PsPM course session 5

Model-based analysis of heart period responses

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Research Group: Adaptive Memory

Summary

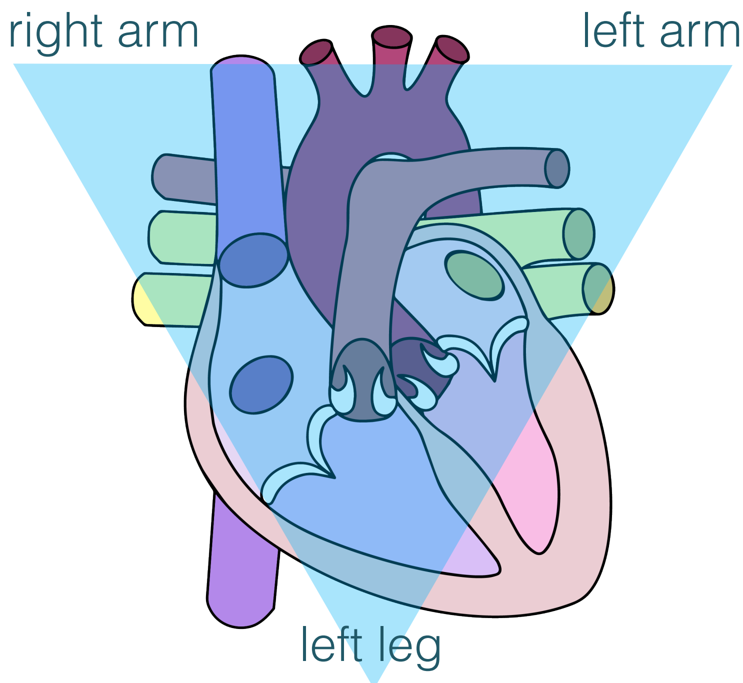
1. **Background**
   anatomy, autonomic input, evoked & fear conditioned responses in operational literature

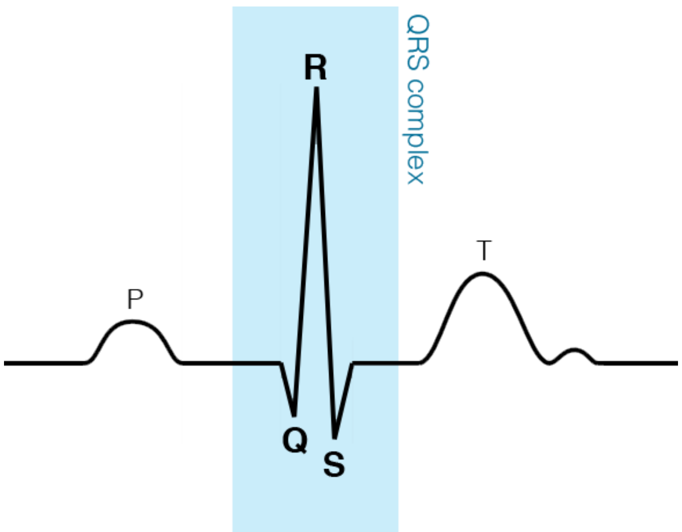
2. **Modeling event-related heart period responses**
   model development, assumptions, accuracy, applications

3. **Fear conditioned bradycardia**
   model development, accuracy, comparison with SCR

4. **Practical implementation**
   how to preprocess, set up 1st level GLM

The anatomy of the heart



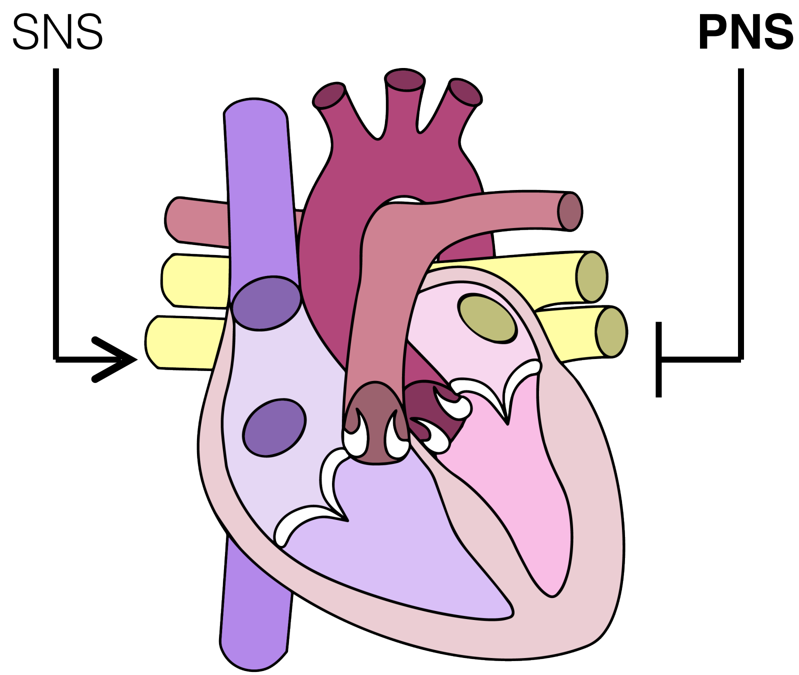


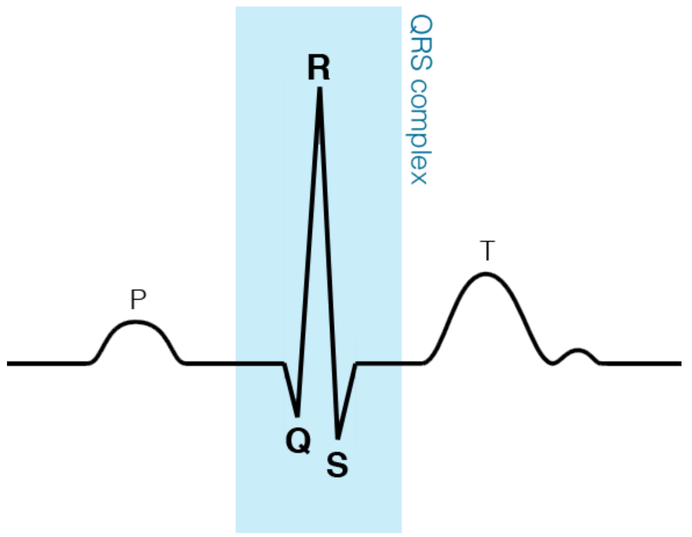
Two main compartments of the heart

- **right** atrium & **ventricle** pump deoxygenated blood into the **lungs**
- **left** atrium & **ventricle** pump oxygenated blood **via aorta into the whole body**

QRS complex marks main contraction of the ventricles that precedes the ejection of blood from the heart

The anatomy of the heart





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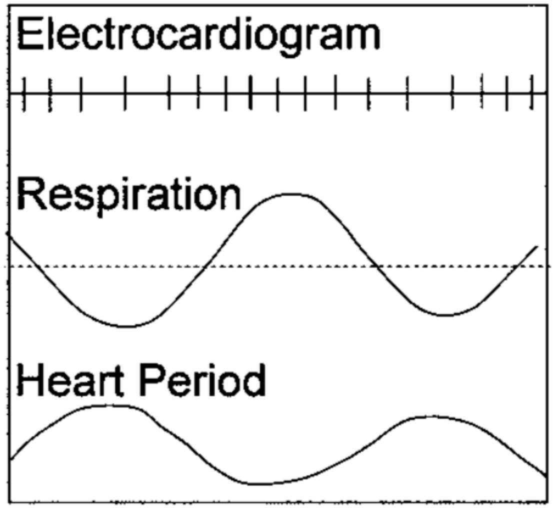
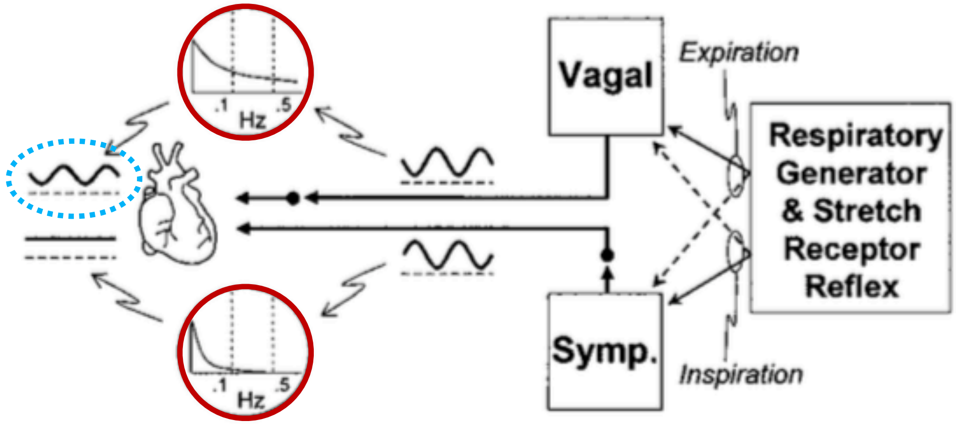
Different time courses for PNS and SNS influence



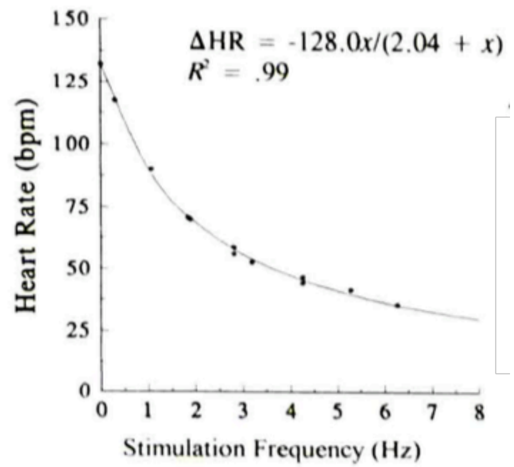


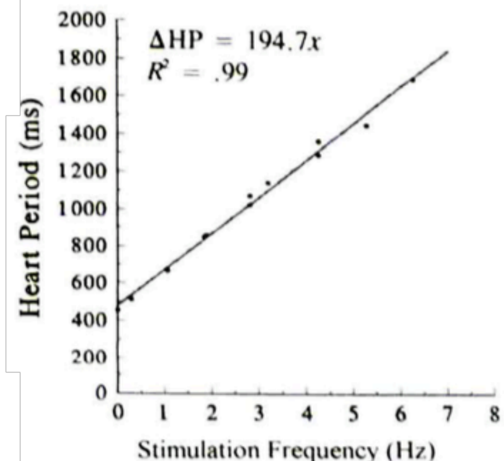
- **SNS** exhibits steady state influence **< .12 Hz**
- **respiration causes HRV** via **PNS** (vagus)

Heart rate vs. heart period (see Berntson et al., 1995)

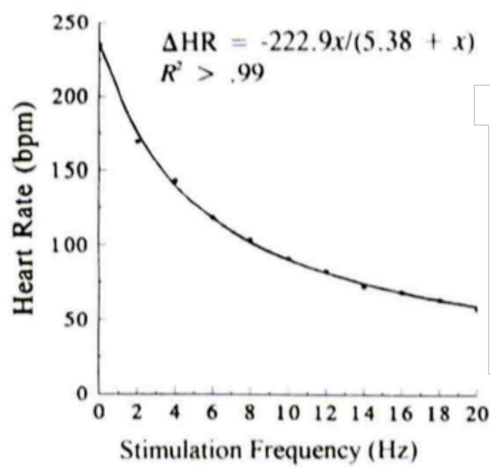
HR (bpm) **HP (ms)**

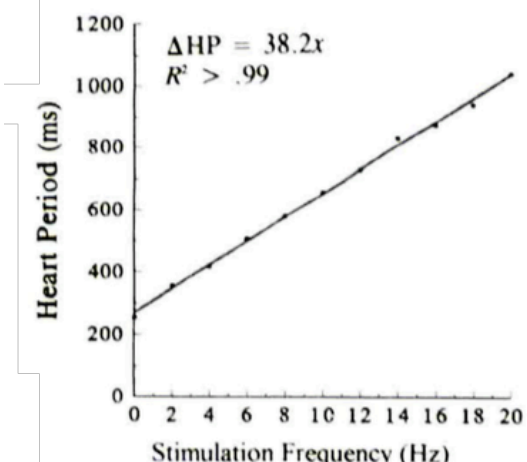
Cat (Rosenblueth & Simeone, 1934)





Dog (Parker et al., 1986)

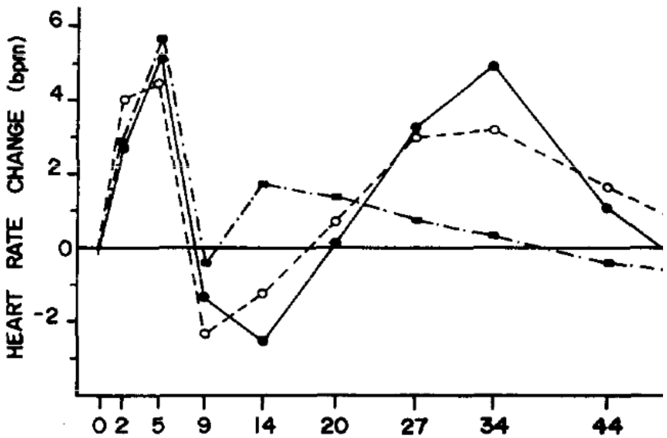




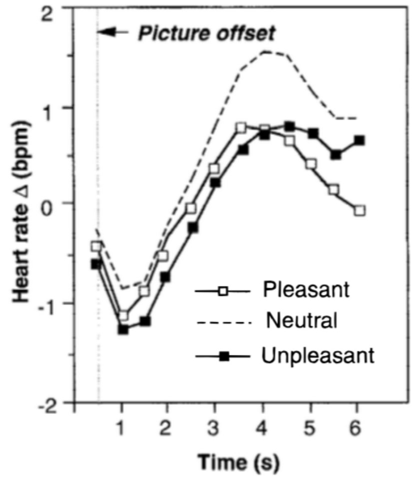
Evoked heart responses in the literature

Auditory white noise (100 dB)

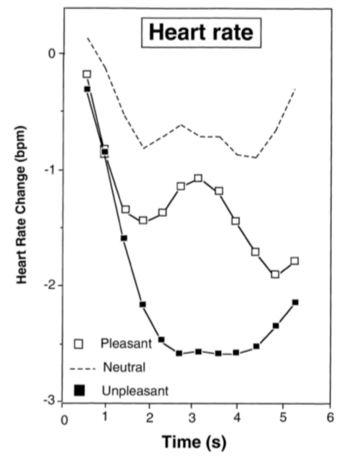
Affective picture viewing



Duration 0.5 s,
n = 42
Reyes del Paso et al (1993)



Duration 1 s,
n = 51
Codispoti et al (2001)

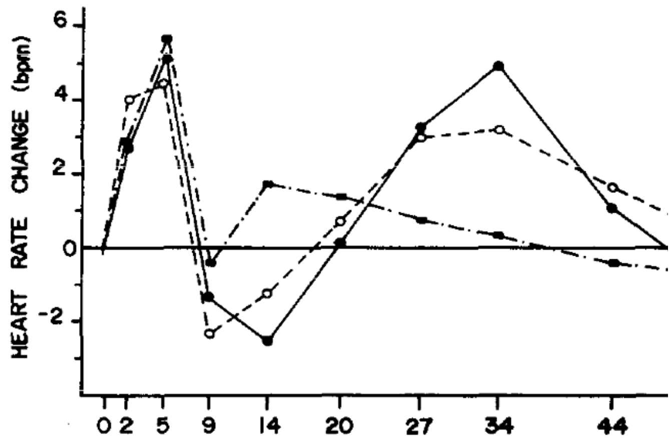


Duration 6 s,
n = 95
Bradley et al (2001)

- **Material type matters:** differential autonomic control modes?

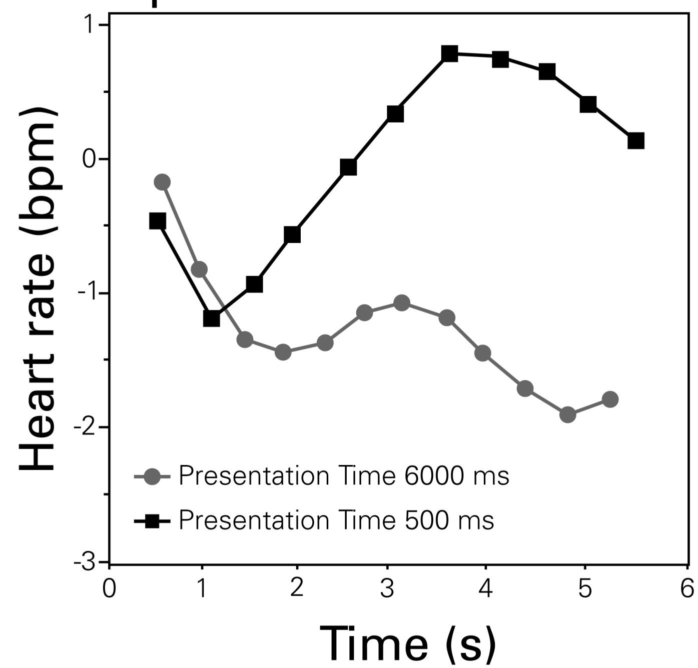
Evoked heart responses in the literature

Auditory white noise (100 dB)



Duration 0.5 s,
n = 42
Reyes del Paso et al (1993)

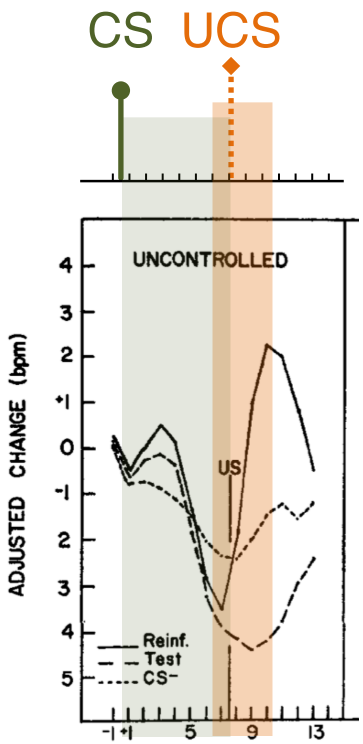
Average responses to pleasant pictures from the IAPS



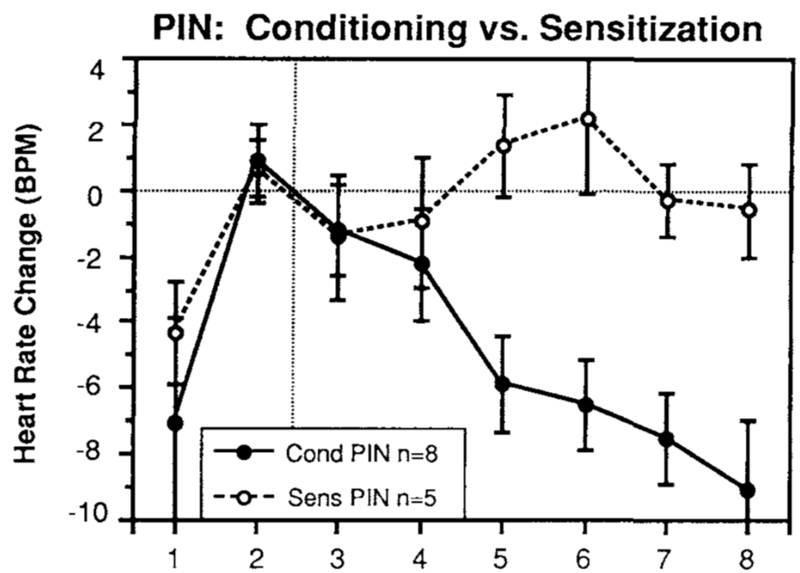
- **Material type matters:** differential autonomic control modes?
- **Stimulation durations matter:** response shape ~ duration
- **Response function unknown:** too few & no systematic experiments

Fear conditioned cardiac responses

in humans (n=60),
Headrick & Graham
(1969)



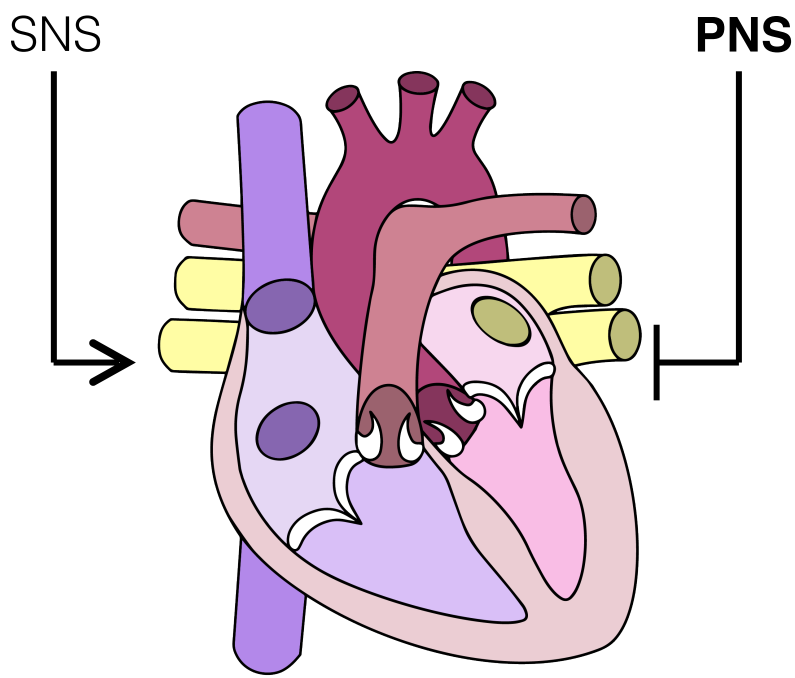
in guinea pigs,
Cruikshank et al. (1992)

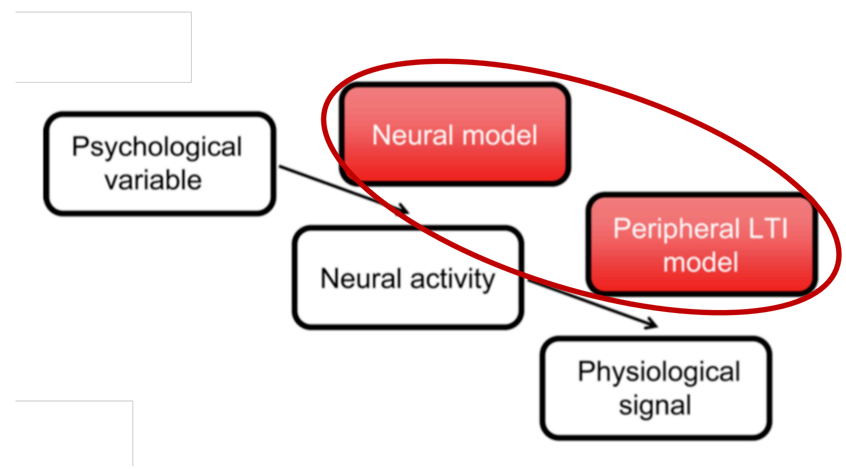


- Secondary **deceleration** (bradycardia) as a **measure of fear memory** in humans and animals
- Repeated **conditioning amplifies bradycardia**

MODELLING EVENT RELATED HEART PERIOD RESPONSES

Developing a model for event related heart period responses



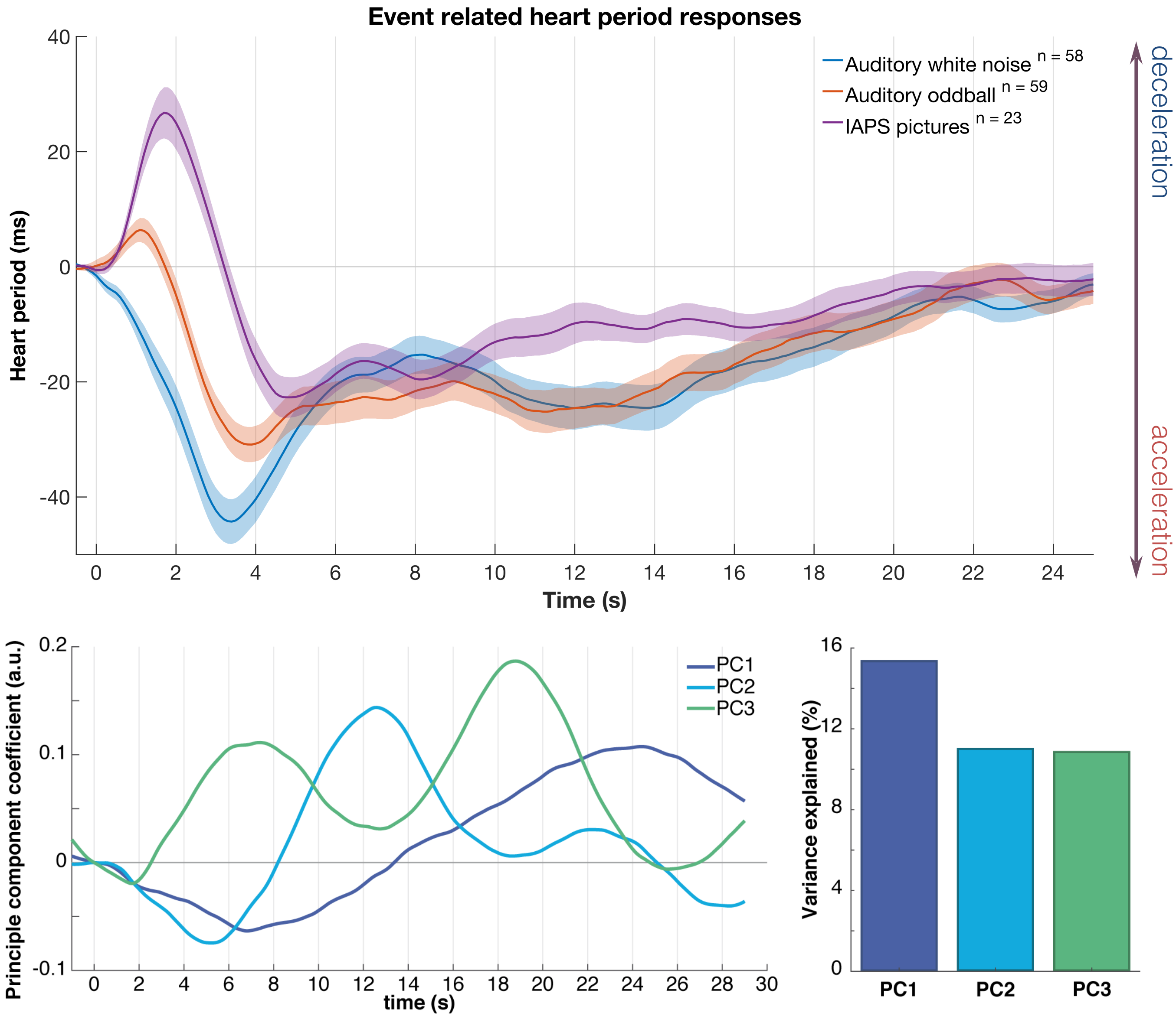


- Elicit **different** sympathetic / parasympathetic **control modes**
- Qualitatively **different experimental situations**

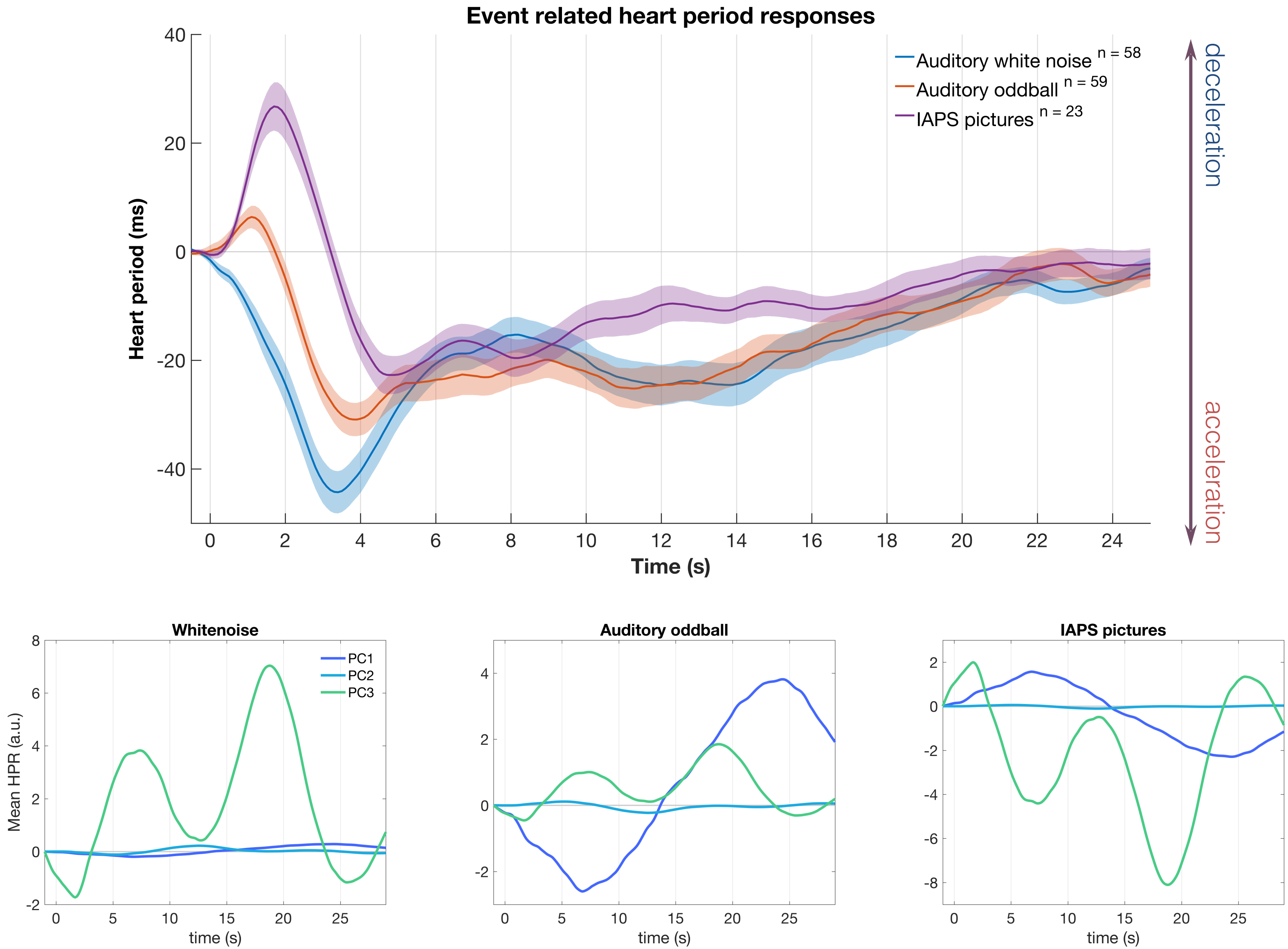
Modeling event-related heart period responses

	n	Design	PNS	SNS
Auditory white noise	61	20 white noise bursts **~ 85dB, duration 1s**, ITI 29 – 39 s	↓	↑
Auditory oddball		6 oddball tones in 1 s series of standard tones, **duration 50ms**,'IOI' 29 – 39 s	↑ ?	↑ ?
IAPS picture viewing	23	48 IAPS pictures (16 neg., 16. neu., 16. pos), **duration 1s**, ITI 43 – 47 s	↑	→ ?

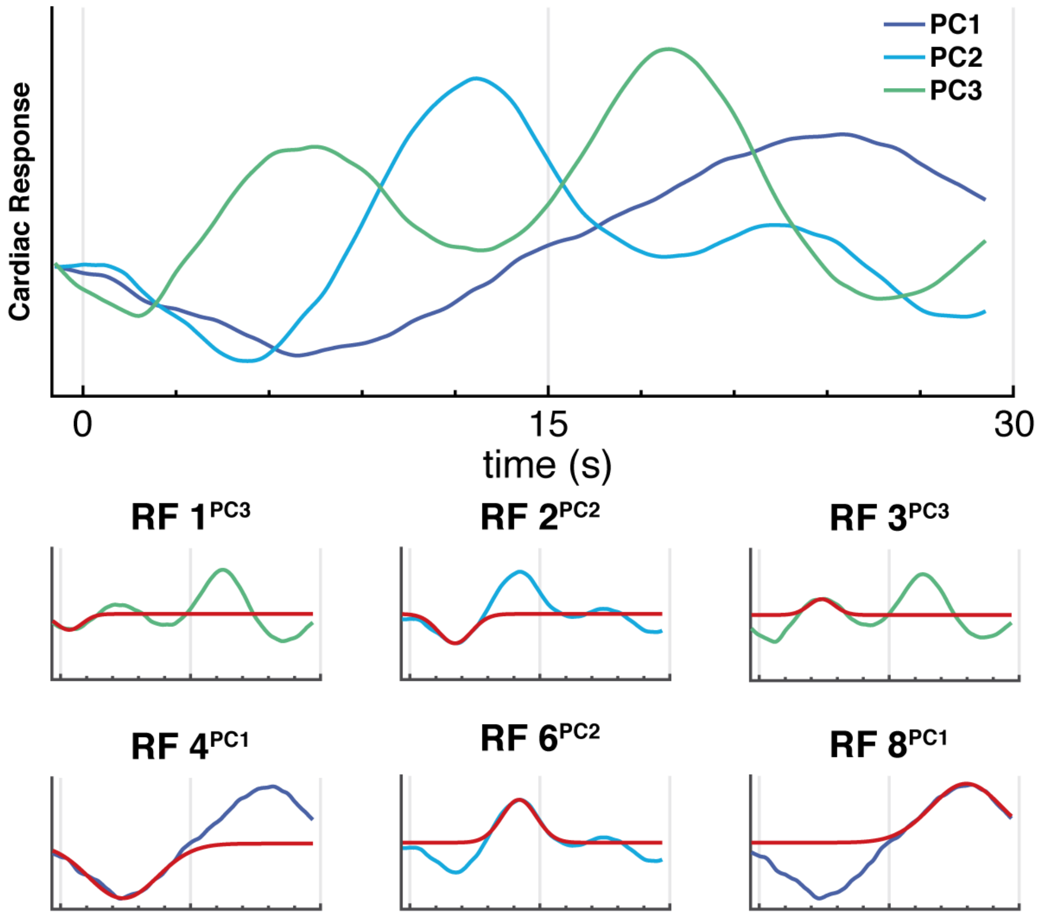
Qualitatively different average responses in all experiments



Qualitatively different average responses in all experiments



Model development: finding response functions

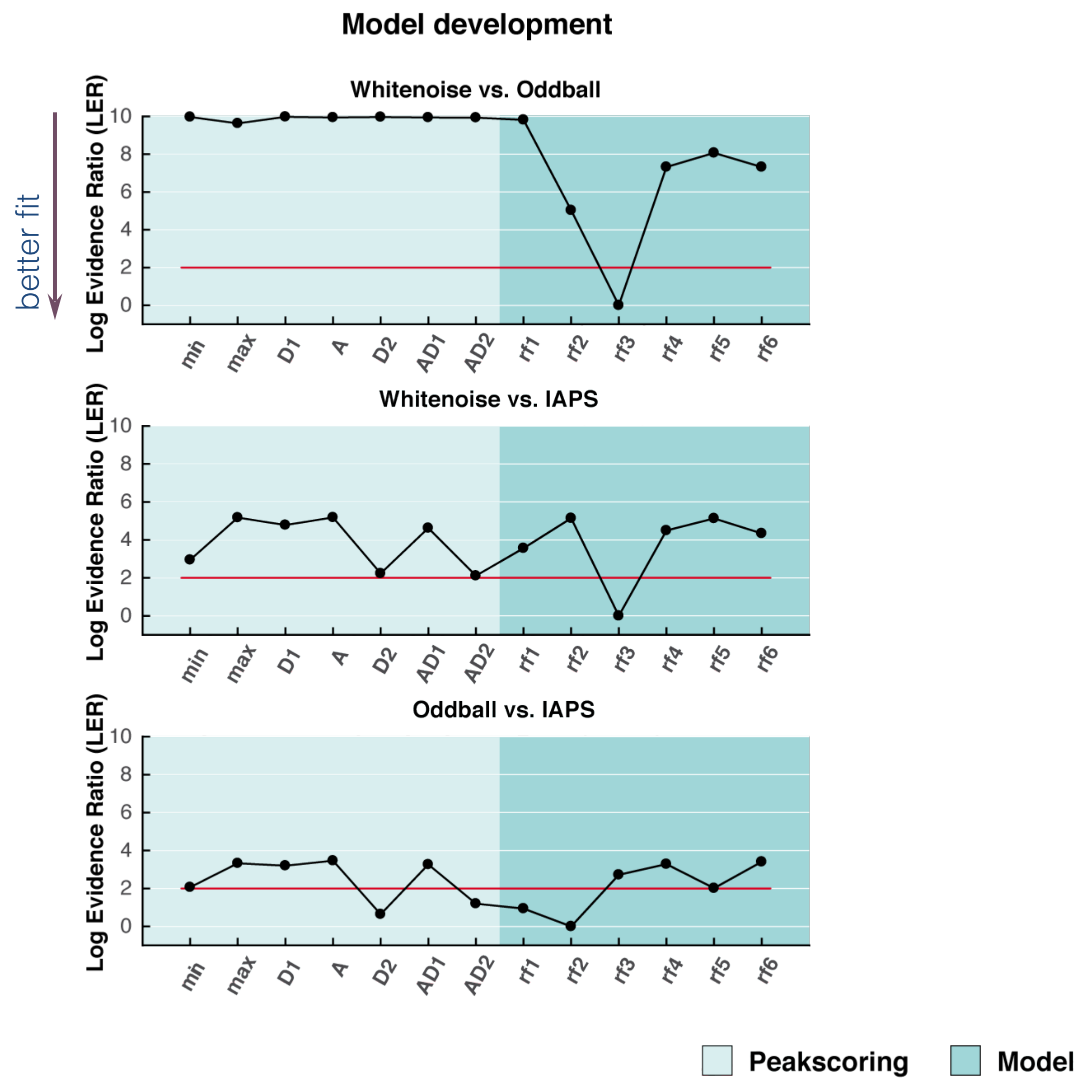


1. model **individual peaks**
2. Select most appropriate function
   → **Gaussian**
3. Set free parameters to fit the peak:
   μ = peak
   σ = shape
4. Set up GLM, test coefficient(s)

Include RF into the final model, if …

1. **stable acceleration/deceleration** across experiments **or**
2. **separation of at least two** out of the three **experiments**

Model accuracy

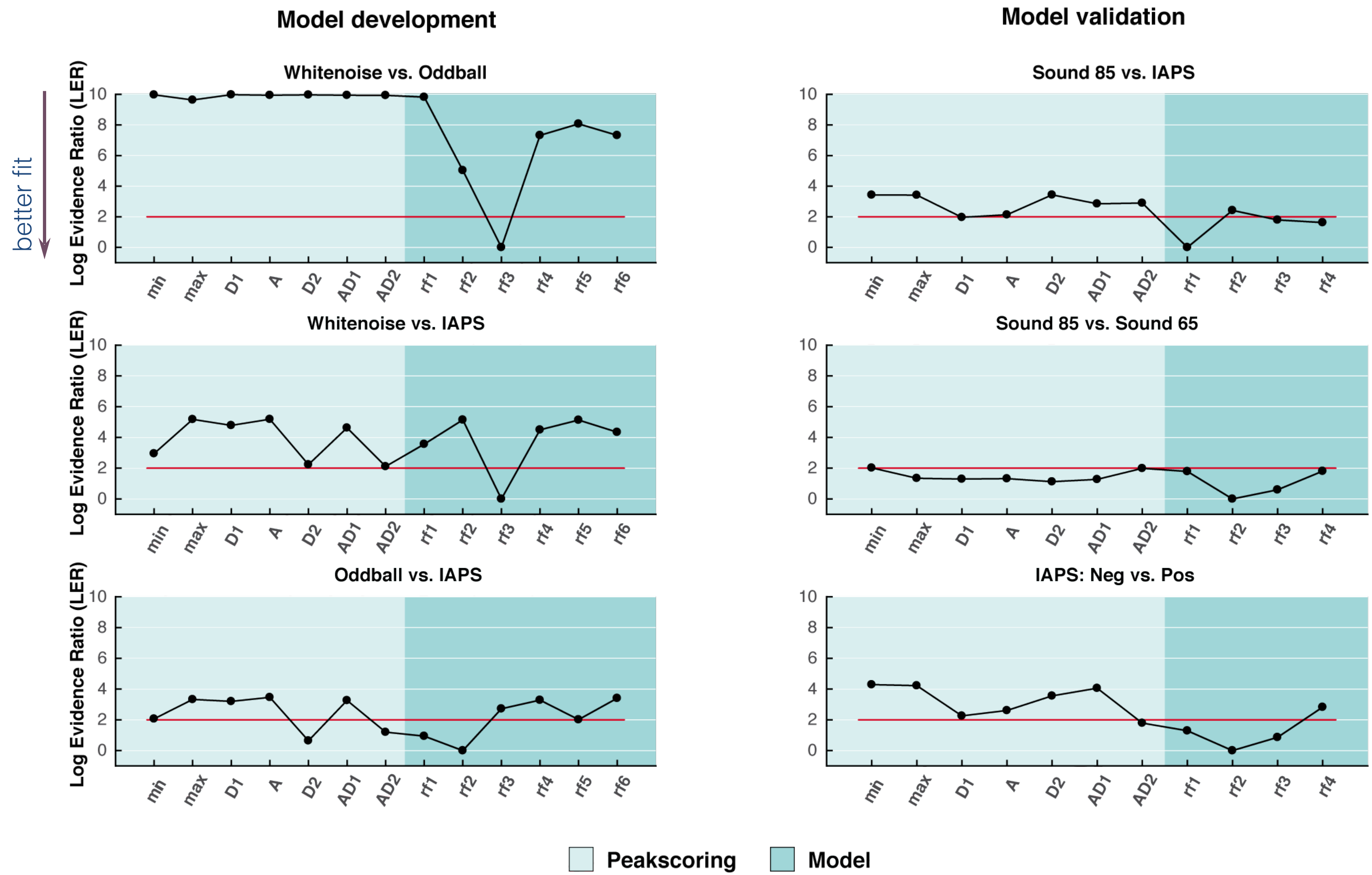


Snipes & Taylor (2014)
Kass & Raftery (1995)

Modeling event-related heart period responses

	n	Design	PNS	SNS
Auditory white noise	61	20 white noise bursts **~ 85dB, duration 1s**, ITI 29 – 39 s	⬇	⬆
Auditory oddball		6 oddball tones in 1 s series of standard tones, **duration 50ms**,'IOI' 29 – 39 s	⬆ ?	⬆ ?
IAPS picture viewing	23	48 IAPS pictures (16 neg., 16. neu., 16. pos), **duration 1s**, ITI 43 – 47 s	⬆	➡ ?
Validation experiment	19	120 trials (30 IAPS neg., 30 IAPS pos., 85 dB white noise, 65 dB white noise), ITI 10s ± 6s		

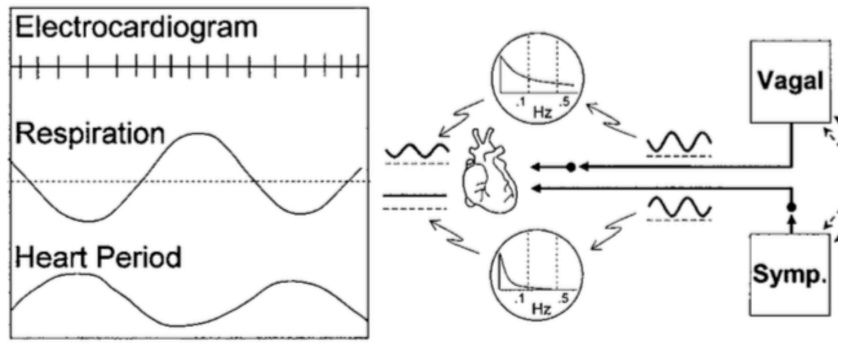
Model accuracy



Snipes & Taylor (2014)
Kass & Raftery (1995)

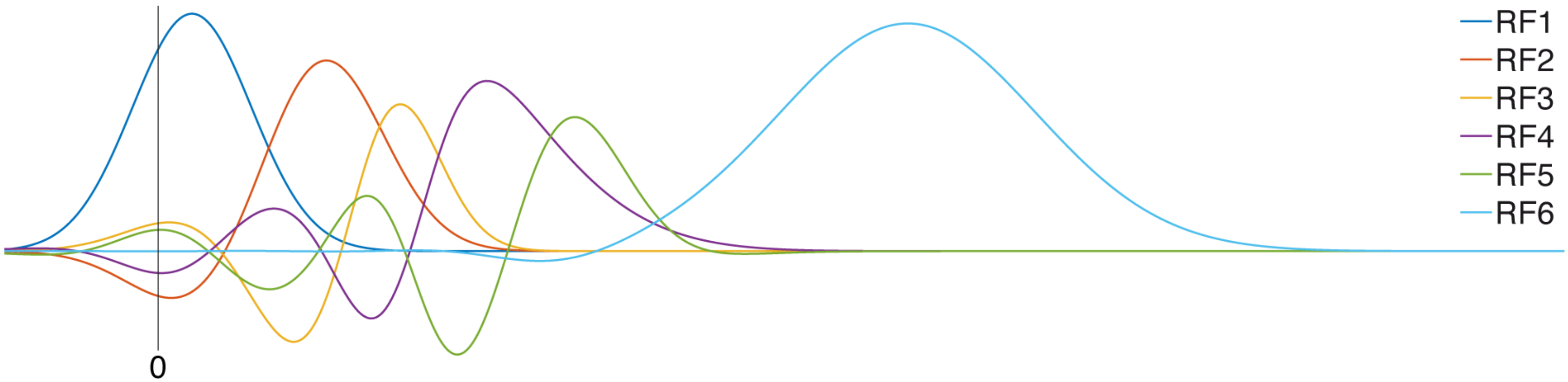
LTI assumptions are only approximately met

Respiratory sinus arrhythmia (RSA)



- RSA is a **nonlinear** influence on HPR
  - → reduce impact: **many trials**
- **range of HP is limited:** system will quickly saturate
  - → use **adequate ITIs:** allow the system to return to baseline

Model for evoked heart period responses

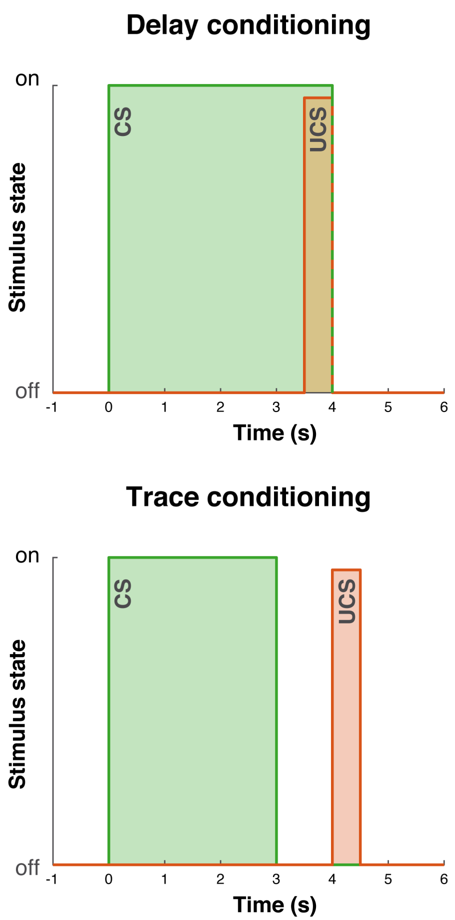


Heuristic model that separates experimental conditions better than all tested operational methods

- Model for **short presentation times** (~1s)
- **LTI assumptions need further testing:** use only RFs that peak within the ITI

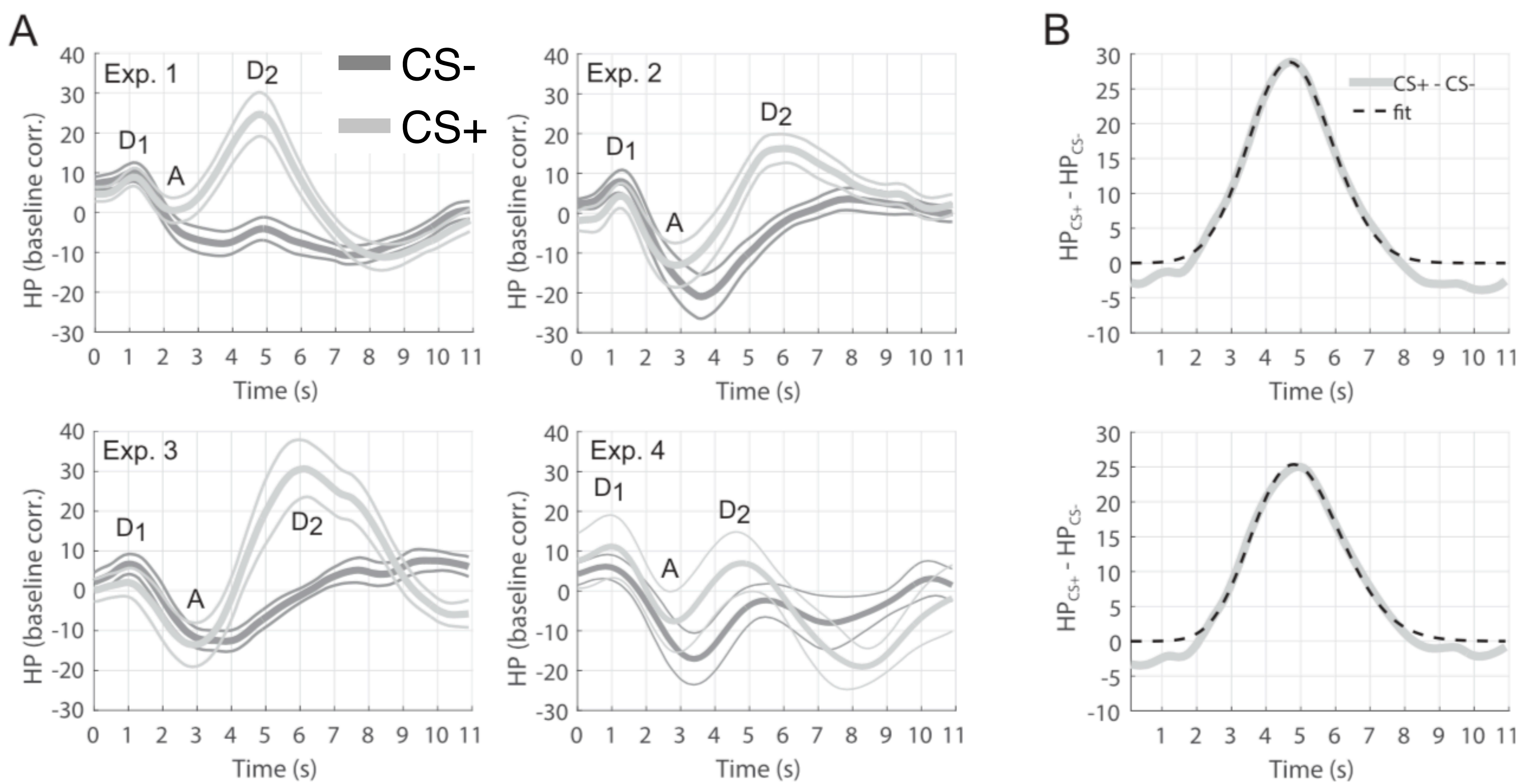
MODELLING FEAR CONDITIONED BRADYCARDIA

Fear conditioned bradycardia



	n	Conditioning	Design
Exp. 1	35	Delay, visual CS	SOA 3.5 s, 160 trials 80 CS+: 50% US, 80 CS-: 0% US
Exp. 2	20	Delay, auditory CS	SOA 3.5 s, 192 trials 96 CS+: 50% US, 96 CS-: 0% US
Exp. 3	23	Trace, visual CS	SOA 4 s, 160 trials 80 CS+: 50% US, 80 CS-: 0% US
Exp. 4	21	Delay, visual CS	SOA 3.5 s, 96 trials 48 CS+: 50% US, 48 CS-: 0% US

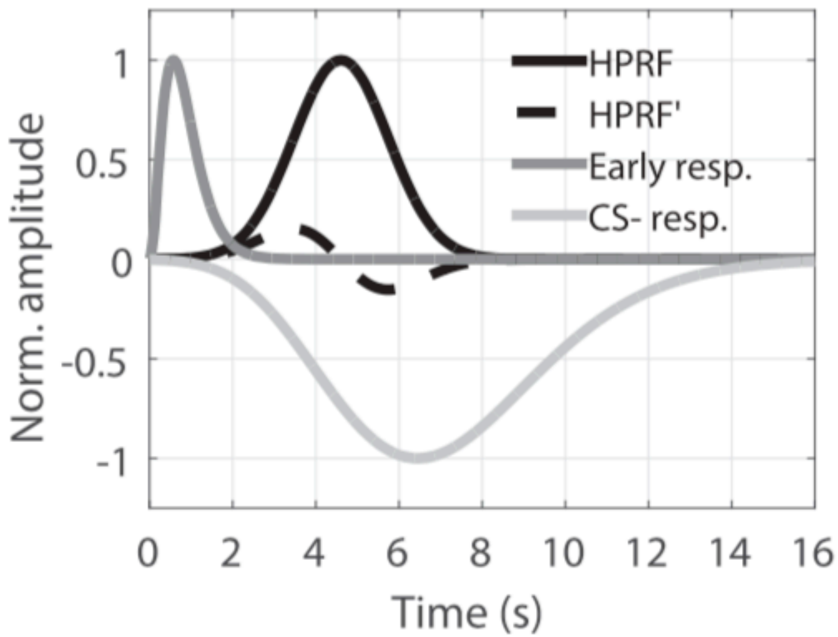
CS+ - CS- difference quantifies fear memory



- Individual **CS+/-** response **shapes not stable** across experiments
- **Difference** between CS+ and CS- **stable** over experiments

→ Model quantifies the **degree** to which a trial is **CS+**

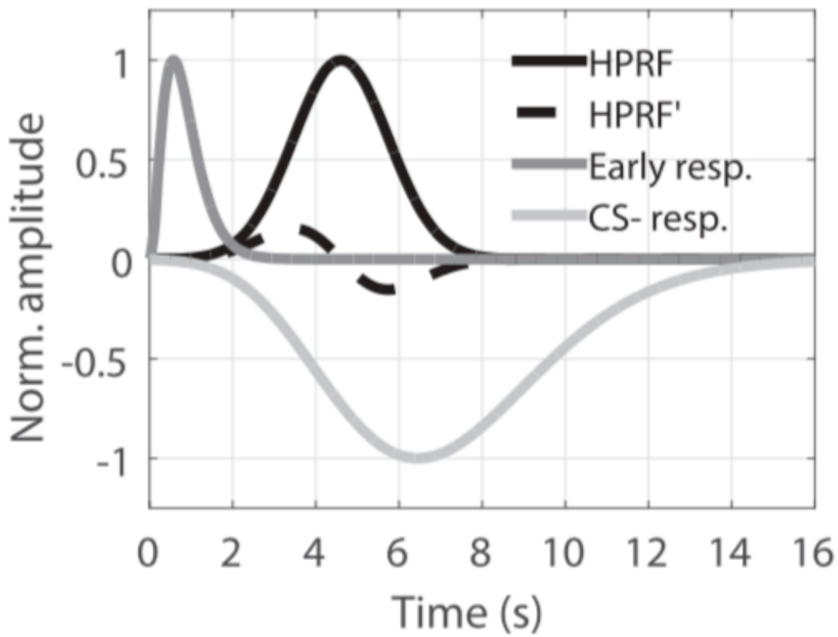
Model structure and accuracy

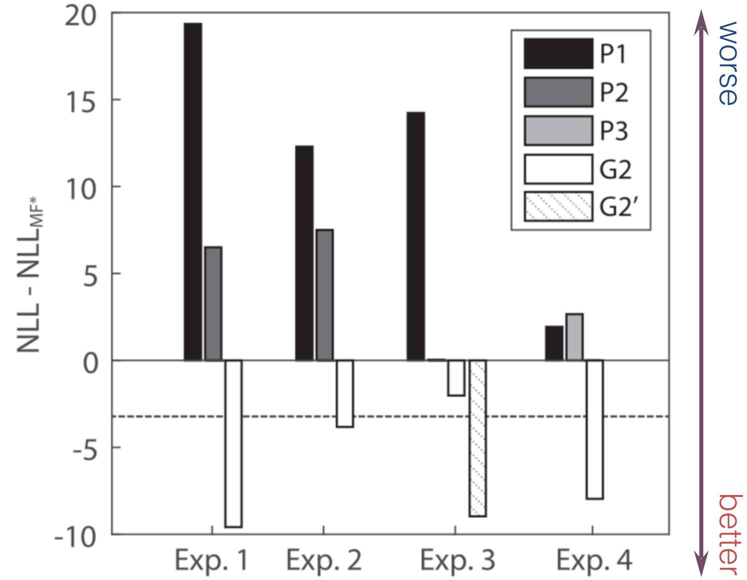


Model components

1. **HPRF:** diff(CS$^+$,CS$^-$)
2. **HPRF':** temporal derivative
3. ~~**Early resp.:** RF1 of evoked model~~
4. ~~**CS- resp.:** fit of CS$^-$ only~~

Model structure and accuracy





Model components

1. **HPRF**: diff(CS$^+$,CS$^-$)
2. **HPRF'**: temporal derivative
3. ~~**Early resp.**: RF1 of evoked model~~
4. ~~**CS- resp.**: fit of CS$^-$ only~~

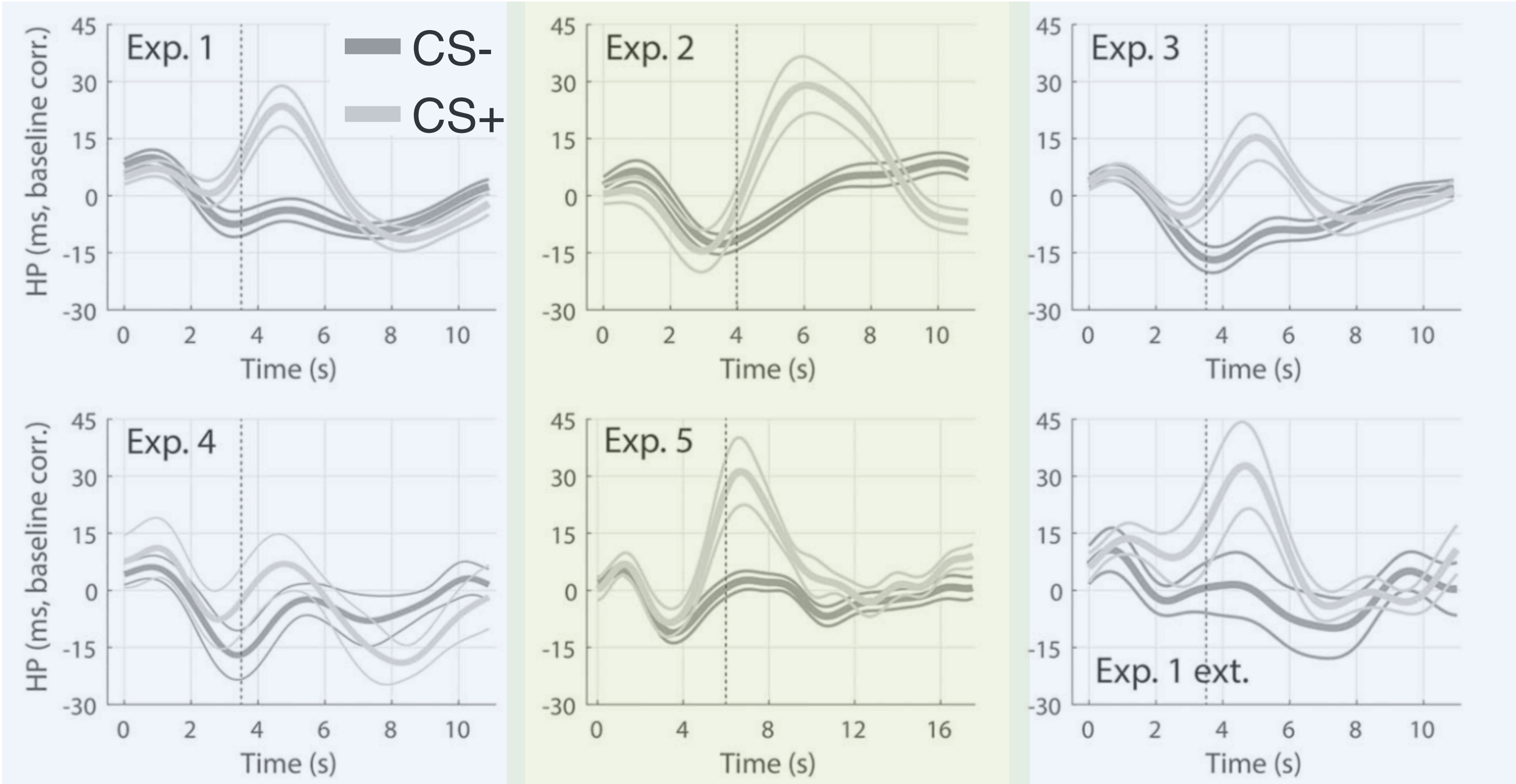
Model accuracy

P1-3 – Peak scoring

G2 – HPRF + HPRF'

G2' – US locked – G2

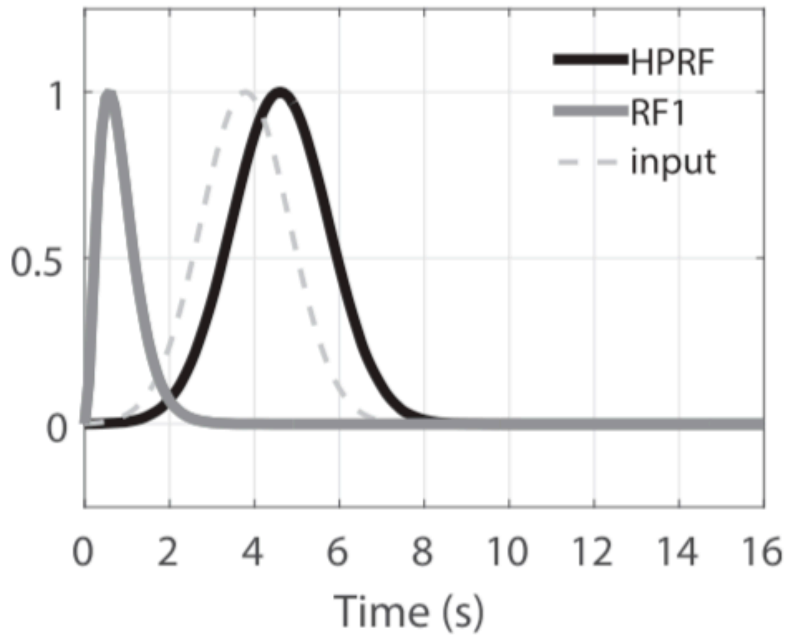
Is fear conditioned bradycardia time locked to CS or US?



Tested by varying CS – US interval:

- **Castegnetti et al. (2016):** SOA **3.5 vs. 4s** – fit for **time lock on US** better than for CS
- **Castegnetti et al. (2017):** SOA **3.5 vs. 4/6s** – fit for **US** better

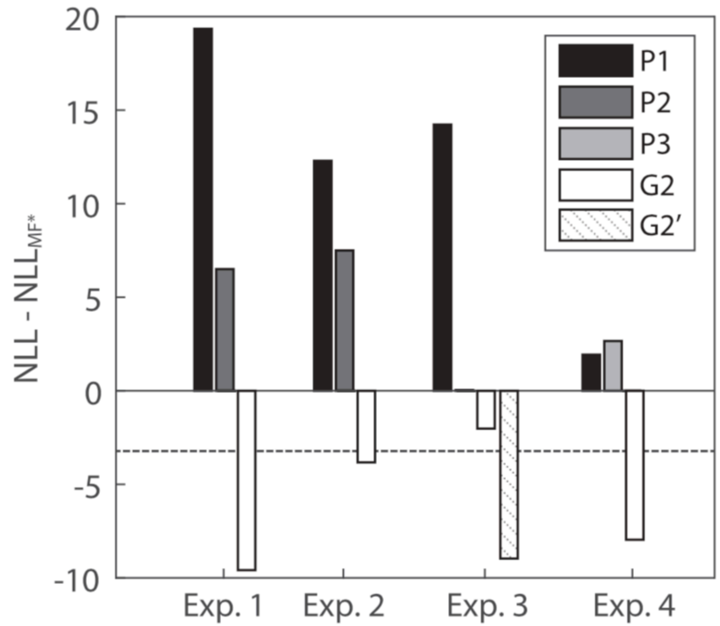
Gaussian input translates evoked HPR to fear bradycardia

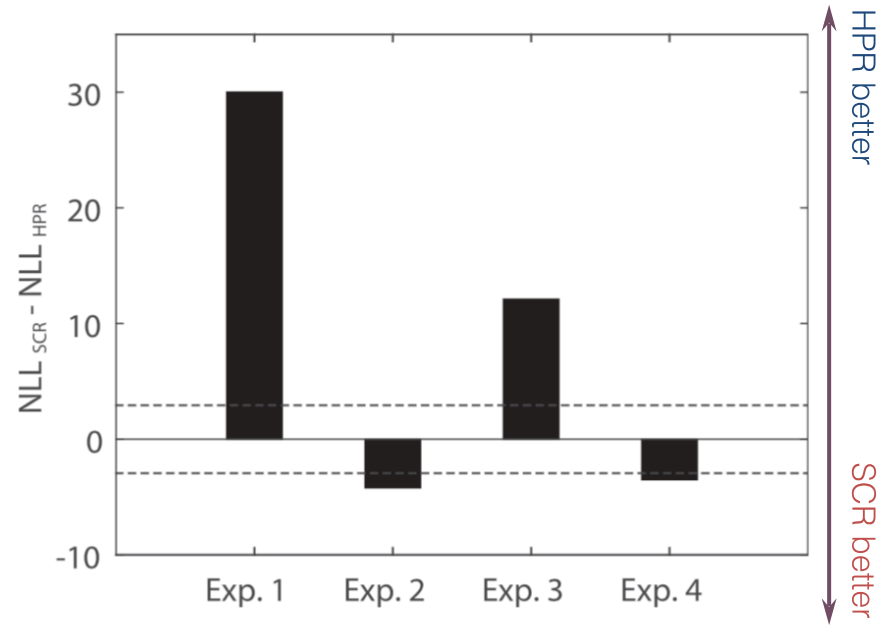


HPRF is **RF1**$_{\text{evoked}}$ with

gaussian input centred at **US**

Model accuracy – compared to SCR

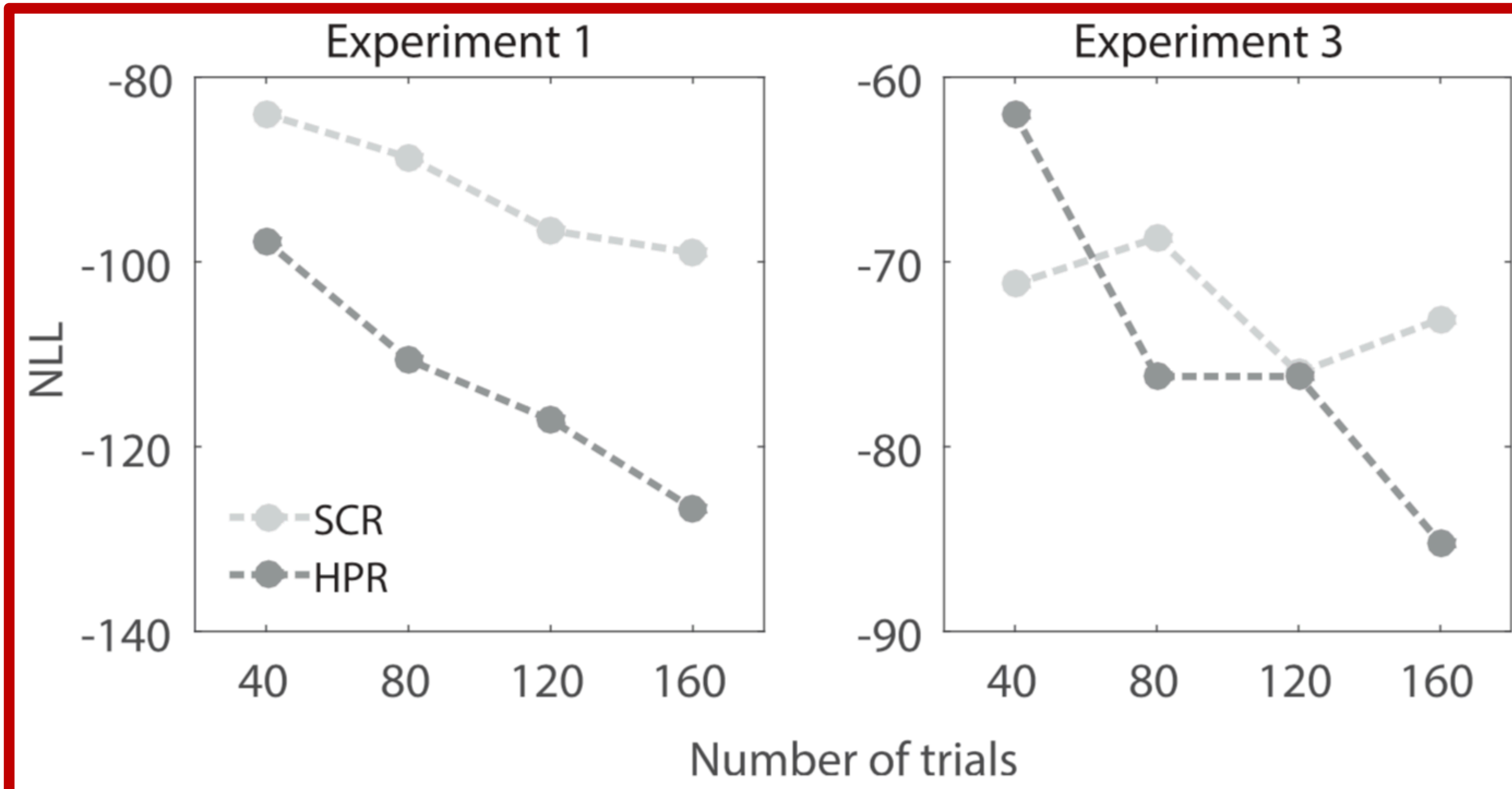




- **Model** is **significantly better** than operational methods

Is fear conditioned bradycardia **even more accurate than SCR?**

Model accuracy – compared to SCR

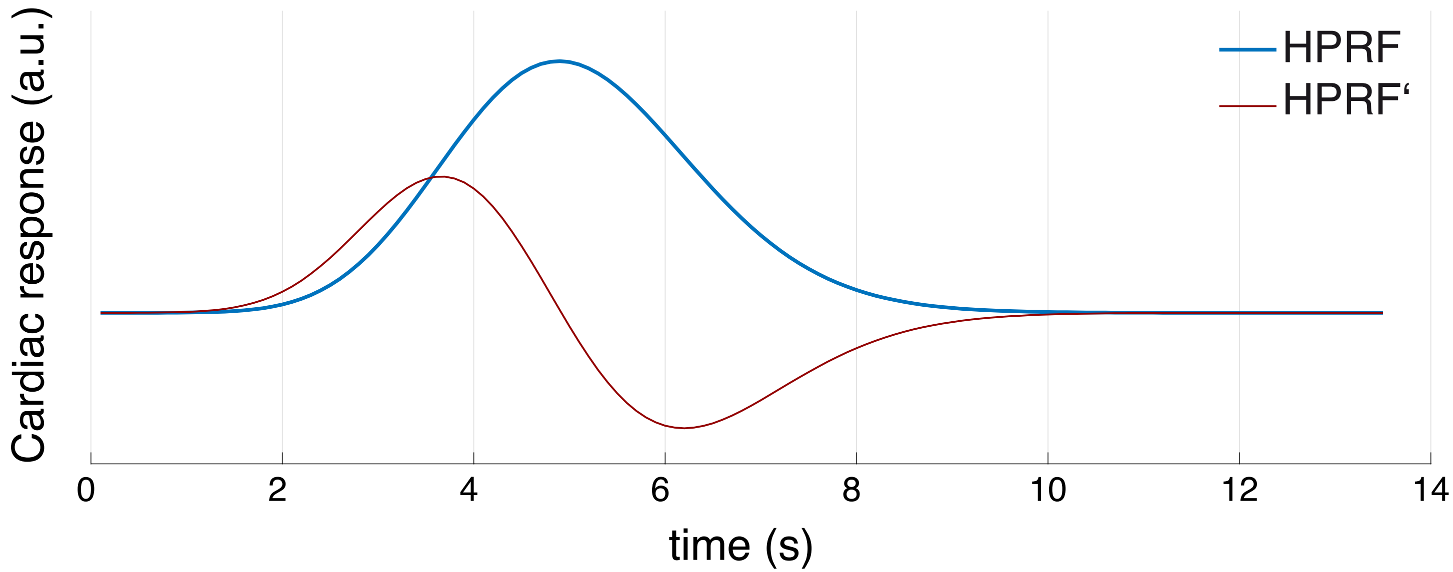


- **Model** is **significantly better** than operational methods

Is fear conditioned bradycardia **even more accurate than SCR?**

- **Large trial numbers:** dominance of respiratory rhythms – single trial estimates in HPR not possible

Summary



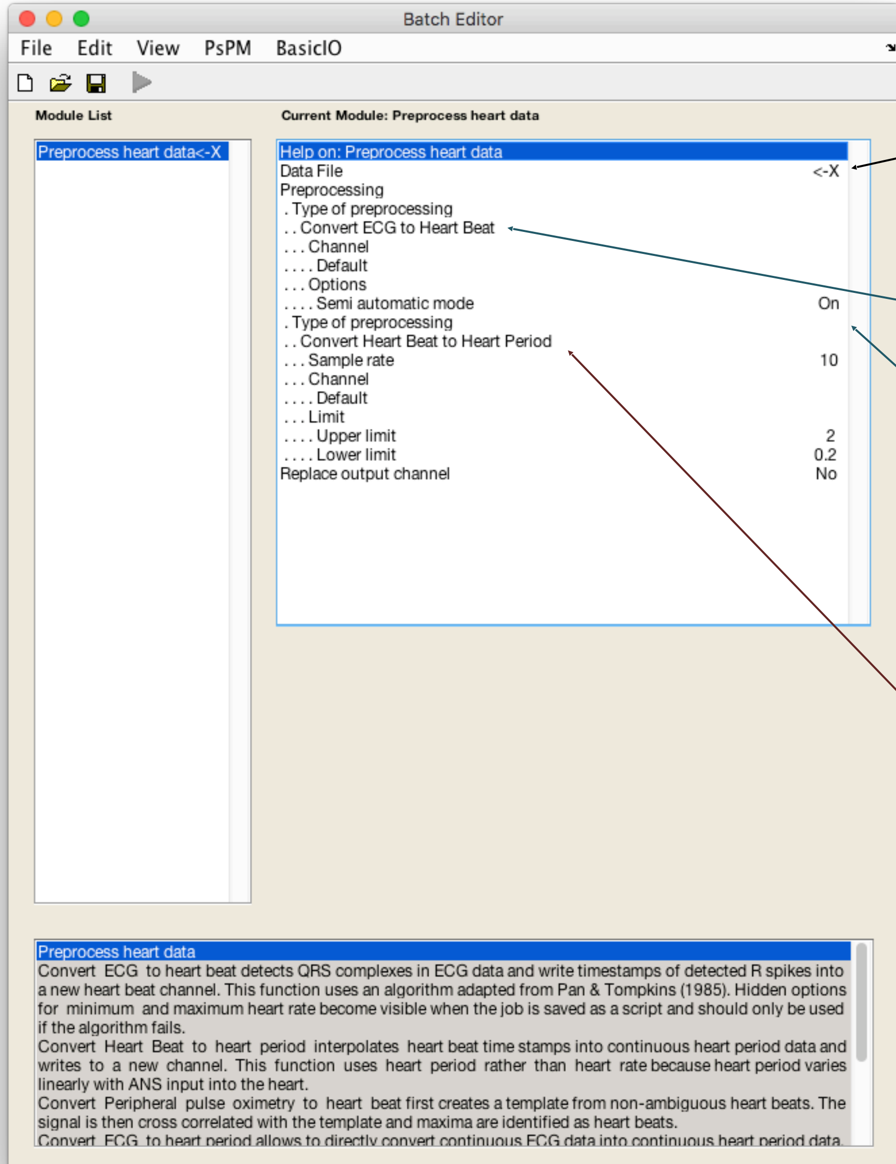
- **model significantly better** than available operational methods
- for **large trial numbers** might even be **more accurate than SCR** (BUT: no single trial estimates)
- **LTI assumptions** approximated for *adequate* **ITIs** & **trial numbers** to average out RSA

HOW TO …

How to model event-related heart period responses?

0. Import
1. Preprocessing
    - Detection of heart beats
    - Interpolation of the time series
    - Quality checks

Preprocessing – ecg2hb, quality checks, hb2hp



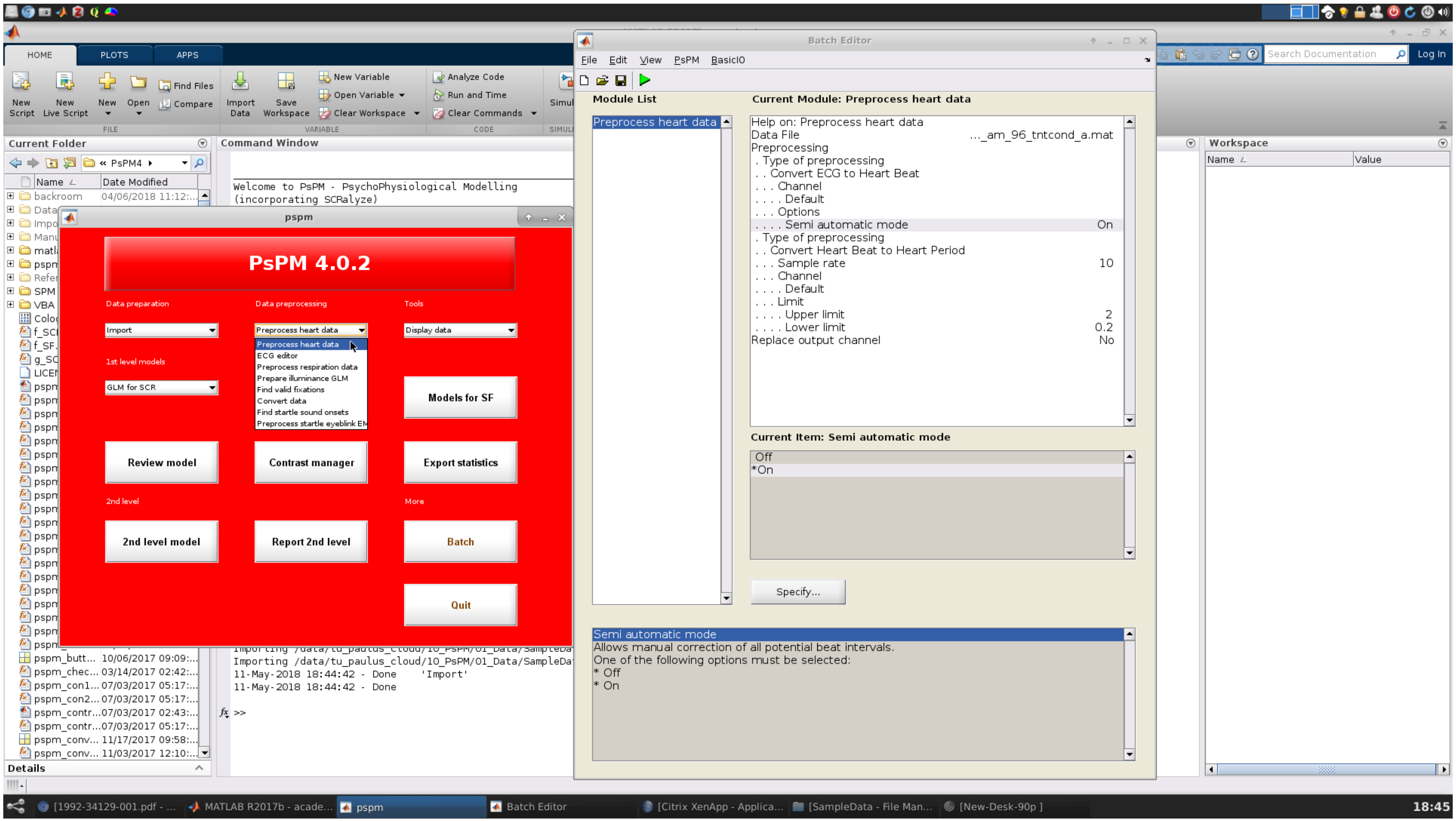
name of a pspm data file that contains ECG data

convert ECG to heart beat mark QRS complexes

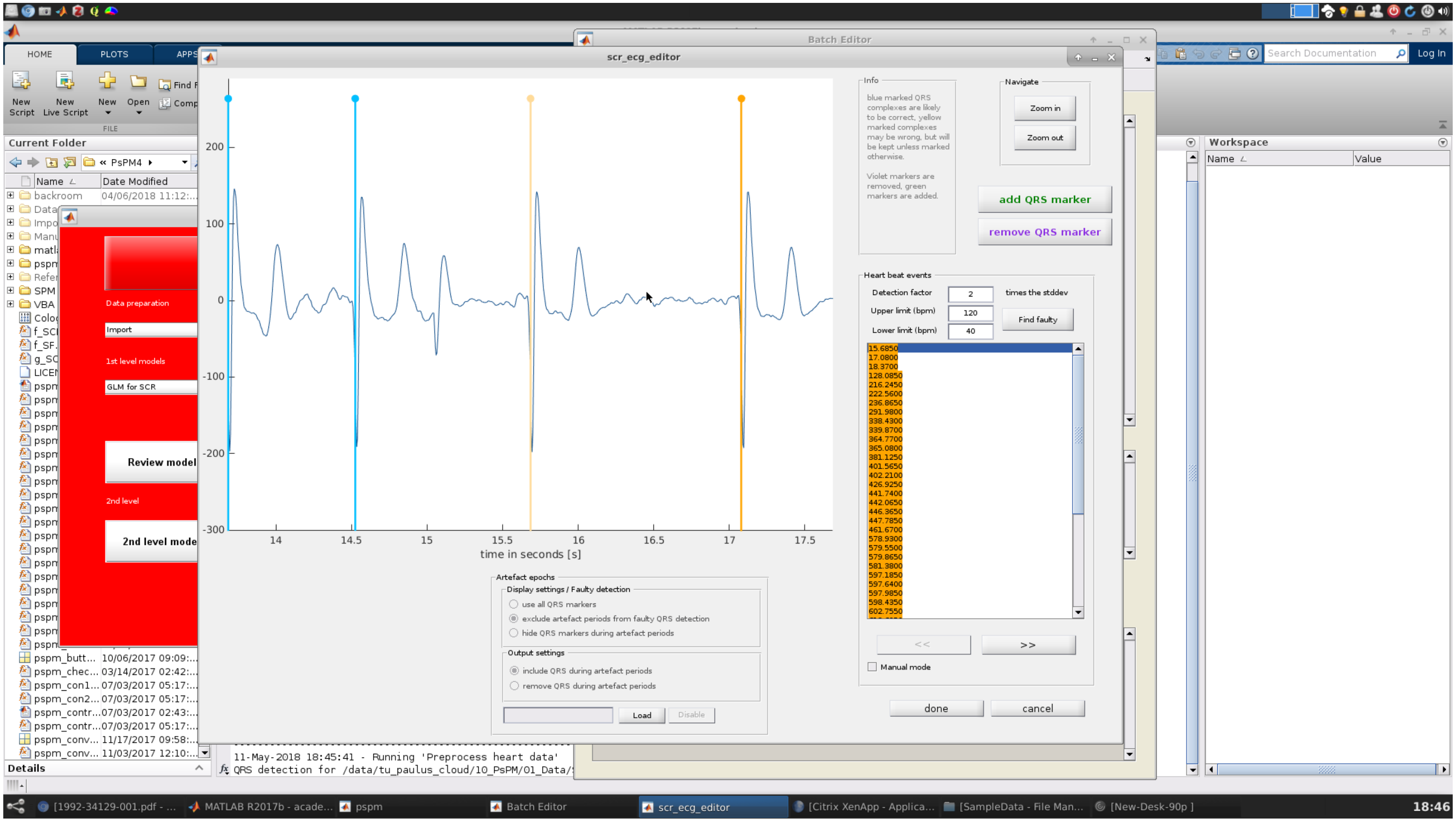
[Optional] inspect result manually to make sure QRS detection was successful

convert heart beat to heart period by interpolating the heart beat time series into a continuous signal

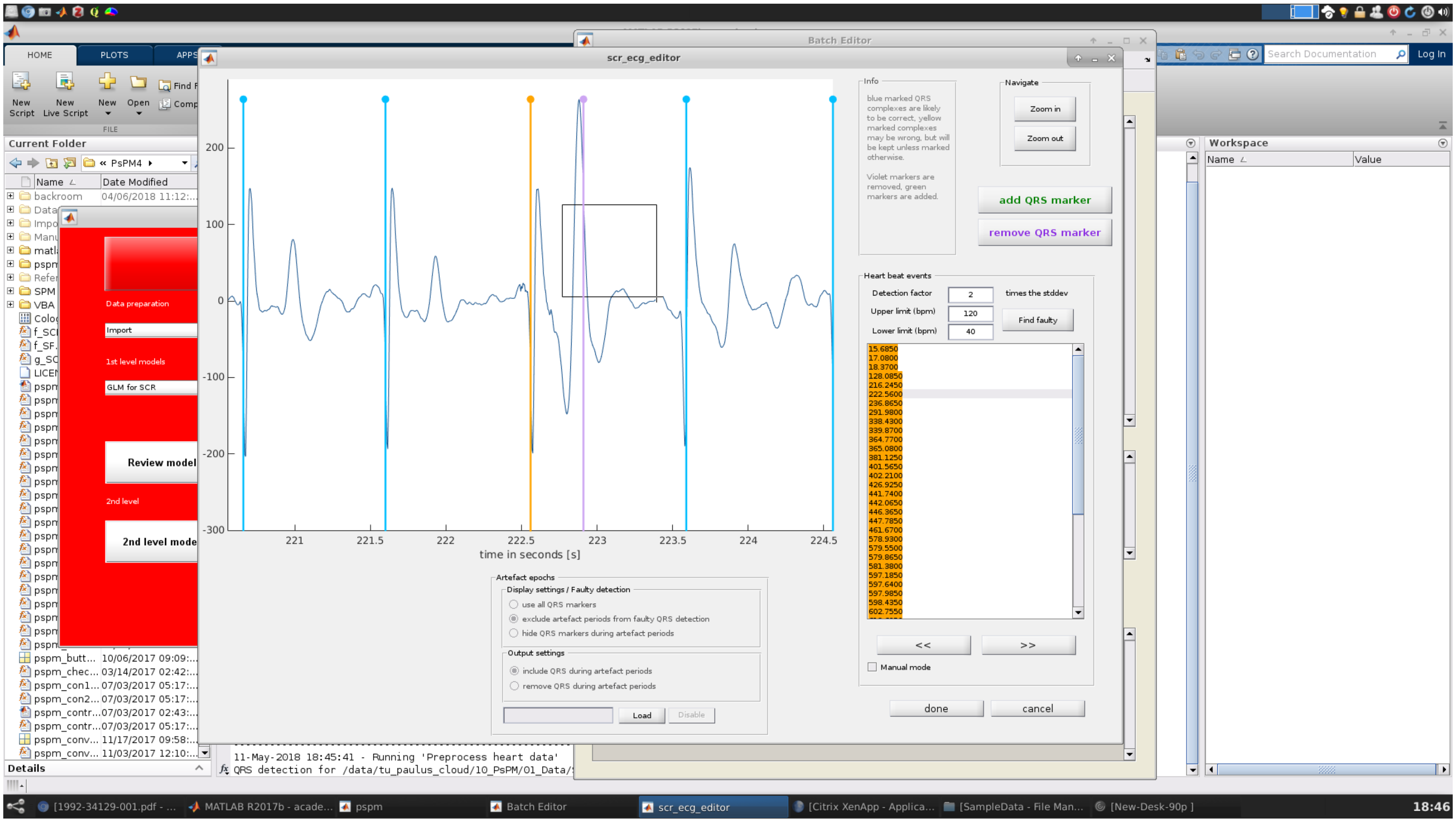
Preprocessing – import, quality checks



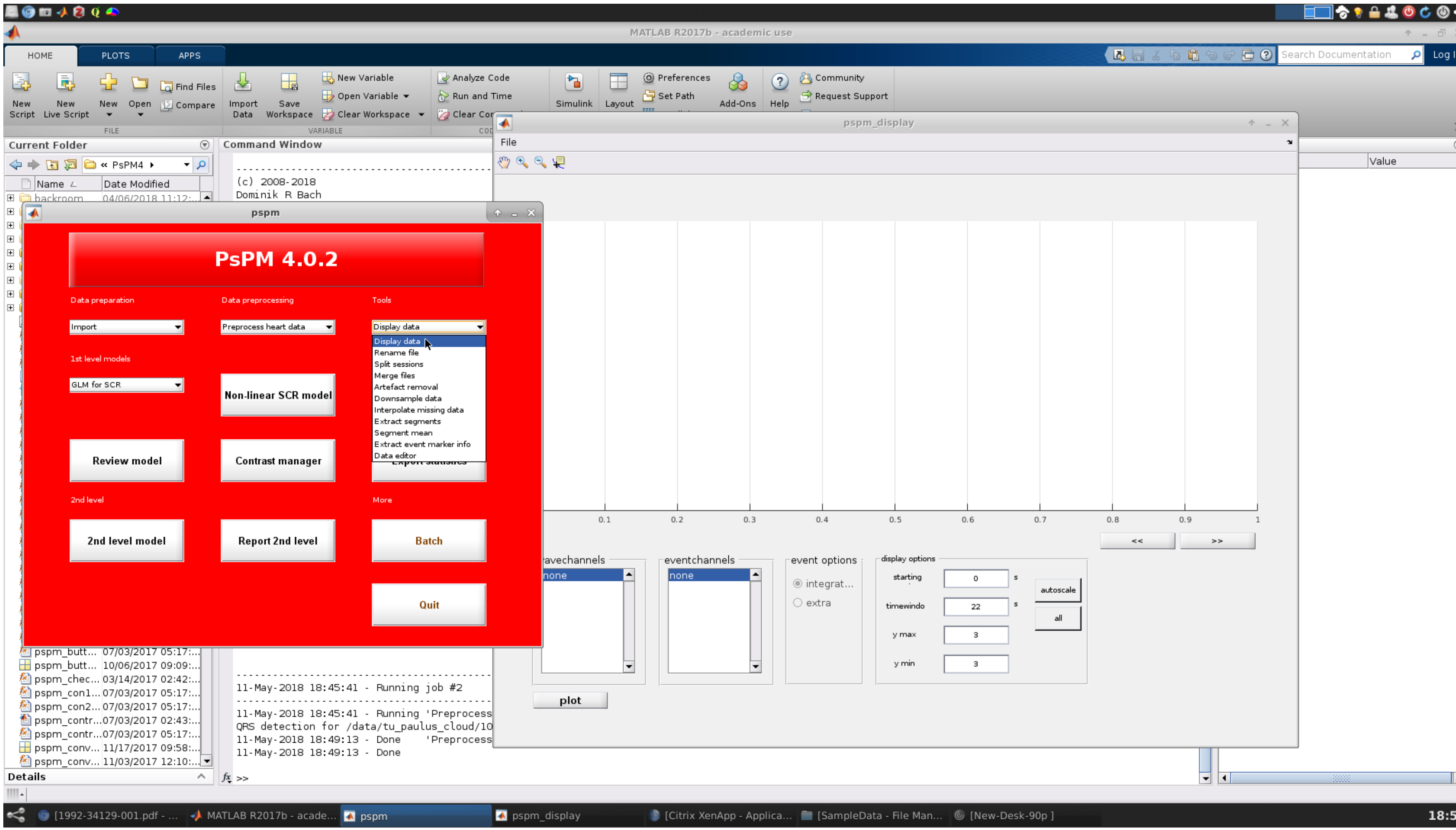
Preprocessing – import, quality checks



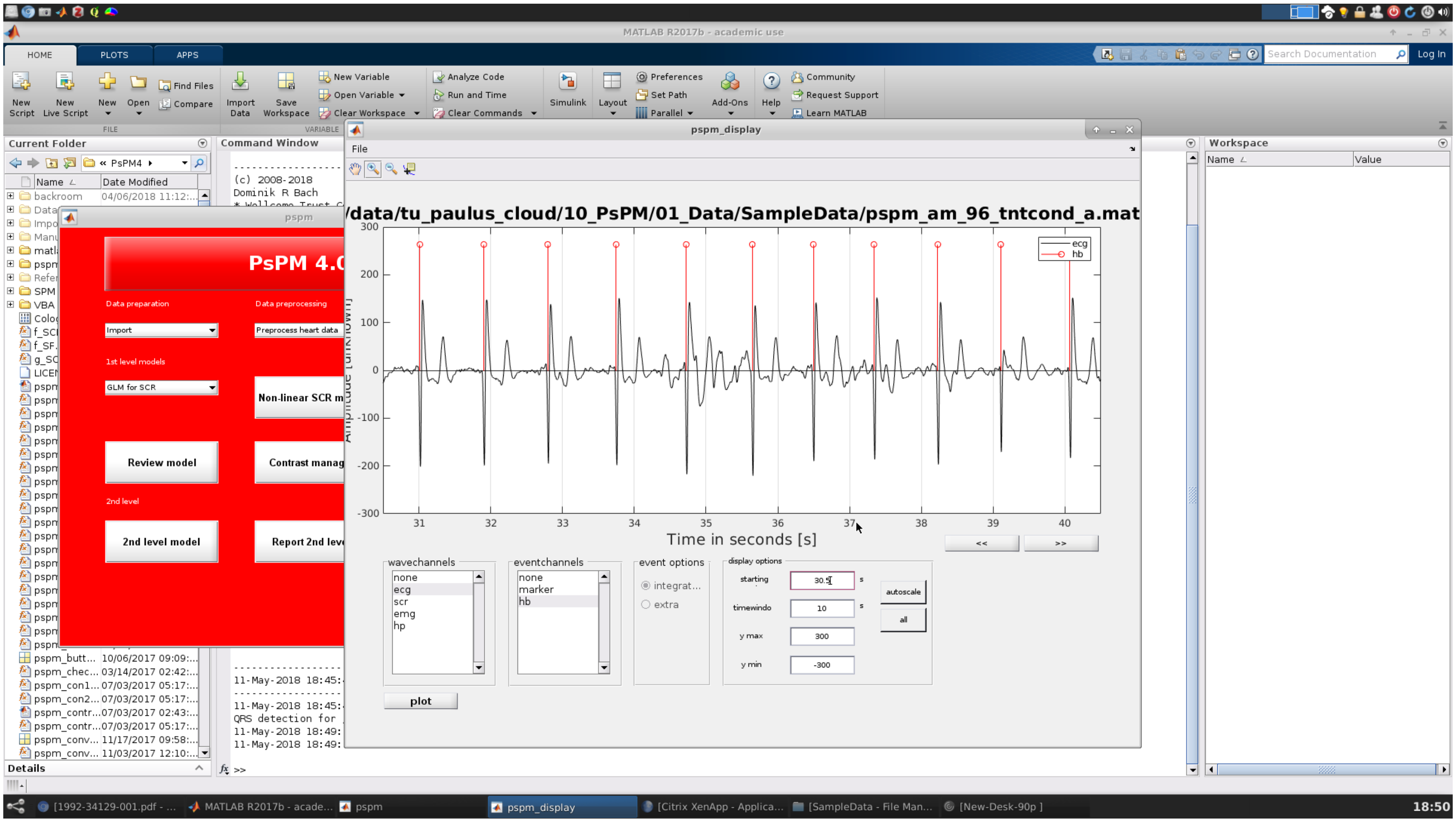
Preprocessing – import, quality checks



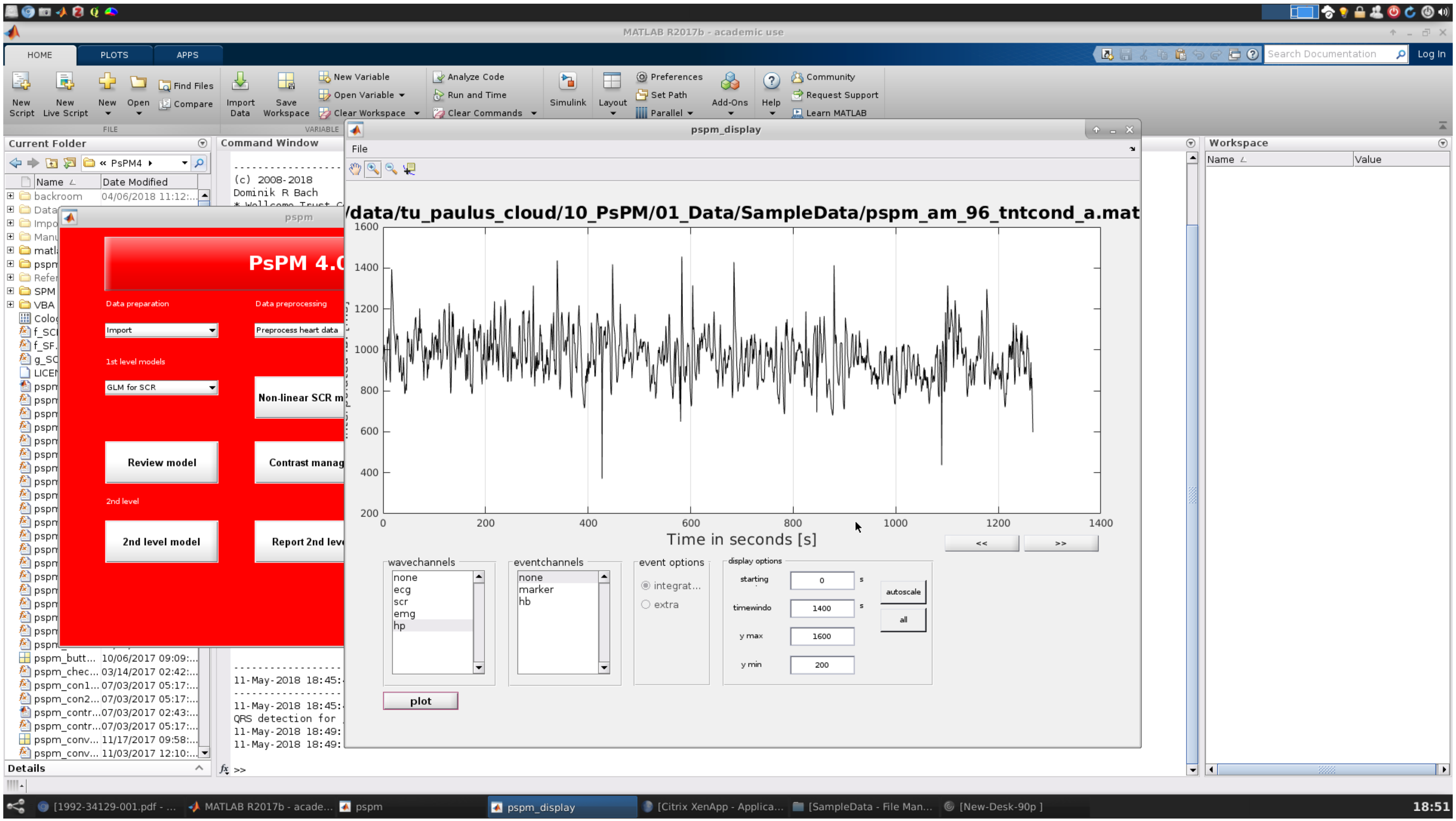
Preprocessing – import, quality checks



Preprocessing – import, quality checks



Preprocessing – import, quality checks

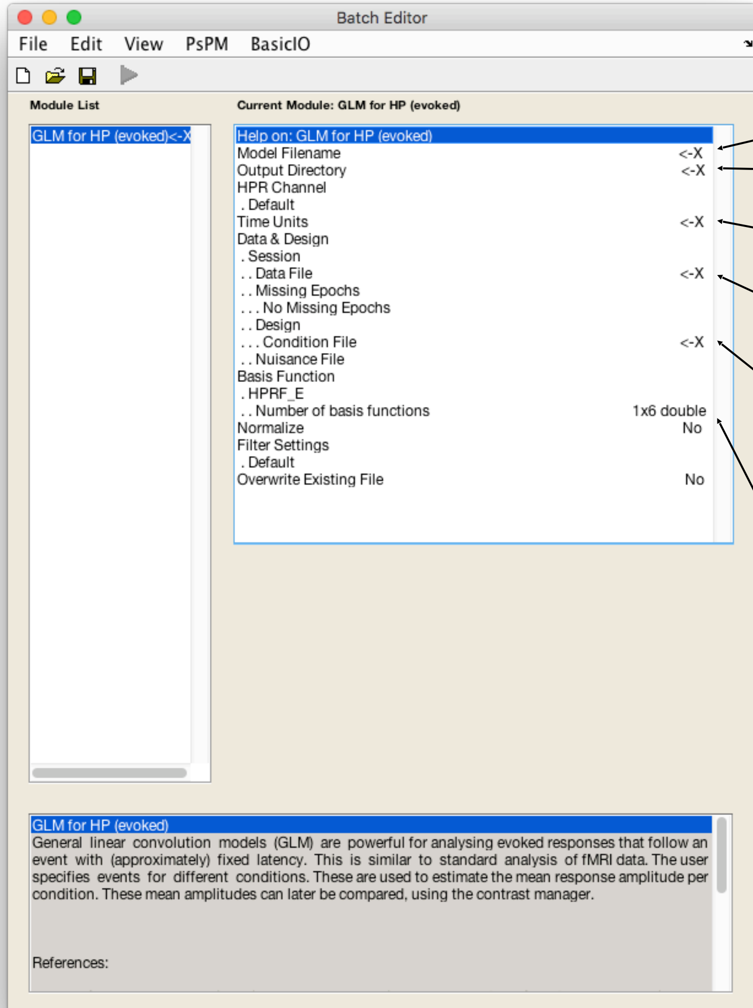


How to model event-related heart period responses?

0. Import
1. Preprocessing
   - Detection of heart beats
   - Interpolation of the time series
   - Quality checks

2. Set up the model
   - Setting up the 1st level GLM
   - Reviewing the model

Evoked responses: setting up the 1st level GLM



name for 1st level GLM

output directory

time units for the design

PsPM data file containing the HP data

condition file containing the onsets for the design

Example

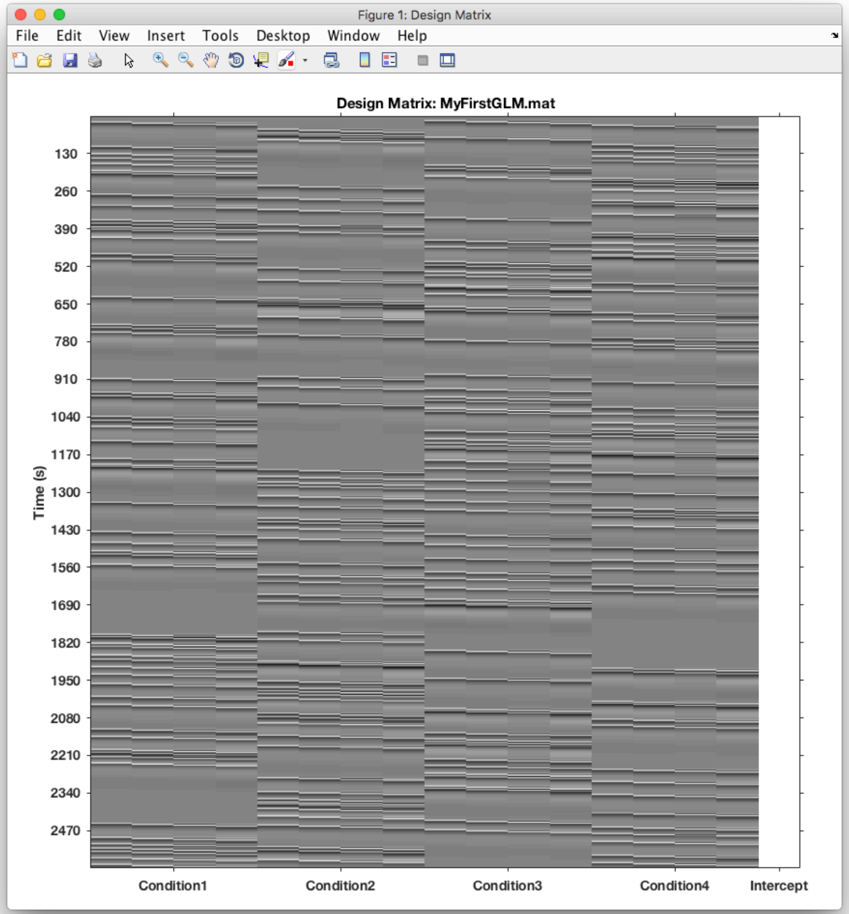
```
>> names = {'Condition1','Condition2','Condition3'};
>> onsets = {[1,4,8,10],[3,5,9,12],[2,6,7,11]};
>> save('001_condfile.mat','names','onsets');
>>
```

number of basis functions [1:6] – Take only those basis functions that peak within your ITI

(see Paulus, Castegnetti, & Bach, 2016)

Review the model

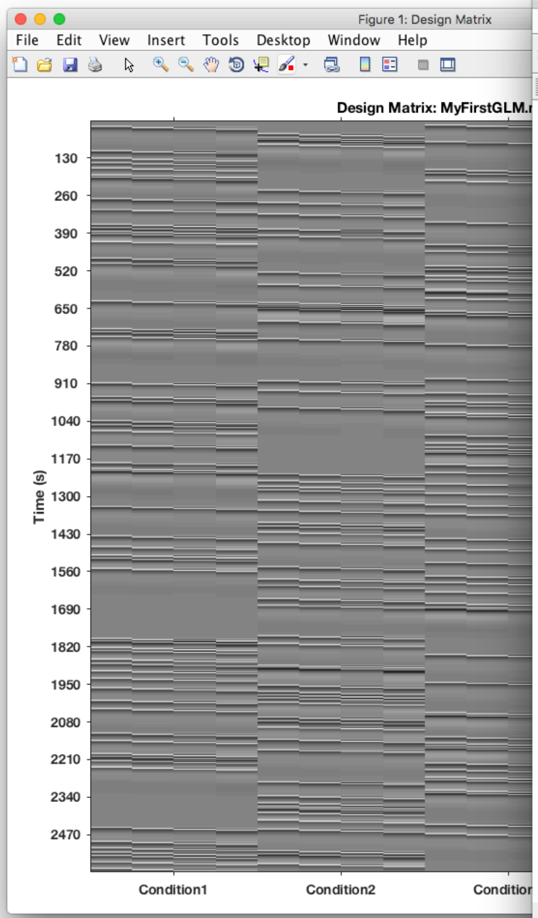
Design matrix

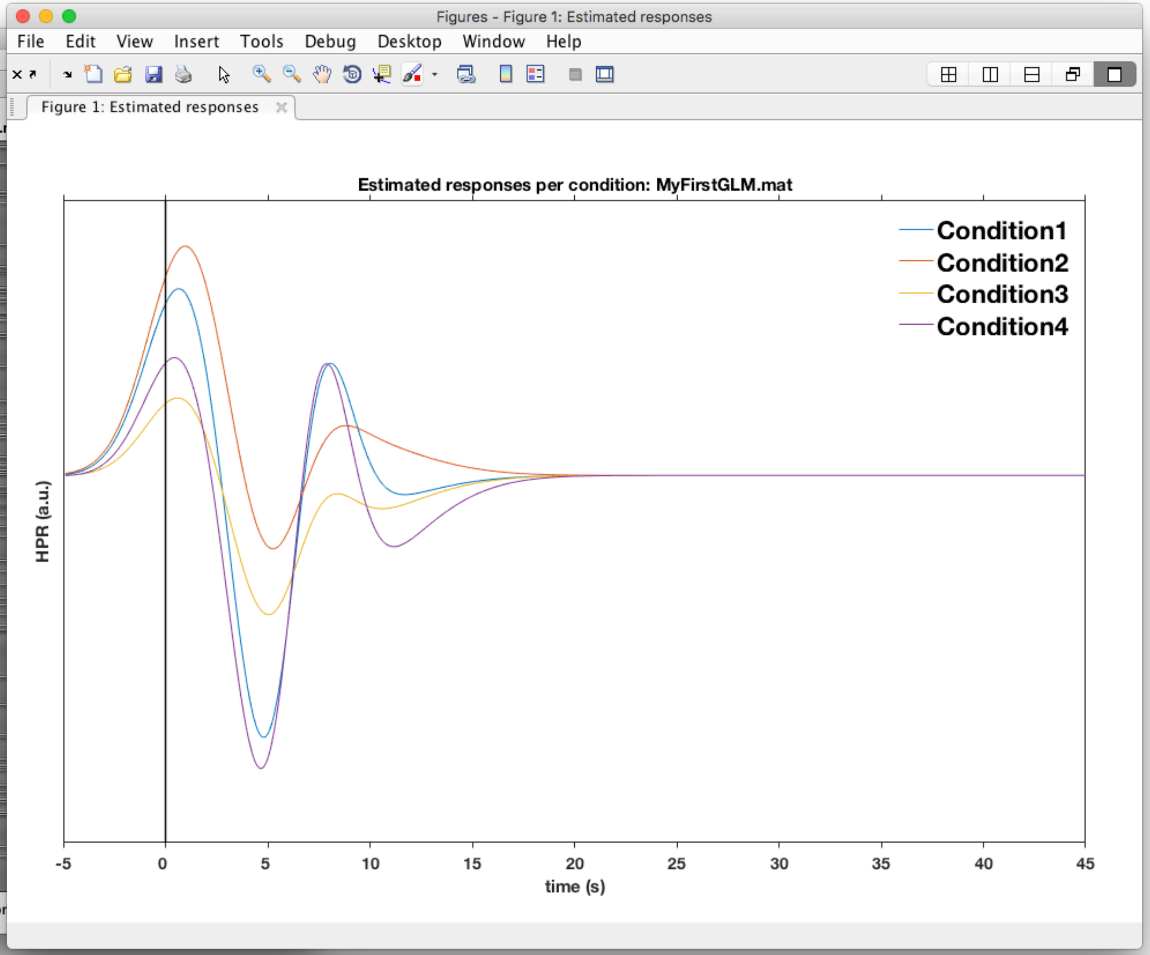


Review the model

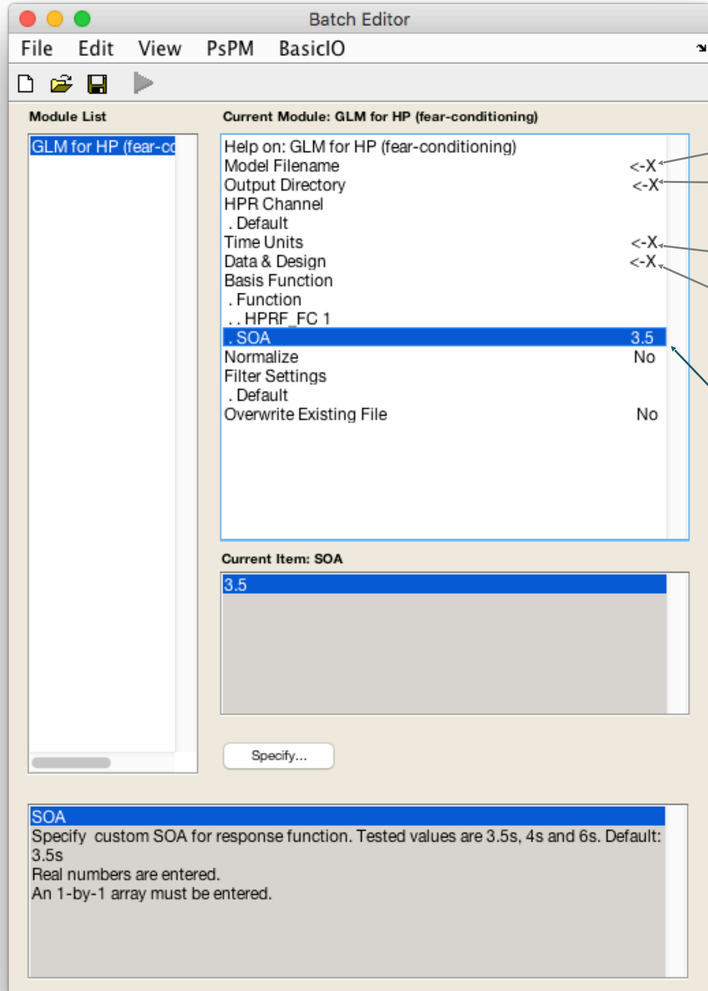
Design matrix

Reconstructed responses





Fear conditioned bradycardia: setting up the 1st level GLM



name for 1st level GLM

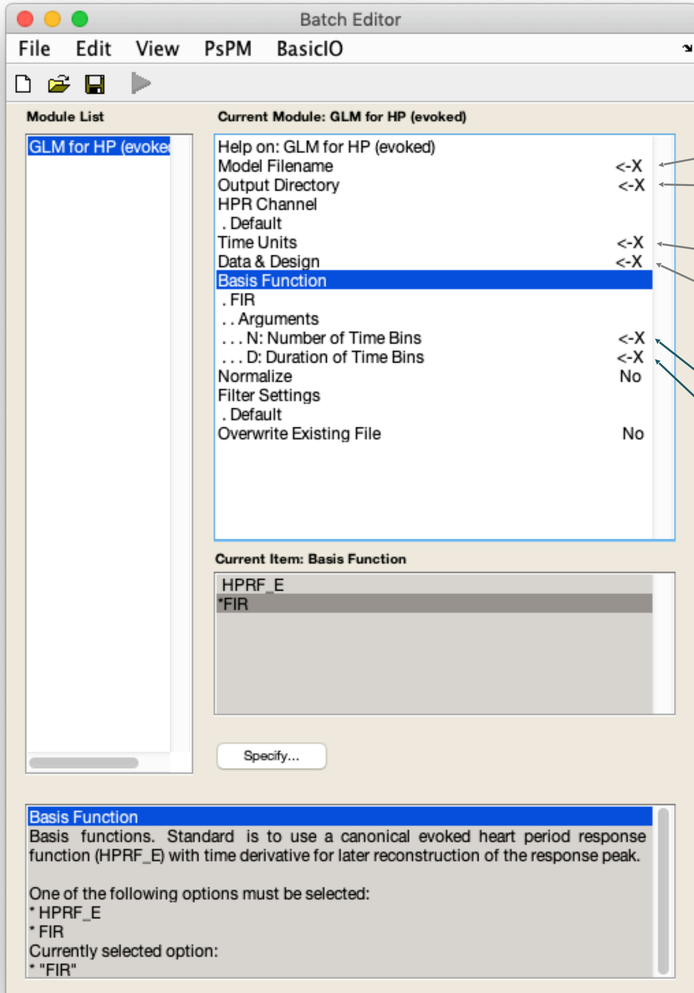
output directory

time units for the design

PsPM data file containing the HP data & **design**

stimulus onset asynchrony in s. Make sure the response function is time locked to the US

FIR model … alternative to the model for evoked responses



name for 1st level GLM

output directory

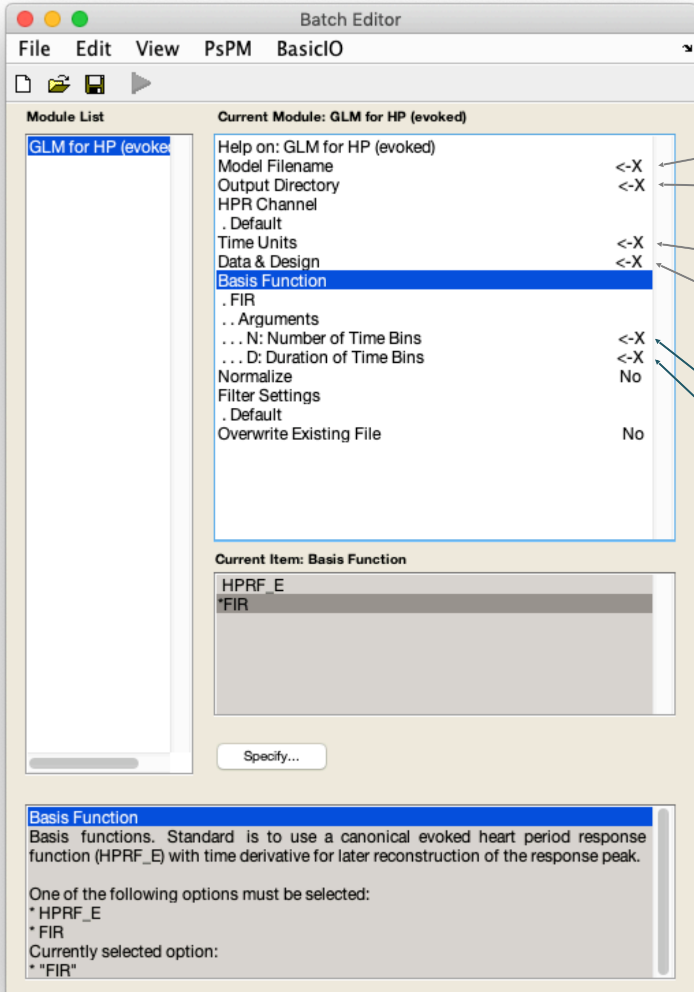
time units for the design

PsPM data file containing the HP data & **design**

Number of time bins

Duration of time bins

FIR model … alternative to the model for evoked responses



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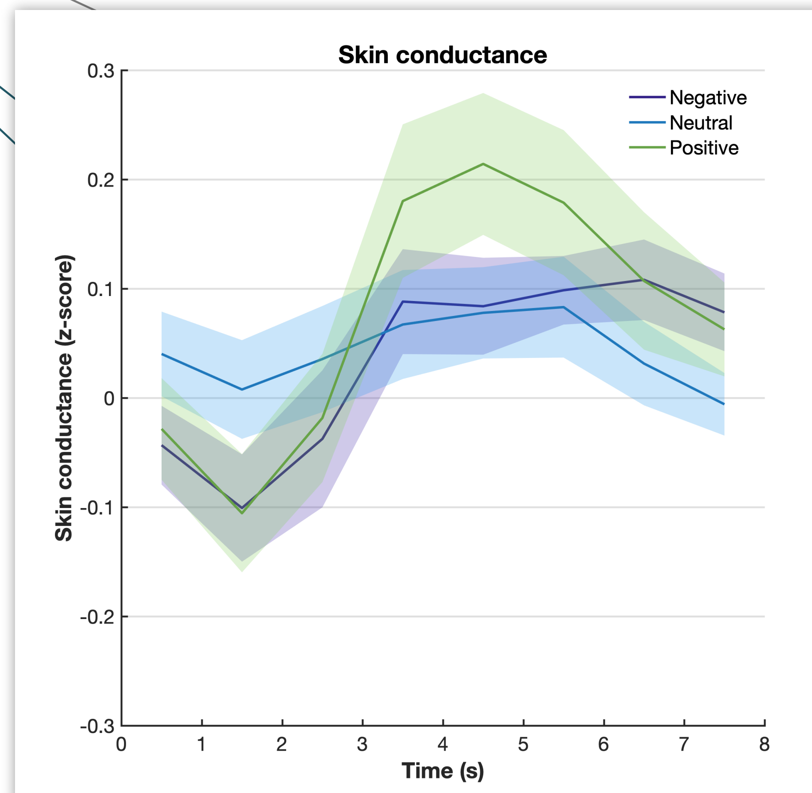

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FOR HUMAN COGNITIVE AND BRAIN SCIENCES

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Thank you …

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