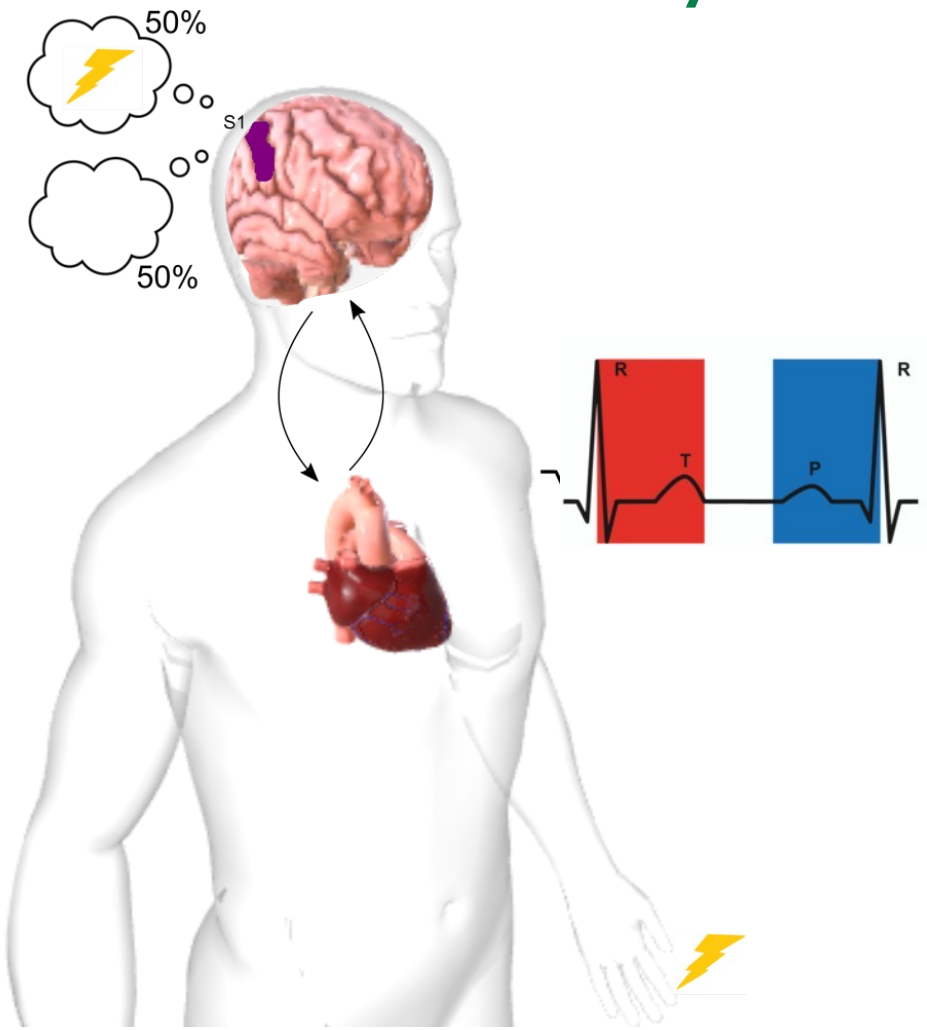
Code: https://github.com/Esra-Al/systole_detection

Vázquez-Seisdedos et al.,BioMedical Engineering, 2011

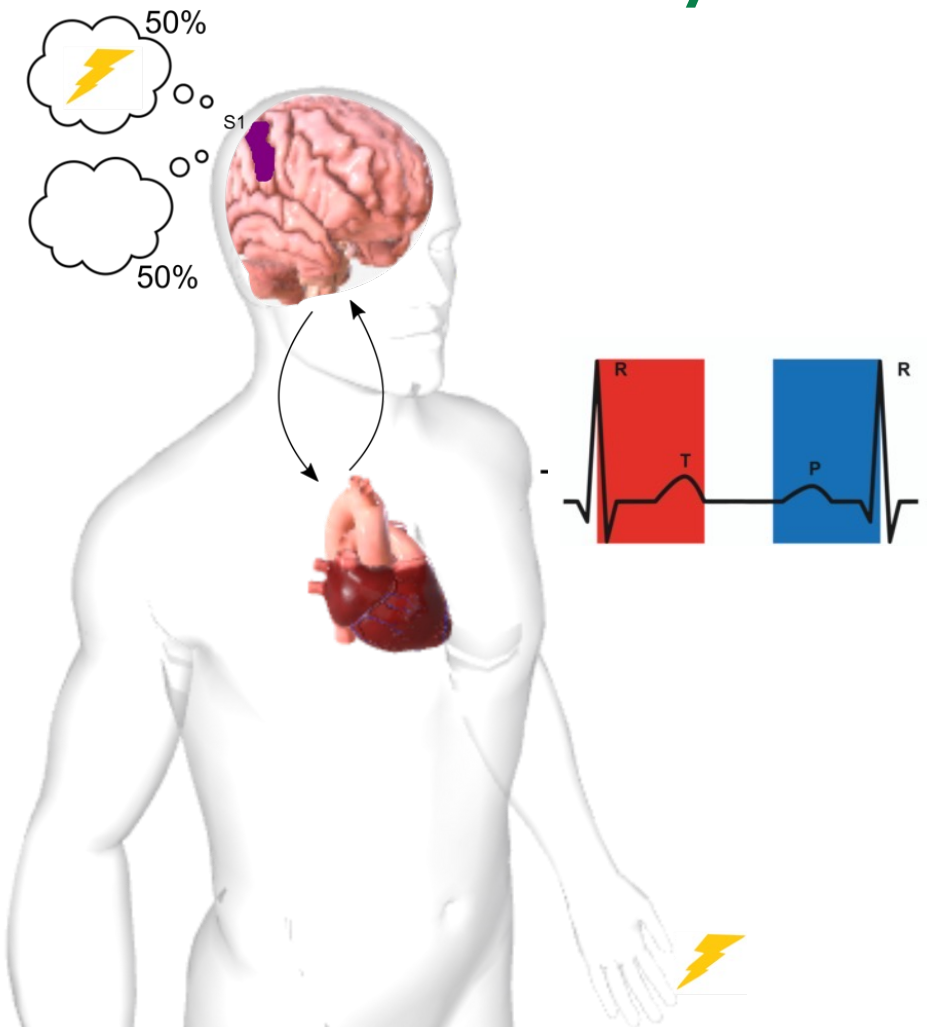
Code

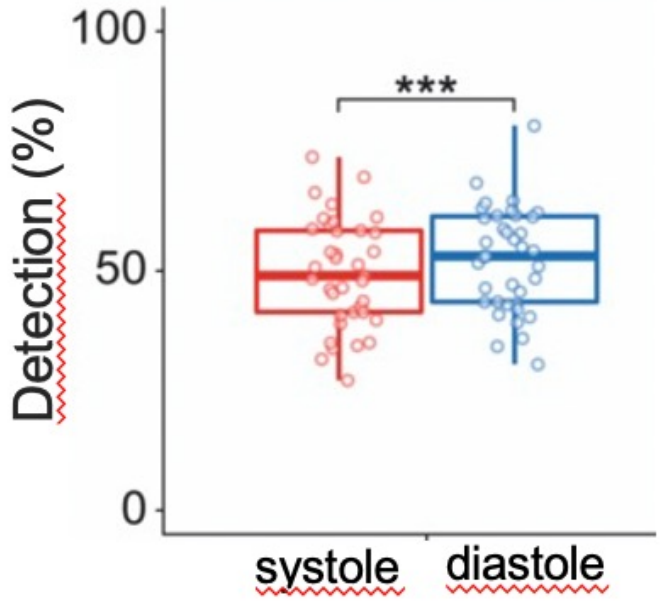
Let’s look into the twave_algorithm.R!

Cardiac Cycle Effect on Perception



Cardiac Cycle Effect on Perception



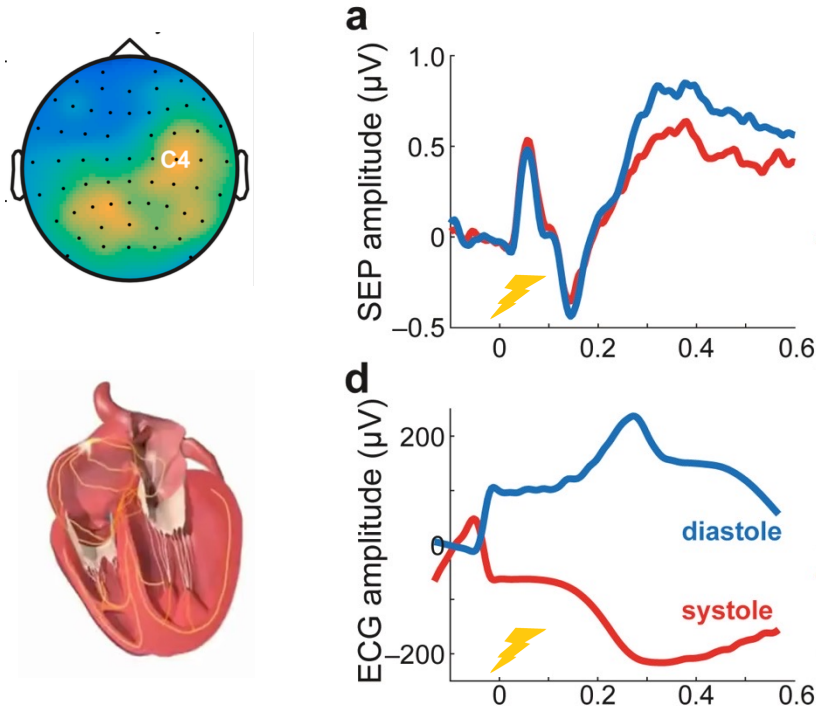


Motyka et al., Psychophysiology, 2019
Al et al., PNAS, 2020; Al et al., Neuroimage, 2021

- Somatosensory detection is less likely during systole compared to diastole

Neural-Evoked Potentials Across Cardiac Cycle

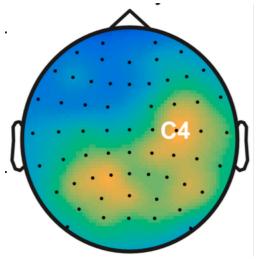
1- Problem: Pulse Artefacts

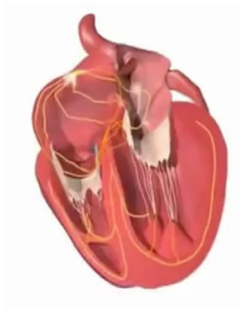


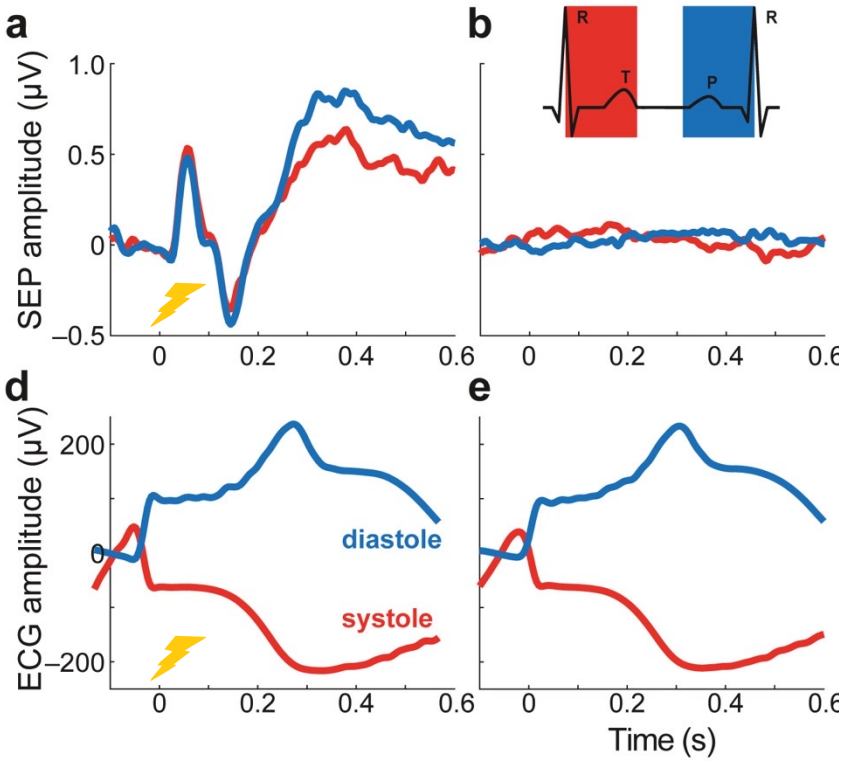
Al et al., PNAS, 2020; Al et al.,2020 (preprint)

Neural-Evoked Potentials Across Cardiac Cycle

2- Estimate the Effect of Pulse Artefacts on EEG data



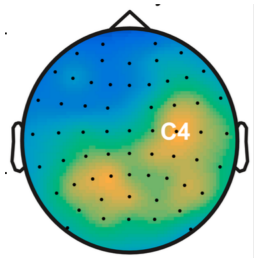


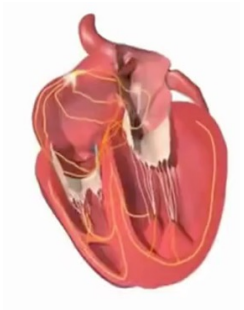


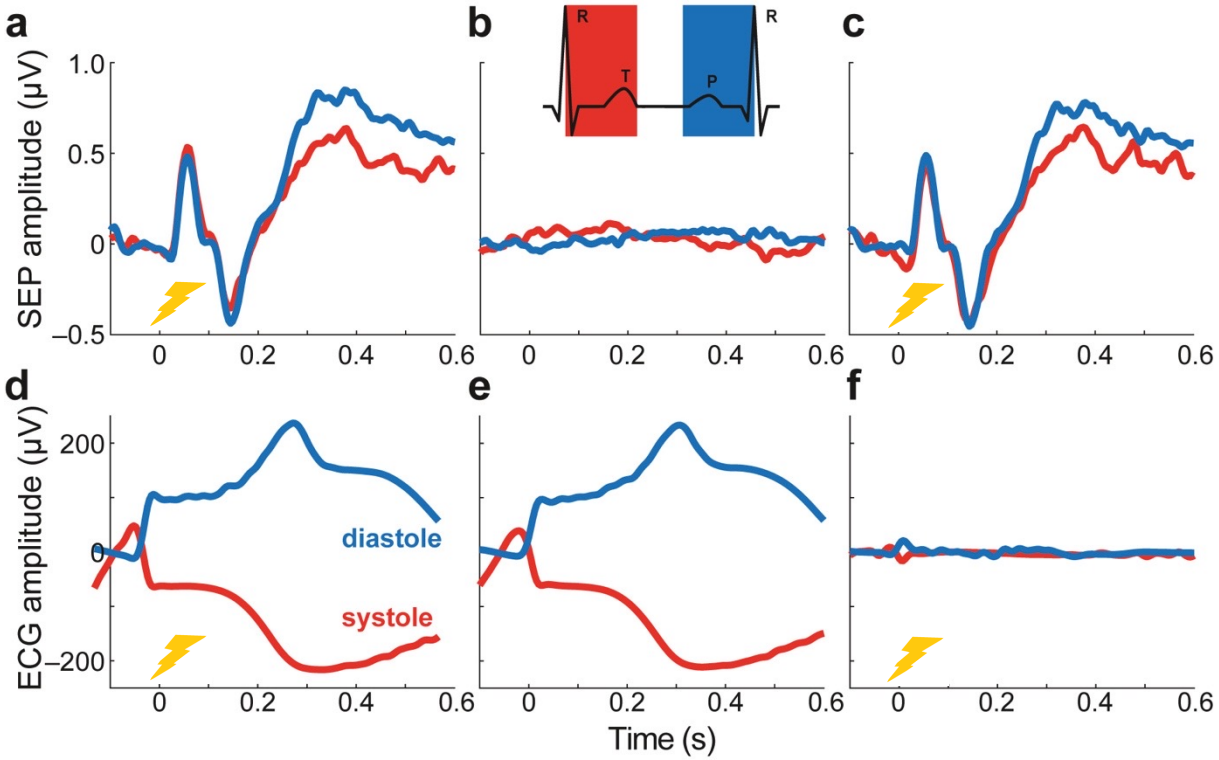
Al et al., PNAS, 2020; Al et al.,2020 (preprint)

Neural-Evoked Potentials Across Cardiac Cycle

3- Subtract the Pulse Artefact Estimation from EEG data

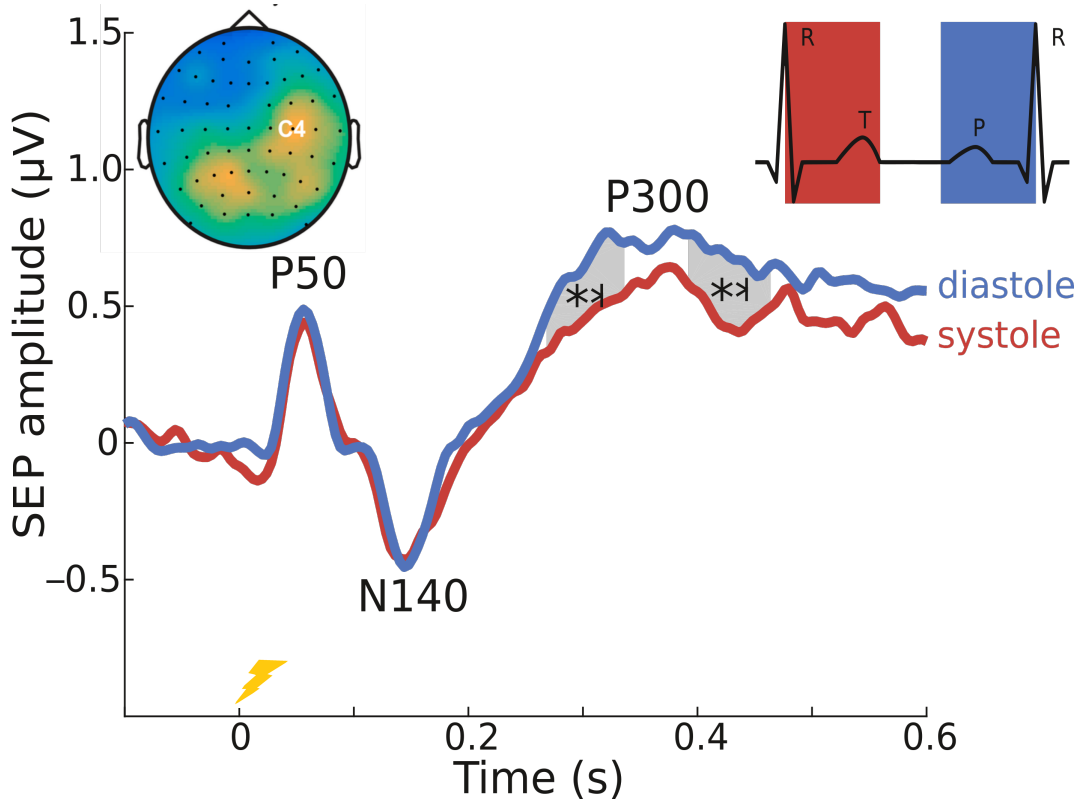






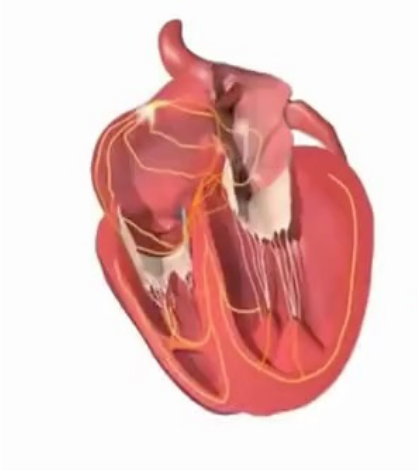
Al et al., PNAS, 2020; Al et al.,2020 (preprint)

Cardiac Cycle Effect on Neural Responses

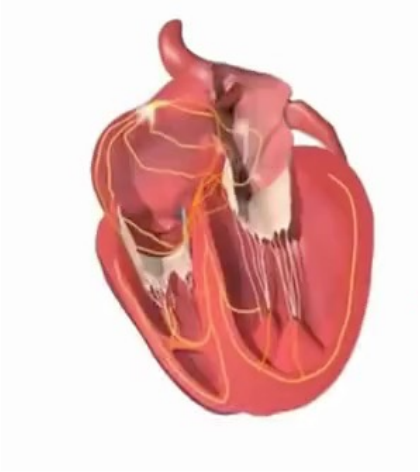


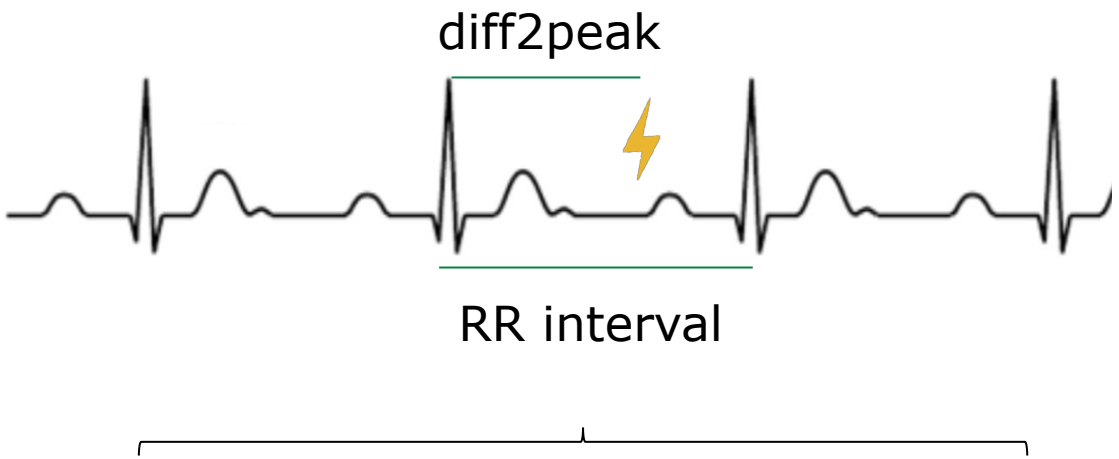
- Decreased somatosensory-evoked activity during systole compared to diastole

Cardiac Cycle – Circular Analyses

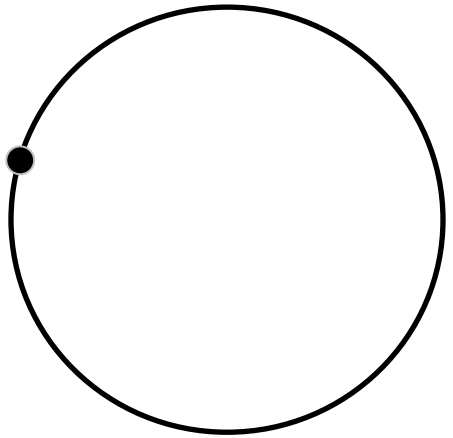


Cardiac Cycle – Circular Analyses





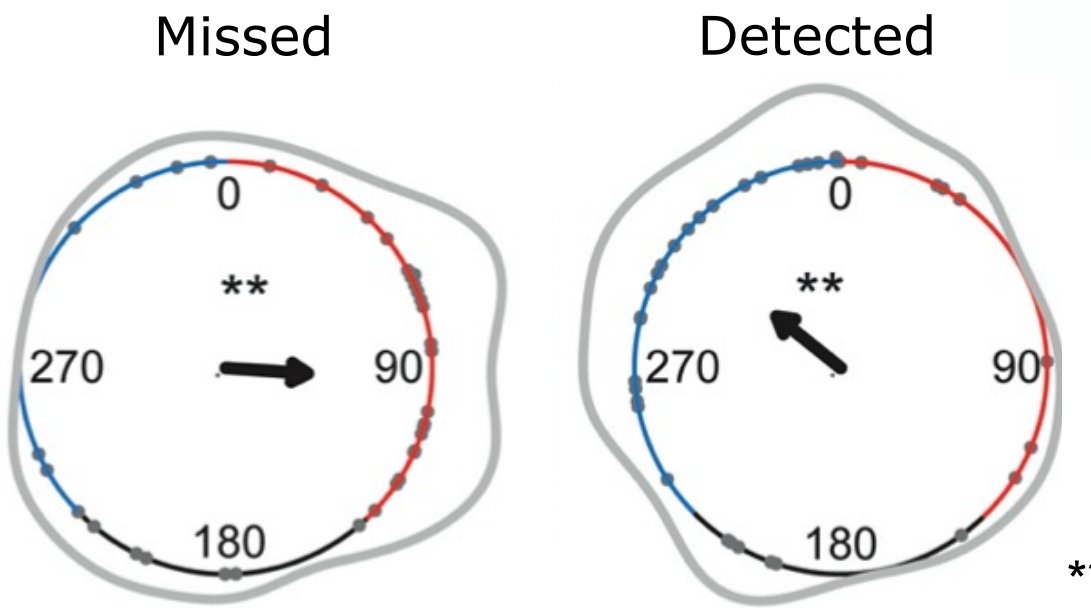
stim_degree=360 * diff2peak/(R_peaks[pos+1] - R_peaks[pos])

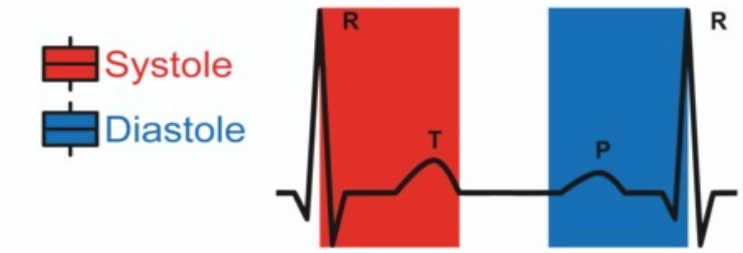


Code

Let’s look into the circular_analyses.R!

Perception Across the Cardiac Cycle

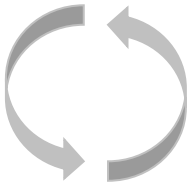




** p<0.005

Al et al., PNAS, 2020

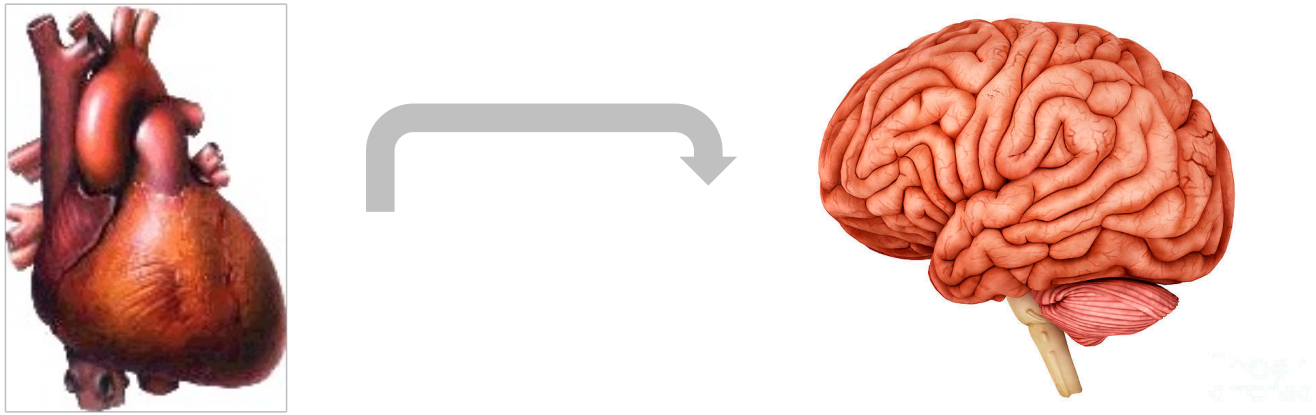
- Detection is less likely during systole compared to diastole.



I - Cardiac Cycle Analyses

II - Heartbeat-Evoked Potentials

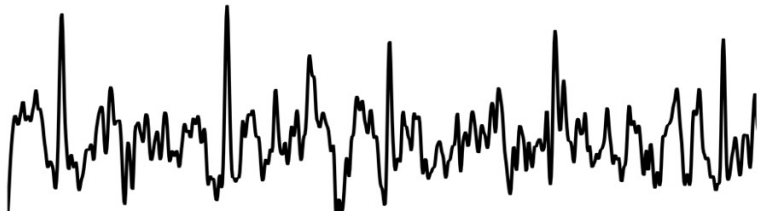
Heartbeat-Evoked Potentials (HEPs)



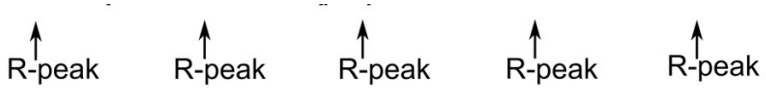
- represent the cortical processing of the heartbeat

How to Deal with Cardiac Artefacts?

Problem: Cardiac Field Artefacts (”Scalp ECG”)



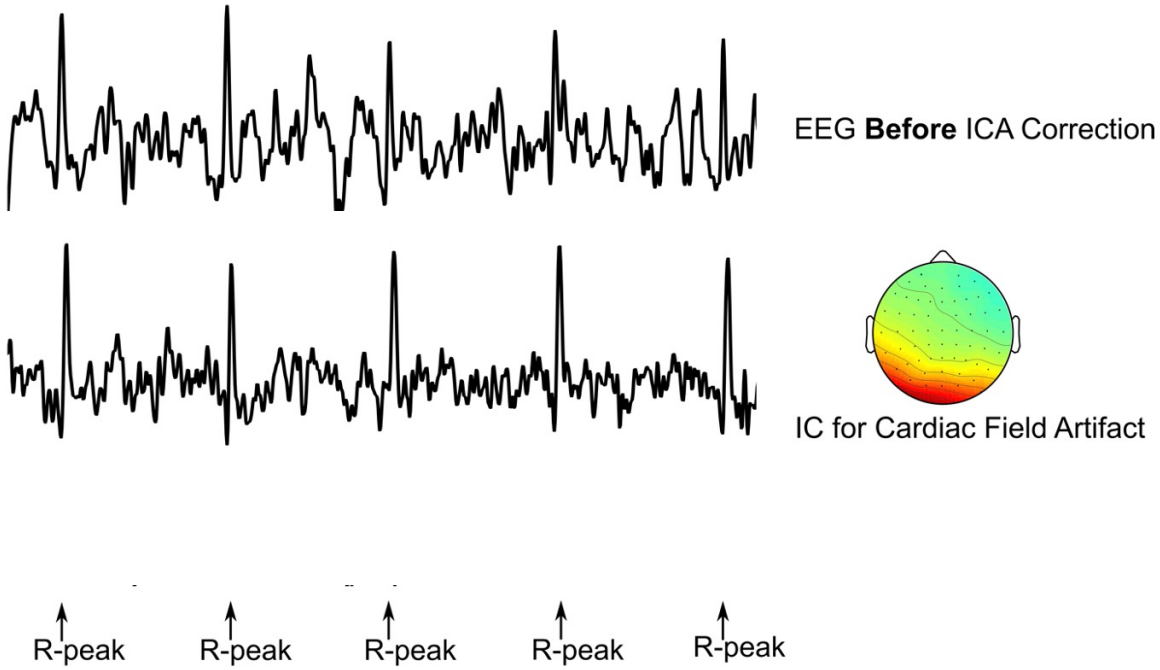
EEG **Before** ICA Correction



How to Deal with Cardiac Artefacts?

Problem: Cardiac Field Artefacts (”Scalp ECG”)

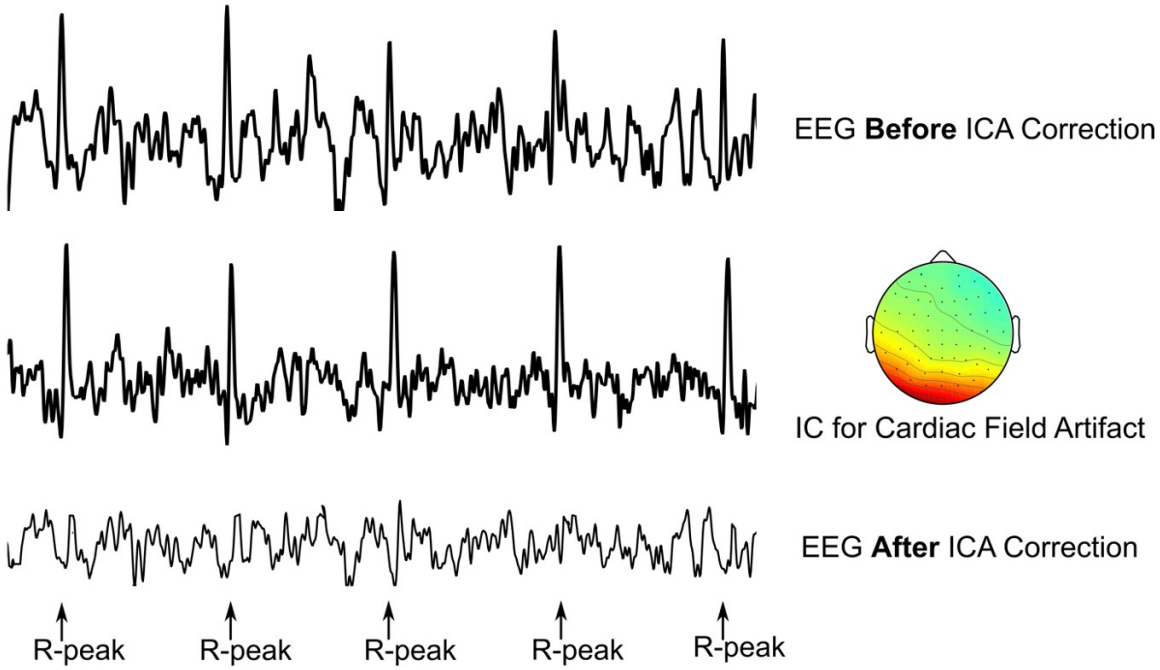
Solution: Independent Component Analysis (ICA)



How to Deal with Cardiac Artefacts?

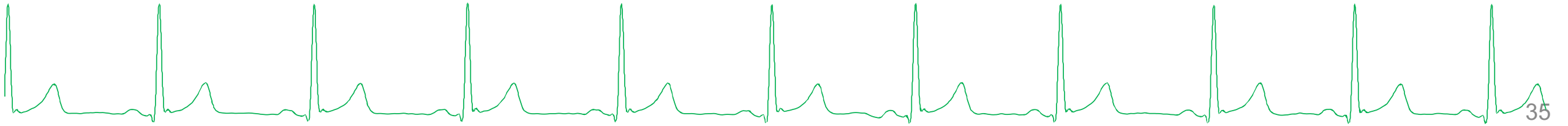
Problem: Cardiac Field Artefacts (”Scalp ECG”)

Solution: Independent Component Analysis (ICA)



How to Optimize ICA for finding ECG artefact?

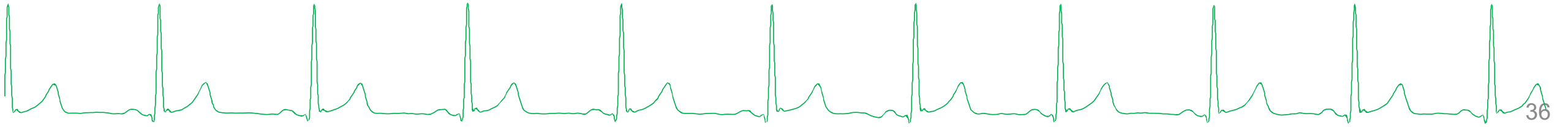
- Check whether R peak latencies are correctly integrated in the downsampled EEG data!



How to Optimize ICA for finding ECG artefact?

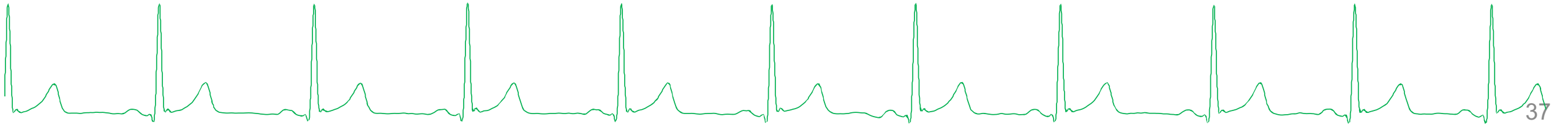
- Check whether R peak latencies are correctly integrated in the downsampled EEG data!

- Don’t include ECG in ICA or rereferencing!



How to Optimize ICA for finding ECG artefact?

- Check whether R peak latencies are correctly integrated in the downsampled EEG data!
- Don’t include ECG in ICA or rereferencing!
- Don’t rereference data before ICA!



How to Identify ECG Artefacts?

- Epoch ICA components around the R-peak [e.g., -100 800ms]

How to Identify ECG Artefacts?

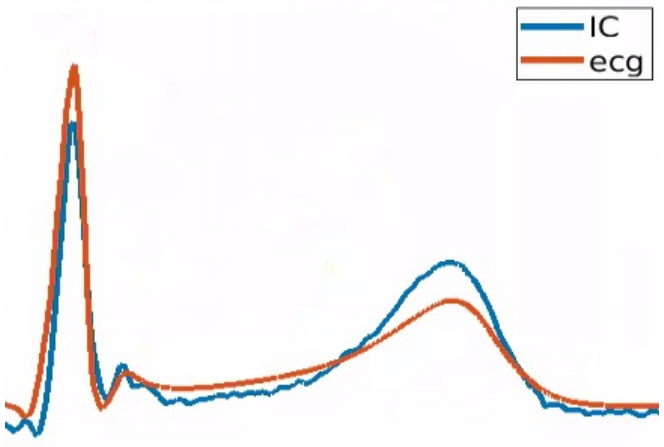
- Epoch ICA components around the R-peak [e.g., -100 800ms]

- Calculate a correlation between ICA activity and ECG electrode

```
ncomp= size(EEG.icawinv,2); % ncomp is number of ica components
icaacts = eeg_getdatact(EEG,'component',1:ncomp);
chanEEG = ECG.data(1,:)'; % ECG data
ICs = icaacts(:,:)';
c  = abs(corr(ICs,chanEEG))';
[B,rej_comps] = maxk(c,5); % rej_comps include 5 ICA components
```

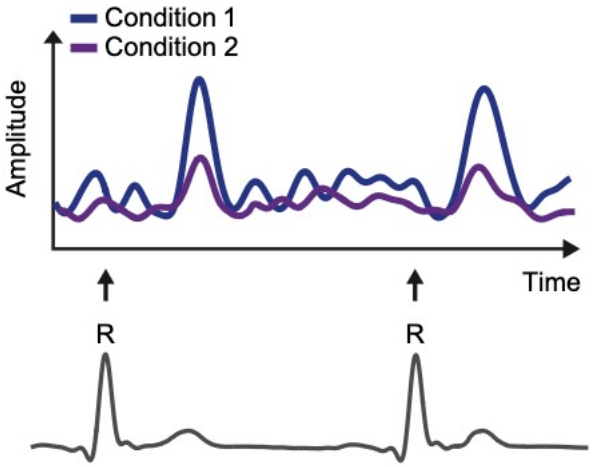
How to Identify ECG Artefacts?

- Epoch ICA components around the R-peak [e.g., -100 800ms]
- Calculate a correlation between ICA activity and ECG electrode
- Visualize the highly correlated 5 ICA components and impose their mean activity with ECG



Best Approaches in HEP analyses

- Apply statistics in a time window away from the cardiac artefact (e.g., 250-400ms window)
- Ensure ECG itself is not different across the conditions
- Within-subject analyses



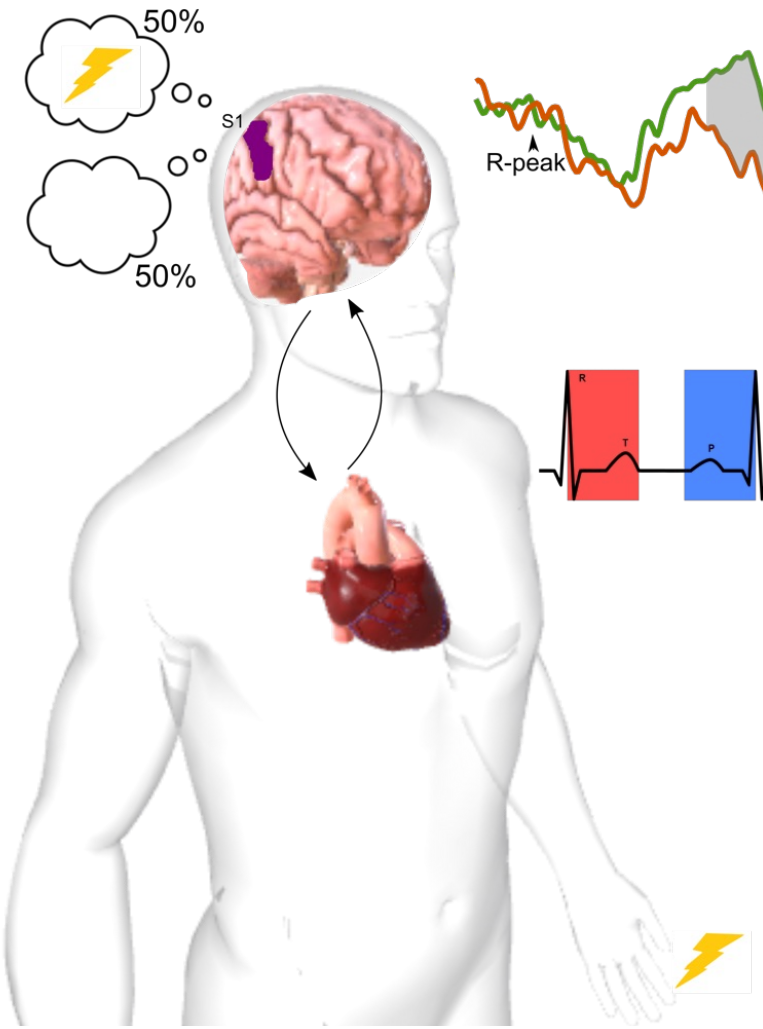
Azzalini et al., TICS, 2019

Regression of ECG activity from EEG

Linear Regression

```
% loop over trials
for triali=1:EEG.trials

    % build the least-squares model as intercept and EKG from this trial
    Xeeg = [ ones(EEG.pnts,1) EEG.data(ek,:,triali)' ];
    X = [ ones(size(eegc,2),1) eegc(ek,:,triali)' ];

    % compute regression coefficients for all channels simultaneously
    b = (X'*X) \ (X'*eegc(:,:,triali)');

    % predicted data
    yHat = Xeeg*b;

    % new data are the residuals after projecting out the best EKG fit
    EEG.rdata(:,:,triali) = ( EEG.data(:,:,triali)' - yHat )';
end
```

code: https://github.com/Esra-Al/Regress_ECG



HEP Amplitude → Keep in mind the ECG artefacts!

Cardiac Phase → Important to define systole and diastole correctly!

Thank you!

_Esra_Al

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Haegens Lab

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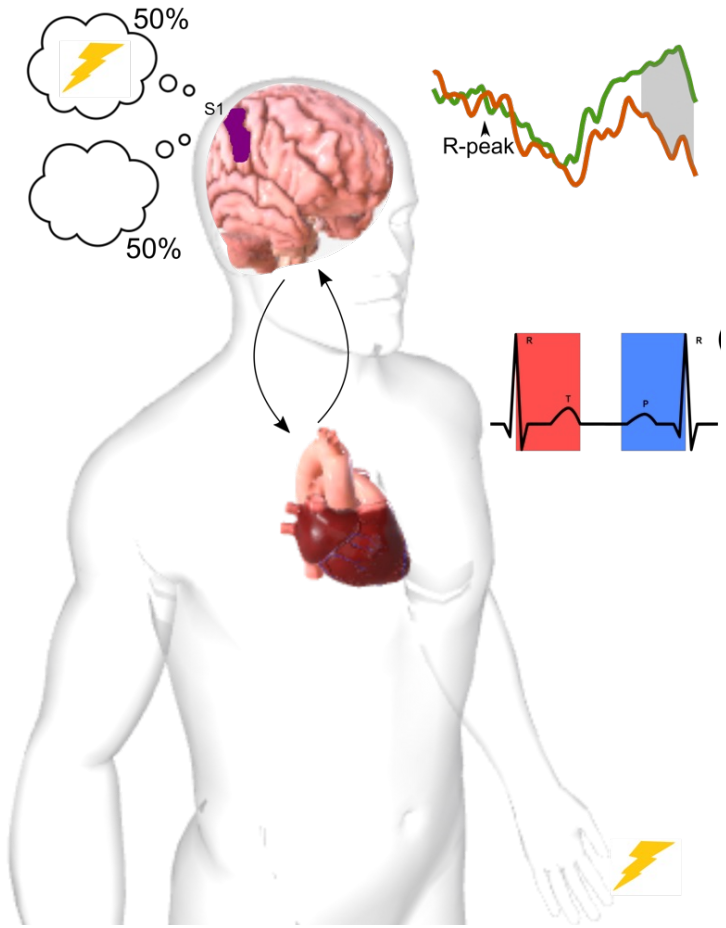
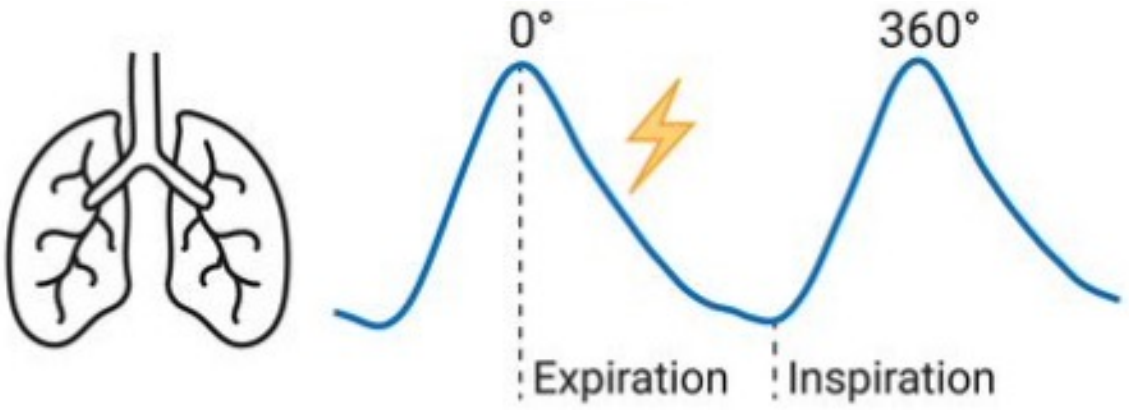
Questions?



Extra Slides

Respiratory Cycle



Grund et al., J. Neurosci, 2022

Respiratory Code

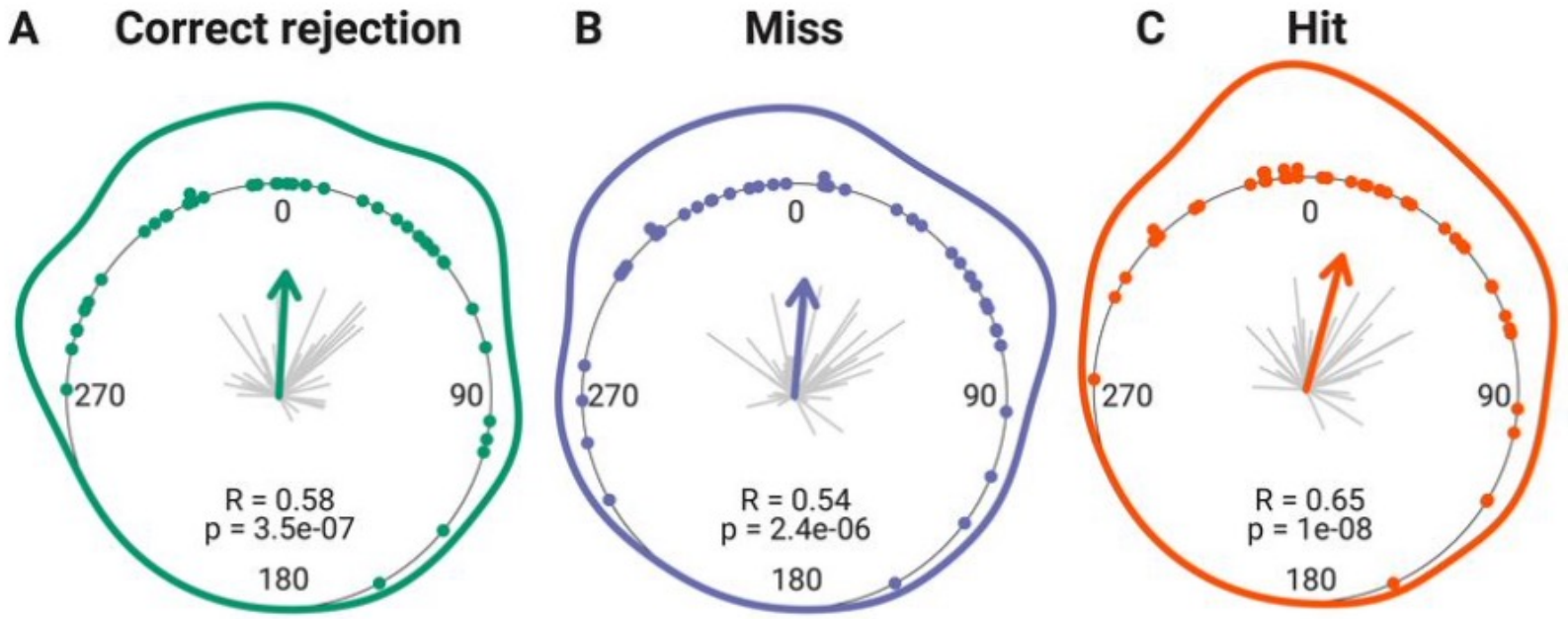
```
trigger_label = 'S 12';
% Minimal temporal distance between two peaks/troughs in seconds
min_peak_dist = 2; % in s
% Fraction of z-smoothed data interquartile range for minimum peak prominence
frac_iqr = 0.9;
% Add trigger latencies
 trigger_lat= cell2mat({resp_data.event(find(contains({resp_data.event.type},trigger_label))).latency});
 srate_tmp = resp_data.srate;
 % Preprocess the respiratory trace (Power et al., 2020)
 resp_raw = resp_data.data;
 resp = filloutliers(resp_raw,'linear','movmedian',srate_tmp); % remove outliers
 smoothresp = smoothdata(resp,'sgolay',srate_tmp); % apply some gentle smoothing
 zsmoothresp = zscore(smoothresp); % z-score
 min_peak_prom = iqr(zsmoothresp)*frac_iqr;
 % Find peaks (exhale onsets) and troughs (inhale onsets)
 [~, exhale_onsets.loc,~,~] = findpeaks(zsmoothresp,'minpeakdistance',min_peak_dist*srate_tmp,'minpeakprominence',min_peak_prom);
 [~, inhale_onsets.loc,~,~] = findpeaks(-zsmoothresp,'minpeakdistance',min_peak_dist*srate_tmp,'minpeakprominence',min_peak_prom);
```

Respiratory Code

```
trigger_label = 'S 12';
% Minimal temporal distance between two peaks/troughs in seconds
min_peak_dist = 2; % in s
% Fraction of z-smoothed data interquartile range for minimum peak prominence
frac_iqr = 0.9;
% Add trigger latencies
 trigger_lat= cell2mat({resp_data.event(find(contains({resp_data.event.type},trigger_label))).latency});
 srate_tmp = resp_data.srate;
 % Preprocess the respiratory signal
 resp_raw = resp_data.data;
 resp = filloutliers(resp_raw,'linear','movmedian',srate_tmp); % remove outliers
 smoothresp = smoothdata(resp,'sgolay',srate_tmp); % apply some gentle smoothing
 zsmoothresp = zscore(smoothresp); % z-score
 min_peak_prom = iqr(zsmoothresp)*frac_iqr;
 % Find peaks (exhale onsets) and troughs (inhale onsets)
 [~, exhale_onsets.loc,~,~] = findpeaks(zsmoothresp,'minpeakdistance',min_peak_dist*srate_tmp,'minpeakprominence',min_peak_prom);
 [~, inhale_onsets.loc,~,~] = findpeaks(-zsmoothresp,'minpeakdistance',min_peak_dist*srate_tmp,'minpeakprominence',min_peak_prom);
```

whether peaks are inhale or exhale depends on the acquisition system!!!!

Respiratory Effects



Grund et al., J. Neurosci, 2022