Analysis of EDA data using Ledalab

Mathias Benedek

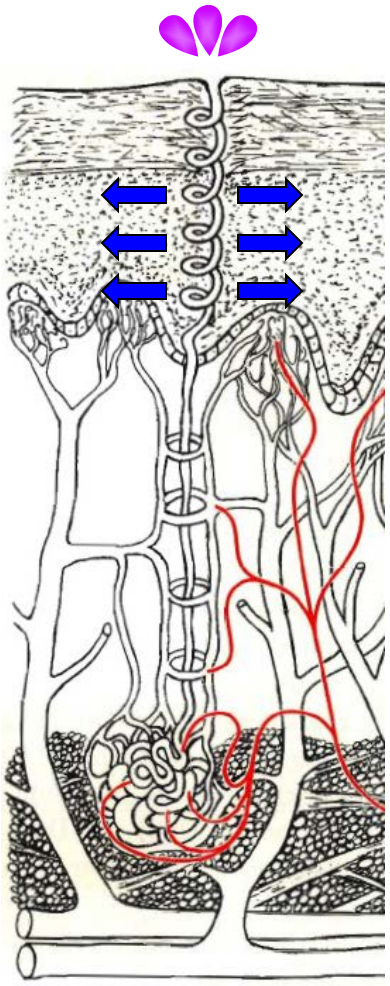
University of Graz, Austria

Physiology of electrodermal activity (EDA)

- Sweat glands controlled by sympathetic nervous system
- One axon innervates about 1.28 cm^2 of skin (Schmelz et al., 1998)
- Each gland innervated by multiple axons (Kennedy et al., 1984; Riedl et al., 1998)
- Sweat secretion causes change in SC
- Onset of SCR > 1s after stim (efference + neuroeffector time)

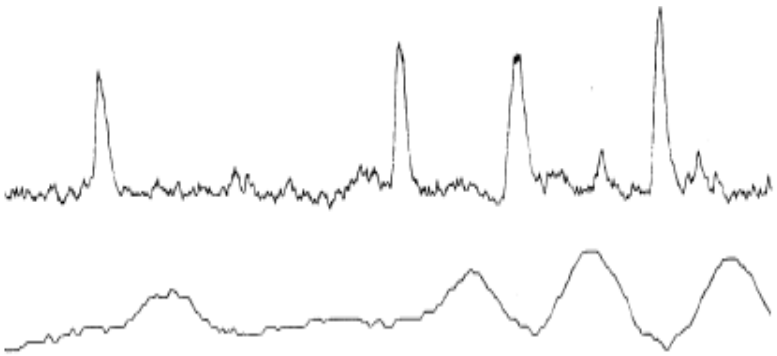
  (Kunimoto et al., 1991; Lim et al., 2003)
- Spike density → nr of activated glands → SCR amplitude

  (Freedman et al., 1994; Nishiyama et al., 2001; Bini et al., 1980; Lidberg and Wallin, 1981)



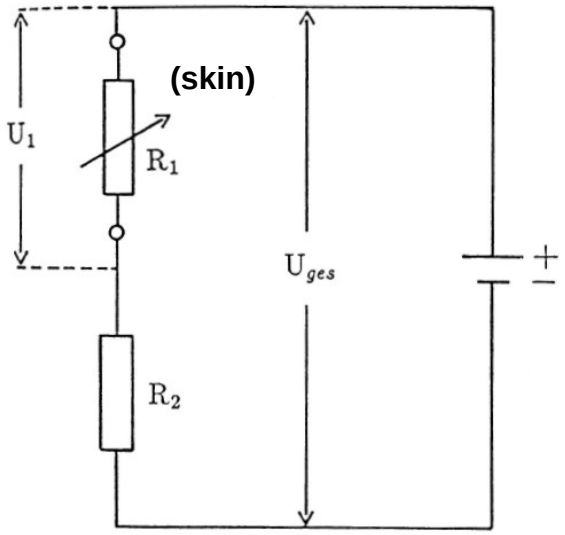
Sudomotor nerve activity (SNA)

Skin conductance (SC)



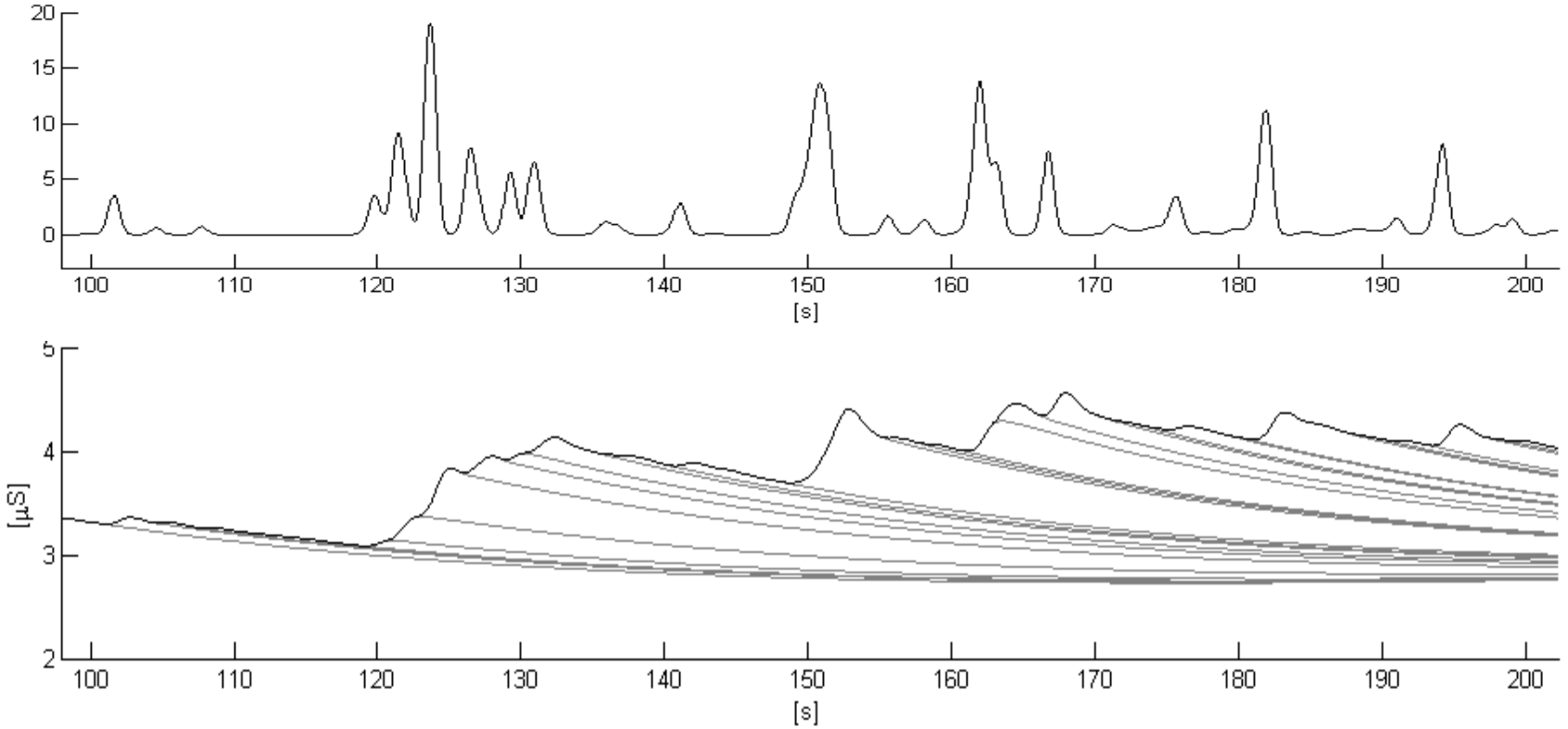
(Macefield & Wallin, 1996)

Recording of EDA



constant current method

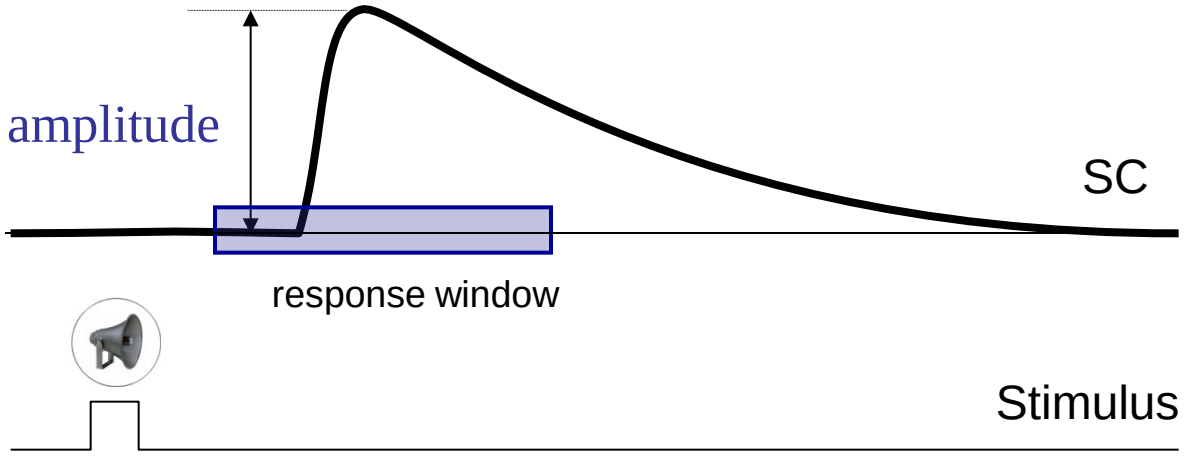
The nature of skin conductance data



Quantification of SCR amplitude

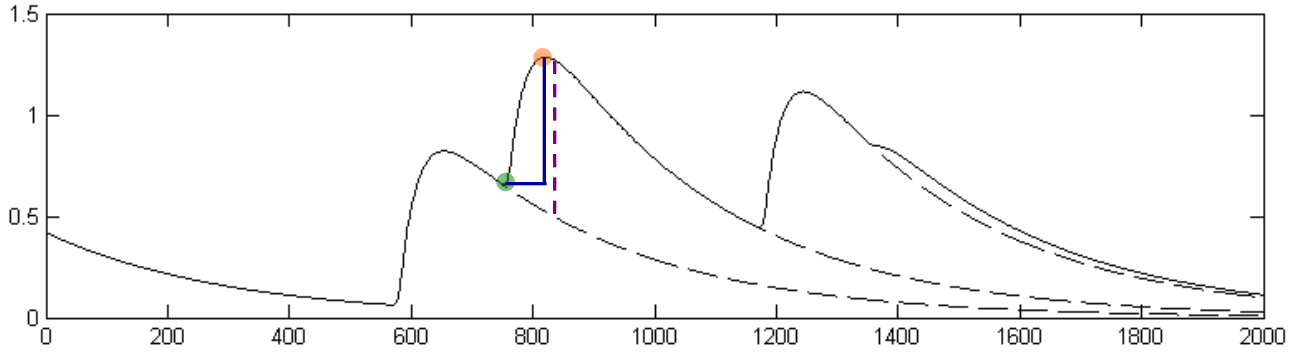
Standard methods and issues

Quantification of SCR amplitude



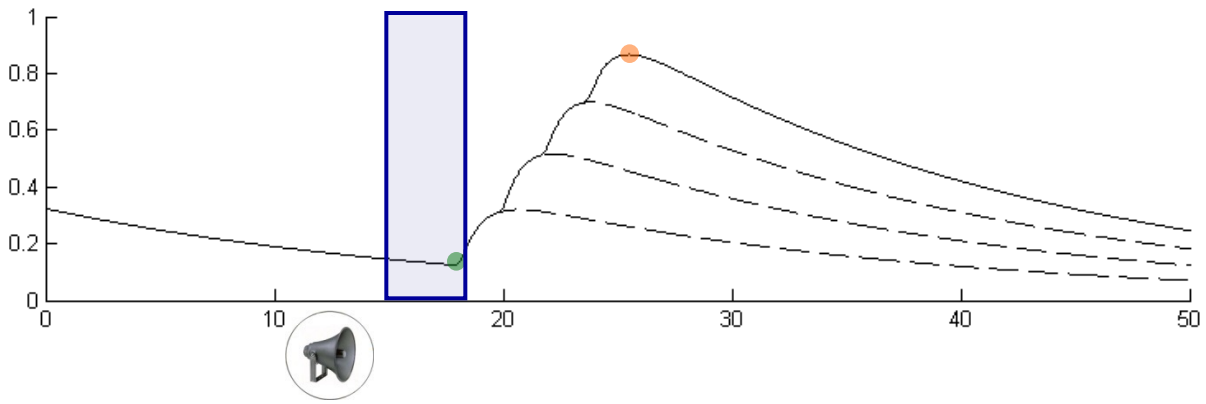
Standard min-max or through-to-peak method
(from local minimum to local maximum)

Quantification of SCR amplitude: common errors



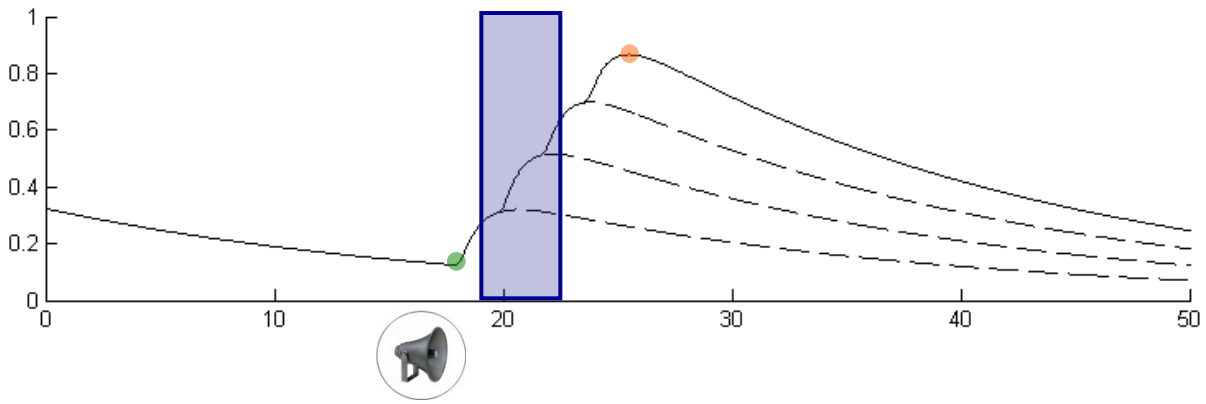
- General underestimation of amplitude

Quantification of SCR amplitude: common errors



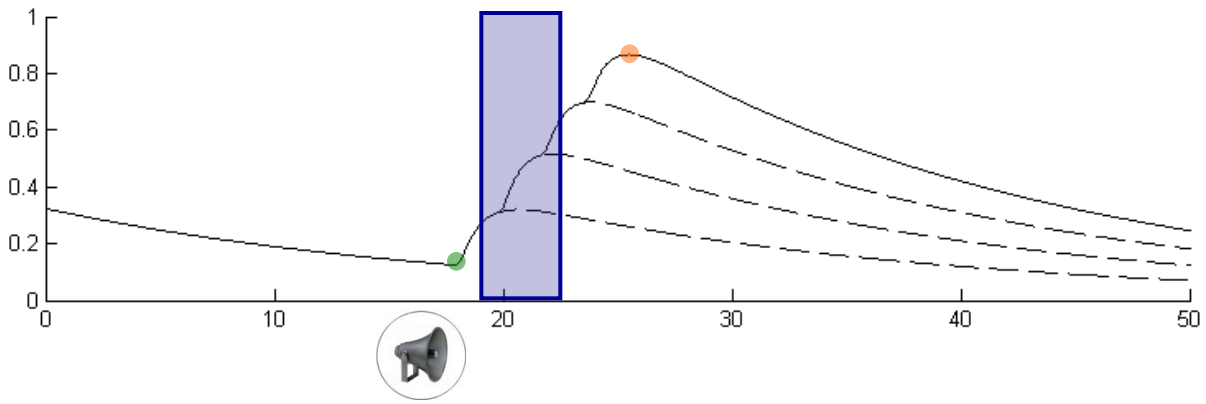
- General underestimation of amplitude
- Misattribution with respect to response window
  → overestimation

Quantification of SCR amplitude: common errors



- General underestimation of amplitude
- Misattribution with respect to response window
  → overestimation / underestimation

Quantification of SCR amplitude: common errors

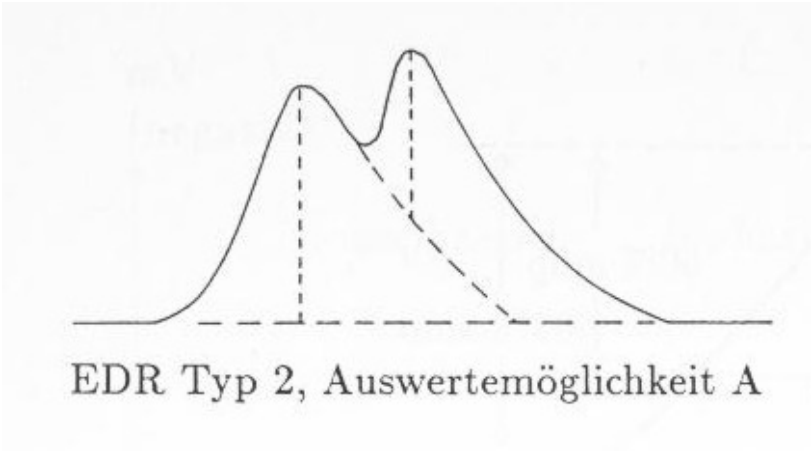


- General underestimation of amplitude
- Misattribution with respect to response window
  → overestimation / underestimation

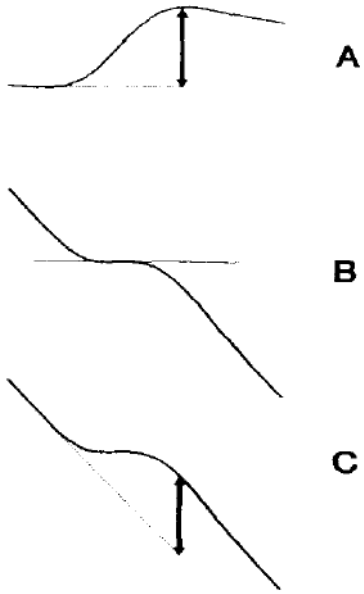
- Desideratum: Get true onset and amplitude of single responses

Decomposition Approaches

Decomposition Approaches – Linear Interpolation



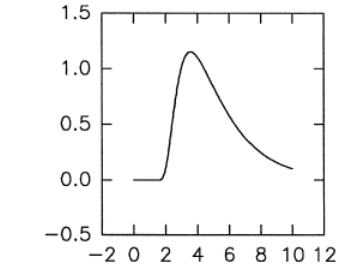
(Hagfors 1964, nach Boucsein, 1992)

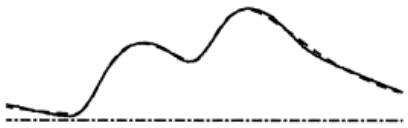


(Barry, 1992)

Decomposition Approaches - Curve Fitting

- 10 sec data segment fitted by 4-8 parameter function (visual inspection!)
- SCR represented by sigmoid-exponetial function



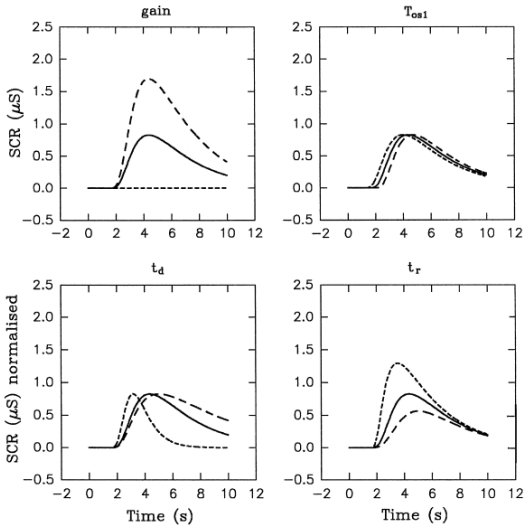


$$f_4 = g \cdot \frac{e^{\frac{-(t-T_{OS})}{t_d}}}{(1+(\frac{t_r}{t-T_{OS}})^2)^2}$$

$$f_6 = a_0 \cdot e^{\frac{-t}{t_d}} + c + f_4(g, T_{OS})$$

$$f_8 = a_0 \cdot e^{\frac{-t}{t_d}} + c + f_4(g_1, T_{OS1}) + f_4(g_2, T_{OS2})$$

g .. gain/amplitude
T_{os} .. onset time
t_r .. rise time
t_d .. decay time

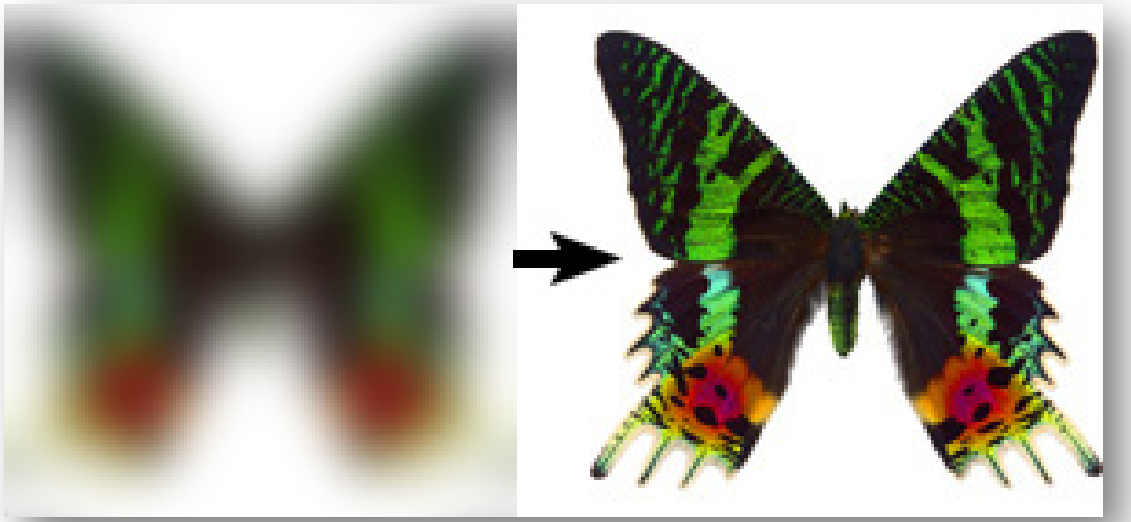


Results:

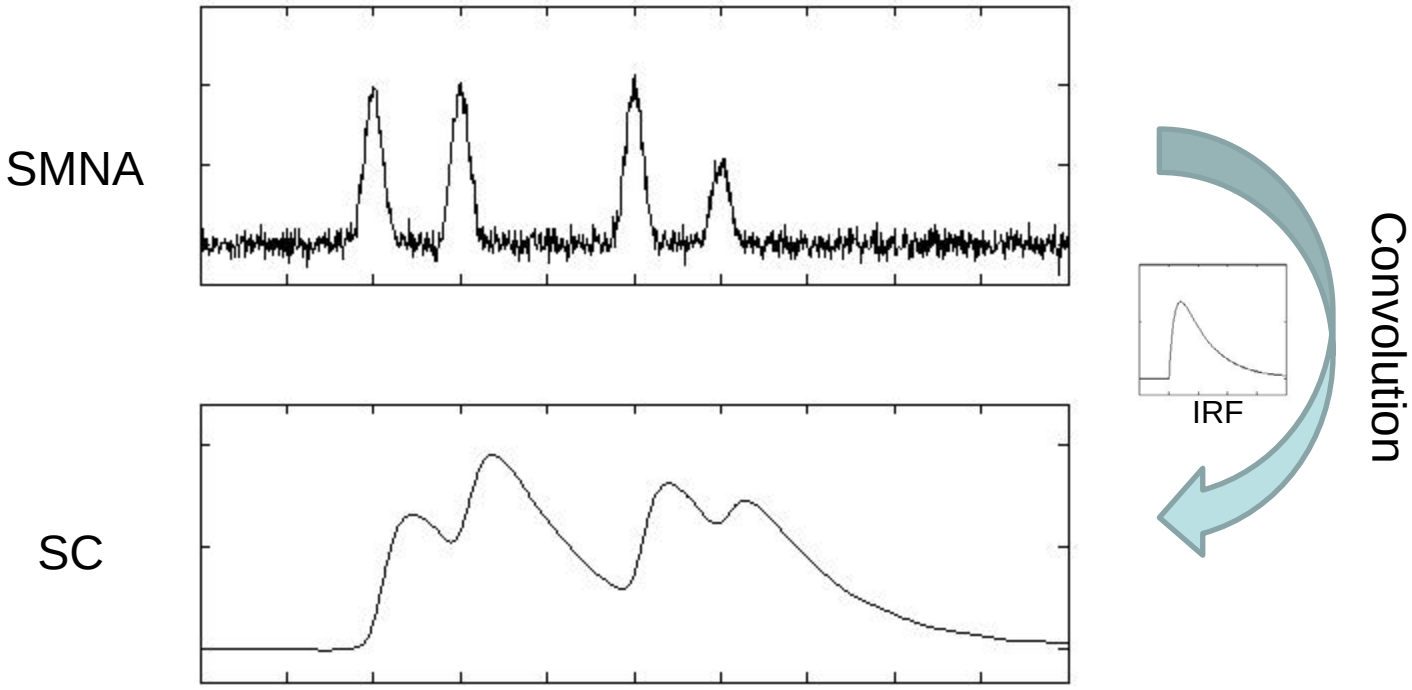
- Amplitude: +15%
- Onset: -140ms

(Lim et al., 1997, Int J Psychoph)

Decomposition Approaches – Deconvolution analysis



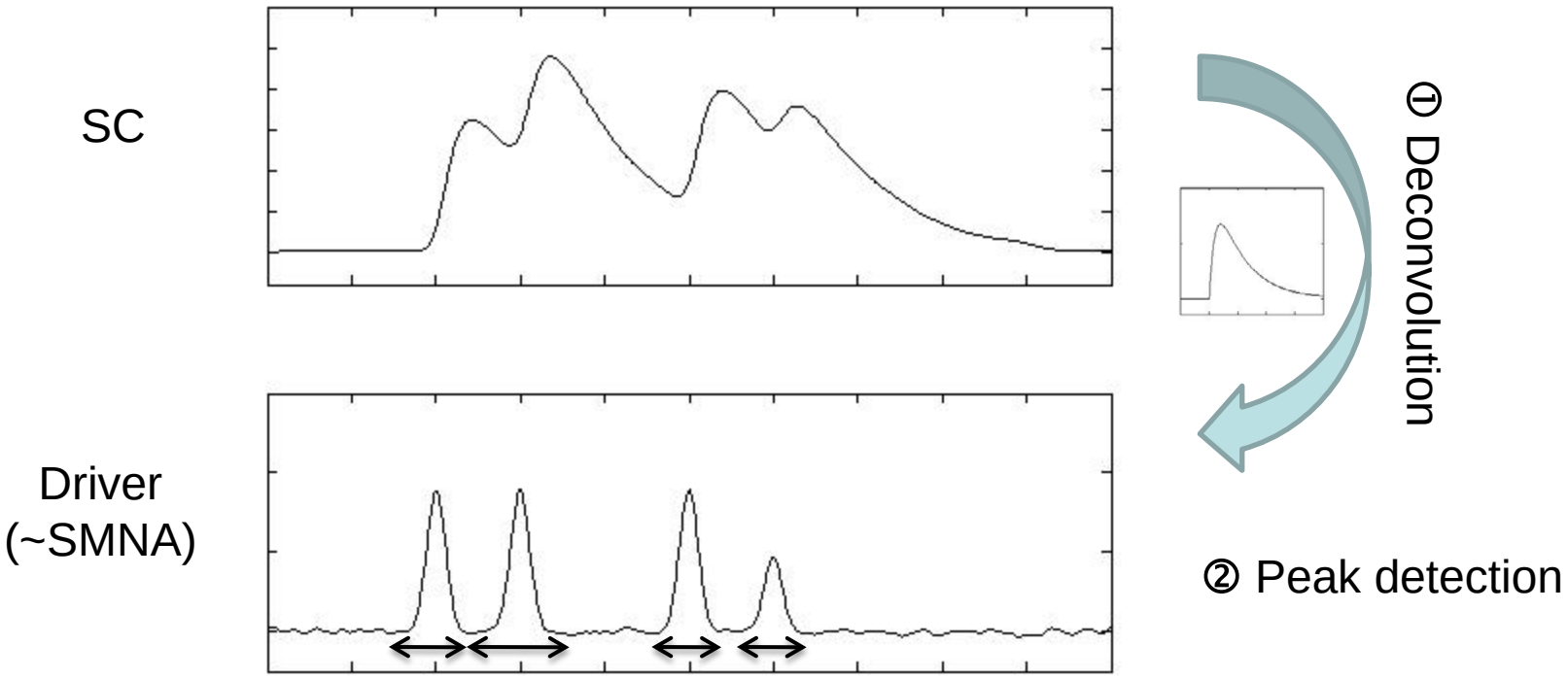
Basic principles of deconvolution analysis



Convolution: *Signal = Driver * IRF (impulse response function)*

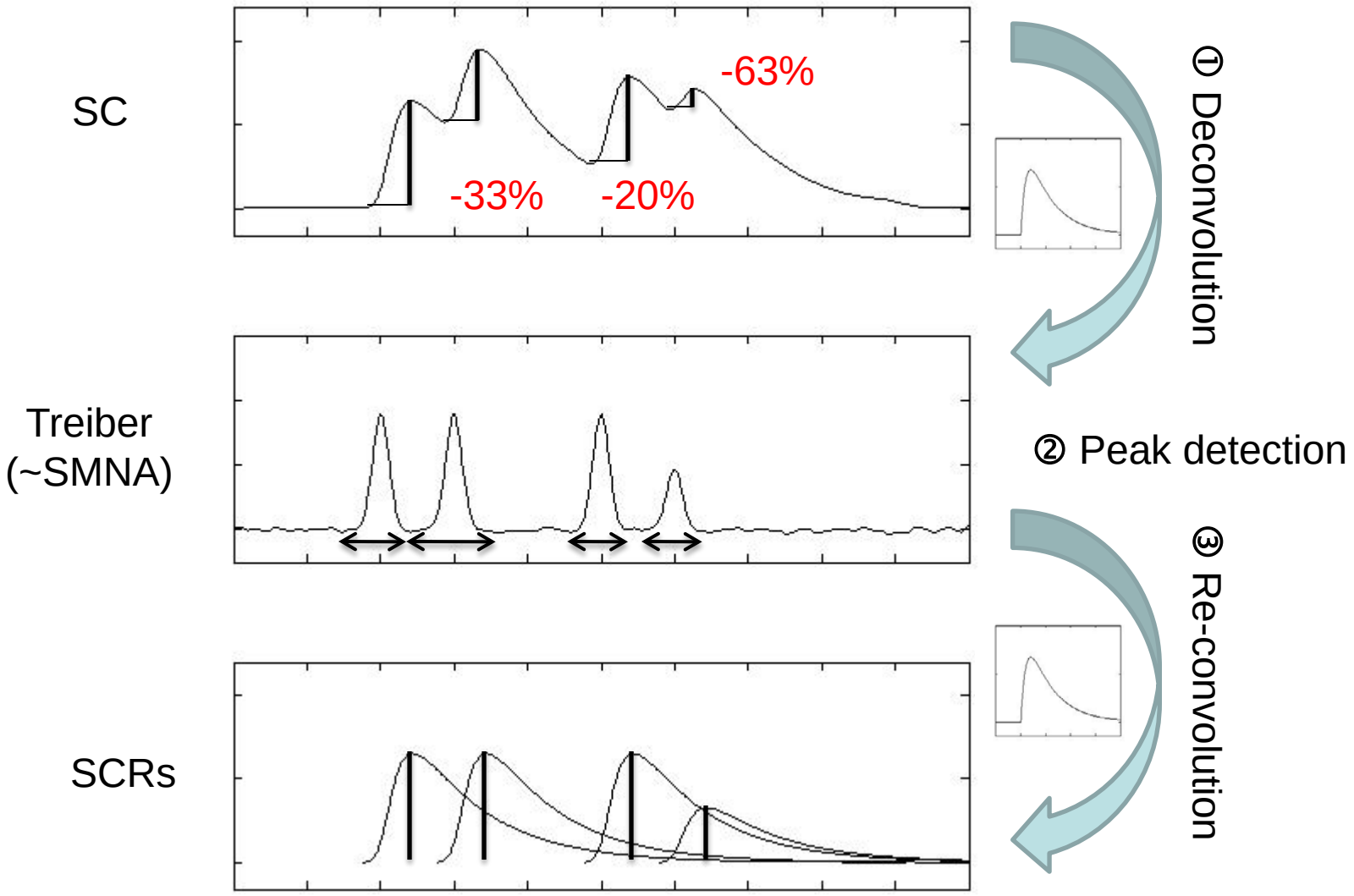
SC = SMNA IRF*

Discrete Decomposition Analysis

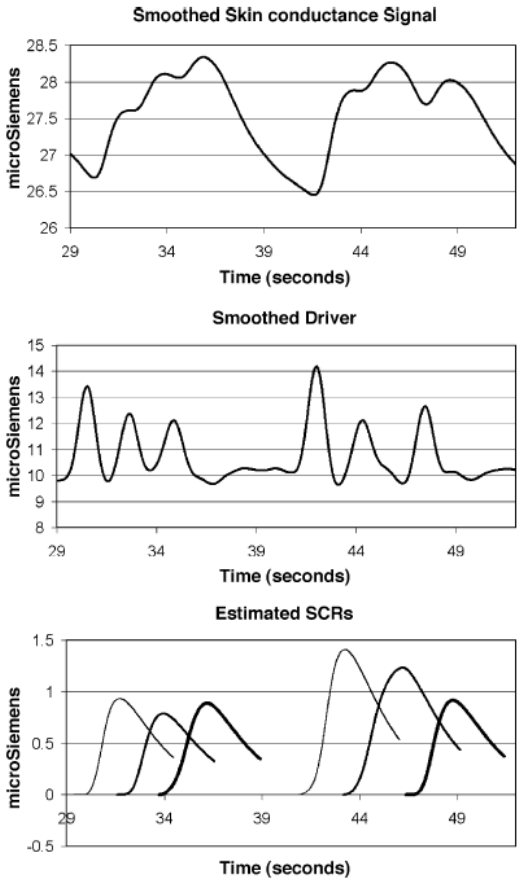


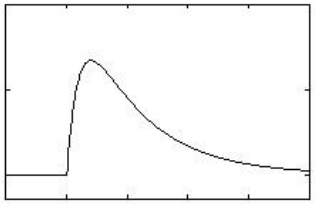
Deconvolution: *SMNA = SC / IRF*

Discrete Decomposition Analysis



Decomposition Approaches - Deconvolution





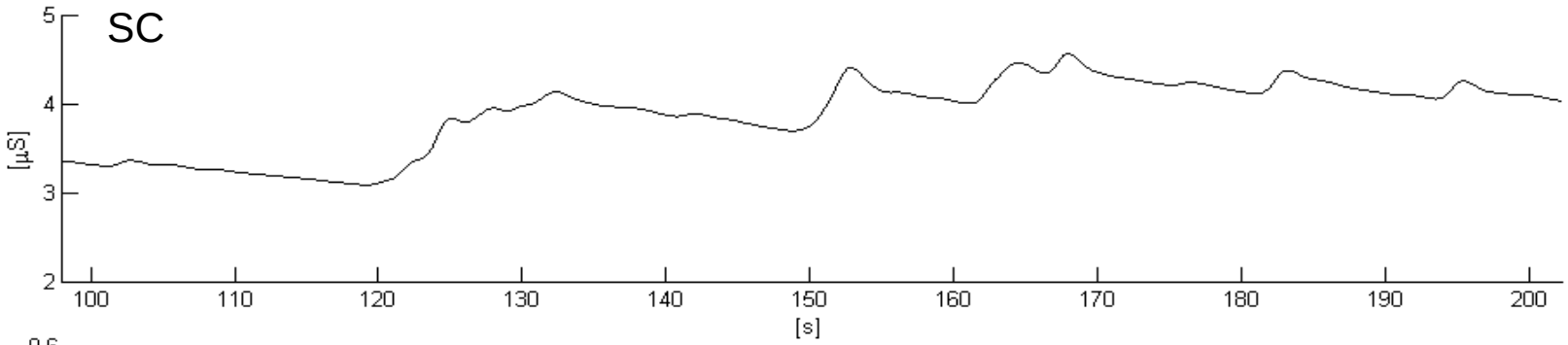
$$IRF = c \cdot \left(e^{-\frac{t}{0.75}} - e^{-\frac{t}{2}} \right)$$

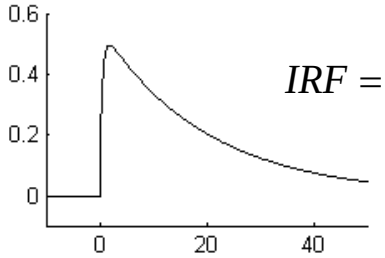
Results:

- Automatic analysis
- Simulation: Discrimination of SCRs with time-lag > 1.3s

(Alexander et al., 2005, J Neurosc Meth)

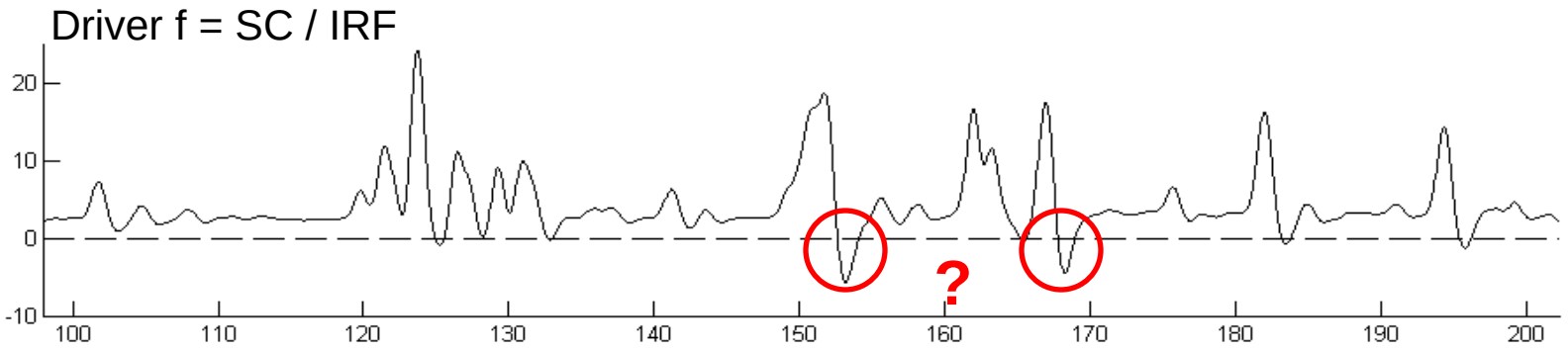
Deconvolution (after Alexander et al., 2005)





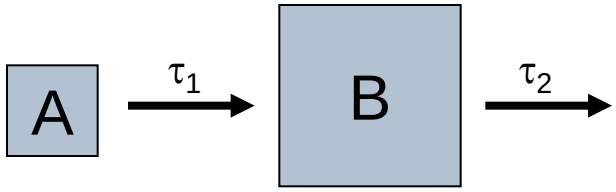
$$IRF = c \cdot \left(e^{-\frac{t}{0.75}} - e^{-\frac{t}{2}} \right)$$

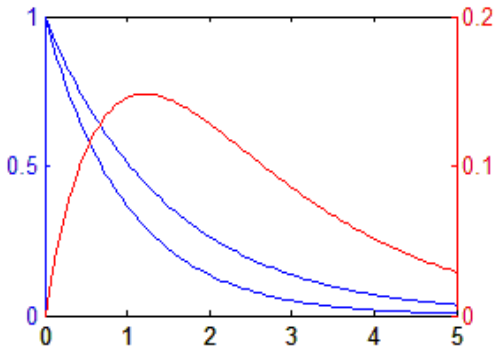
Rationale of SCR shape?



Rationale of SCR shape

Two-compartment diffusion model

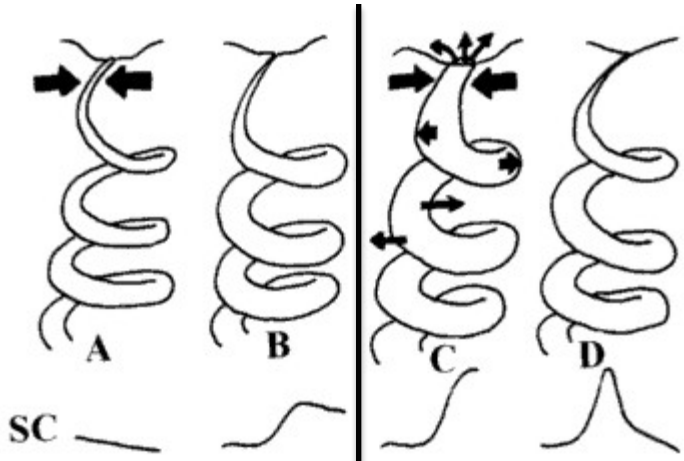




$$\dot{a} = -\frac{a}{\tau_1} \qquad \dot{b} = -\frac{b}{\tau_2} + \frac{a}{\tau_1}$$

$$b = C \cdot \left(e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}} \right)$$

Bateman function

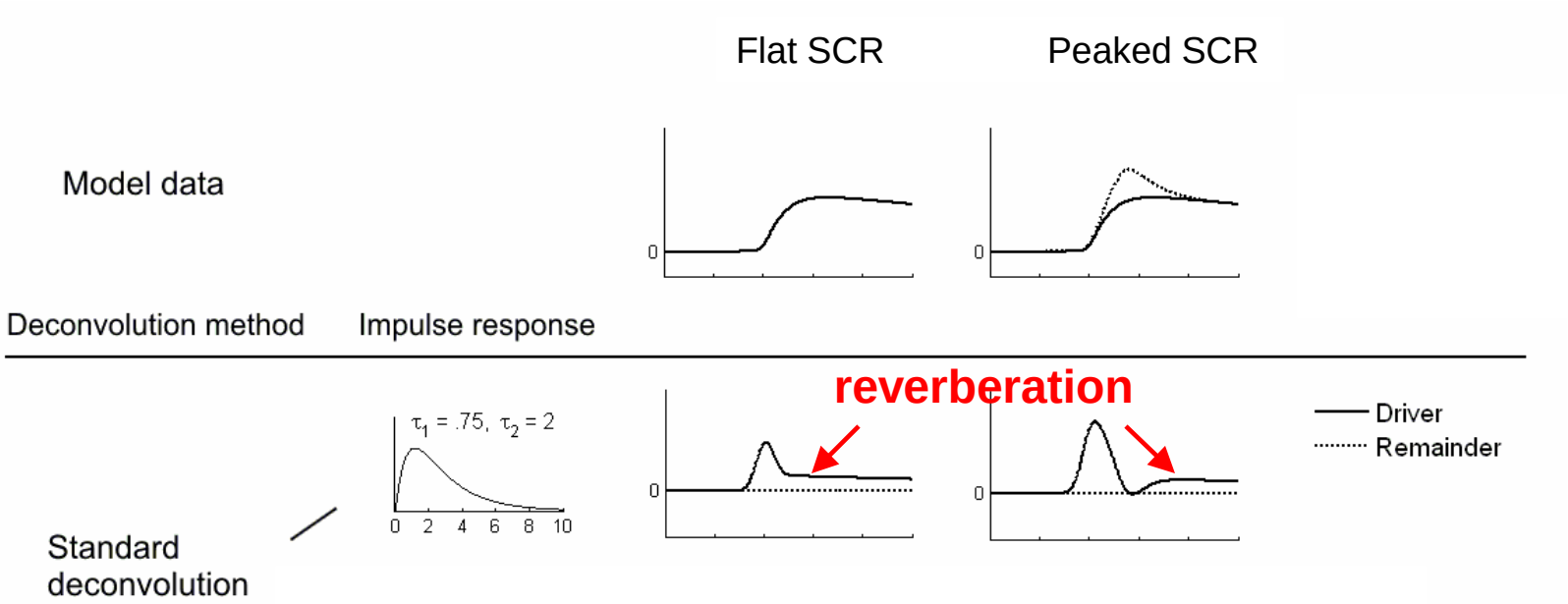


Poral valve model (Edelberg, 1993)

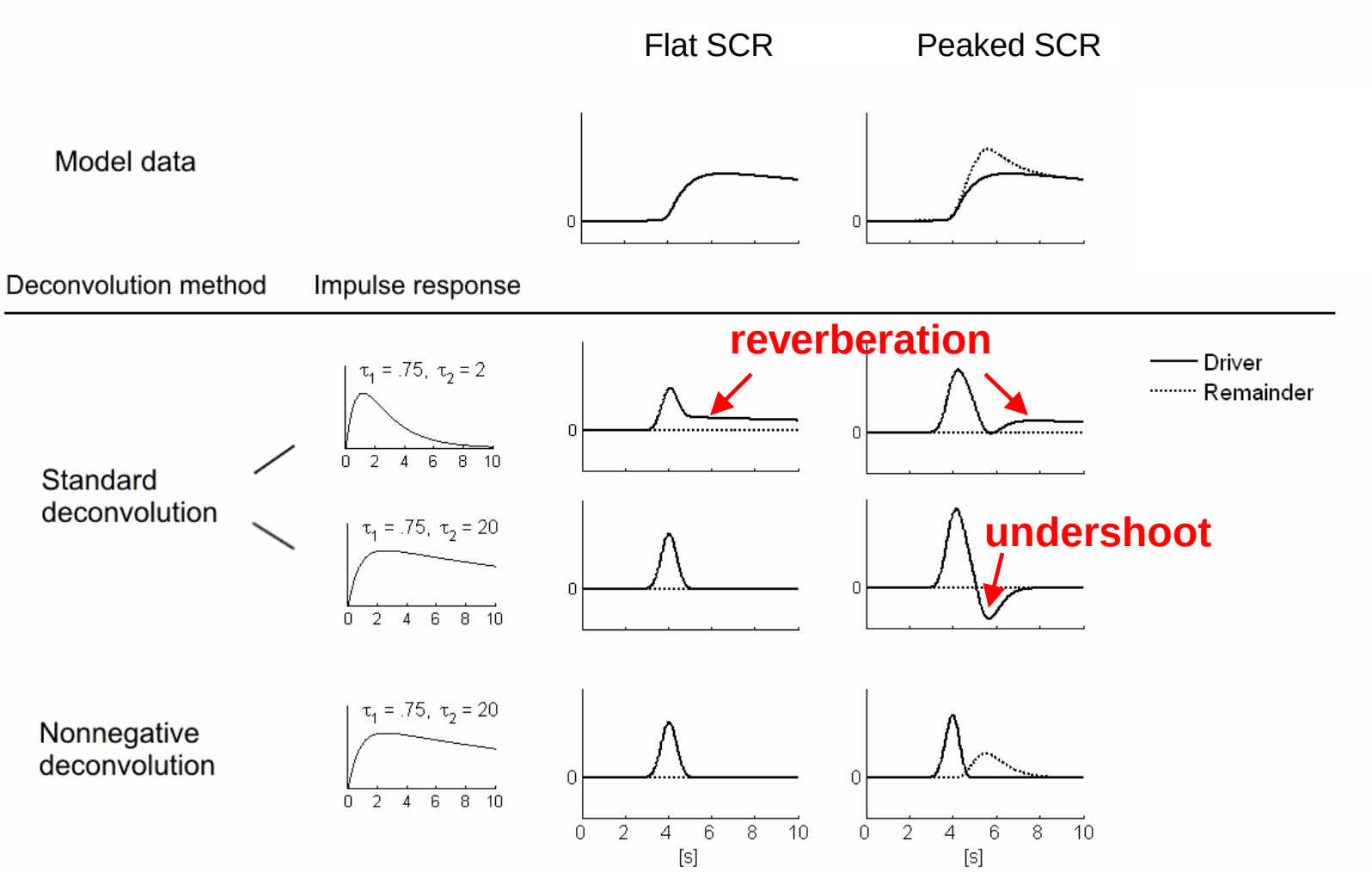
Flat SCR
(Diffusion)

Peaked SCR
(Diffusion + pore opening)

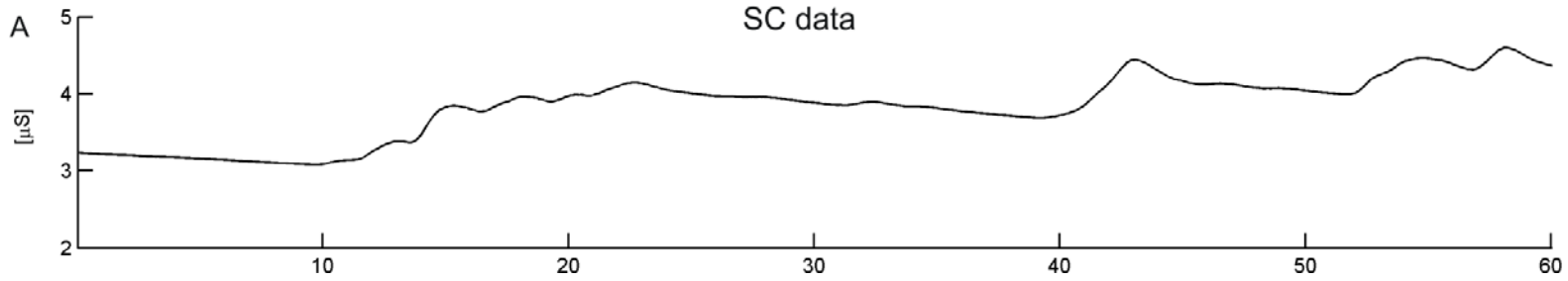
Deconvolution: Effect of differences in SCR shape



Rationale of Nonnegative Deconvolution

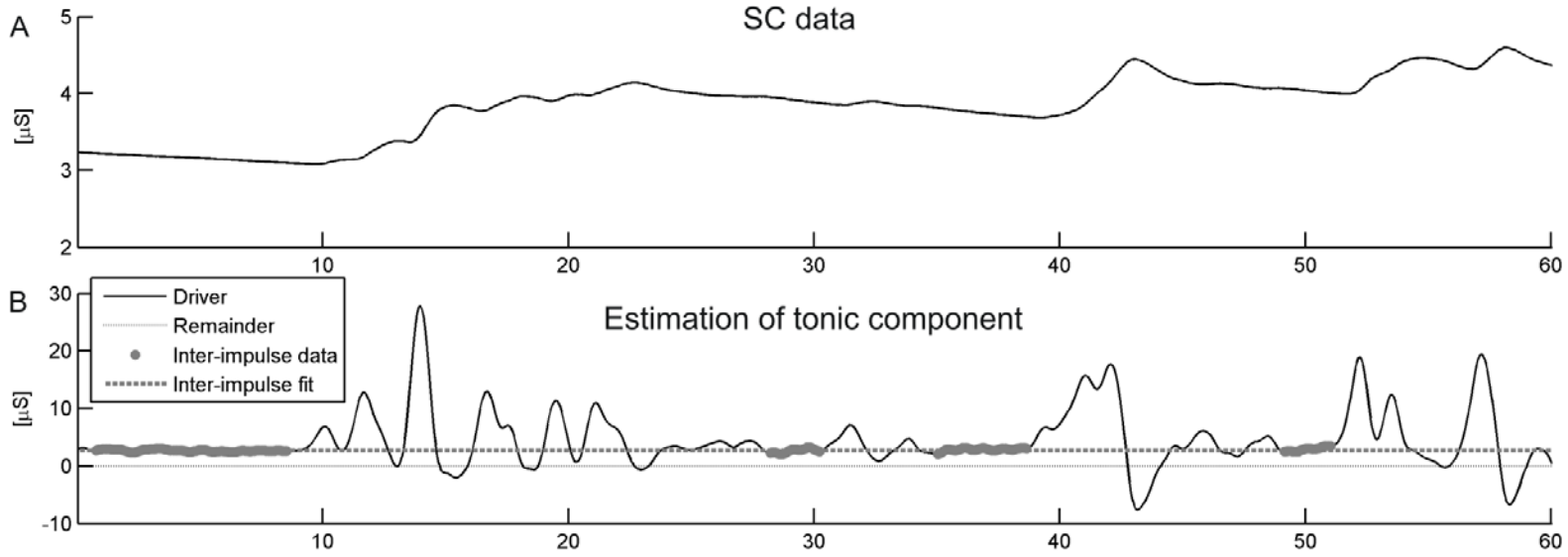


Discrete Decomposition Analysis (Nonnegative Deconvolution)



(Benedek & Kaernbach, 2010, Psychophysiology)

Discrete Decomposition Analysis (Nonnegative Deconvolution)



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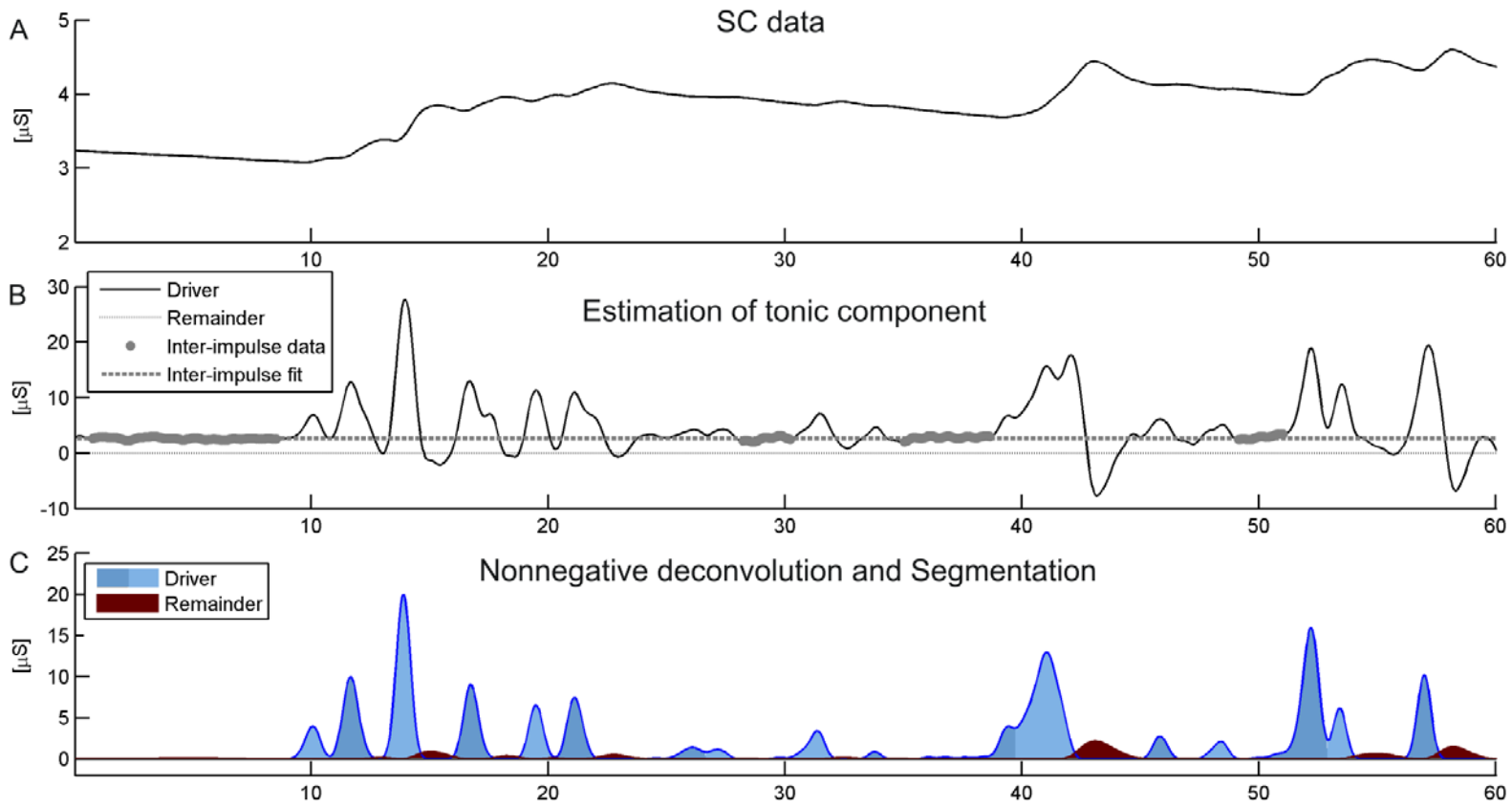
Discrete Decomposition Analysis (Nonnegative Deconvolution)



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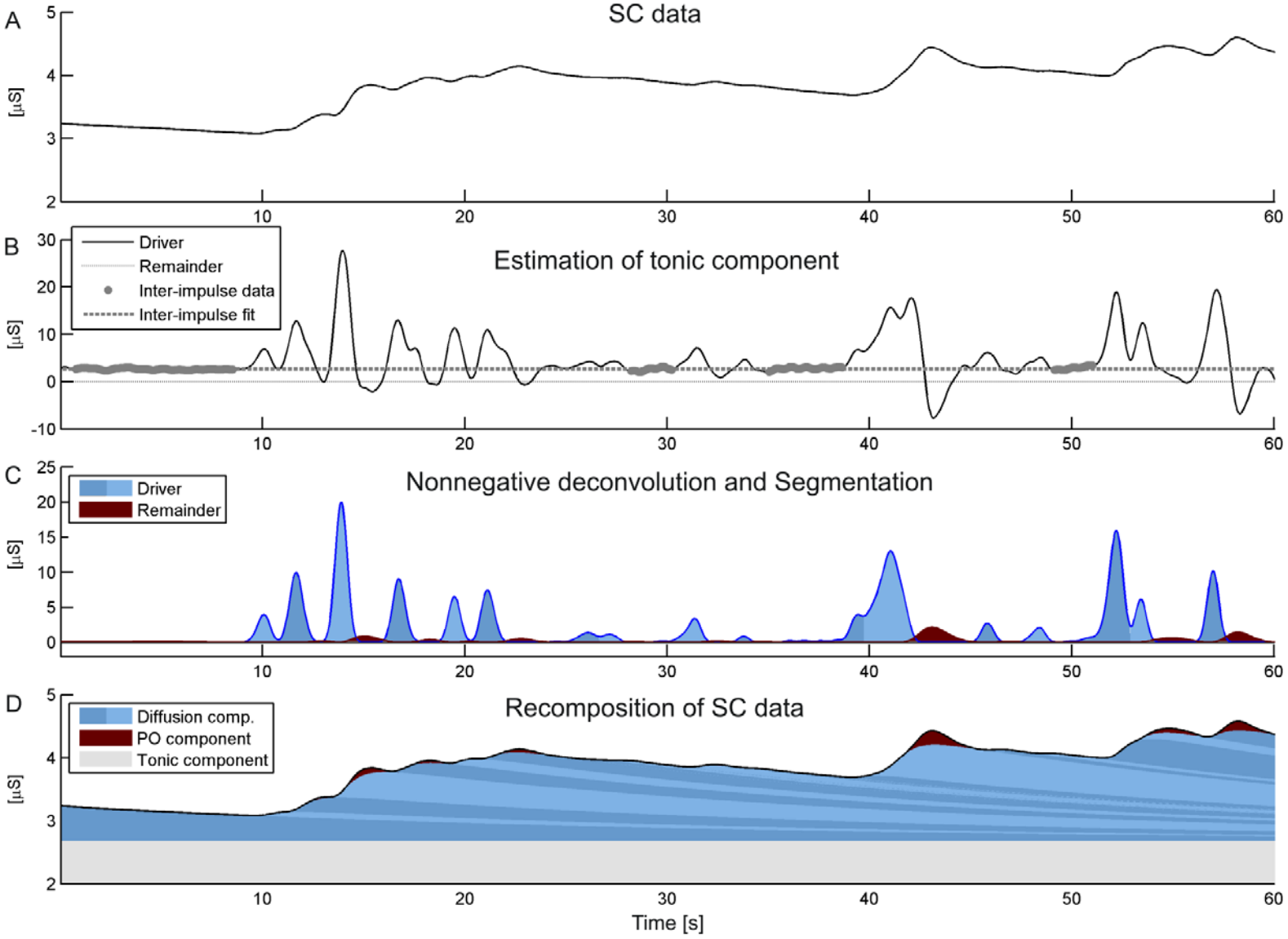

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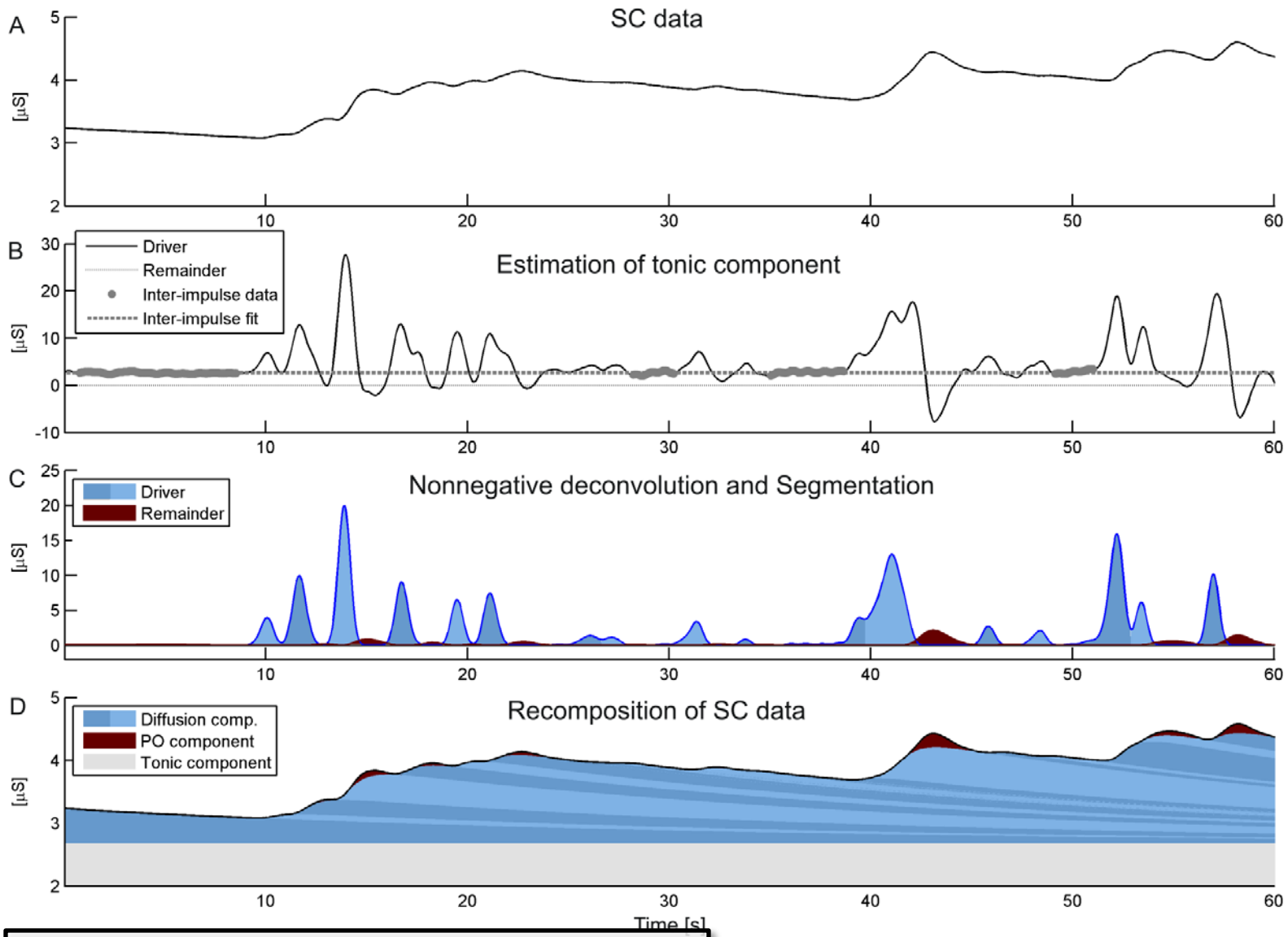
Discrete Decomposition Analysis (Nonnegative Deconvolution)



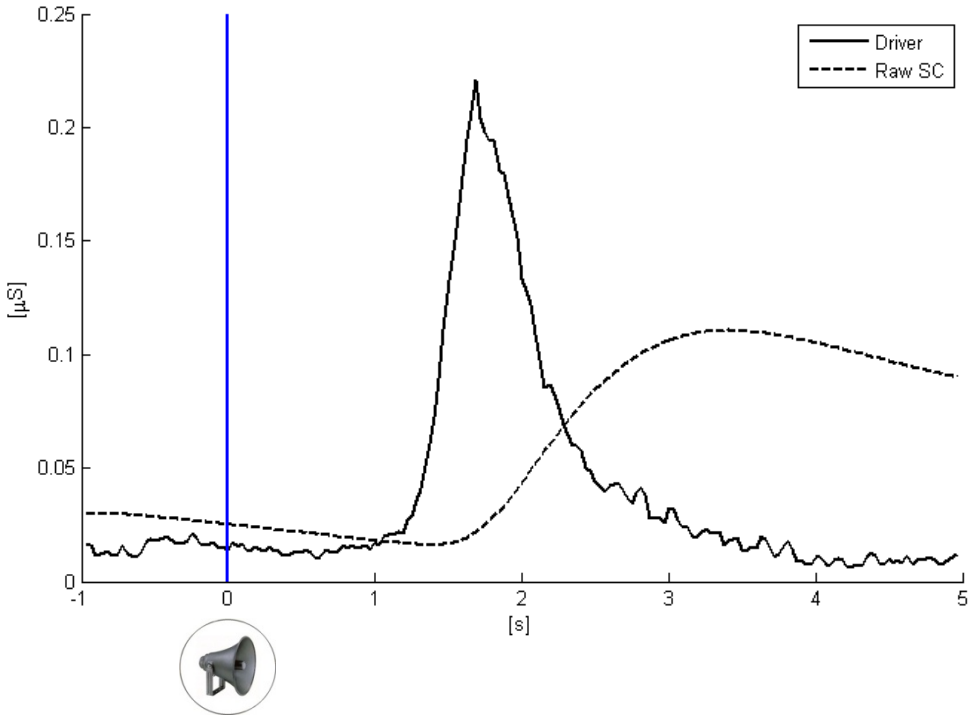
E **Optimization of τ:** $RMSE \cdot n_{response} \cdot indist \rightarrow 0$

(Benedek & Kaernbach, 2010, Psychophysiology)

General effect of deconvolution

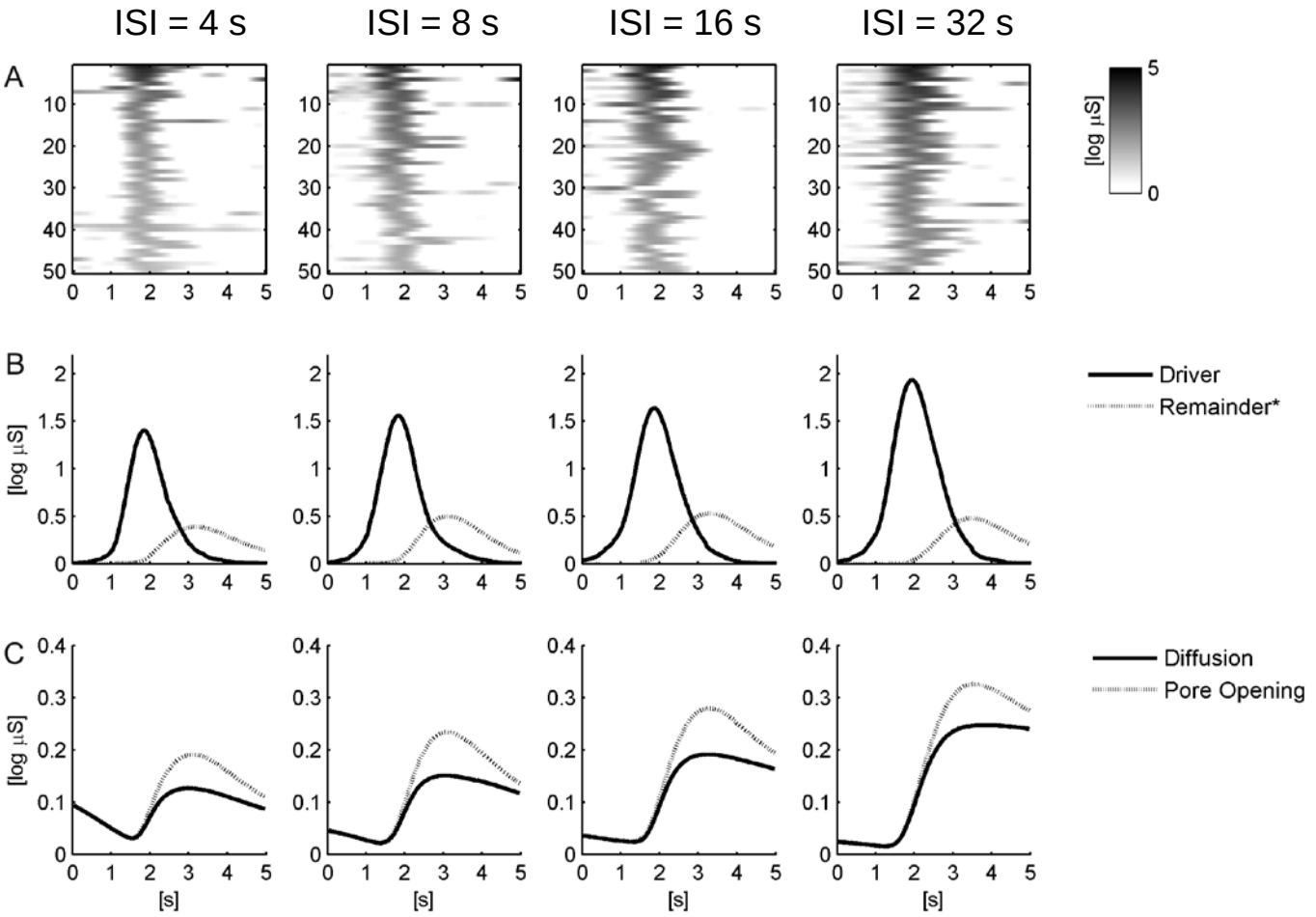
Experiment

- N = 48
- Noise bursts (95 dB, 120ms)
- ISI = 4, 8, 16, 32 sec



- Duration of driver impulse more constrained
- Onset of driver impulse more precisely defined

Event-related response by ISI



Results:

Amplitude: + 17%
Onset: -340ms

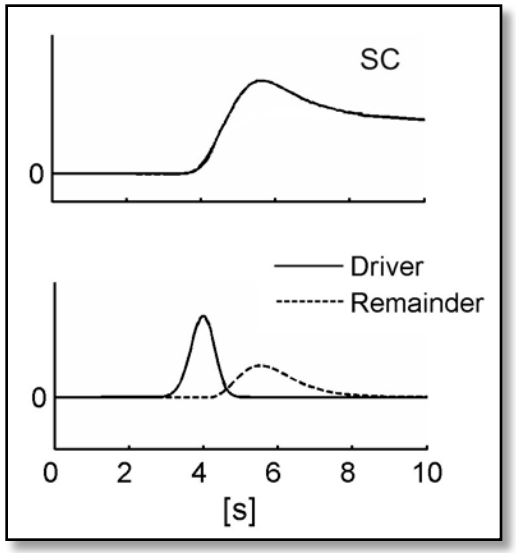
Discrete Decomposition Analysis (Nonnegative Deconvolution)

Features:

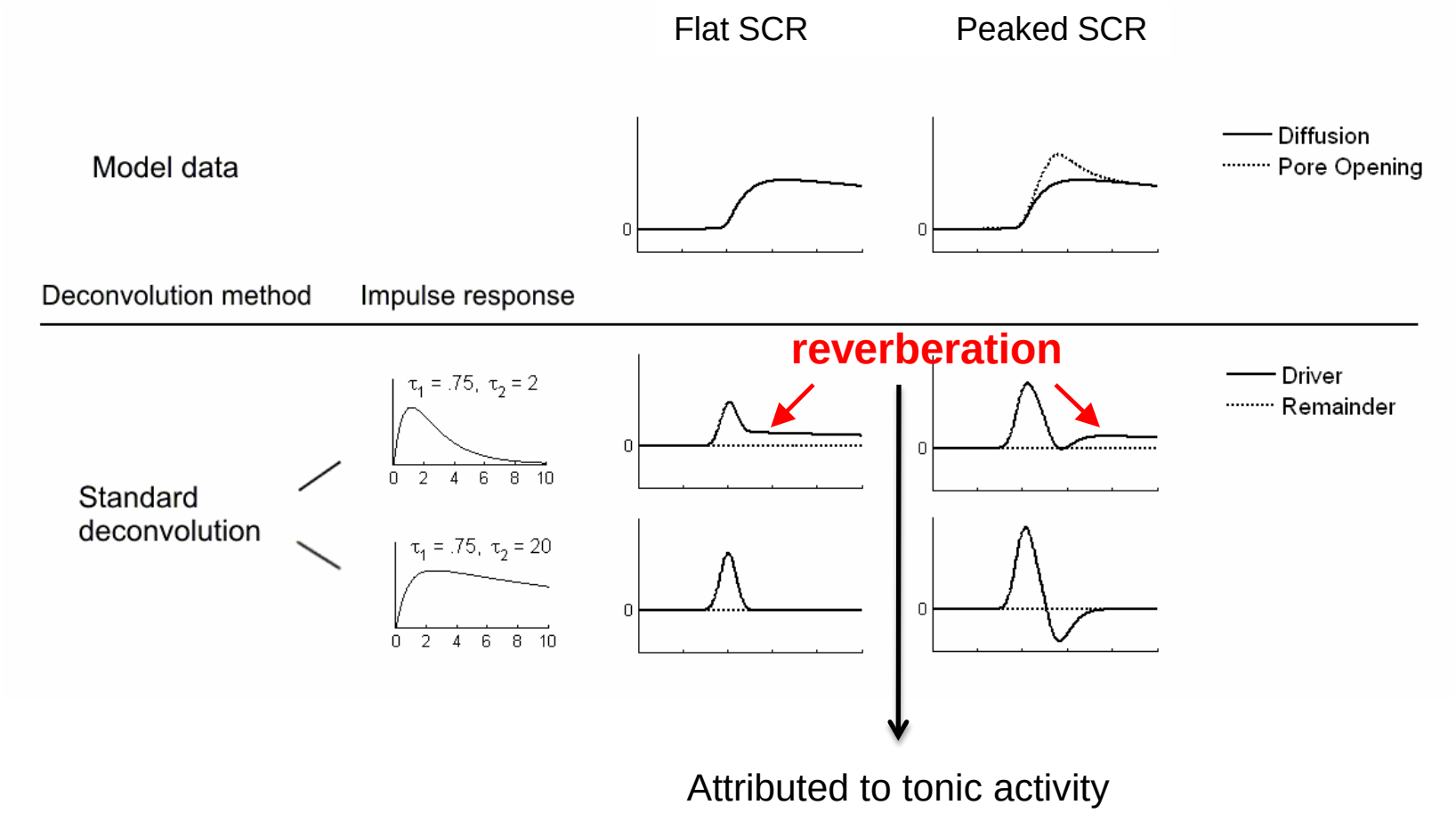
- Physiological rationale of SCR shape
- Estimation of tonic component
- Estimation of inter-individual SCR shape (τ)
- Full component-model of raw SC data
- Unbiased estimation of SCR-magnitude
- Facilitates study of physiological model of SCR

Challenges:

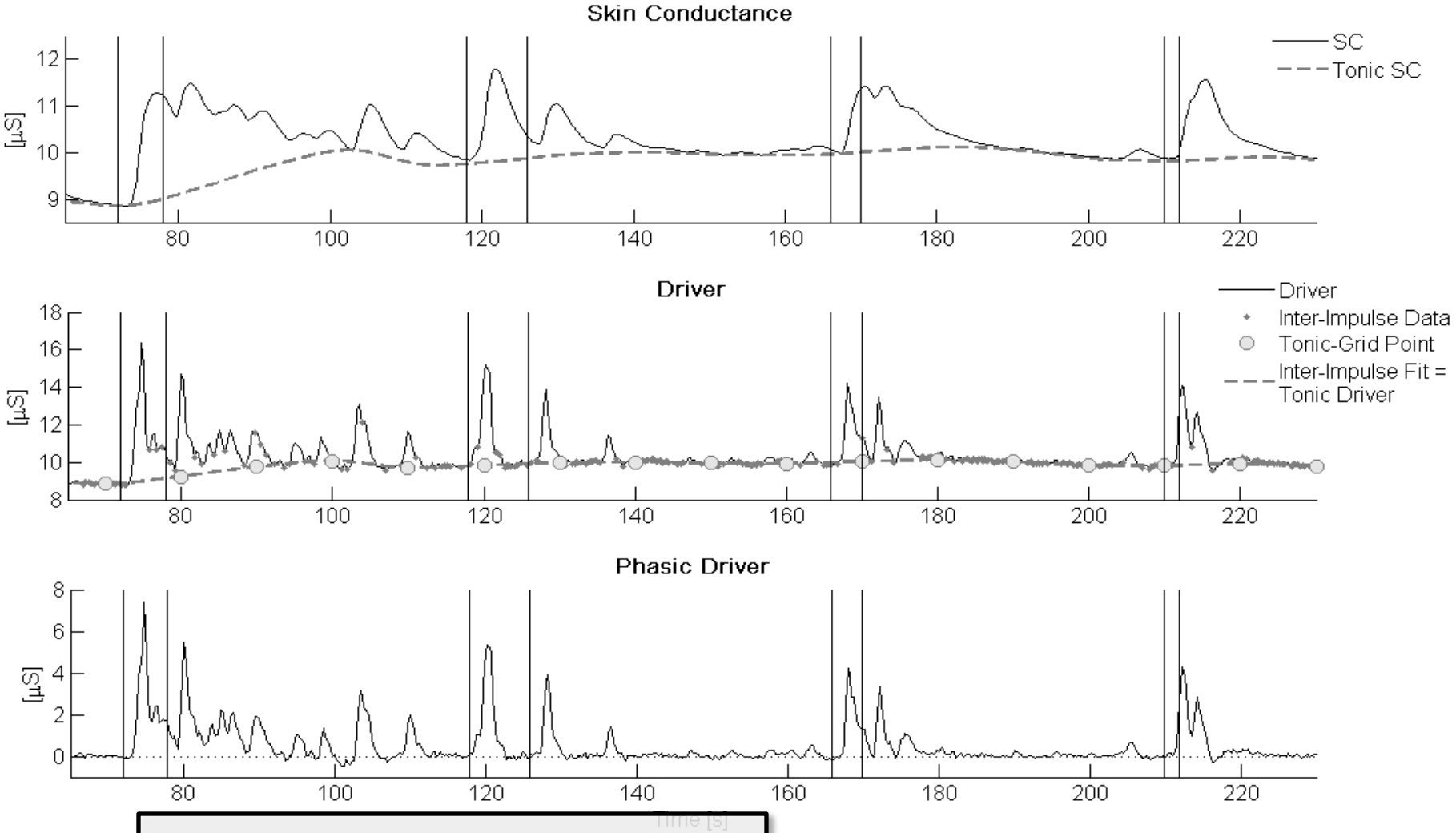
- Sensitive to data quality (e.g., artifacts)
- Time consuming procedure
- Driver may not fully reflect SNA



Rationale of Continuous Decomposition Analysis



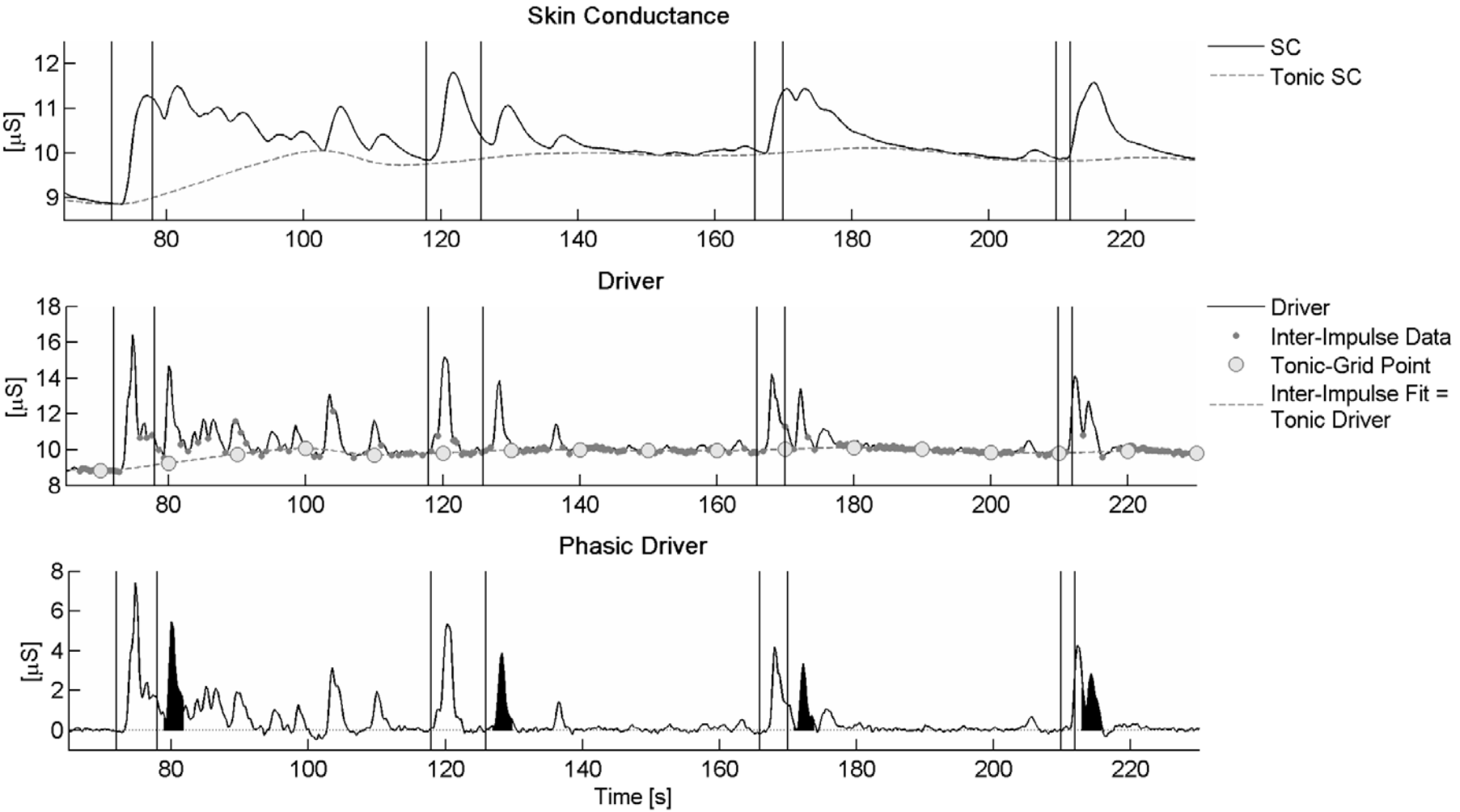
Continuous Decomposition Analysis (Phasic Driver Extraction)



Optimization of τ: $indist + neg \rightarrow 0$

(Benedek & Kaernbach, 2010, J Neurosc Methods)

Continuous Decomposition Analysis (Phasic Driver Extraction)



Integrated SCR (ISCR): Time integral of phasic driver over response window

(Benedek & Kaernbach, 2010, J Neurosc Methods)

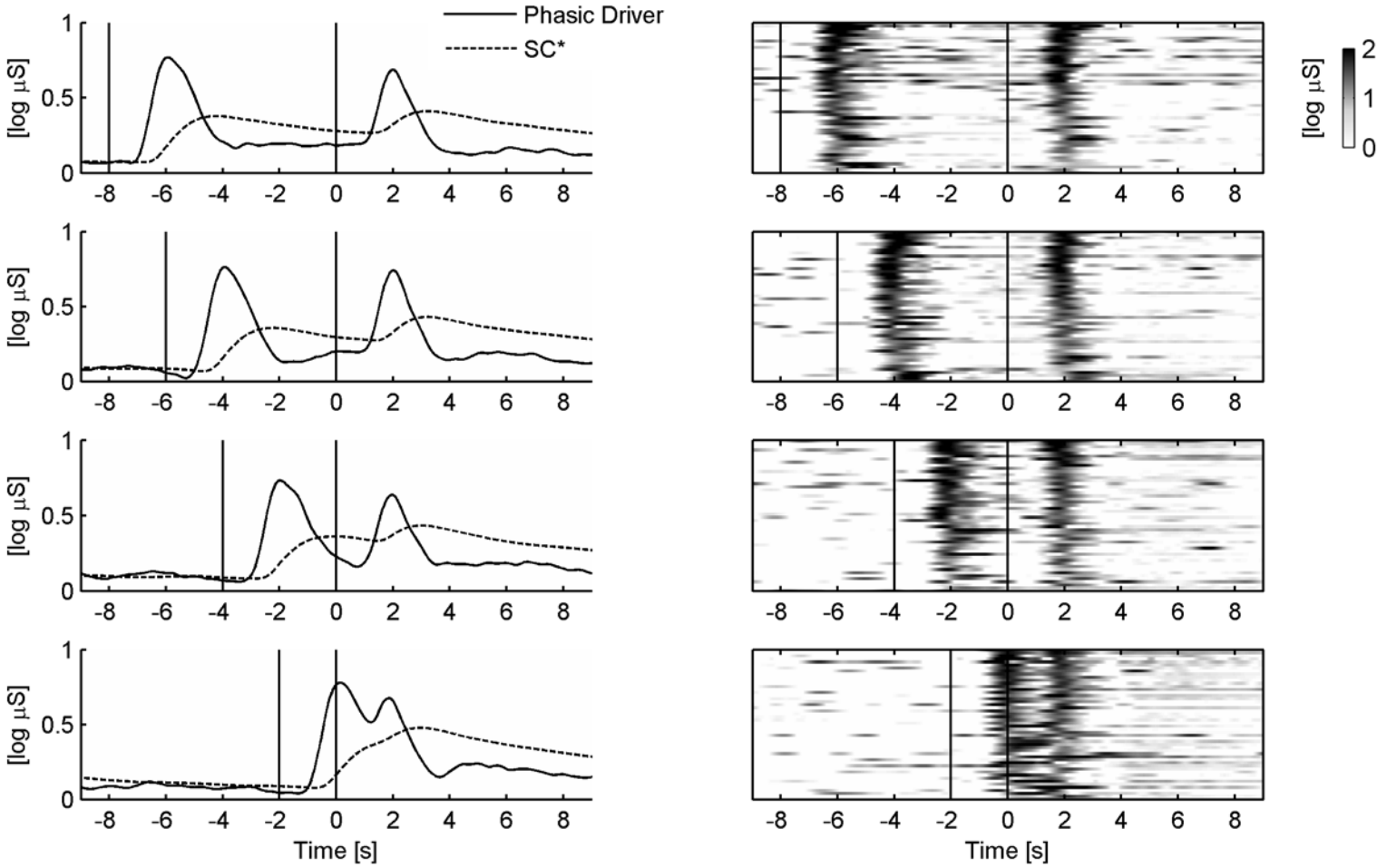
Event-related response by ISI

ISI = 8s

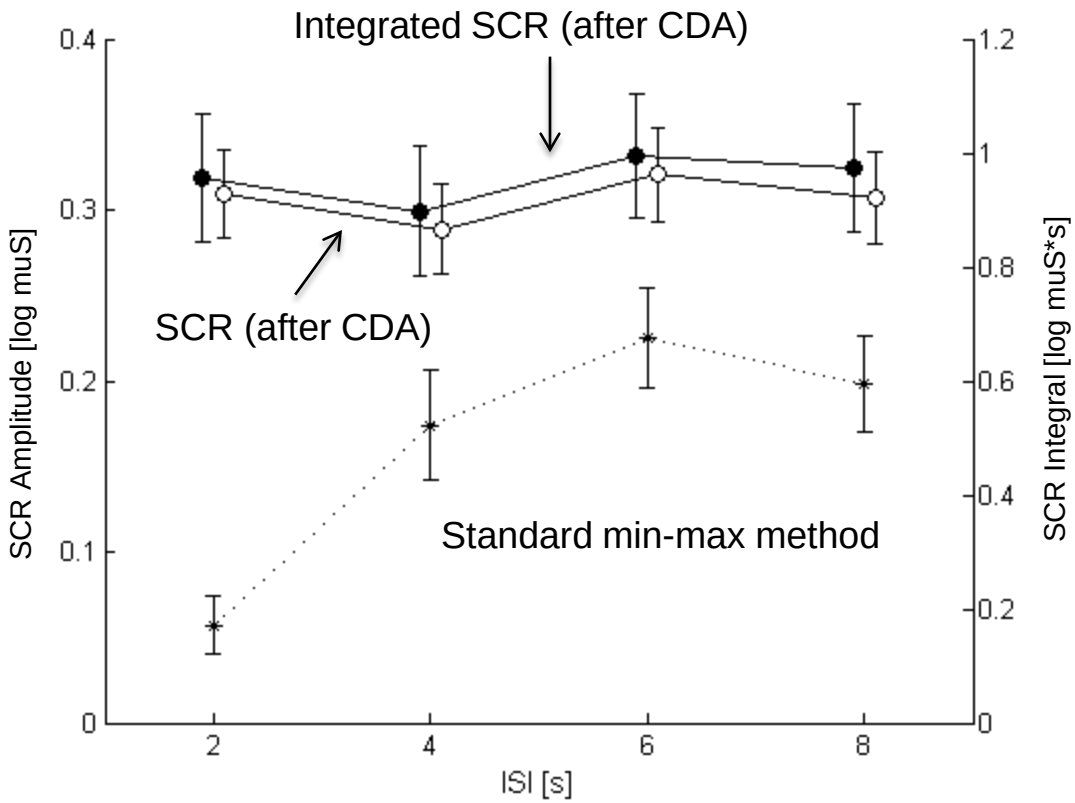
ISI = 6s

ISI = 4s

ISI = 2s

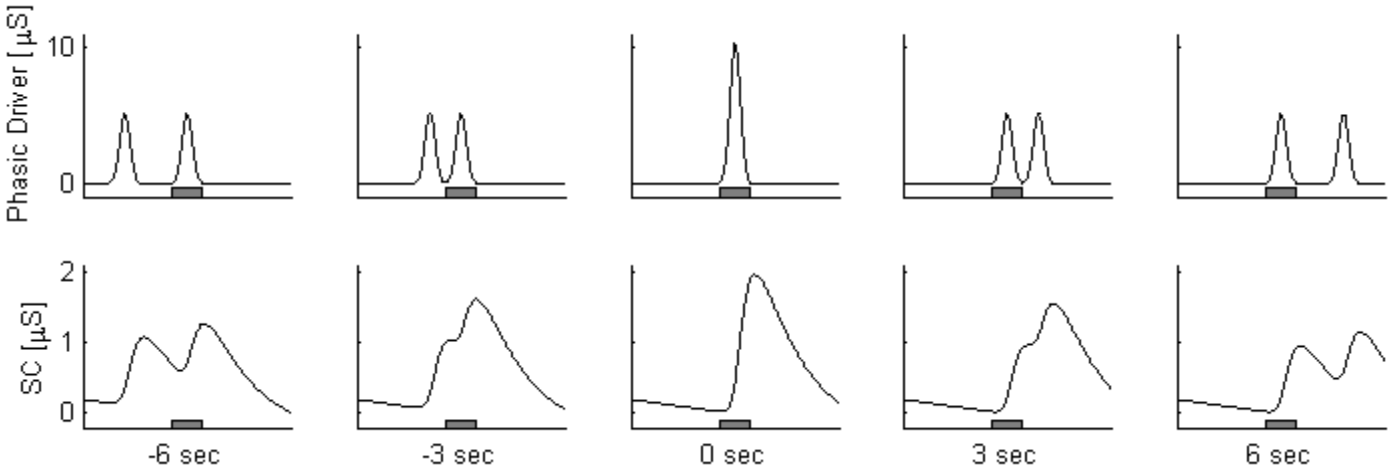


SCR amplitude by method

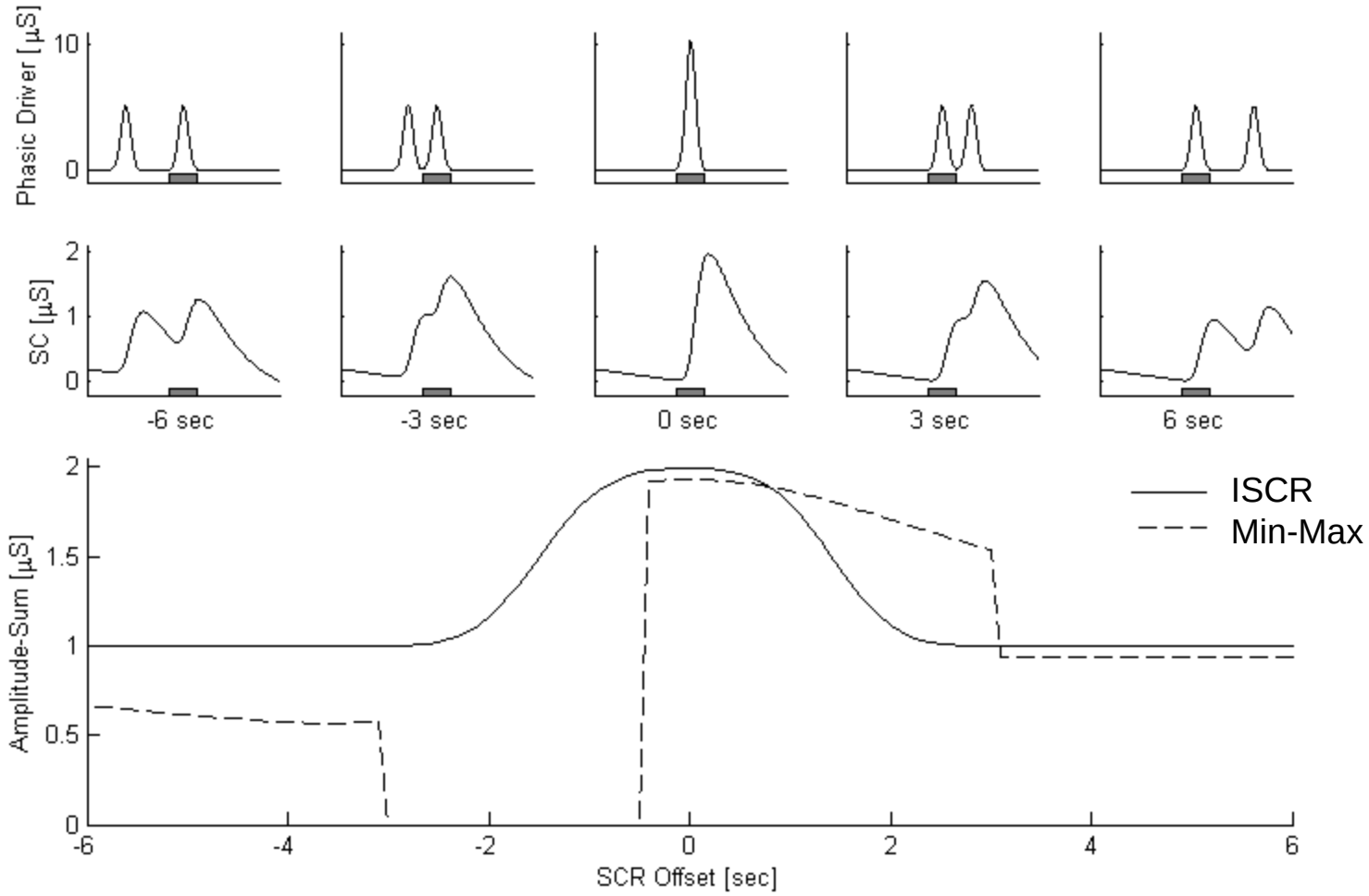


+82% +42% +35% +35%

Simulation: Effect of SCR offset on amplitude



Simulation: Effect of SCR offset on amplitude



Continuous Decomposition Analysis

Features:

- Physiological rationale of SCR shape
- Estimation of tonic component
- Estimation of inter-individual SCR shape (τ)
- Full component-model of raw SC data
  → Separation of continuous tonic and phasic data
- Unbiased estimation of SCR-magnitude
  + Consideration of continuous response information
- (Facilitates study of physiological model of SCR)

Challenges:

- Sensitive to data quality (e.g., artifacts) → Robust
- Time consuming procedure → Fast and efficient
- Driver may not fully reflect SMNA → Driver may reflect SMNA
- Avoids quantization effect

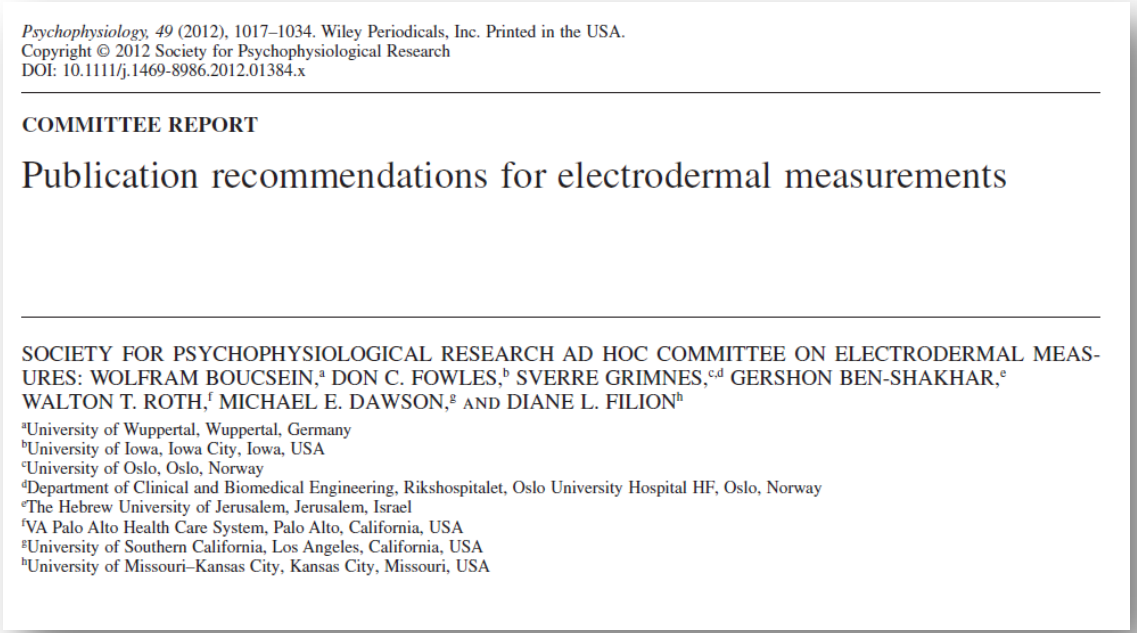
Documentation and References

On **Continuous Decomposition Analysis (CDA) method** and/or
Avoiding biases of classic peak detection methods:

- Benedek, M. & Kaernbach, C. (2010). A continuous measure of phasic electrodermal activity. *Journal of Neuroscience Methods, 190*, 80-91. [link]

On **Discrete Deconvolution Analysis (DDA) method** and/or
the **Consideration of the individual physiological shape of the SCR** :

- Benedek, M. & Kaernbach, C. (2010). Decomposition of skin conductance data by means of nonnegative deconvolution. *Psychophysiology, 47*, 647-658. [link]



Psychophysiology, 49 (2012), 1017–1034. Wiley Periodicals, Inc. Printed in the USA.
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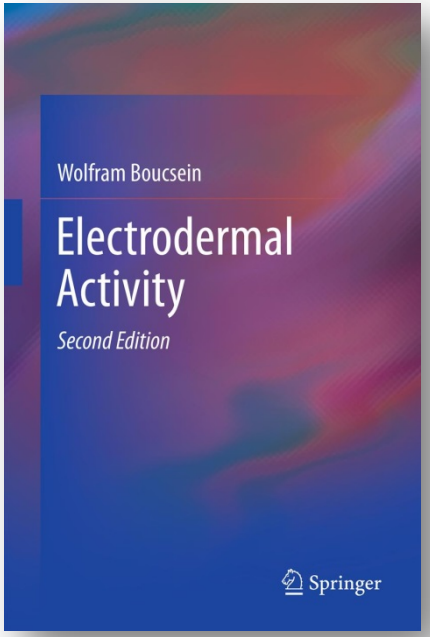
DOI: 10.1111/j.1469-8986.2012.01384.x

COMMITTEE REPORT

Publication recommendations for electrodermal measurements

SOCIETY FOR PSYCHOPHYSIOLOGICAL RESEARCH AD HOC COMMITTEE ON ELECTRODERMAL MEASURES: WOLFRAM BOUCSEIN,[a] DON C. FOWLES,[b] SVERRE GRIMNES,[c,d] GERSHON BEN-SHAKHAR,[e] WALTON T. ROTH,[f] MICHAEL E. DAWSON,[g] AND DIANE L. FILION[h]

[a]University of Wuppertal, Wuppertal, Germany
[b]University of Iowa, Iowa City, Iowa, USA
[c]University of Oslo, Oslo, Norway
[d]Department of Clinical and Biomedical Engineering, Rikshospitalet, Oslo University Hospital HF, Oslo, Norway
[e]The Hebrew University of Jerusalem, Jerusalem, Israel
[f]VA Palo Alto Health Care System, Palo Alto, California, USA
[g]University of Southern California, Los Angeles, California, USA
[h]University of Missouri–Kansas City, Kansas City, Missouri, USA

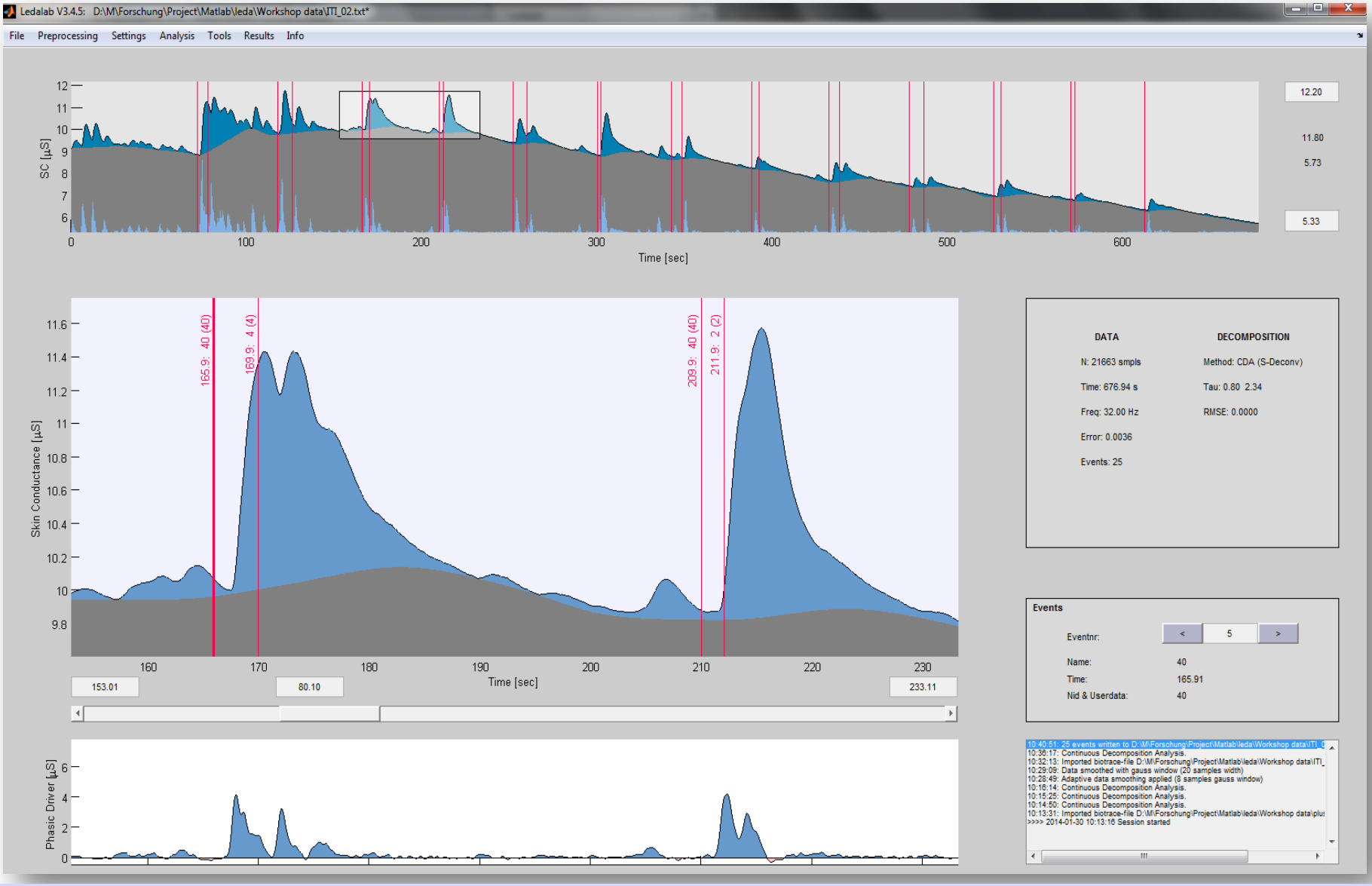


Using Ledalab for EDA analysis

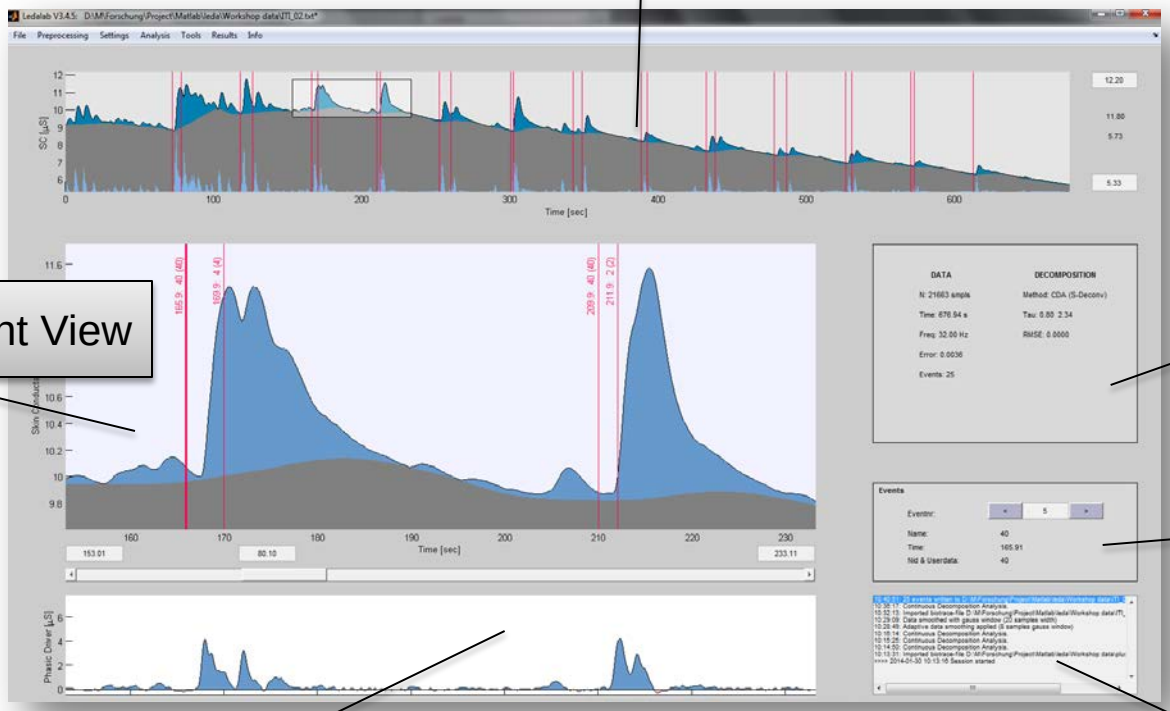
Ledalab

- Open Software (Matlab is required)
- Download at website: www.ledalab.de
  - Software updates
  - Online documentation

EDA Analysis Software: Ledalab

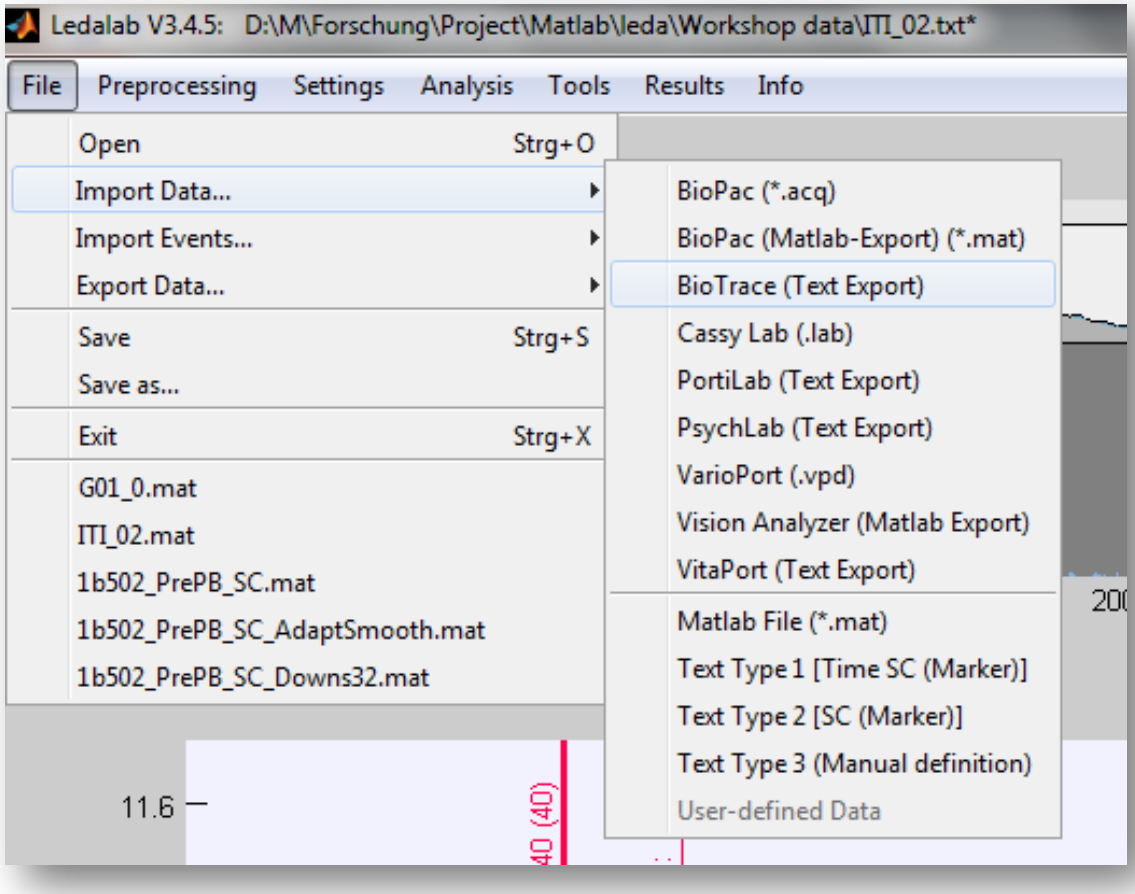


Graphical user interface (GUI)



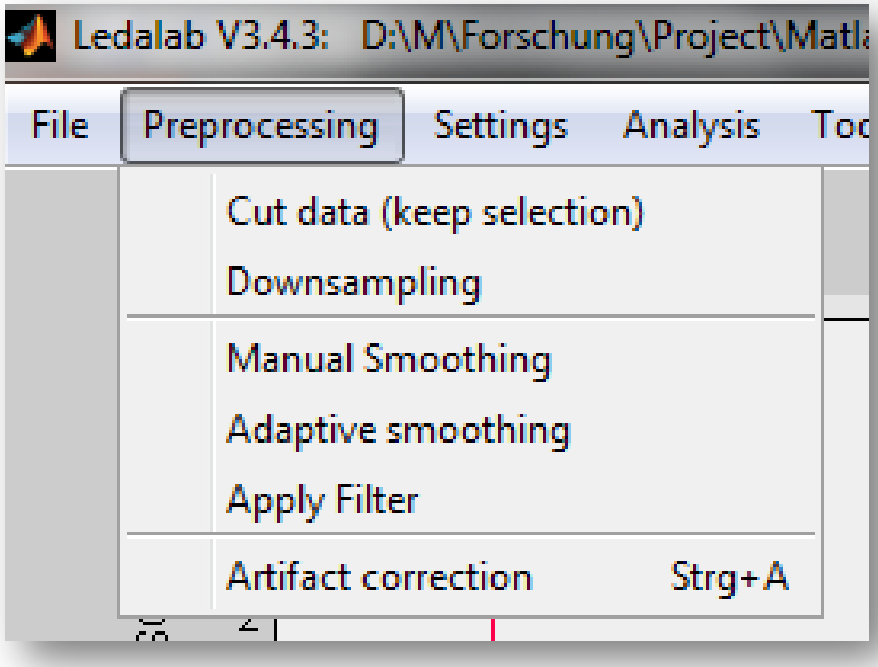
Data Import

Ledalab supports the import of various data formats (see screenshot).



Preprocessing functions

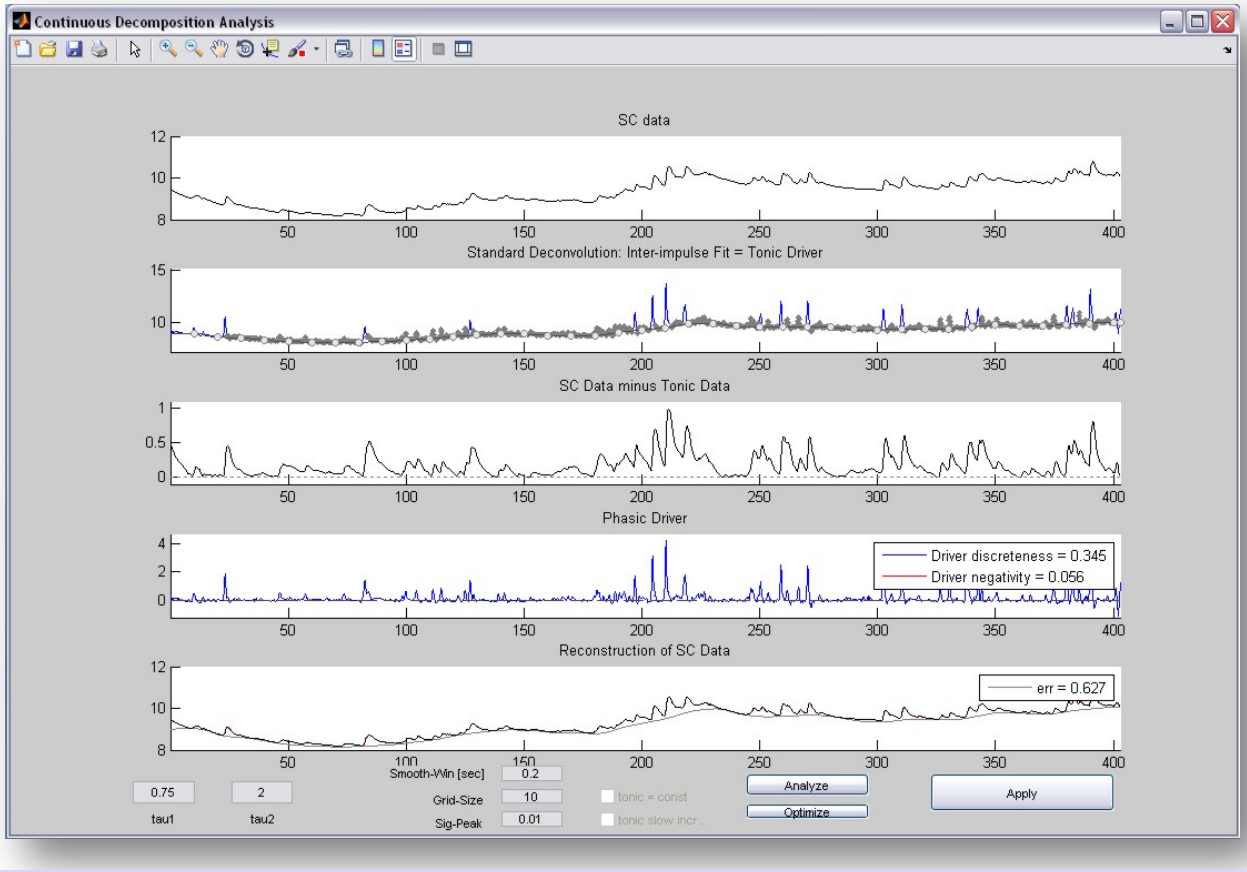
Ledalab can be used for data preprocessing including cutting, downsampling, smoothing and artifact correction.



Analysis

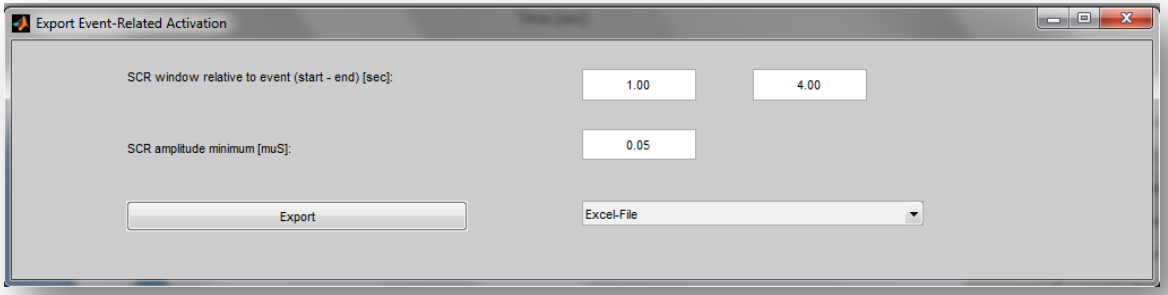
- Methods:
  - Continuous Decomposition Analysis (recommended)
  - Discrete Decomposition Analysis (Nonnegative Deconvolution)
  - Min-max analysis (trough-to-peak): always included

- Steps:
  - Run analysis
  - Optimize analysis
  - Apply to data



Results Export

- Export event-related activation to Excel, Text, or Matlab file
- Many parameters of phasic and tonic activity (see online documentation)
- Additionally, you can save a list of detected SCRs



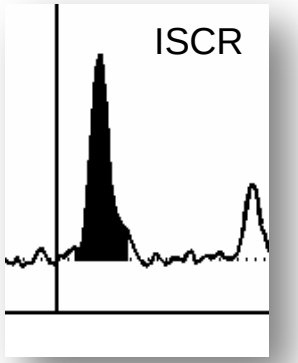
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Event.Nr	Event.NID	Event.Name	CDA.nSCR	CDA.Latency	CDA.AmpSur	CDA.SCR [mu	CDA.ISCR [m	CDA.Tonic [n	TTP.nSCR	TTP.Latency	TTP.AmpSun	Global.Mean	Global.MaxDeflection [muS]	
2	1	40	40	2	1,96875	2,26055825	4,78365526	14,3509658	8,87134346	1	1,09375	2,43218966	9,70570103	2,192	
3	2	6	6	3	1,9375	1,54782657	3,08160458	9,24481373	8,94547752	1	1,71875	0,73850732	11,1500515	0,744	
4	3	40	40	1	2,03125	1,92769854	4,05411157	12,1623347	9,50071467	0		0	10,8609691	1,885	
5	4	8	8	2	2	1,10829658	2,30122665	6,90367996	9,56859947	1	1,5	0,88077371	10,6203196	0,882	
6	5	40	40	3	1,9375	1,51575672	3,12254105	9,36762316	9,90697815	1	1,5	1,43171832	10,6008351	1,362	
7	6	4	4	1	2,0625	0,65561007	1,31329089	3,93987267	9,90414345	1	1,90625	0,25978327	11,3316289	0,263	
8	7	40	40	1	2,15625	1,31319598	3,13263561	9,39790684	9,80841218	1	1,375	1,69976442	10,4420309	1,335	
9	8	2	2	1	2,09375	0,64604663	1,35570432	4,06711295	9,8025814	0		0	11,3358557	0,742	
10	9	40	40	1	1,96875	1,14867999	2,29203518	6,87610555	9,28853441	1	1,1875	1,07693163	9,97553608	1,079	
11	10	8	8	1	2,03125	0,5187511	0,98023017	2,94069052	9,26552051	1	1,65625	0,33674132	10,0179381	0,338	
12	11	40	40	2	2,09375	2,15988871	3,70534434	11,116033	8,78265404	1	1,125	1,9204384	9,4421134	1,487	
13	12	2	2	1	2,03125	0,7844172	1,76229338	5,28688014	8,77417991	0		0	10,4496598	0,972	
14	13	40	40	1	2,40625	0,25911277	0,49789999	1,49369998	8,61134059	1	1,8125	0,19614261	8,83040206	0,197	
15	14	6	6	1	2,34375	1,03895703	2,04301844	6,12905533	8,59005273	1	1,53125	0,97918108	9,16015464	0,981	
16	15	40	40	1	2,25	0,5817176	1,19414358	3,58243073	8,18418926	1	1,65625	0,53804267	8,46364948	0,539	

What EDA scores to use?

Ledalab computes classic and novel scores of phasic and tonic EDA.

EDA scores based on decomposition methods are claimed to be more sensitive (Benedek & Kaernbach, 2010a,b).
They include (for Continuous Decomposition Analysis) e.g.:

- **AmpSum** = Sum of amplitudes of all reconvolved SCR with onset in response window (cf. ITTP in Benedek & Kaernbach, 2010b)
- **ISCR** = Integrated phasic driver activity within response window (thought to correspond to total average sudomotor nerve activity SMNA; Benedek & Kaernbach, 2012b)
- **SCR** = Average phasic driver activity within response window (equals ISCR divided by size of response window; units are muS)
- .. and more



But classic EDA measures such as min-max/through-to-peak amplitudes are always provided additionally if you wish to fall back on them (they do not rely decomposition methods, but on simple peak detection).

Command line batch-analysis

- Run *Ledalab* directly from Matlab command window
- Analyze all files in folder
- Use Ledalab functions related to import, preprocessing, analysis, and results export

Command Window

```
>> Ledalab('D:\M\Forschung\Project\Matlab\leda\Workshop data', 'open', 'biotrace', 'downsample',2, 'analyze','CDA', 'optimize',2, 'export_era',[1 4 .01 1])
```

Command Window

```
11:34:56: Starting Ledalab batch for D:\M\Forschung\Project\Matlab\leda\Workshop data\ (10 file/s)

11:34:56: Batch-Analyzing ITI_01.txt
Optimized parameter:  1.99   5.61    Error:  0.734 (Initial parameter:  1.00     3.75    Error:  1.467)
Optimized parameter:  2.04   5.40    Error:  0.731 (Initial parameter:  1.00     2.00    Error:  2.750)
Final optimized parameter:   2.04     5.40   Error:  0.731

11:35:08: Batch-Analyzing ITI_02.txt
Optimized parameter:  0.96   2.17    Error:  0.681 (Initial parameter:  1.00     3.75    Error:  0.980)
Optimized parameter:  1.42   1.70    Error:  0.668 (Initial parameter:  1.00     2.00    Error:  0.826)
Final optimized parameter:   1.42     1.70   Error:  0.668

11:35:16: Batch-Analyzing ITI_03.txt
Optimized parameter:  0.52   0.73    Error:  0.404 (Initial parameter:  1.00     3.75    Error:  8.832)
Optimized parameter:  0.40   0.88    Error:  0.410 (Initial parameter:  1.00     2.00    Error:  4.030)
Final optimized parameter:   0.52     0.73   Error:  0.404

11:35:23: Batch-Analyzing ITI_04.txt
```

Aggregate and save results across files

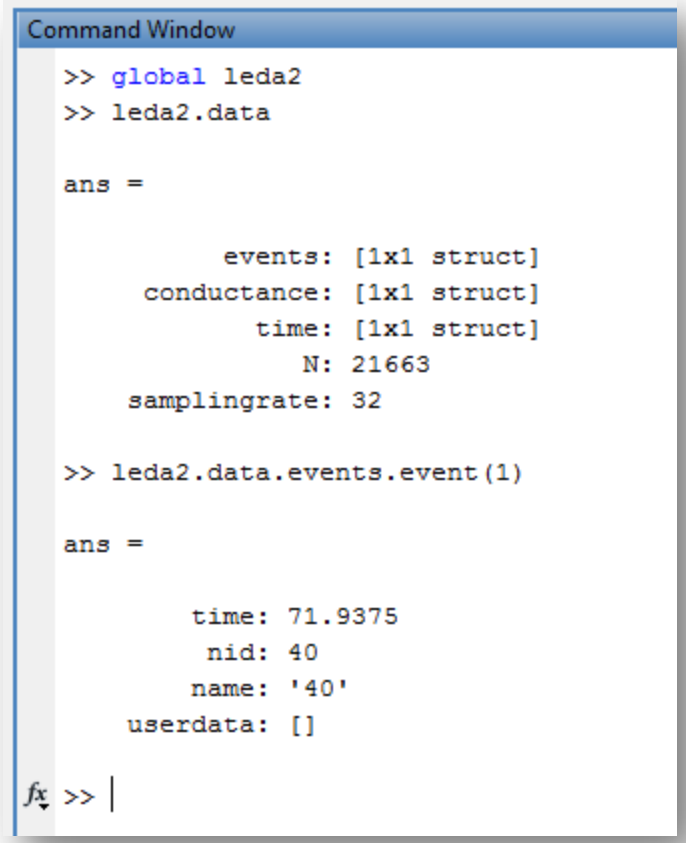
This is done with the separate script EDA_Results.m (located in Ledalab main directory)

Steps:

1. Analyze all your EDA data with Ledalab (e.g. using Continous Decomposition Analysis – CDA)
2. Export event-related activation results (to *_era.mat files)
   (steps 1 and 2 can be done with the command line batch analysis)
3. Edit script EDA_Results.m
   a) Indicate directory where exported result files (*_era.mat) are located
   b) Indicate whether to use event-IDs or event-names for identifying events (default = event-IDs)
   c) Select, add, or modify EDA scores to be saved
4. Run script EDA_Results.m (in Matlab command window) to save averaged event-related scores of all experiment subjects to one Excel-file for further statistical analysis

Direct access to all (raw and analyzed) data

All data can be accessed via the Matlab command window. This could be used for further processing with own scripts.




```
>> leda2.analysis

ans =

                tau: [0.8018 2.3359]
          smoothwin: 0.2000
      tonicGridSize: 10
             driver: [1x21663 double]
         tonicDriver: [1x21663 double]
          remainder: [1x21663 double]
             kernel: [1x569 double]
        phasicData: [1x21663 double]
          tonicData: [1x21663 double]
    phasicDriverRaw: [1x21663 double]
              error: [1x1 struct]
        opt_history: [1x1 struct]
             method: 'sdeco'
       impulseOnset: [1x538 double]
    impulsePeakTime: [1x538 double]
         impulseAmp: [1x538 double]
              onset: [1x538 double]
                amp: [1x538 double]
           peakTime: [1x538 double]
```