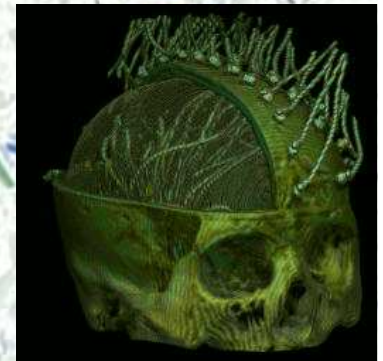


# Using Graphs to Mine Brain Dynamics



**Department of Informatics**  
Aristotle University of Thessaloniki





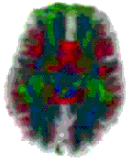
*Introduction*

*Methodological framework* (short description)

**Application to Auditory M100-responses  
to detect the influence of attention**



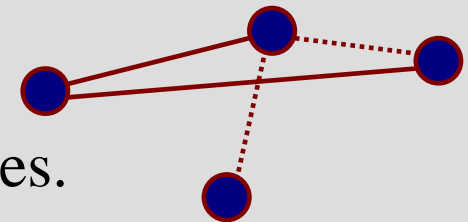
**Future trends**



## ***Introductory comments***

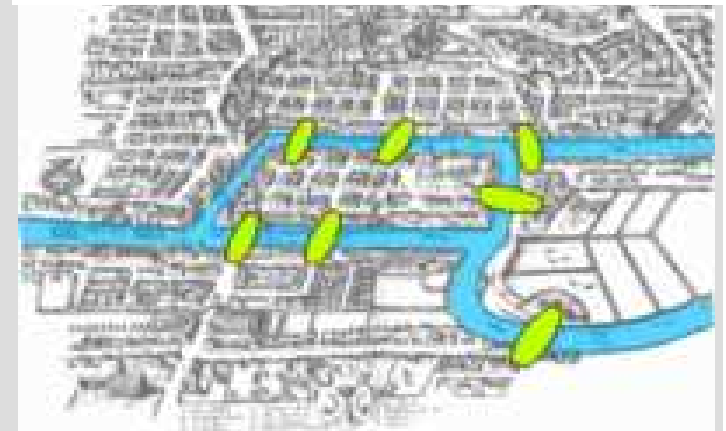
*Graph theory* is the study of **graphs**:  
mathematical structures used to model pairwise relations  
between objects from a certain collection.

A "graph" is collection of vertices (or 'nodes')  
and a collection of edges that connect pairs of vertices.



Initiated with *Euler's* paper in 1736

***"Seven Bridges of Königsberg"***

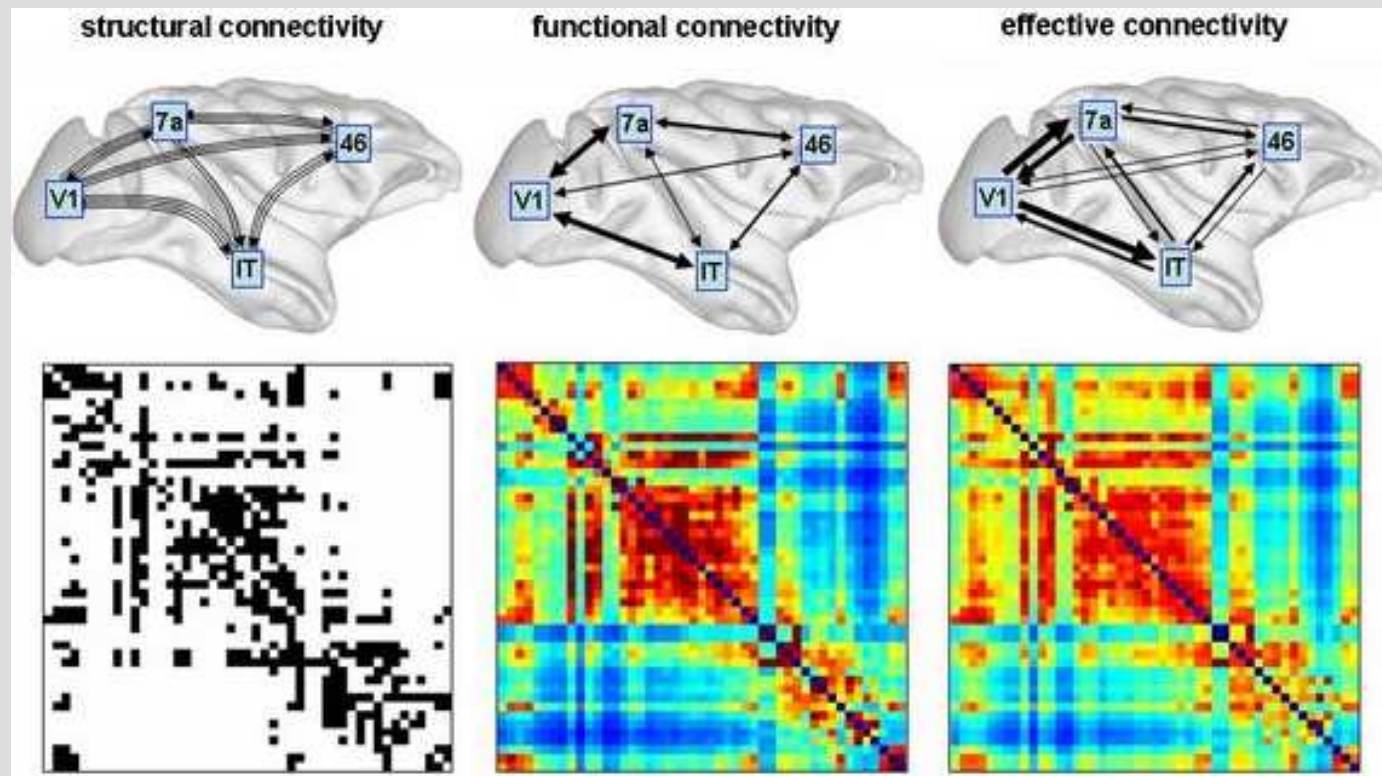




## *Graphs in Brain Research :*

1

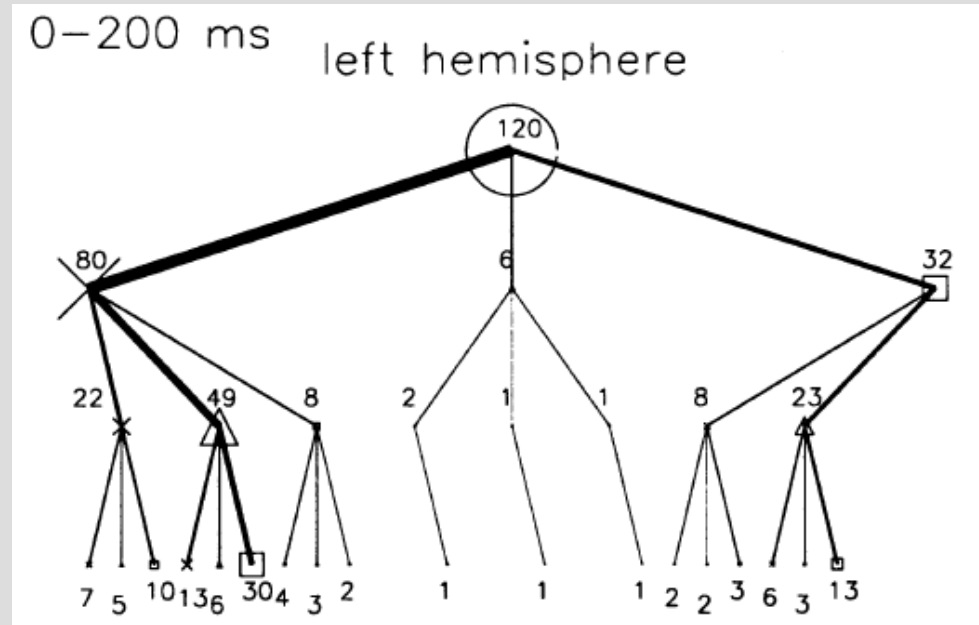
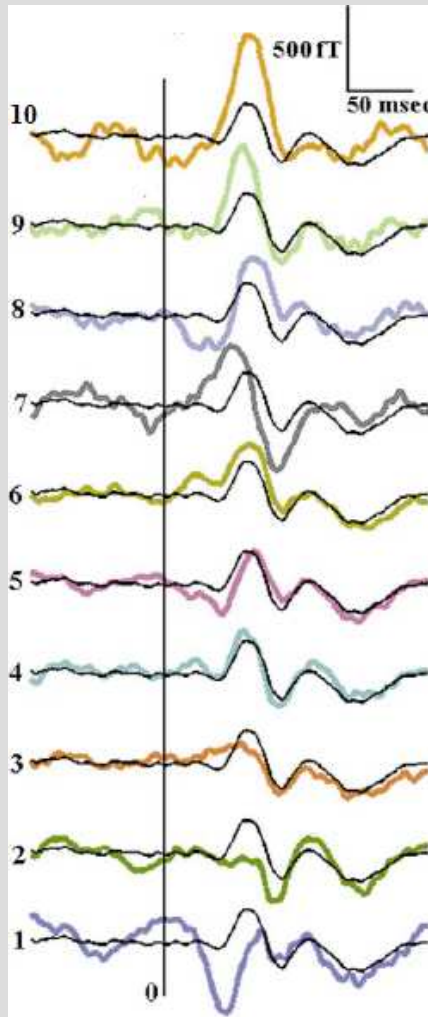
network analysis (*small-world network*)  
systems-approach (MI-maps)



created by O. Sporns

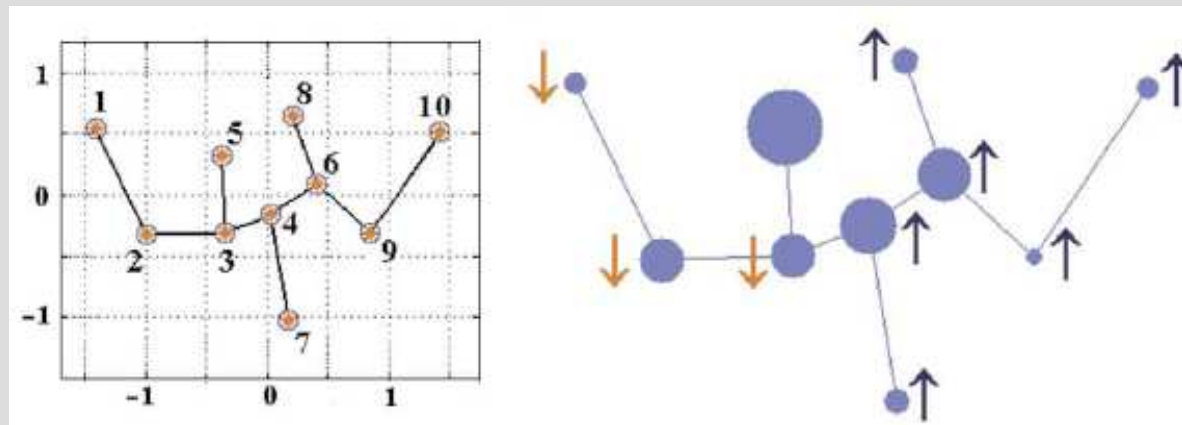
## ② Graphs for *Single-Trial Analysis* ➤ Past

### ➤ Current-practise

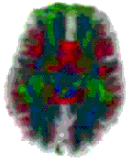


**Liu, Ioannides, Gartner**

*Elect. and clinical Neurophysiology* 106 (1998) 64–78



### ➤ Future-trends (*mining information* from multisite recordings) <sup>5</sup>



# ***I. Outline of our methodological approach***

A synopsis of response dynamics and its variability  
by means of ***Semantic Geodesic Maps***

Graphs play an instrumental role in :

**computing neighborhood relations,**

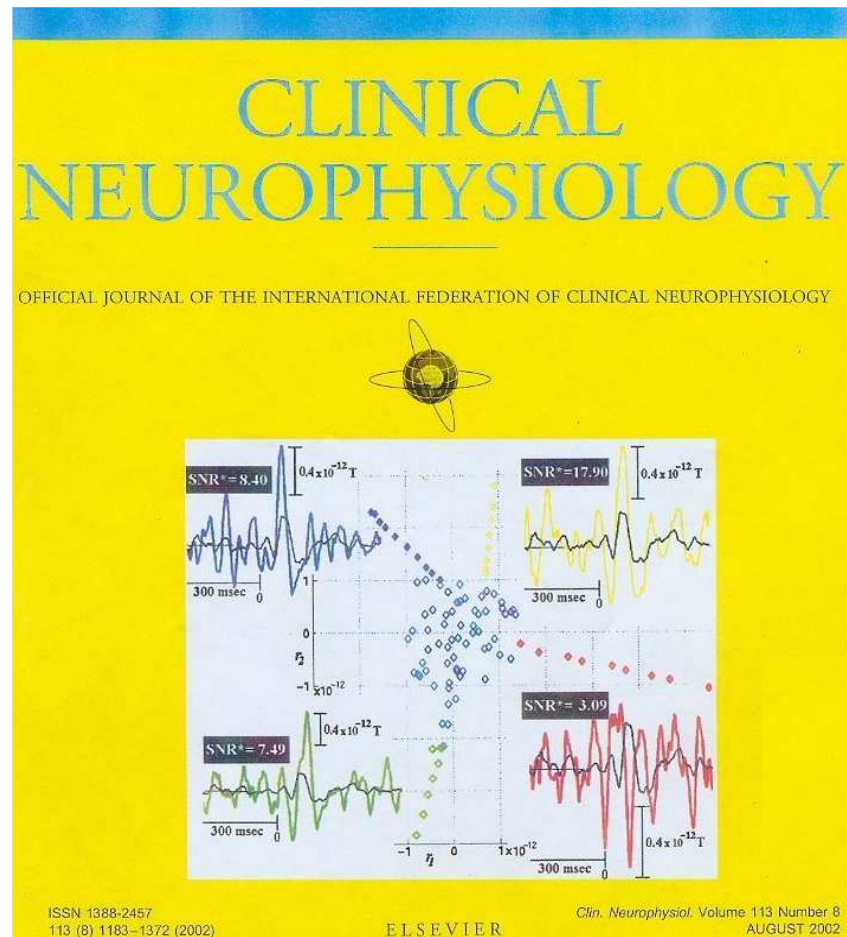
**deriving faithful visualizations of reduced dimensionality**

**describing and contrasting  
the essence of response variability in *an objective way***

MST, WW-test , ISOMAP, Laplaceans , *commute times*, etc

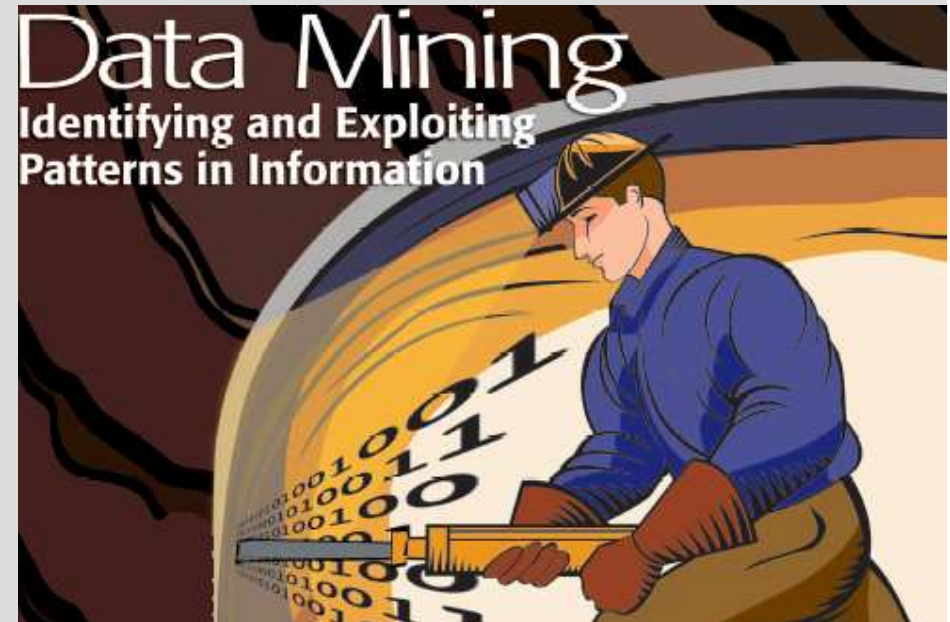
Brain dynamics can be compared ***at a glance***





[ Laskaris & Ioannides, 2001 & 2002 ]

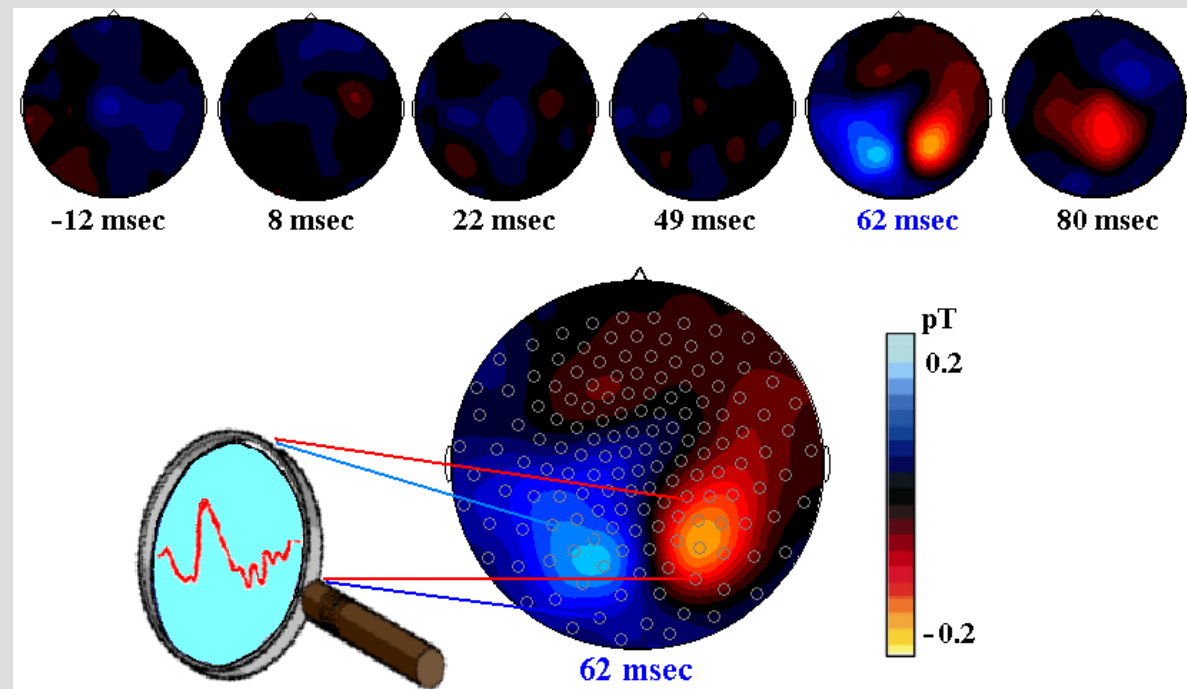
*IEEE SP Magazine, 2004*



A user-friendly framework for intelligent single-trial analysis of multichannel encephalographic recordings

## Step\_①

the spatiotemporal dynamics are decomposed

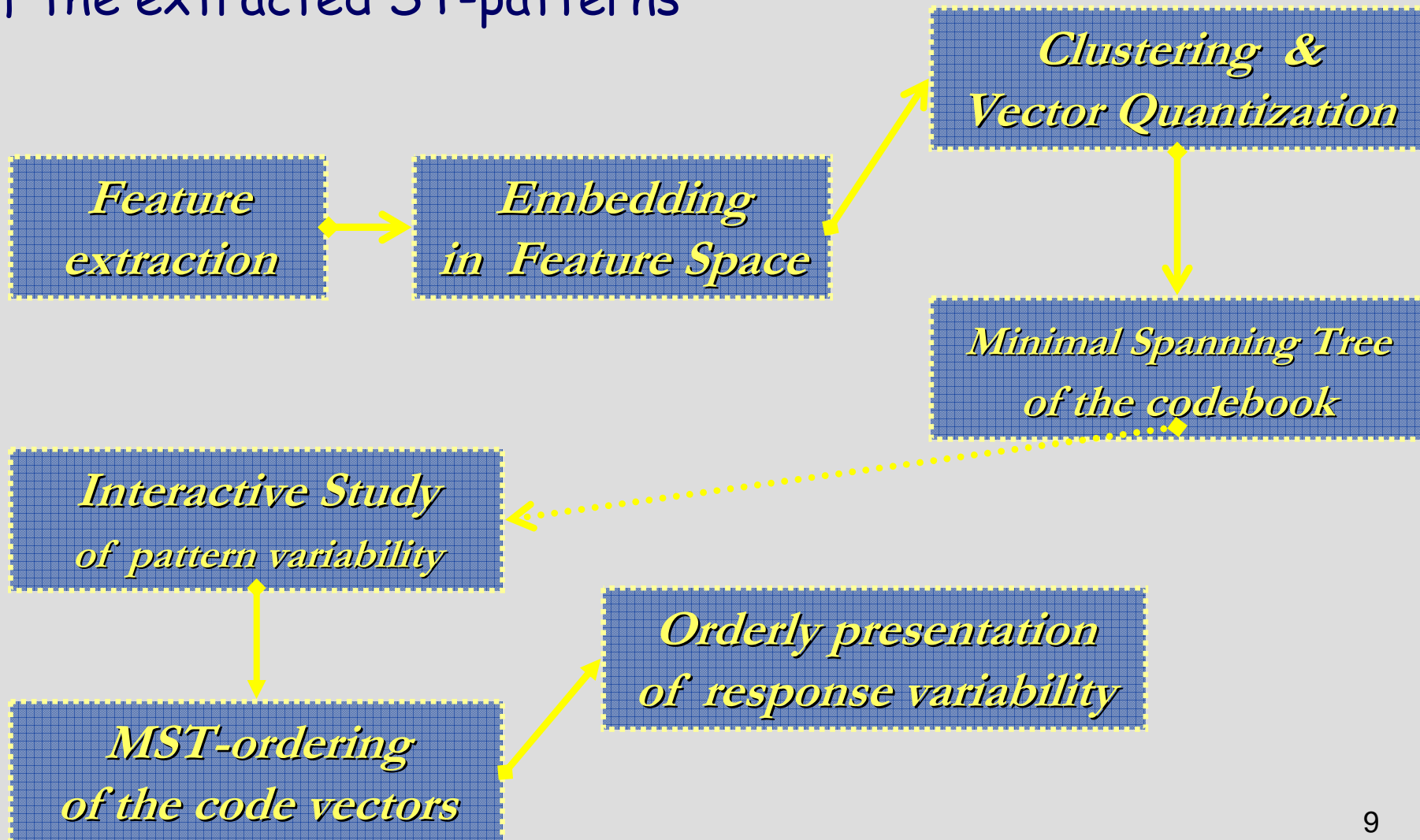


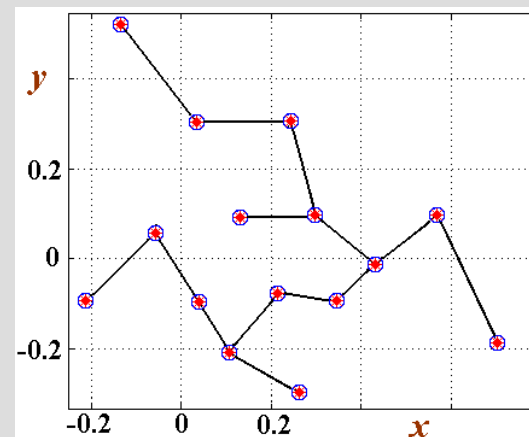
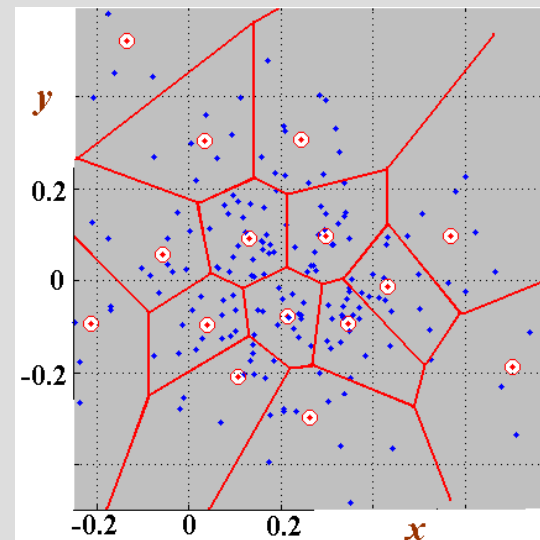
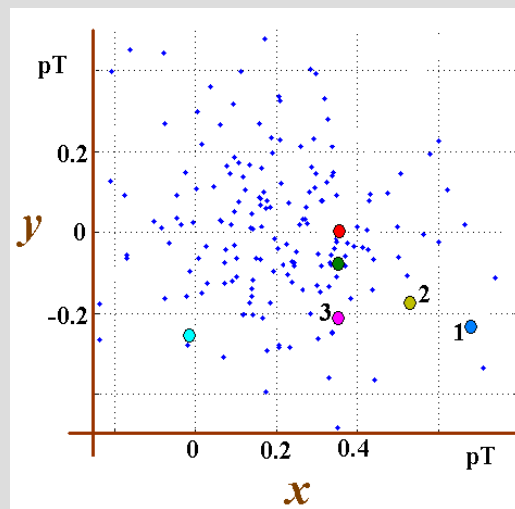
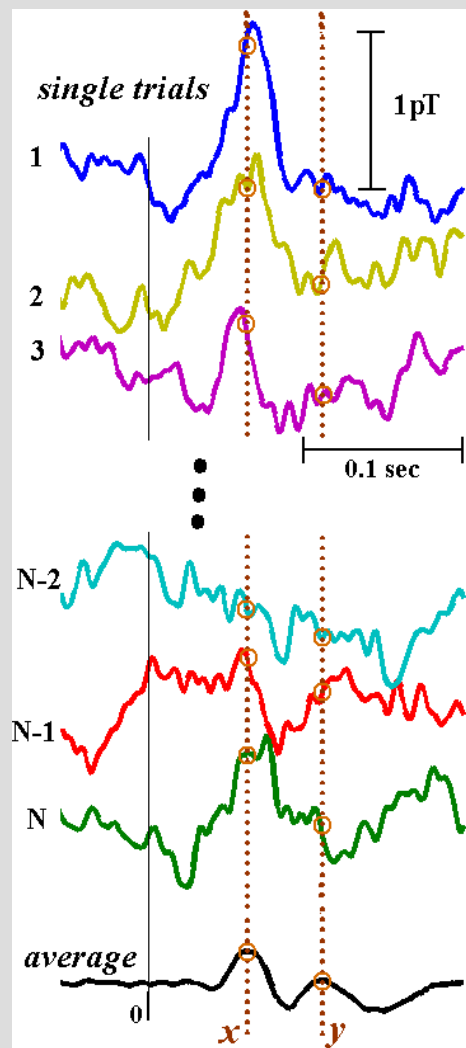
Design of the *spatial filter* used to extract  
the *temporal patterns* conveying  
the *regional response dynamics*

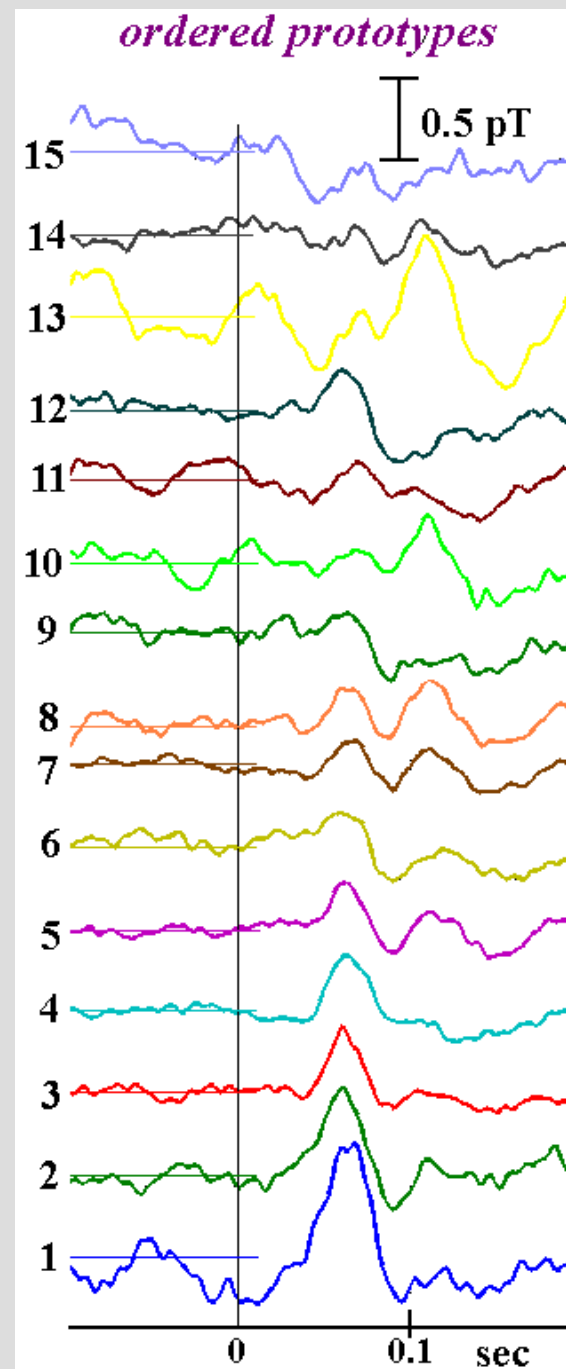
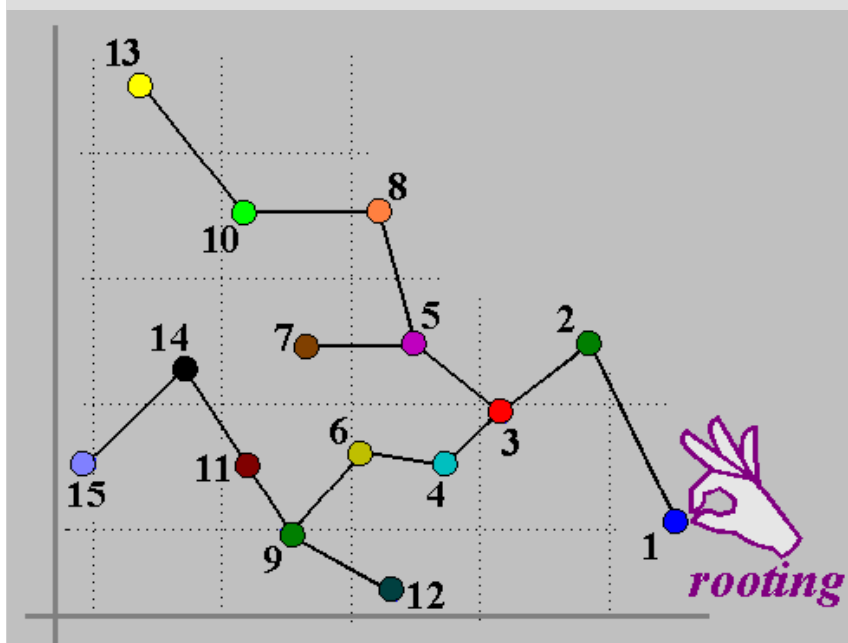
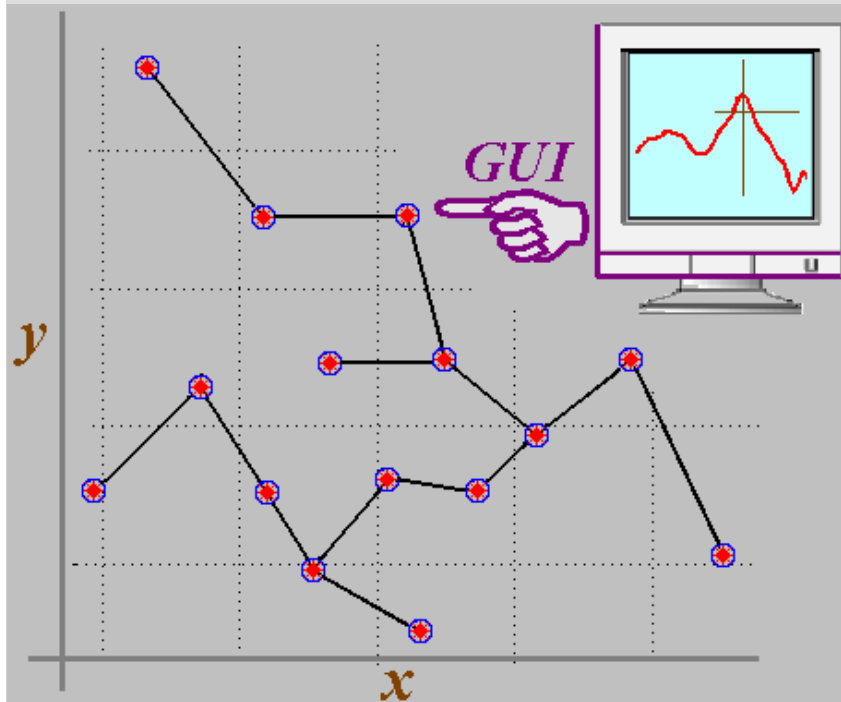


## Step\_②

### *Pattern & Graph-theoretic Analysis* of the extracted ST-patterns

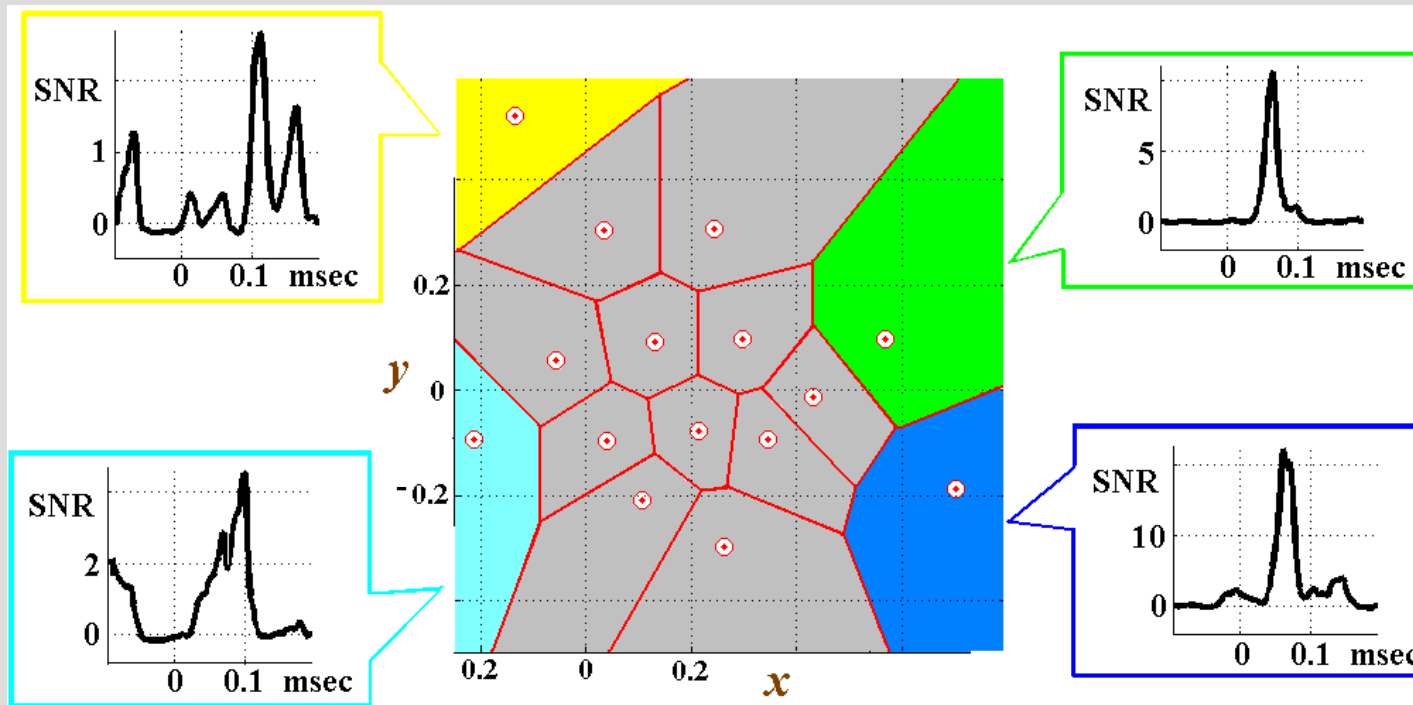






## Step\_③

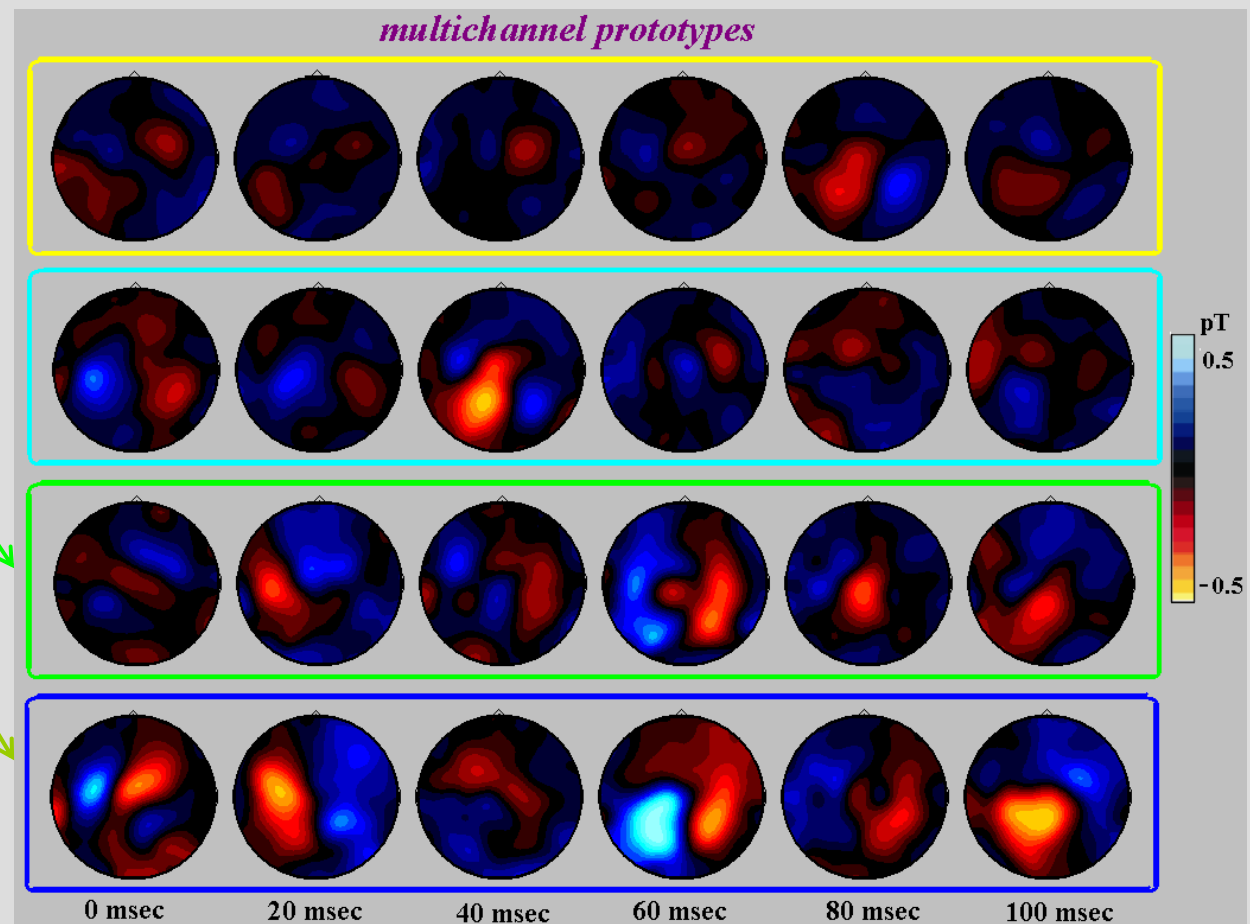
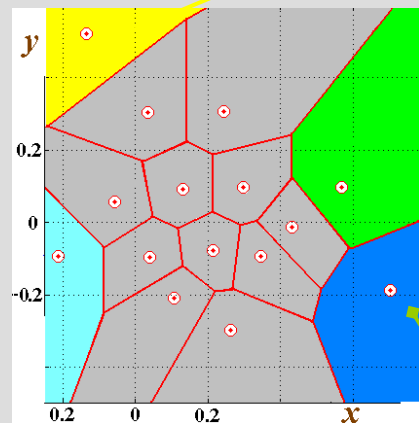
### *Within-group Analysis* of regional response dynamics





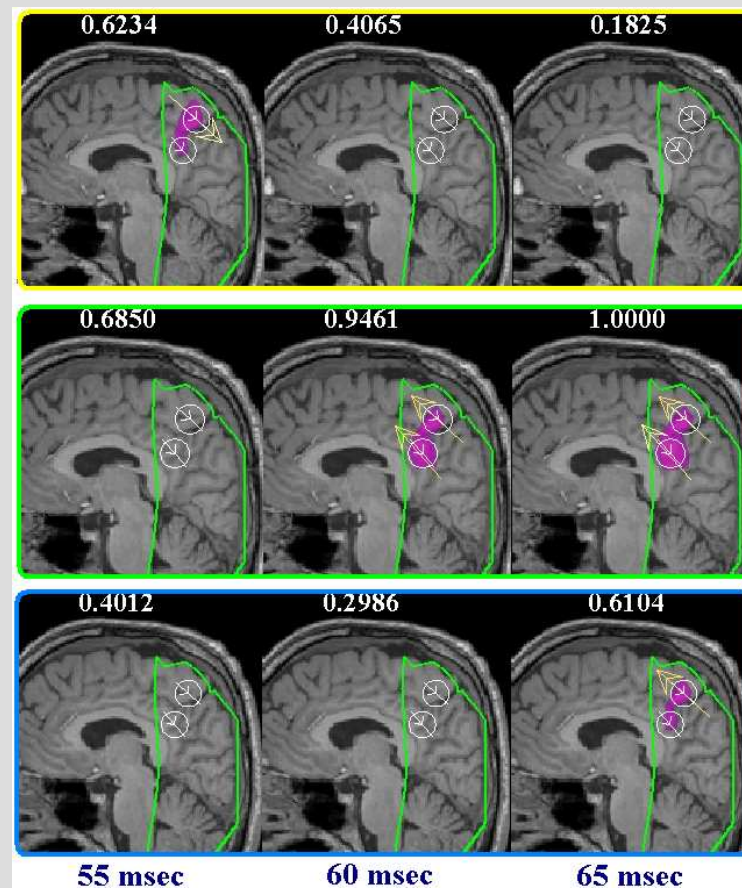
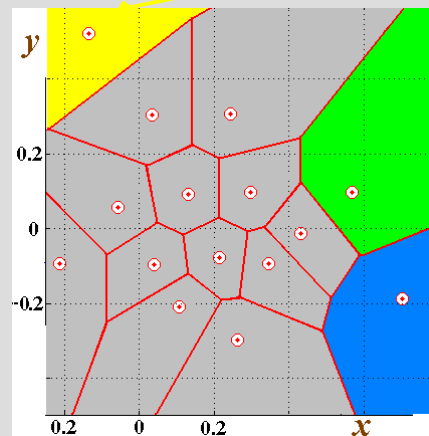
## Step\_④

### *Within-group Analysis* of multichannel single-trial signals



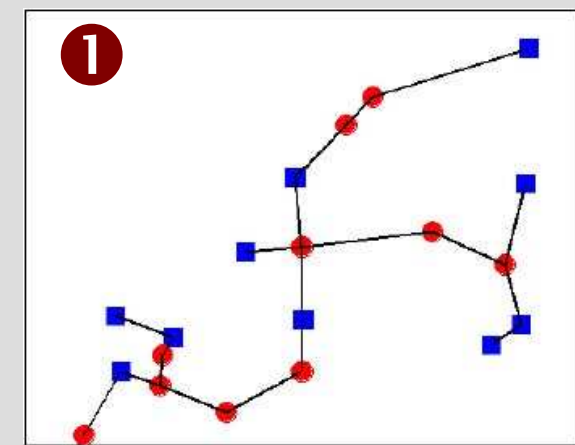
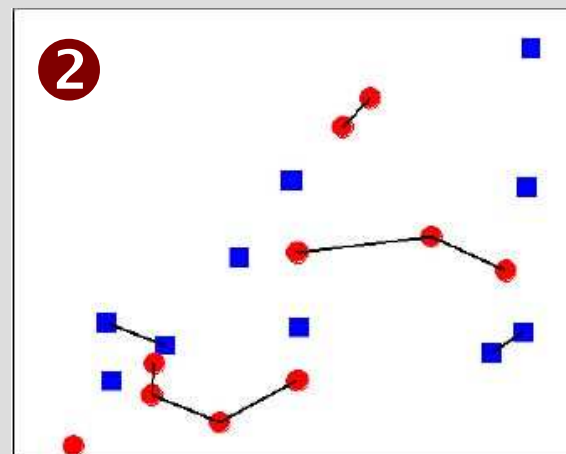
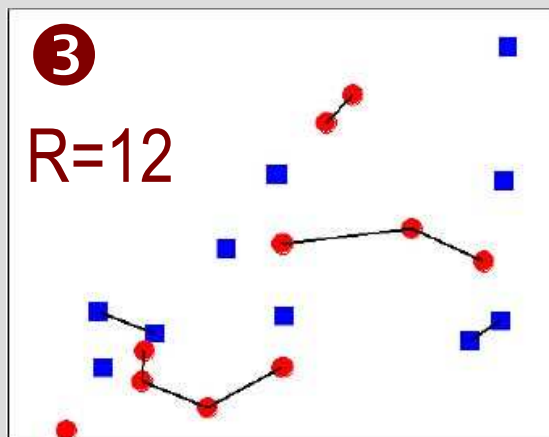
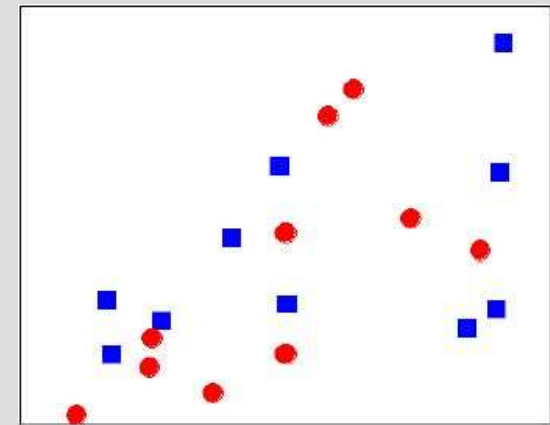
# Step\_⑤

## *Within-group Analysis* of single-trial **MFT-solutions**



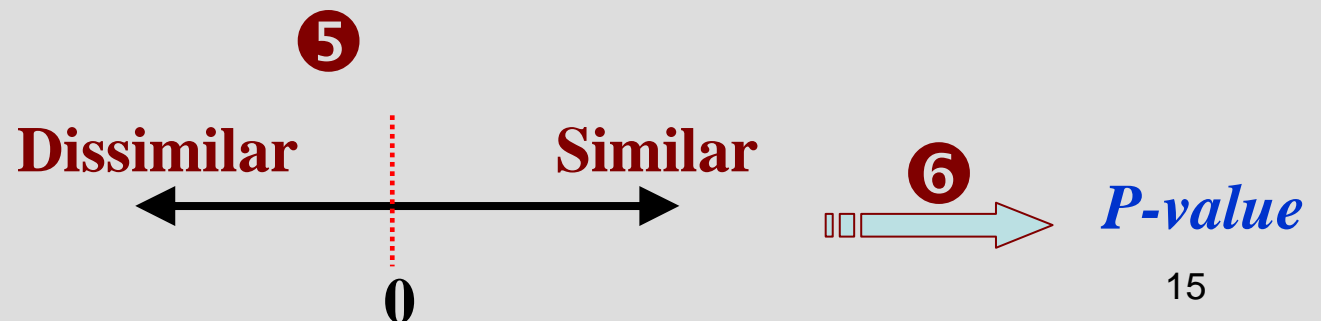
# Wald-Wolfowitz test (WW-test) $\{X_i\}_{i=1\dots N}$ vs $\{Y_j\}_{j=1\dots M}$

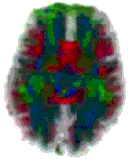
A non-parametric test  
for comparing distributions



④

$$W = \frac{R - E[R]}{\sqrt{\text{Var}[R]}}$$





## ***II. Application to MEG Auditory (M100) responses***

### **The Scope :**

**to understand the emergence of M100-response  
(in averaged data)**

**characterize its variability (at Single-Trial level)**

**and describe the influence (if any) of **attention****

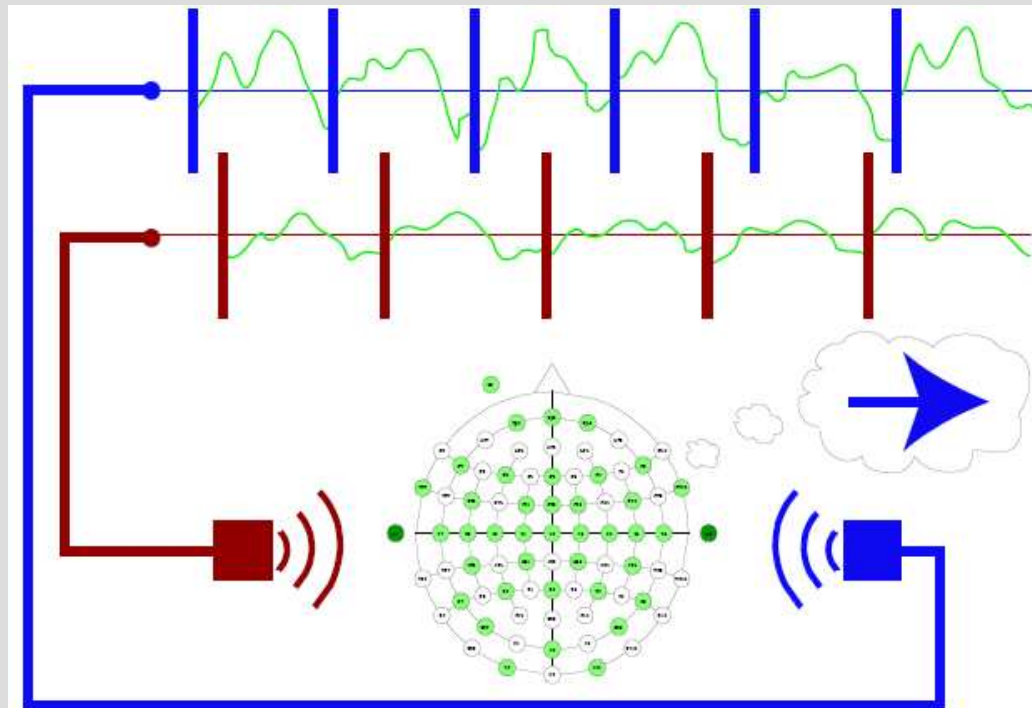


# The Motive : “ New BCI approaches based on selective Attention to Auditory Stimulus Streams ”

N. Hill, C. Rathes (mda\_07)

Exogenous (i.e. stimulus-driven) BCI's rely on the conscious direction of the user's attention.

For paralysed users, this means *covert attention*  
Covert attention do affect auditory ERPs.



# MEG-data were recorded at RIKEN (BSI, Japan)

理化学研究所 脳科学総合研究センター  
認知脳科学研究グループ  
脳機能ダイナミクス研究チーム 研究員

理学博士 ニコラオス・ラスカリス

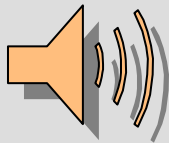
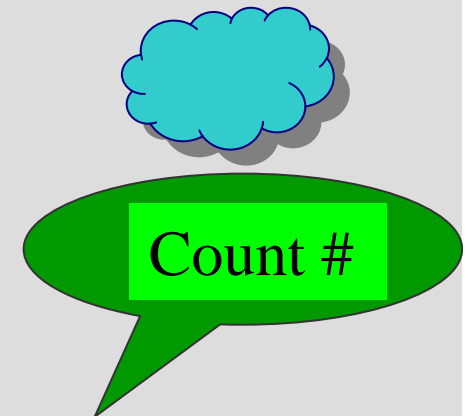
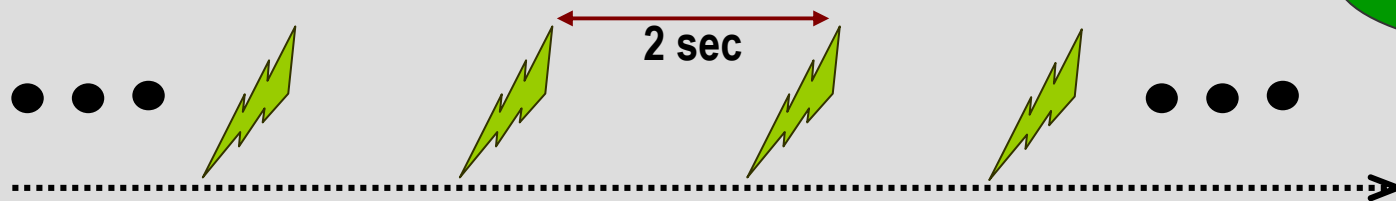
〒351-0198 埼玉県和光市広沢 2-1  
電話 (048) 462-1111 (内線 7185)  
FAX (048) 467-9731  
e-mail Nikos@brain.riken.go.jp



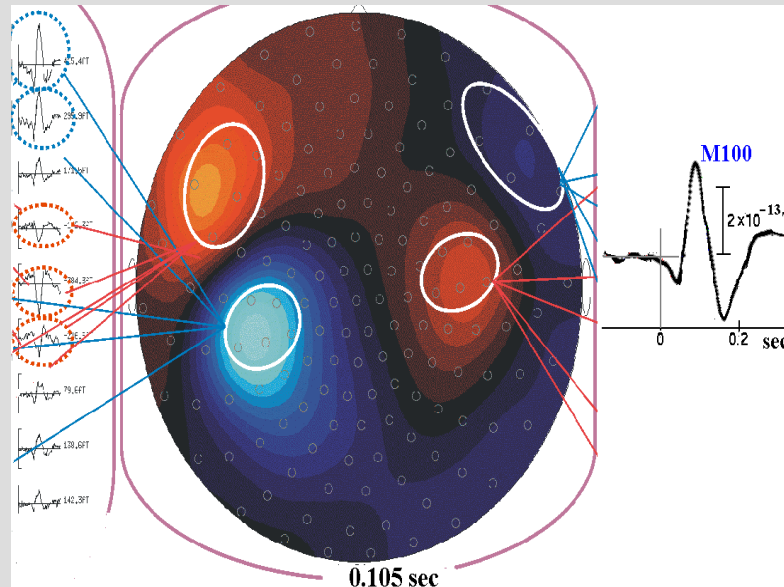
**CTF-OMEGA (151-channels)**

# Repeated stimulation ( ISI: 2sec )

binaural-stimuli [ 1kHz tones, 0.2s, 45 dB ],  
**passive listening** task ( 120 trials )  
& **attending** task (  $120 \pm 5$  trials )



**left-hemisphere**  
response

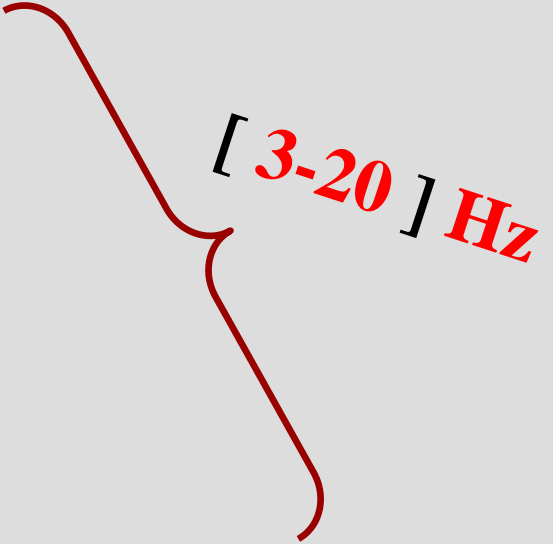


**right-hemisphere**  
response

***Ila. Ensemble characterization  
of (M100-related) brain waves***

***Ilb. Unsupervised classification  
of (M100-related) brain waves  
and Prototyping***

***[ 3-20 ] Hz***



***Ilc. Empirical Mode Decomposition  
for enhancing (M100-related) brain waves  
multiscale analysis  
single-channel ICA for oscillatory components***

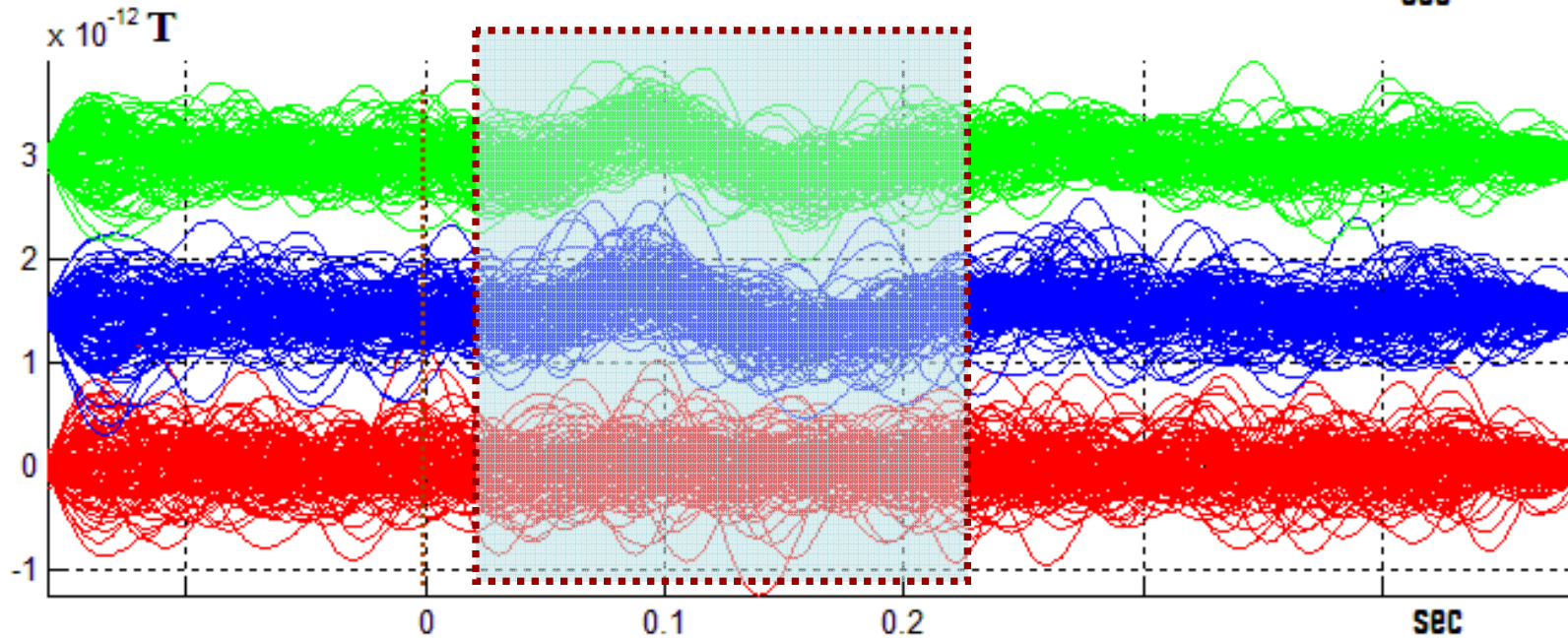
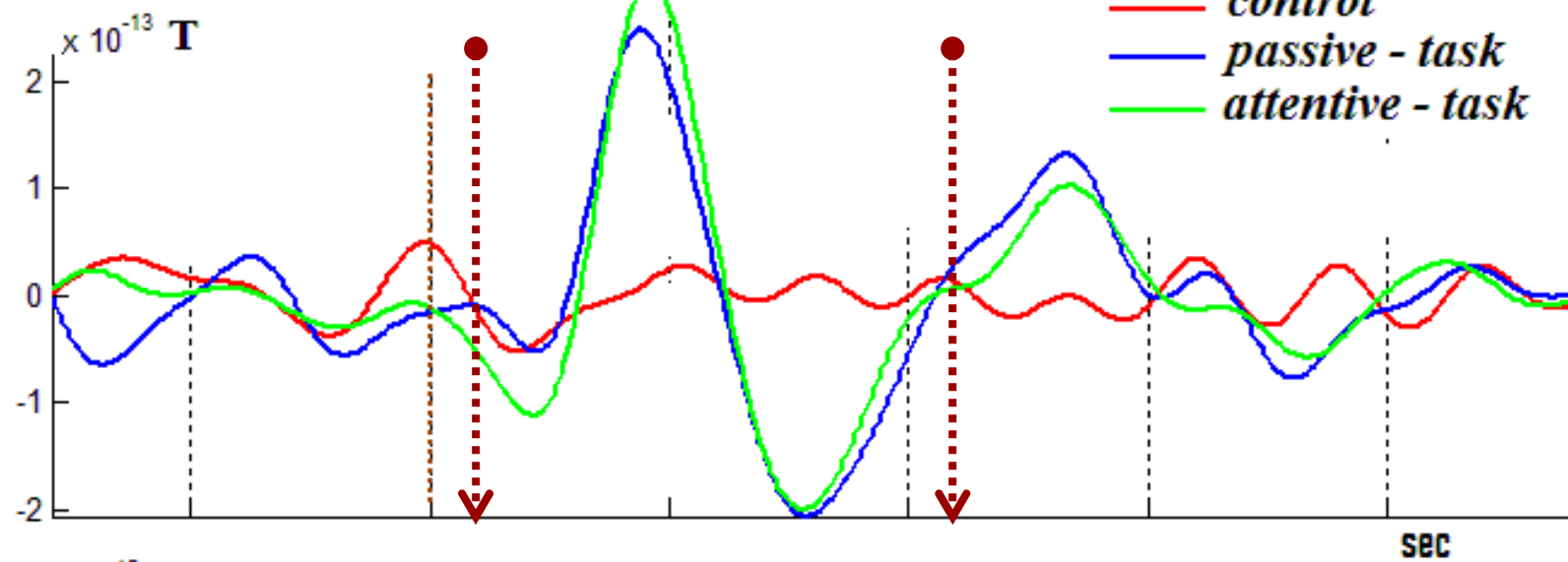


## ***Ila. Ensemble characterization of (M100-related) brain waves***



**S<sub>2</sub> right - hemisphere**

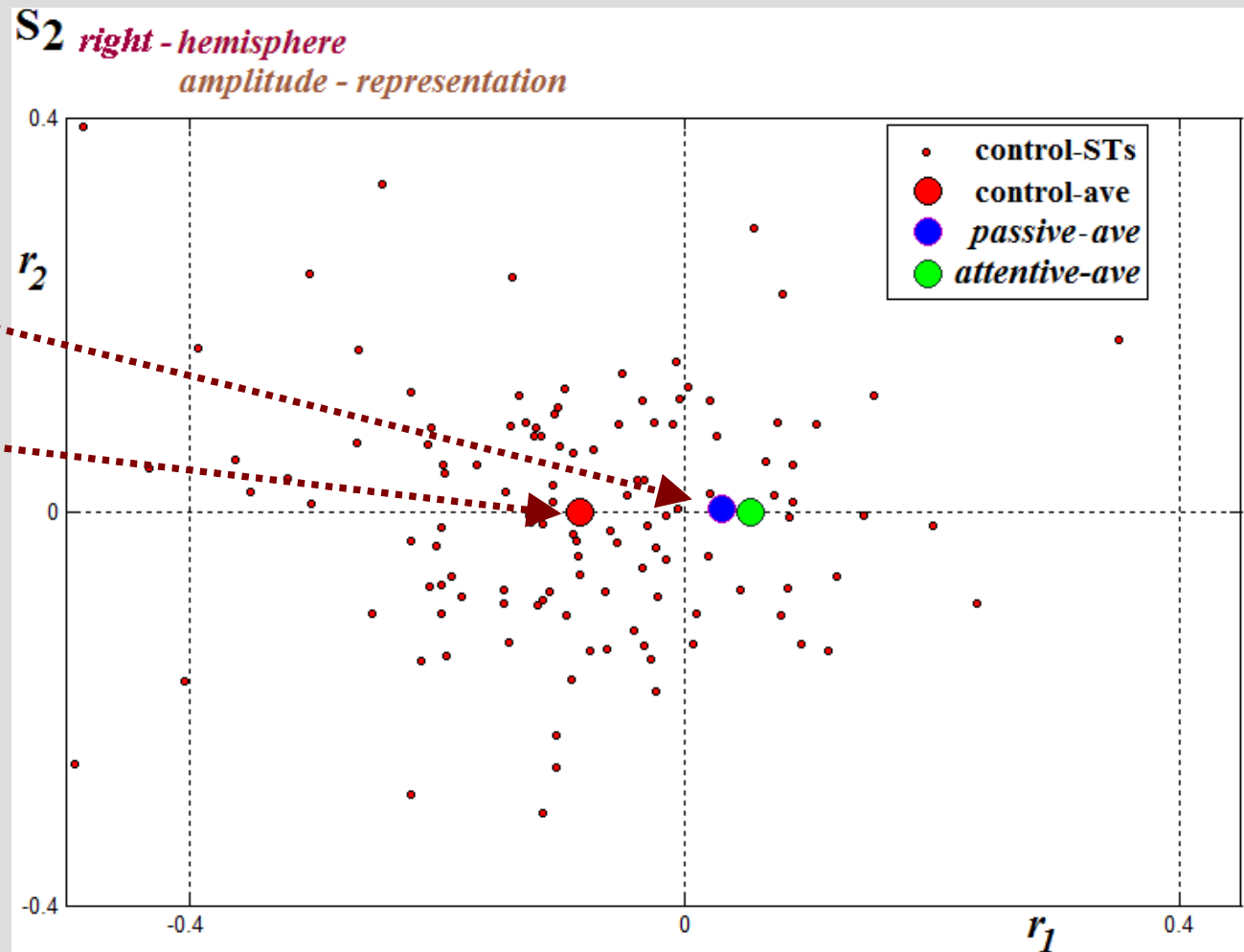
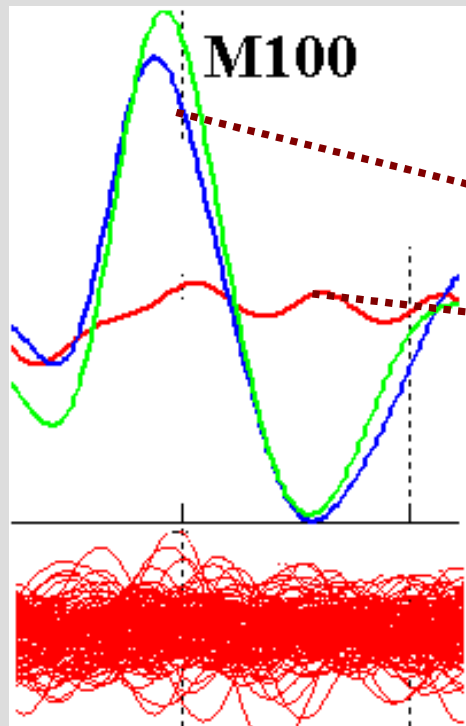
**M100**



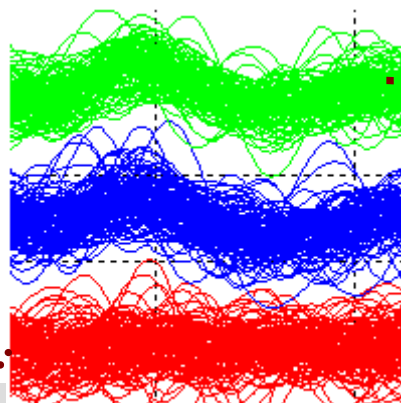
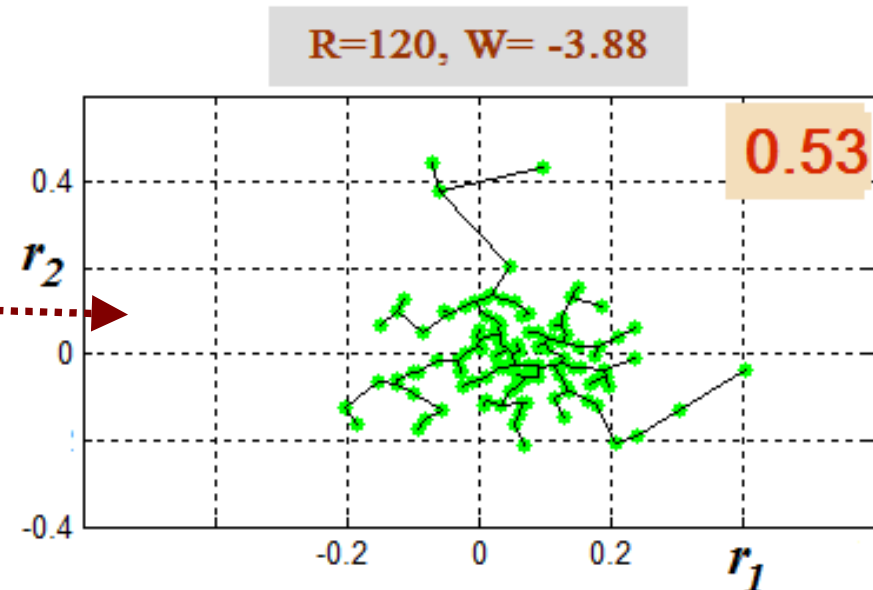
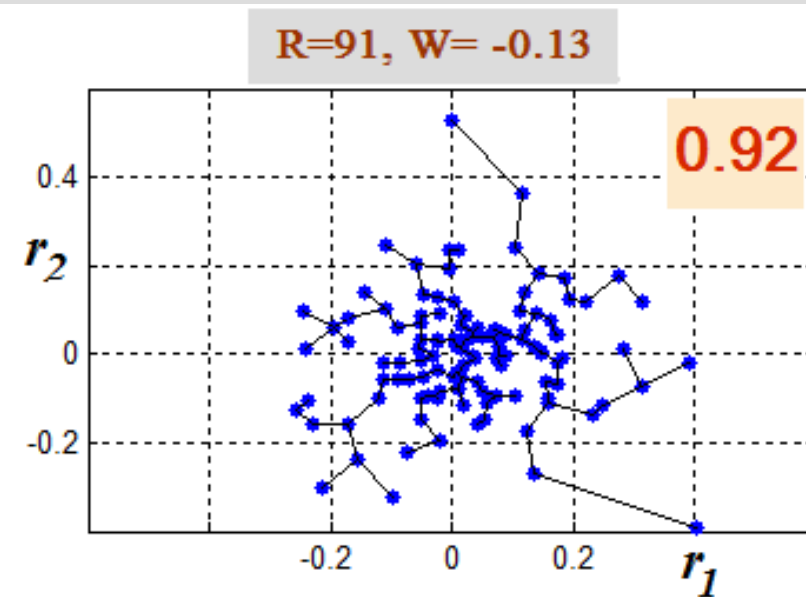
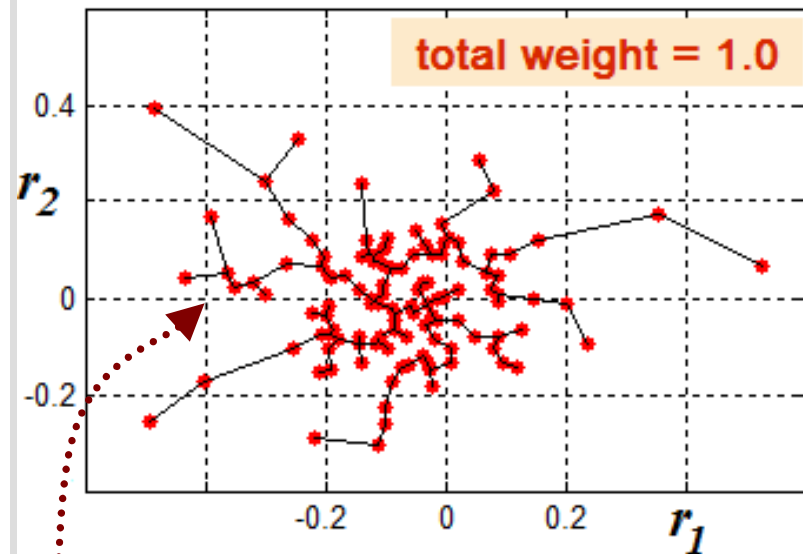
time-aligned ST-segments are extracted

brought to common feature space  
and subsequently transformed ( via **MDS** )

to point-diagrams representing brain-waves relative scattering



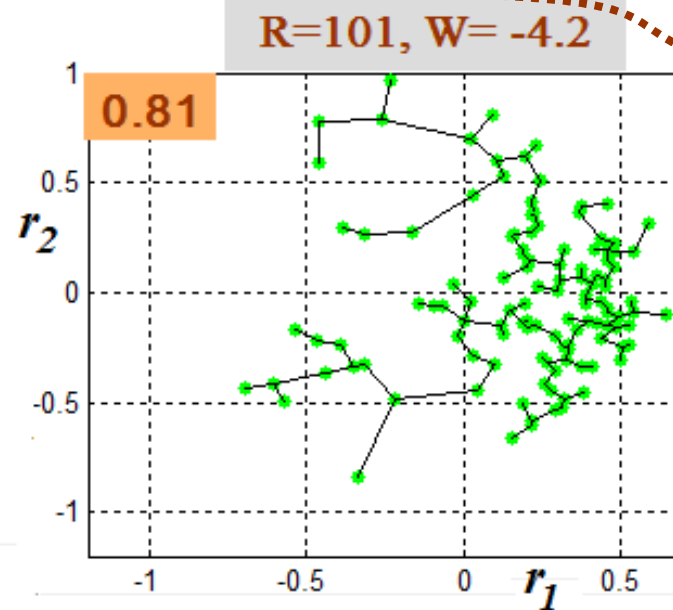
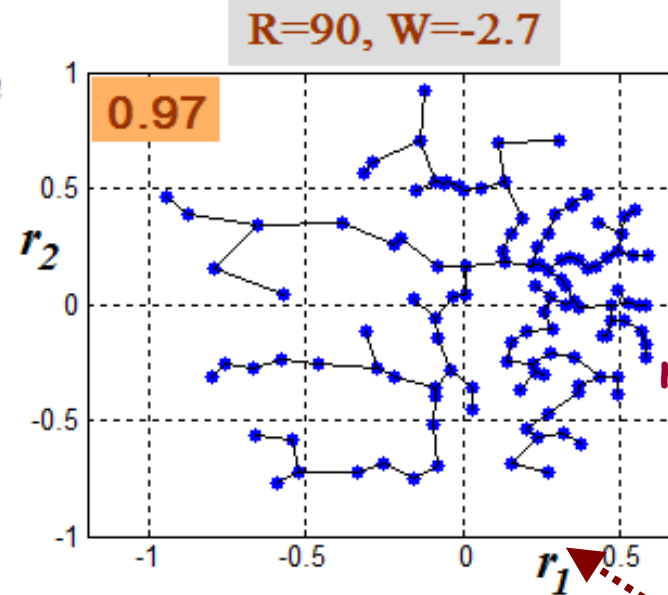
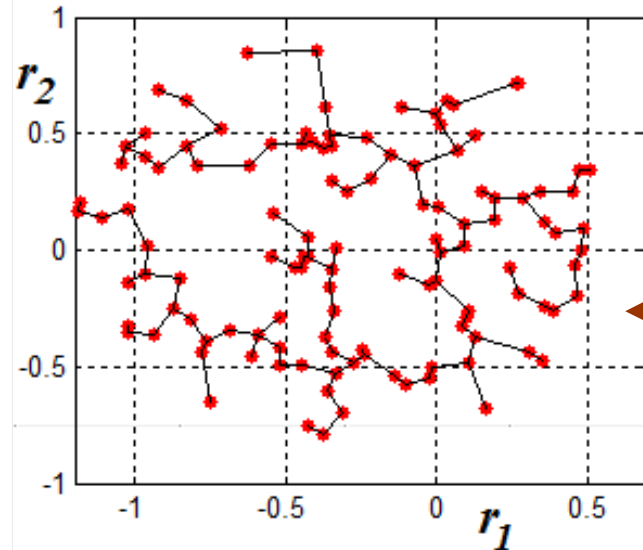
**S2** *right - hemisphere*  
*amplitude - representation*



**Attentive-responses** show significantly **reduced scattering** :  
**smaller MST-length**

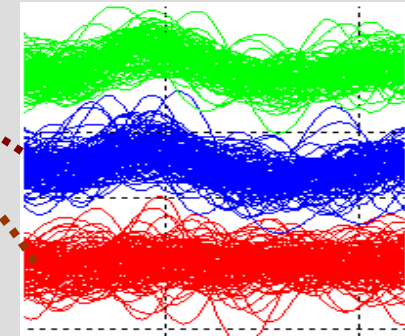


**S2** *right - hemisphere*  
*phase - representation*



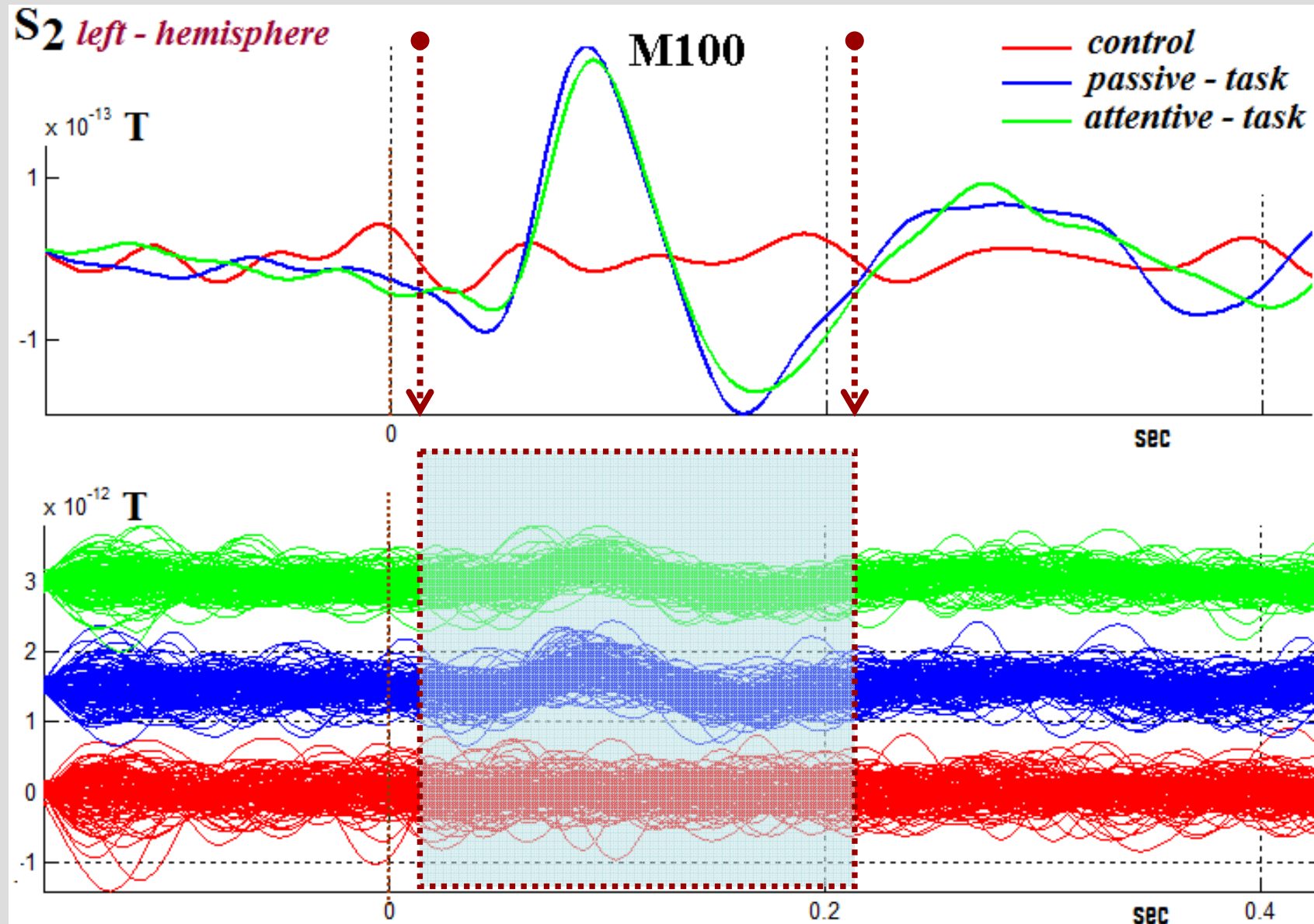
normalize

$$X_i \rightarrow \frac{X_i}{\|X_i\|}$$

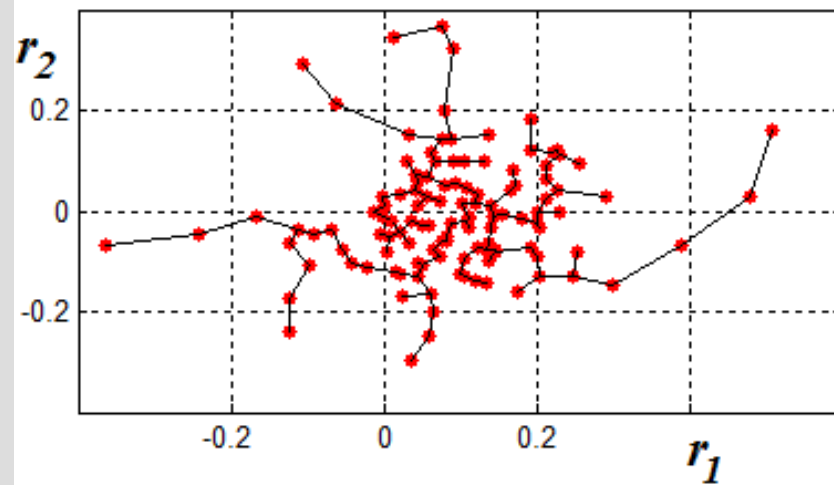


*Clustering tendencies* are apparent in **phase-representation space** and higher for the **attentive responses**

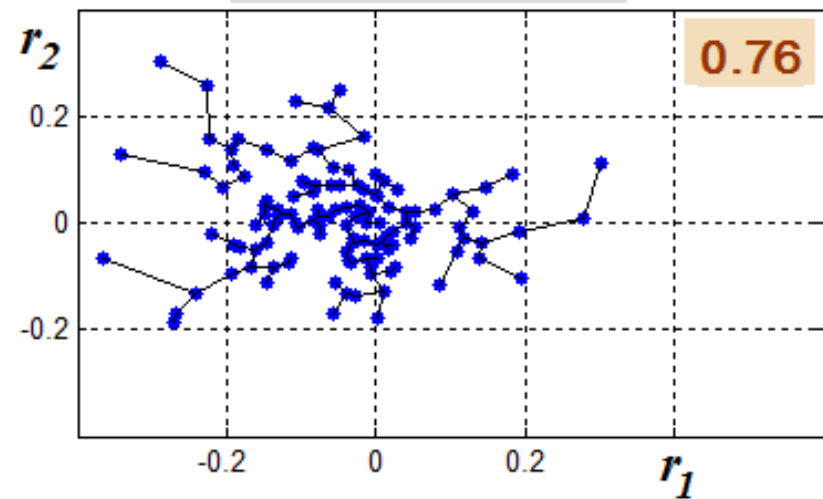
Similar observations can be made  
for the other hemisphere *of the same subject*



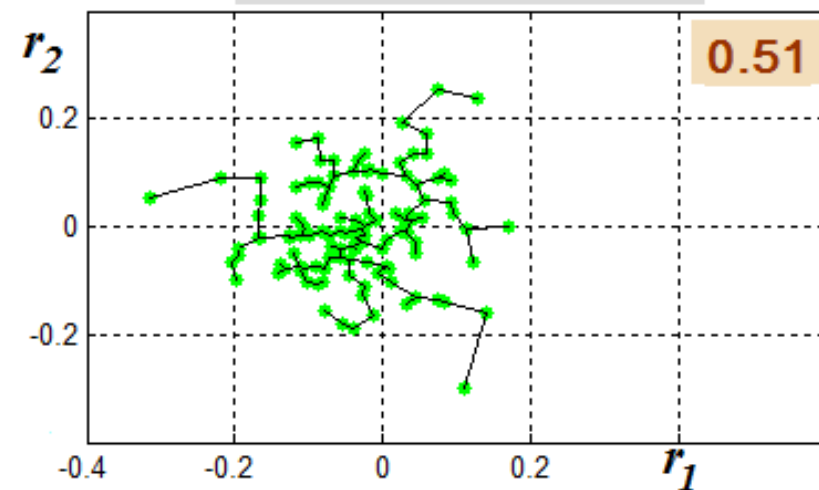
**S2** *left - hemisphere*  
*amplitude - representation*



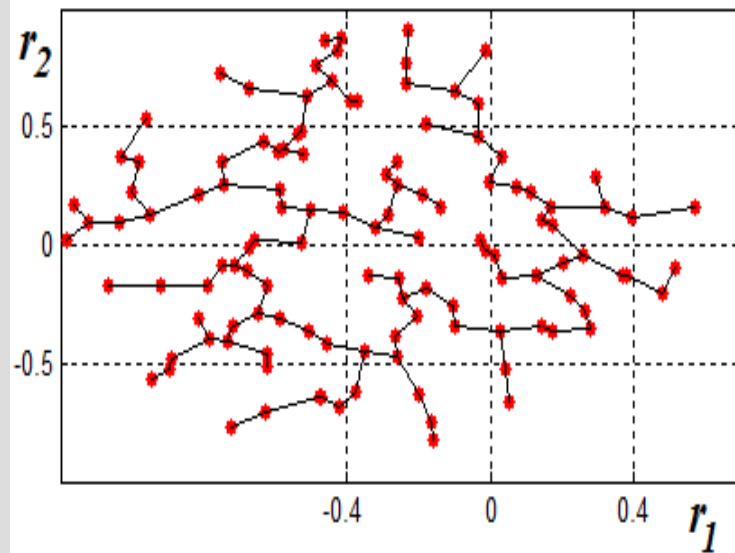
**R=79, W= -5.6**



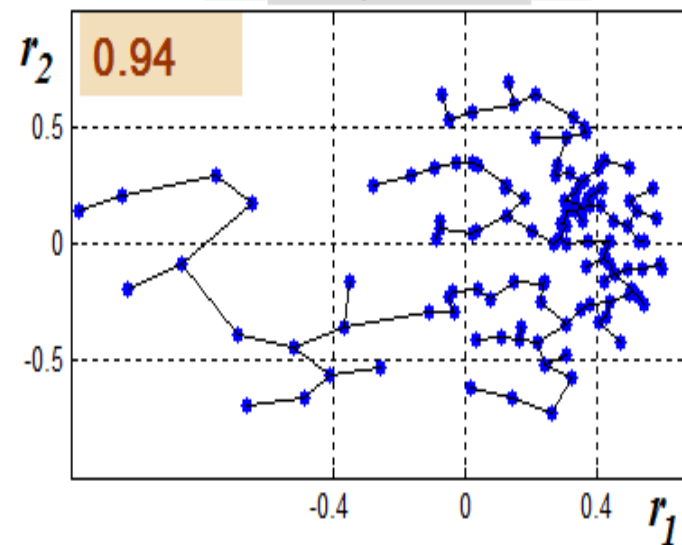
**R=77, W= -5.43**



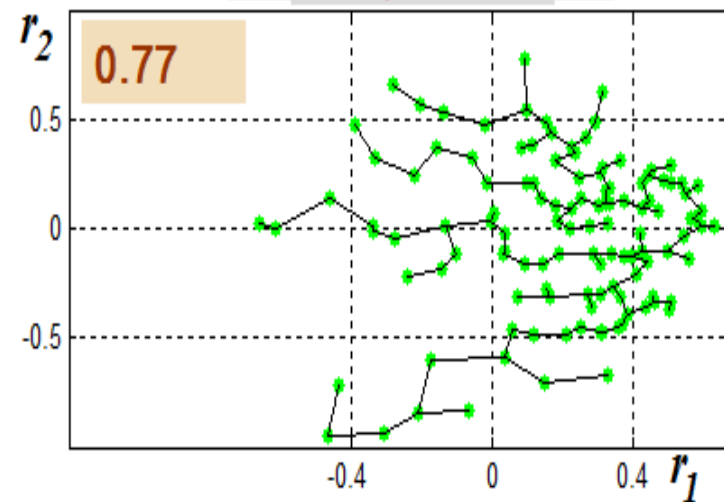
**S<sub>2</sub>** *left - hemisphere*  
*phase - representation*



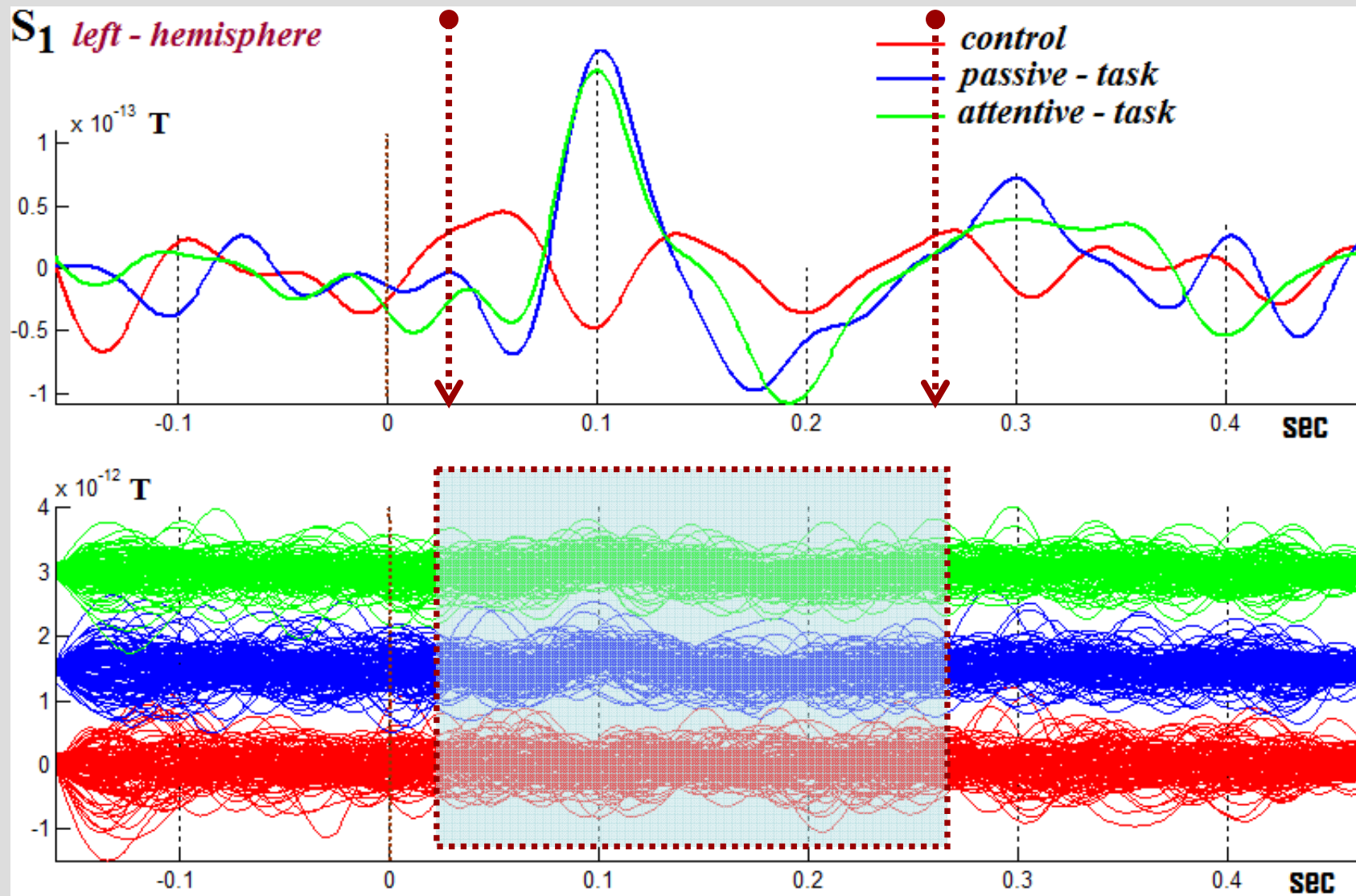
**R=81, W= -4.5**



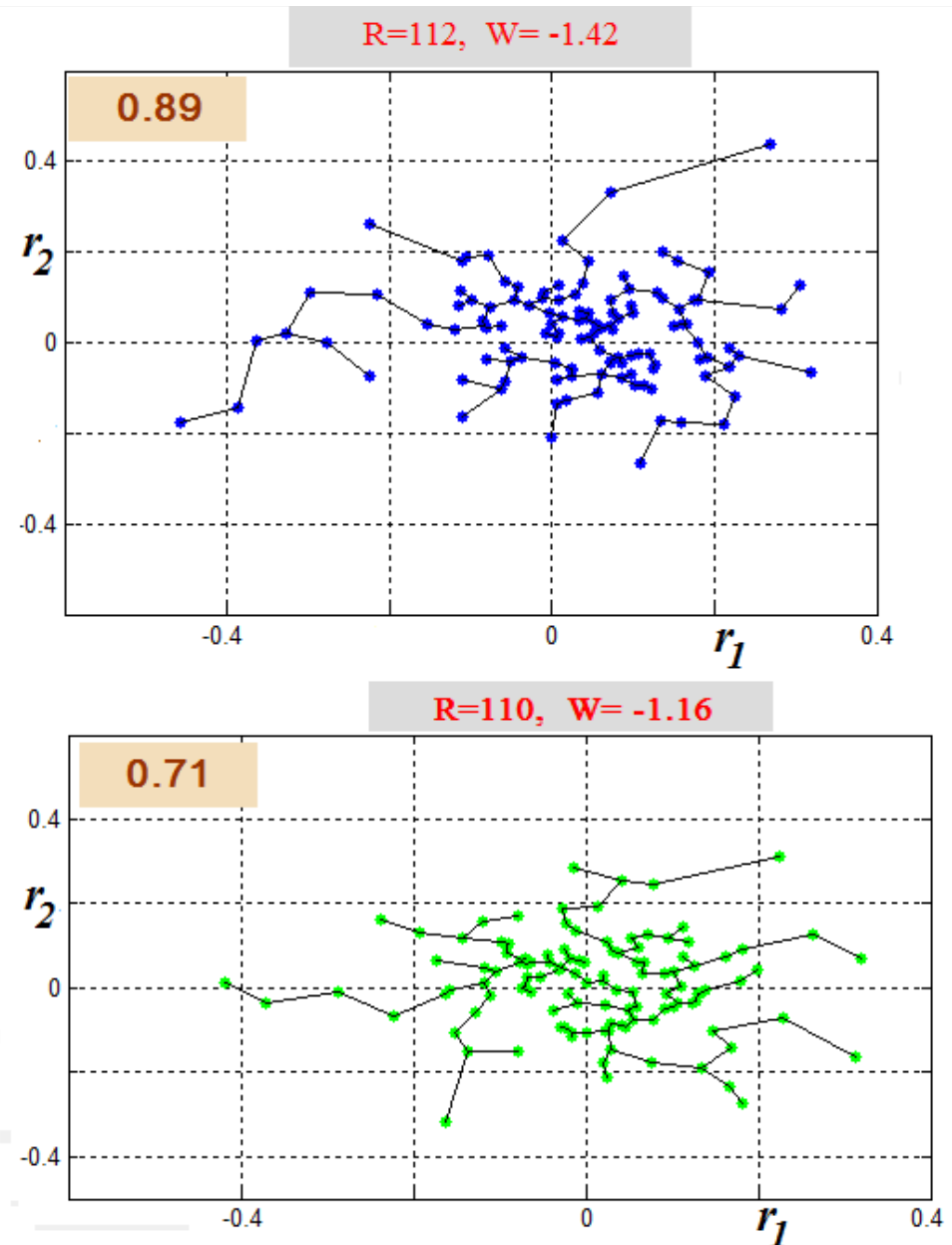
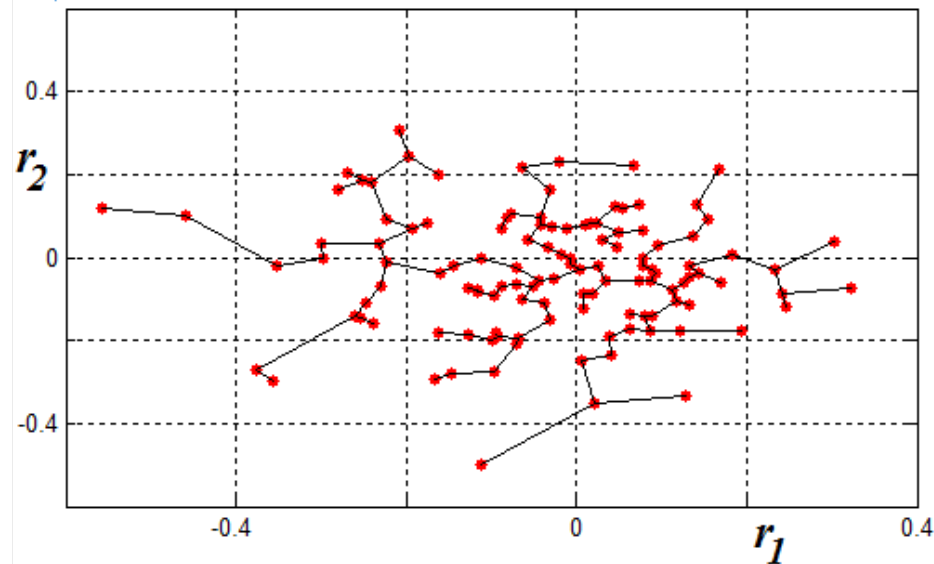
**R=86, W= -5.2**



And for other subjects as well



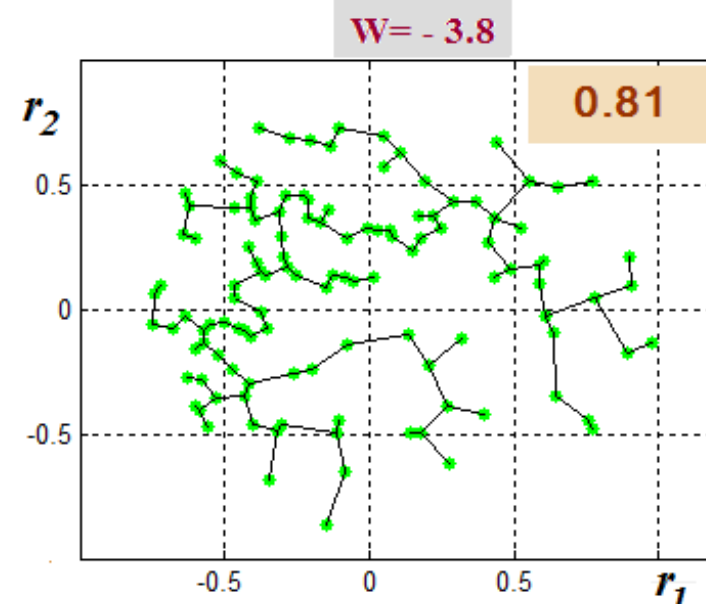
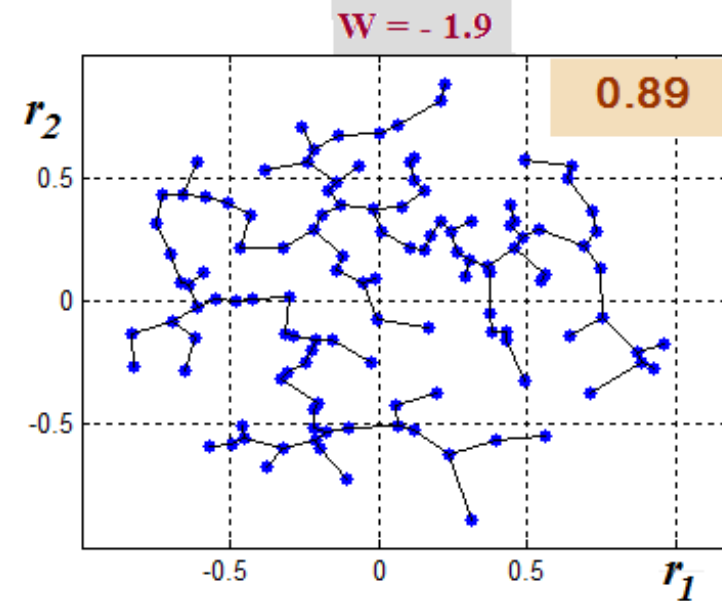
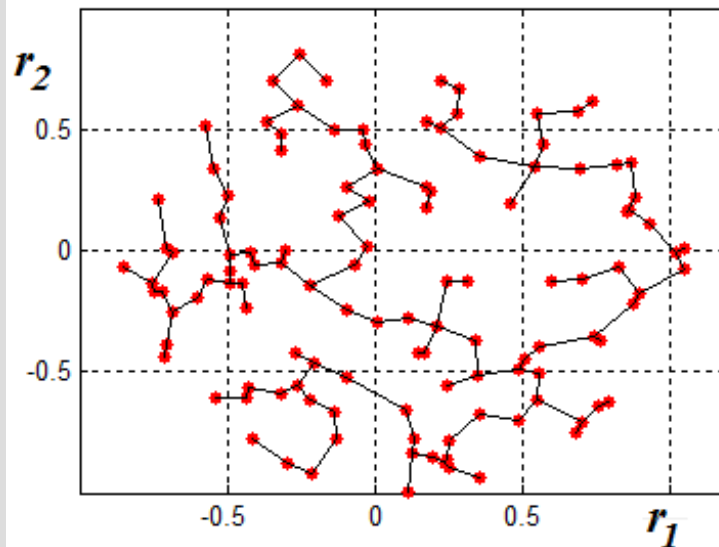
**S<sub>1</sub>** *left - hemisphere*  
*amplitude - representation*



**The variability of (snapshots of) Brain-waves  
is smaller for the attentive task**



**S<sub>1</sub>** *left - hemisphere*  
*phase - representation*



**The clustering of (snapshots of) Brain-waves  
is higher within the phase-representation domain**

## *IIb. Unsupervised classification of (M100-related) brain waves and Prototyping*



# ***Discriminative Prototyping***

Kokiopoulou & Saad, Pattern Recognition :

*“Enhanced graph-based dimensionality reduction  
with repulsion Laplaceans”*

By contrasting brain-waves from **control condition**  
against the M100-related brain waves

we deduce an abstract space

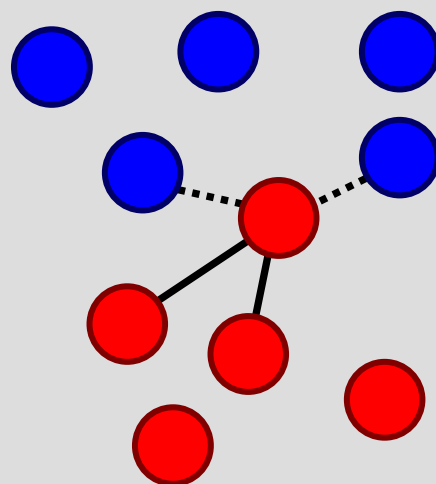
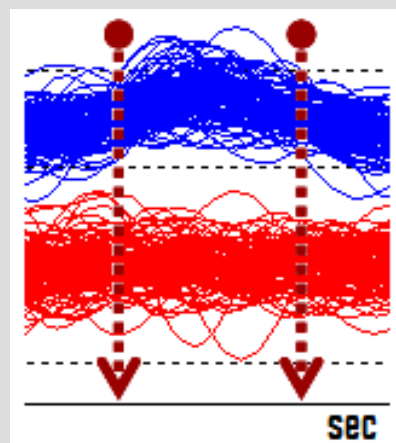
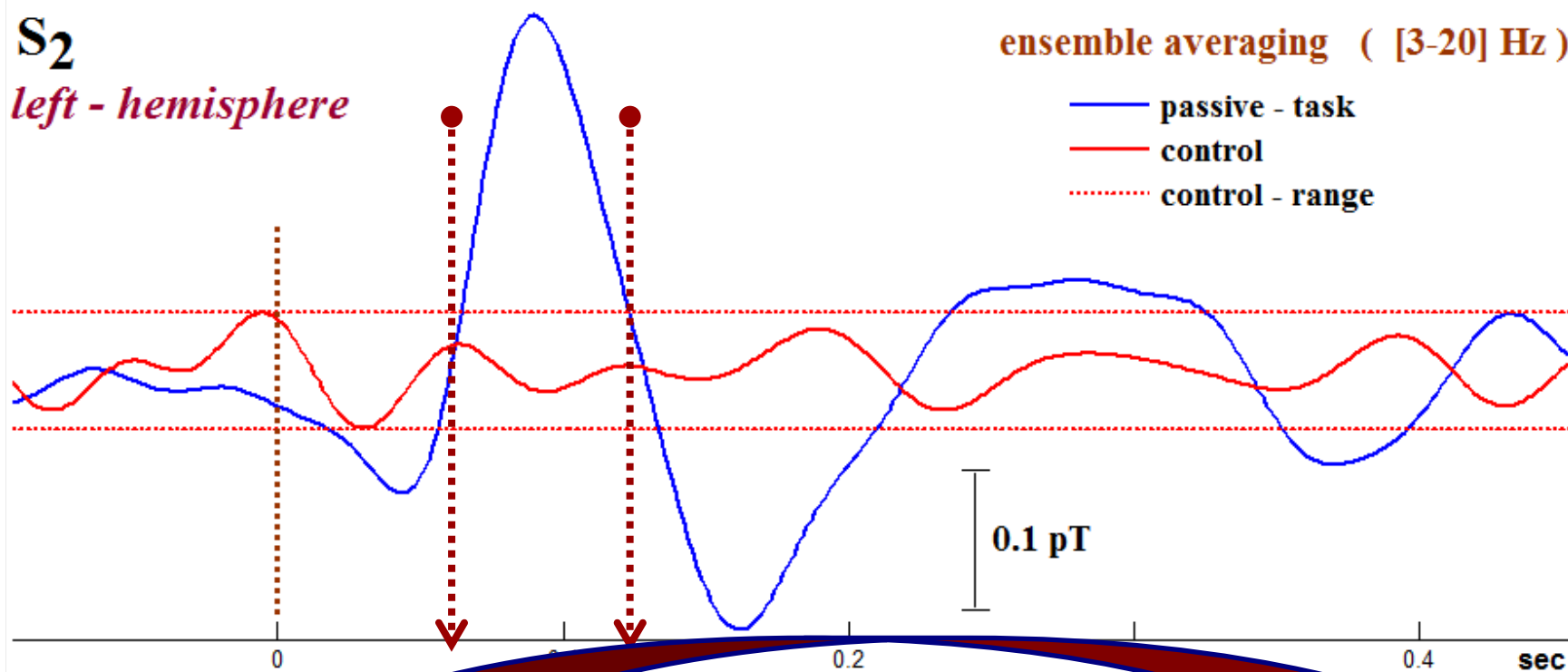
wherein ***Neural-Gas based Prototyping*** is first carried out  
and then prototypes are ranked based on an ***“SNR-classification index”***

**S<sub>2</sub>**

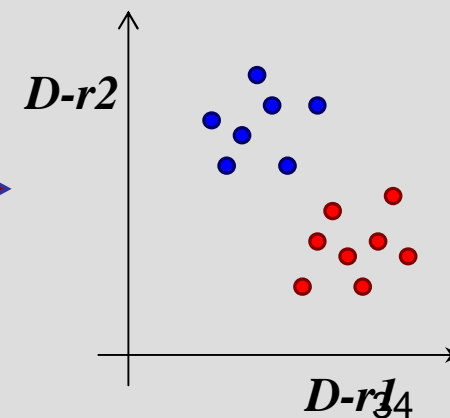
*left - hemisphere*

ensemble averaging ( [3-20] Hz )

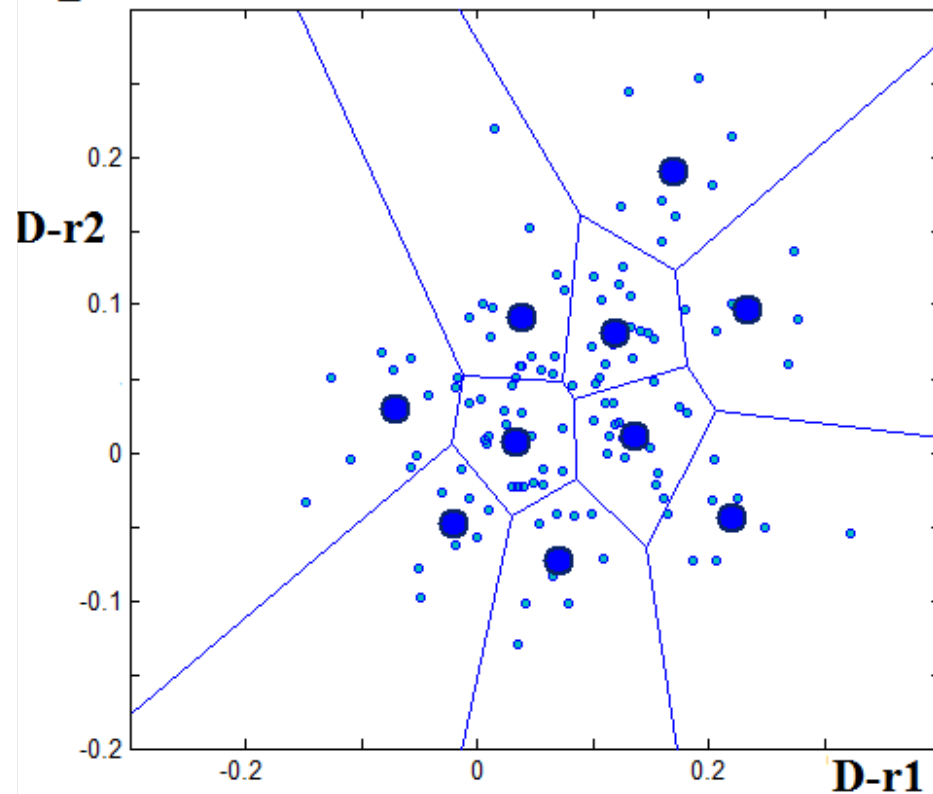
- passive - task
- control
- ⋯ control - range



*Laplacian & eigenanalysis*



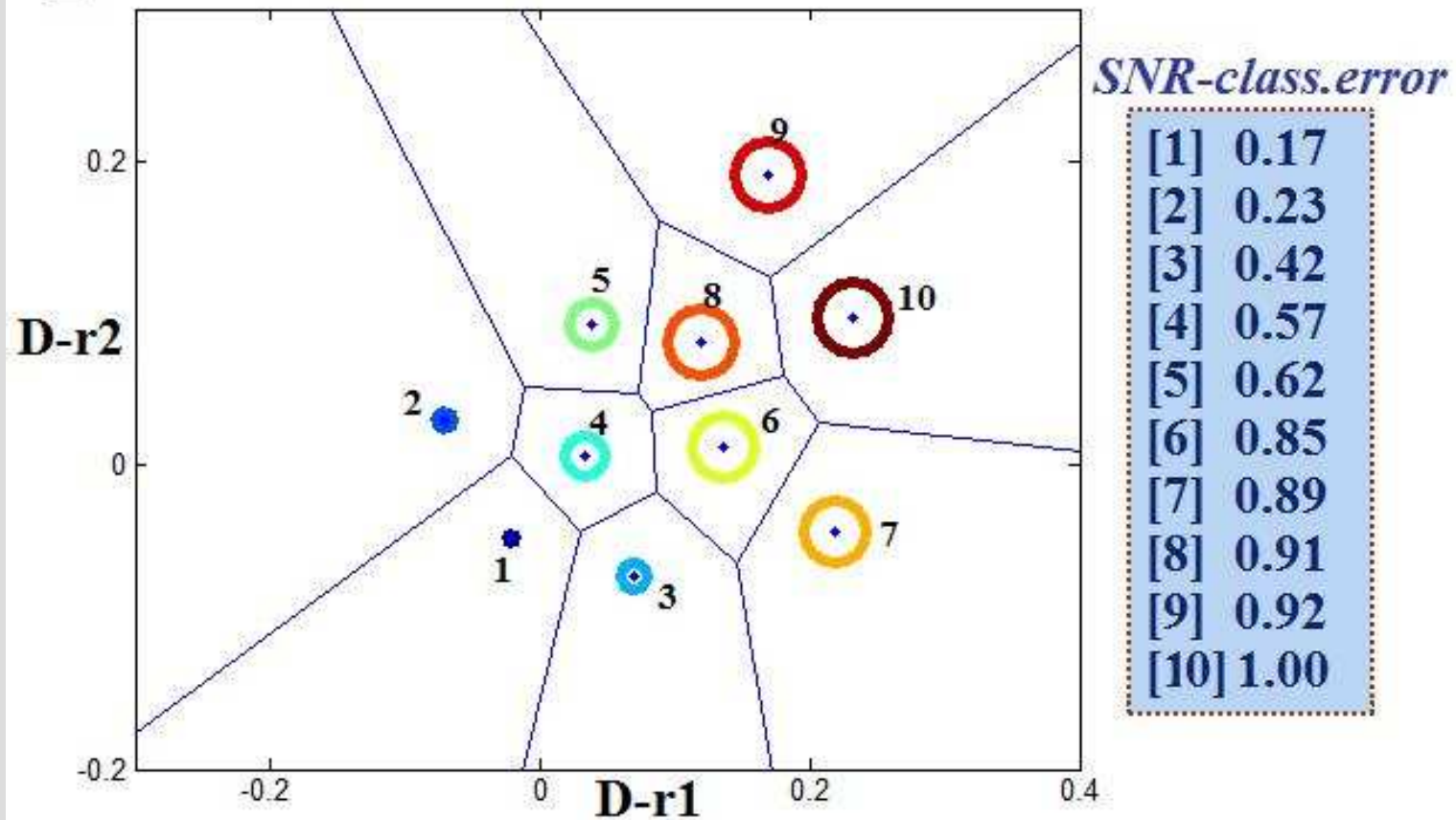
## $S_2$ left - hemisphere



By embedding brain-waves from *control condition*,  
we can define high-SNR regions in the reduced-space

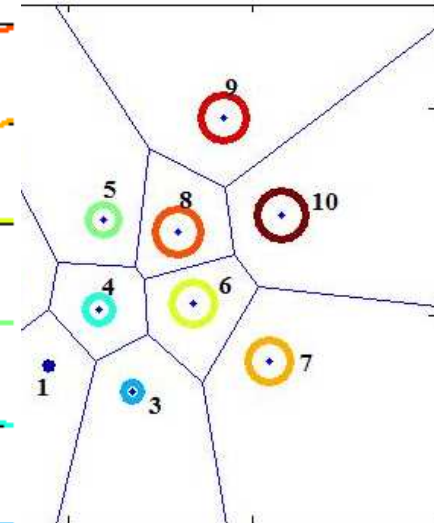
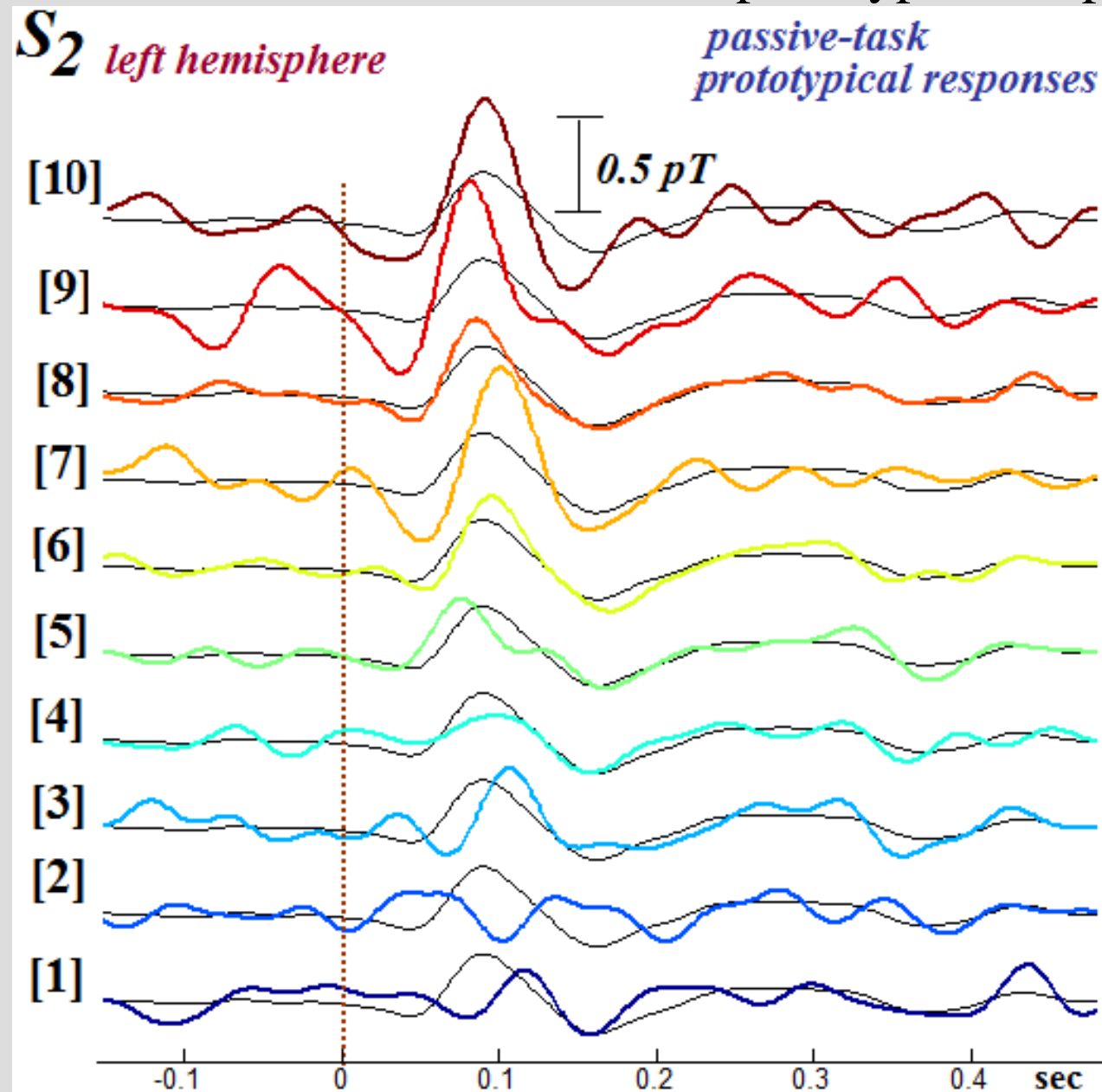
Exploiting the abundance of *spontaneous brain activity* snapshots,  
we can accurately/precisely *rank* the different voronoi regions.

## $S_2$ left - hemisphere

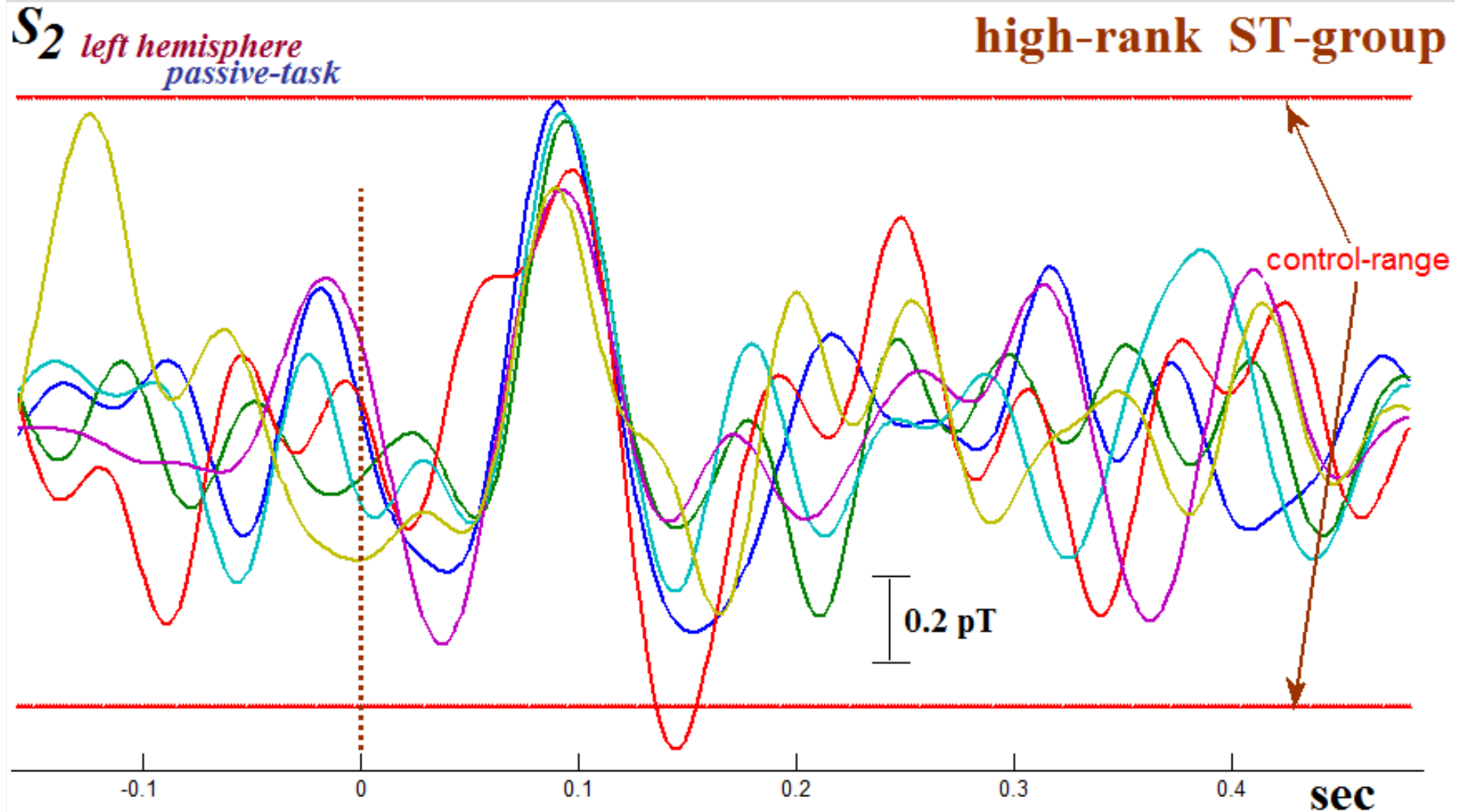




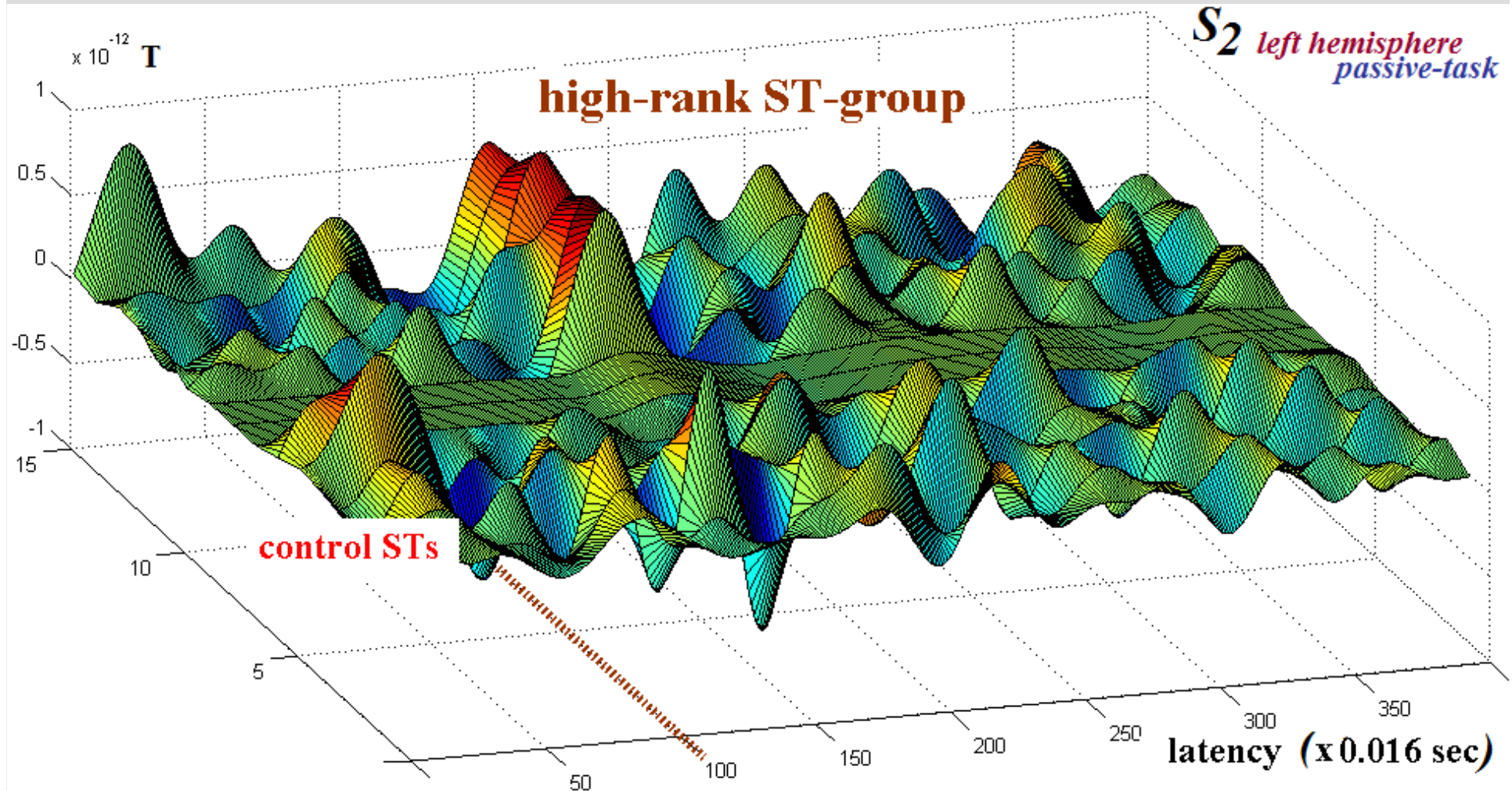
The derived ranks are utilized to order the prototypical responses accordingly



Taking a closer look at the high-SNR group of STs,  
a ‘**highlighting**’ of response dynamics is achieved



that can be enhanced via a ‘*Trial-Temporal*’ format



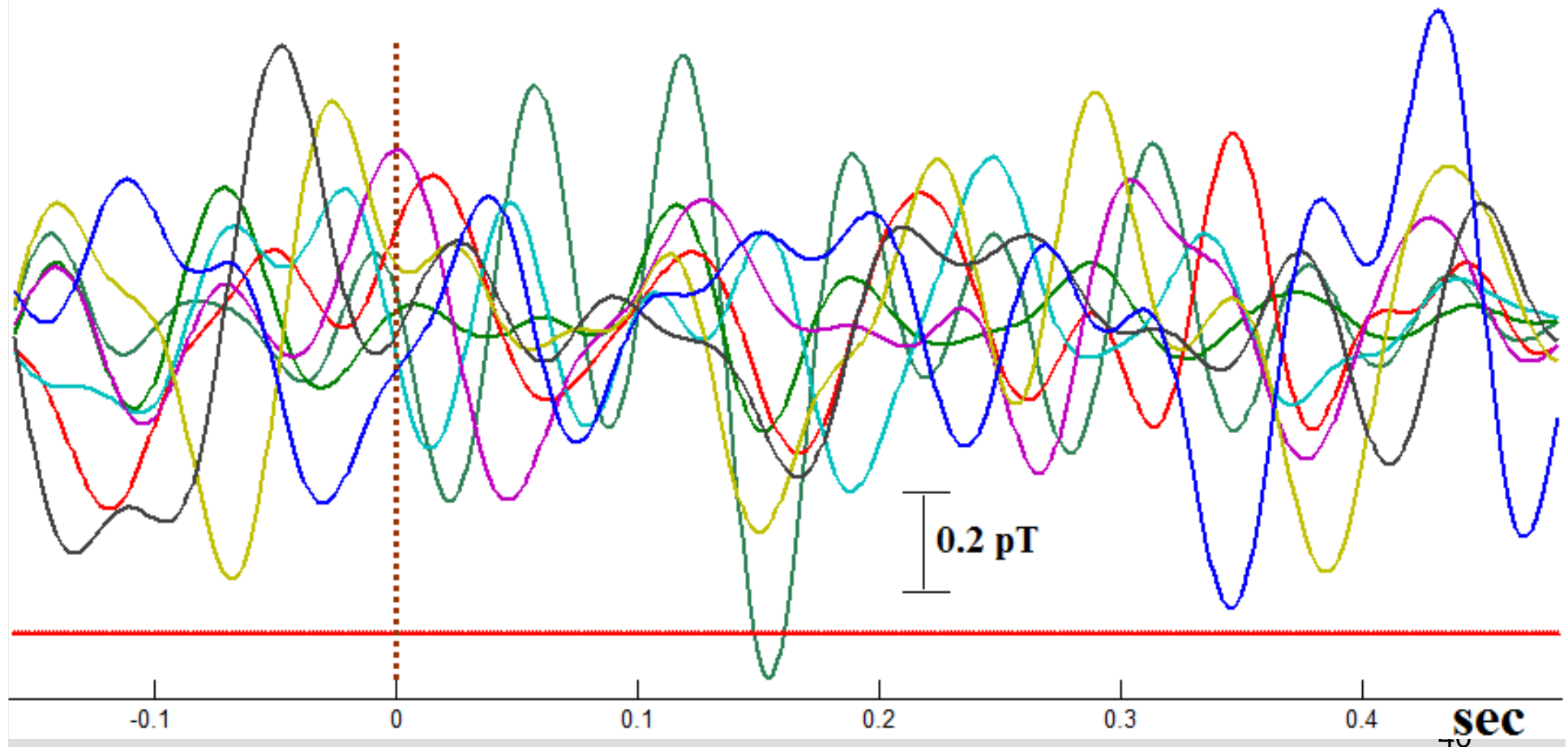
**There is an apparent organization in the brain waves @ 100 ms**

And be enriched via contrast  
with the **‘void-of-M100-response’** ST-group

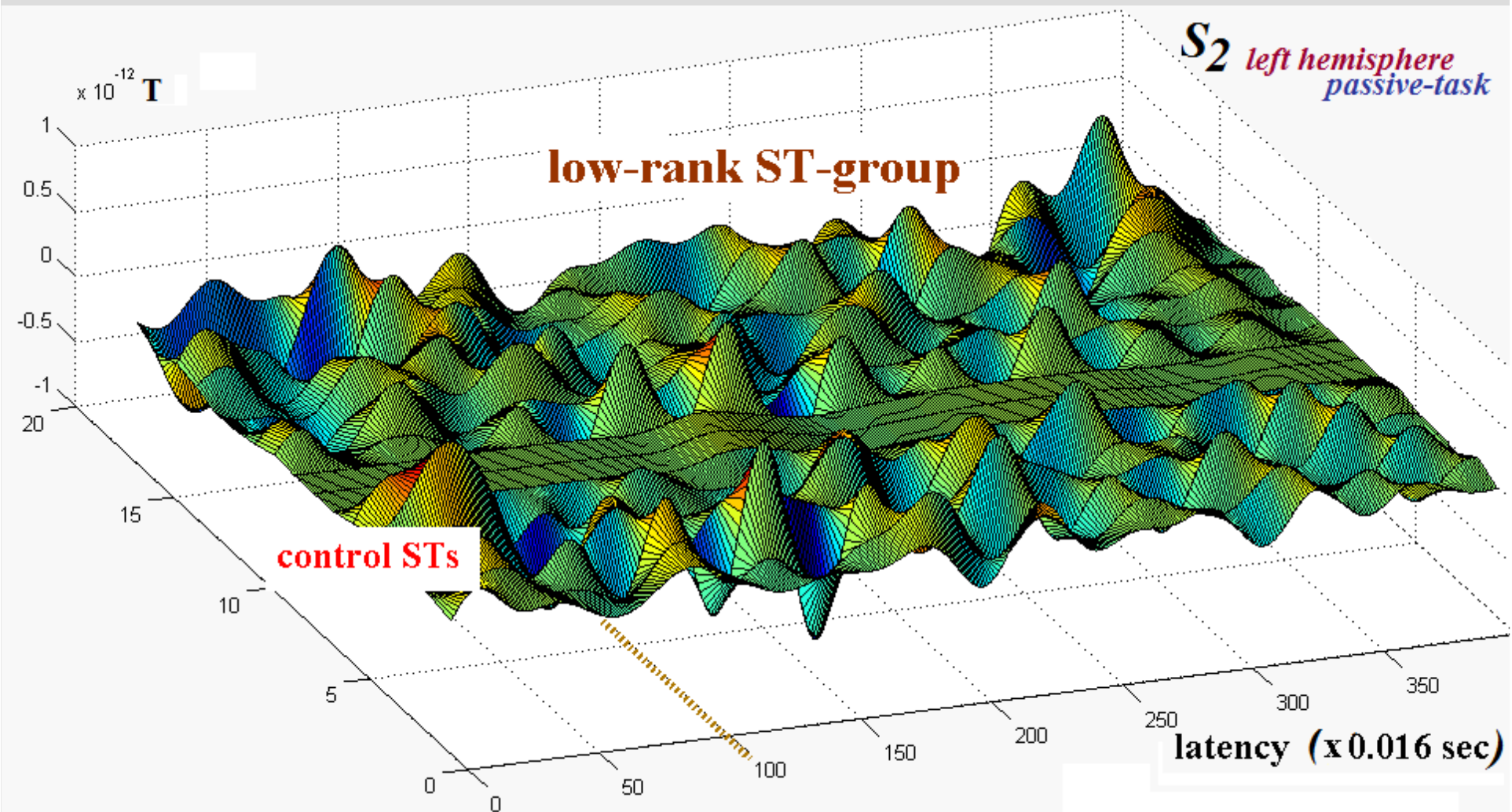
**S<sub>2</sub>** *left hemisphere*  
*passive-task*

16, 27, 32, 47, 57, 67, 70, 79

**low-rank ST-group**

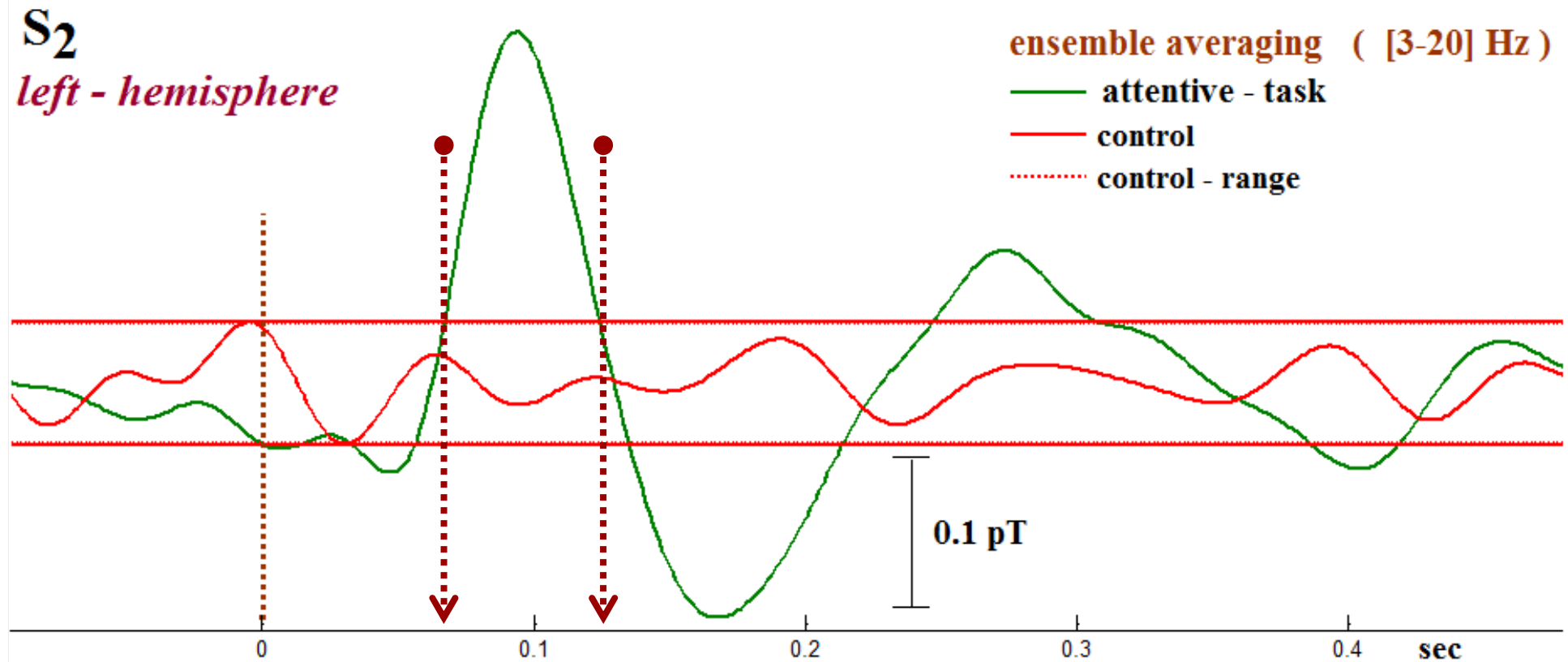






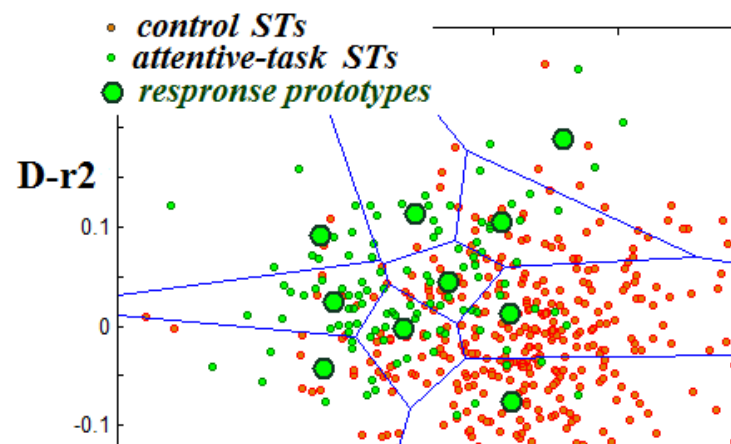
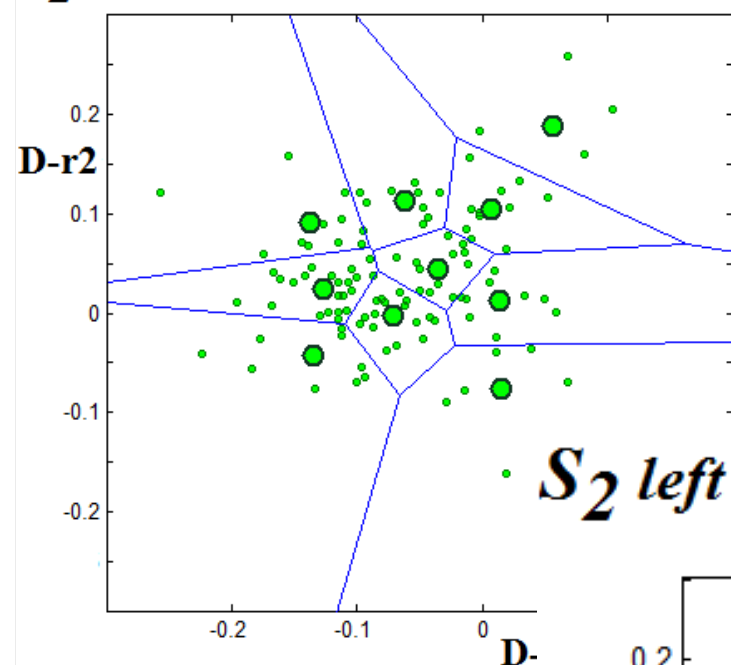
**There is lack of any kind of organization in the brain waves**

# ***Discriminative Prototyping*** for **attentive** (M100) responses

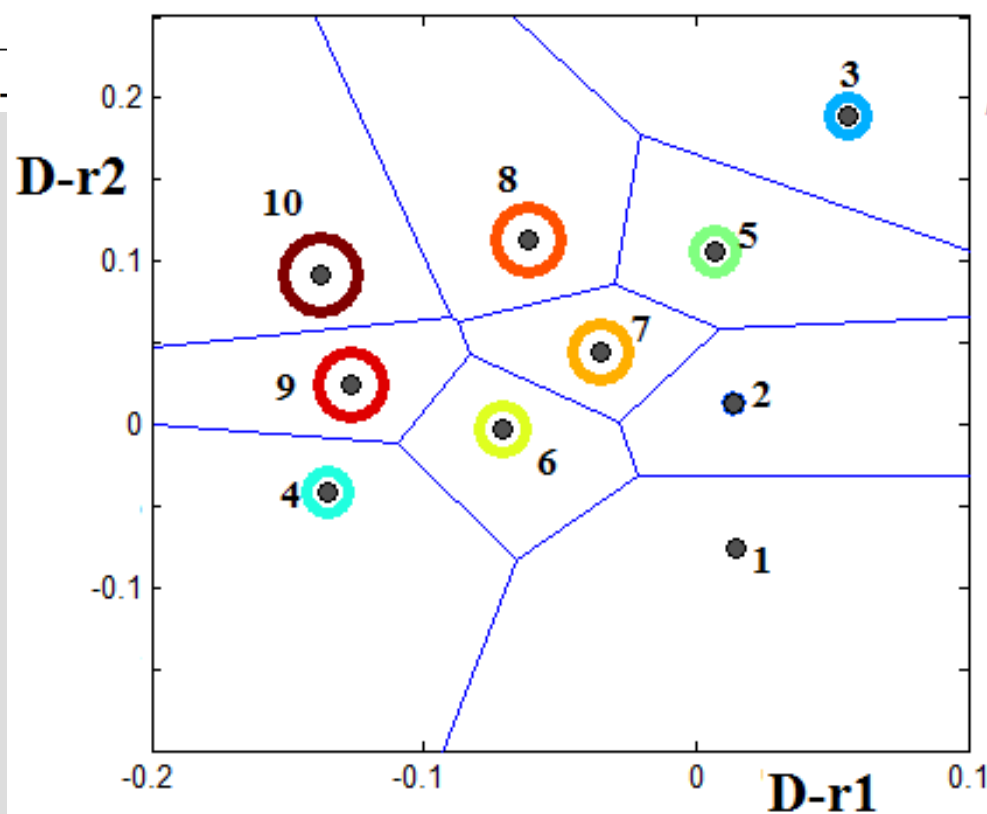




$S_2$  left - hemisphere

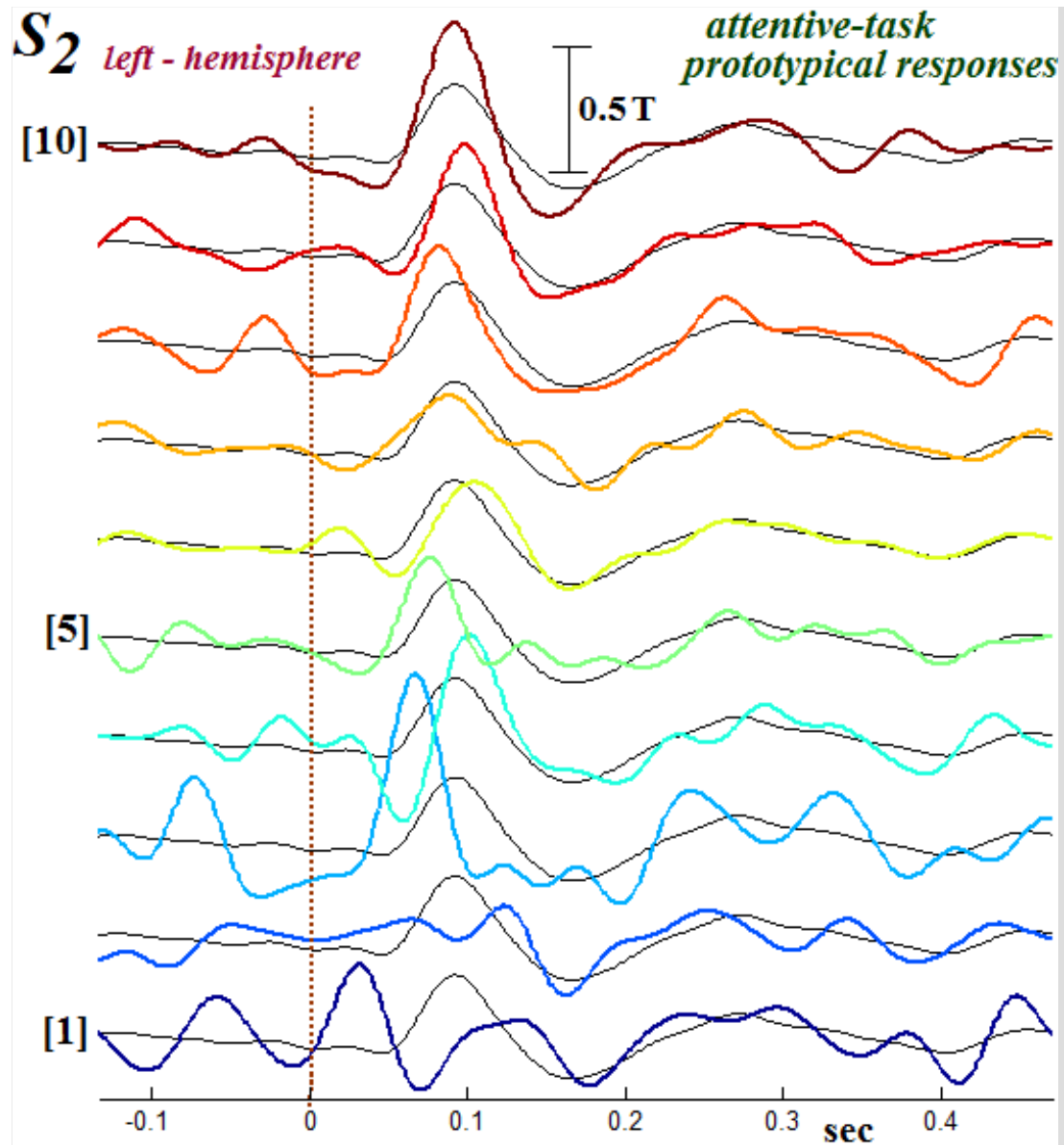


$S_2$  left - hemisphere  
attentive - task



$SNR$ -class.error

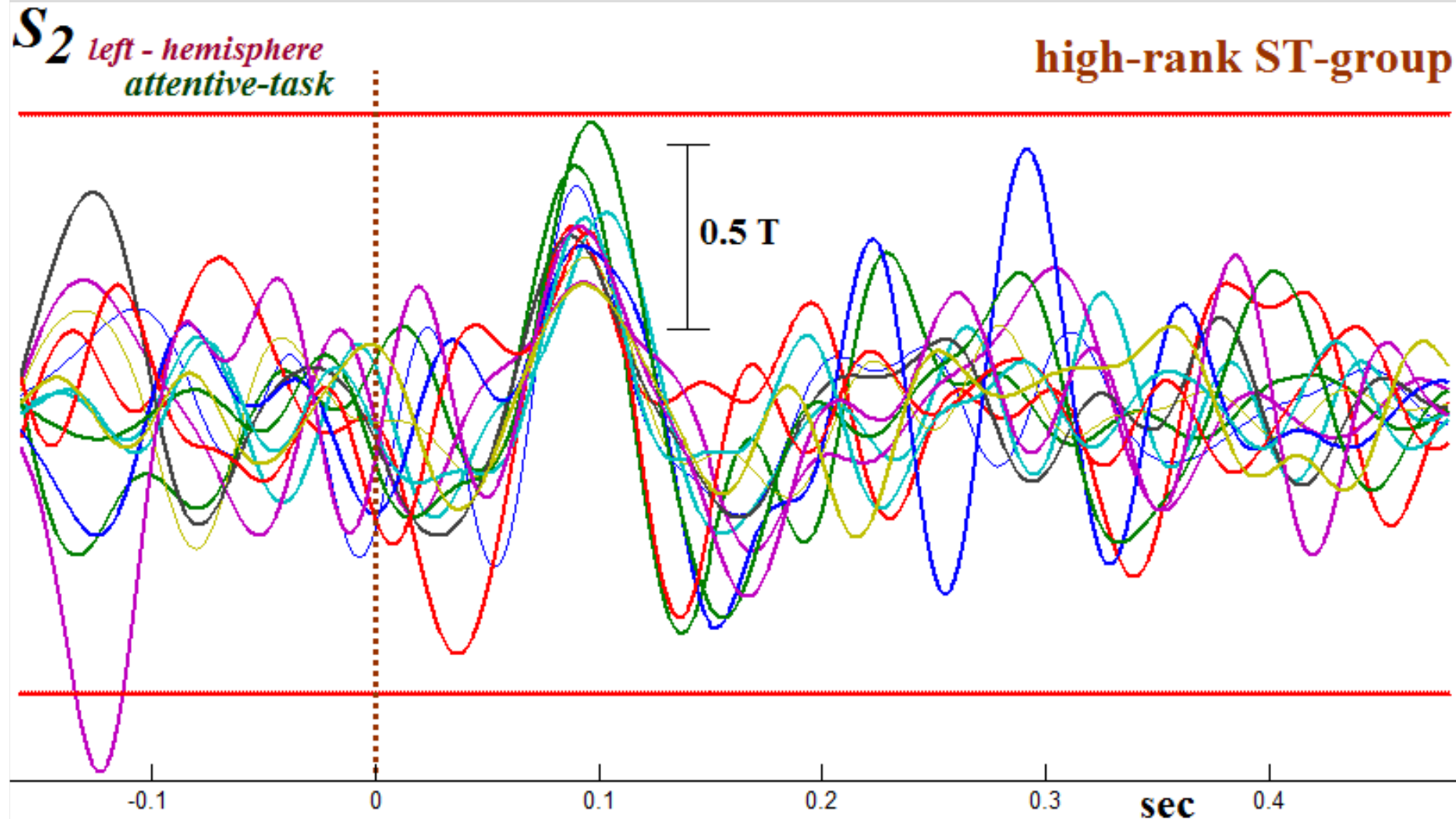
[1]	0.13
[2]	0.19
[3]	0.48
[4]	0.56
[5]	0.57
[6]	0.60
[7]	0.74
[8]	0.87
[9]	0.89
[10]	0.95



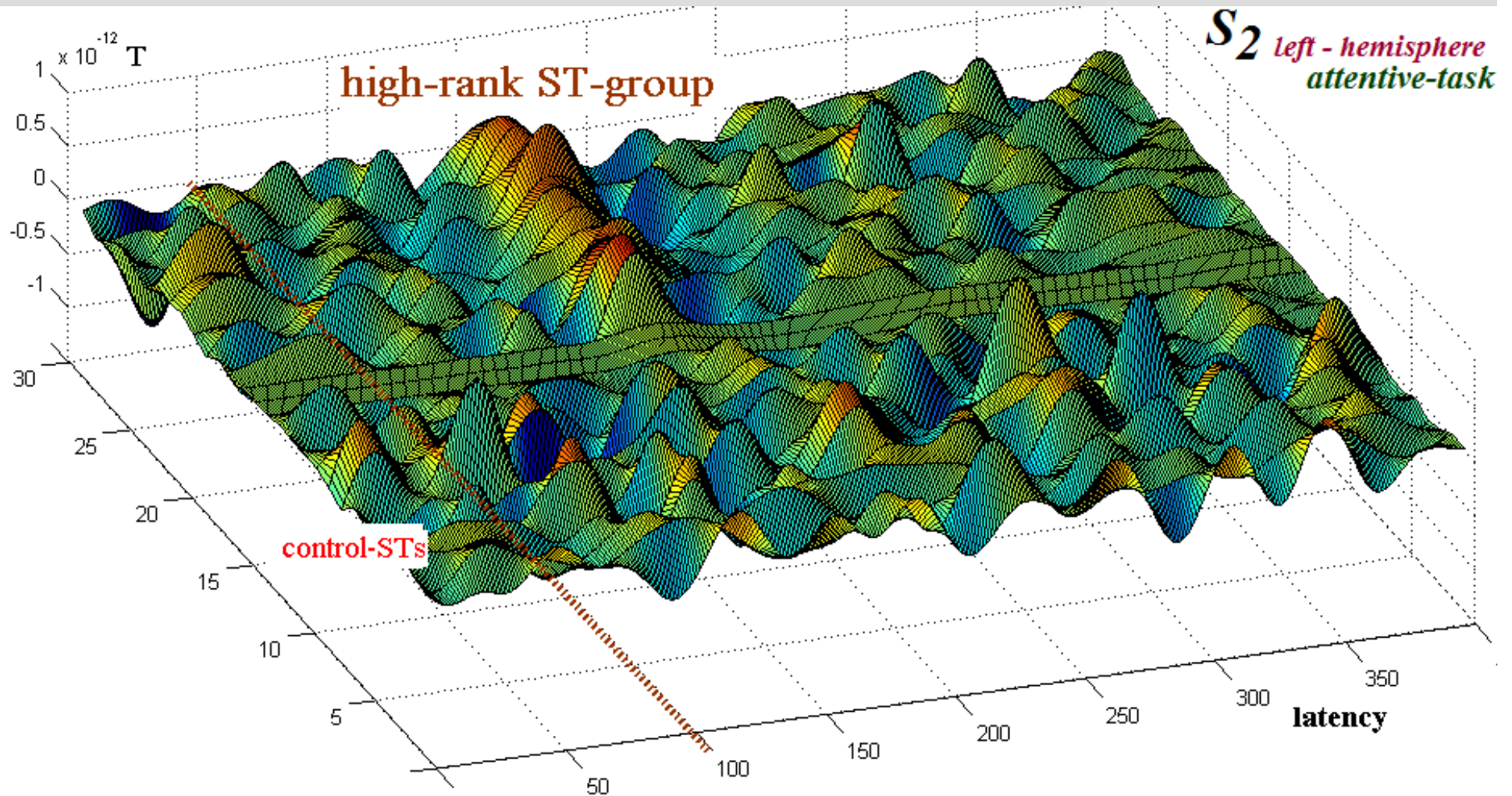
Even for the *attentive-task*

there are ST-groups 'void-of-M100'

The *high-SNR group* of STs, clearly shows a *phase-reorganization* of prestimulus activity accompanied with an enhancement of oscillations



portrayed even better in the ***‘Trial-Temporal’*** format

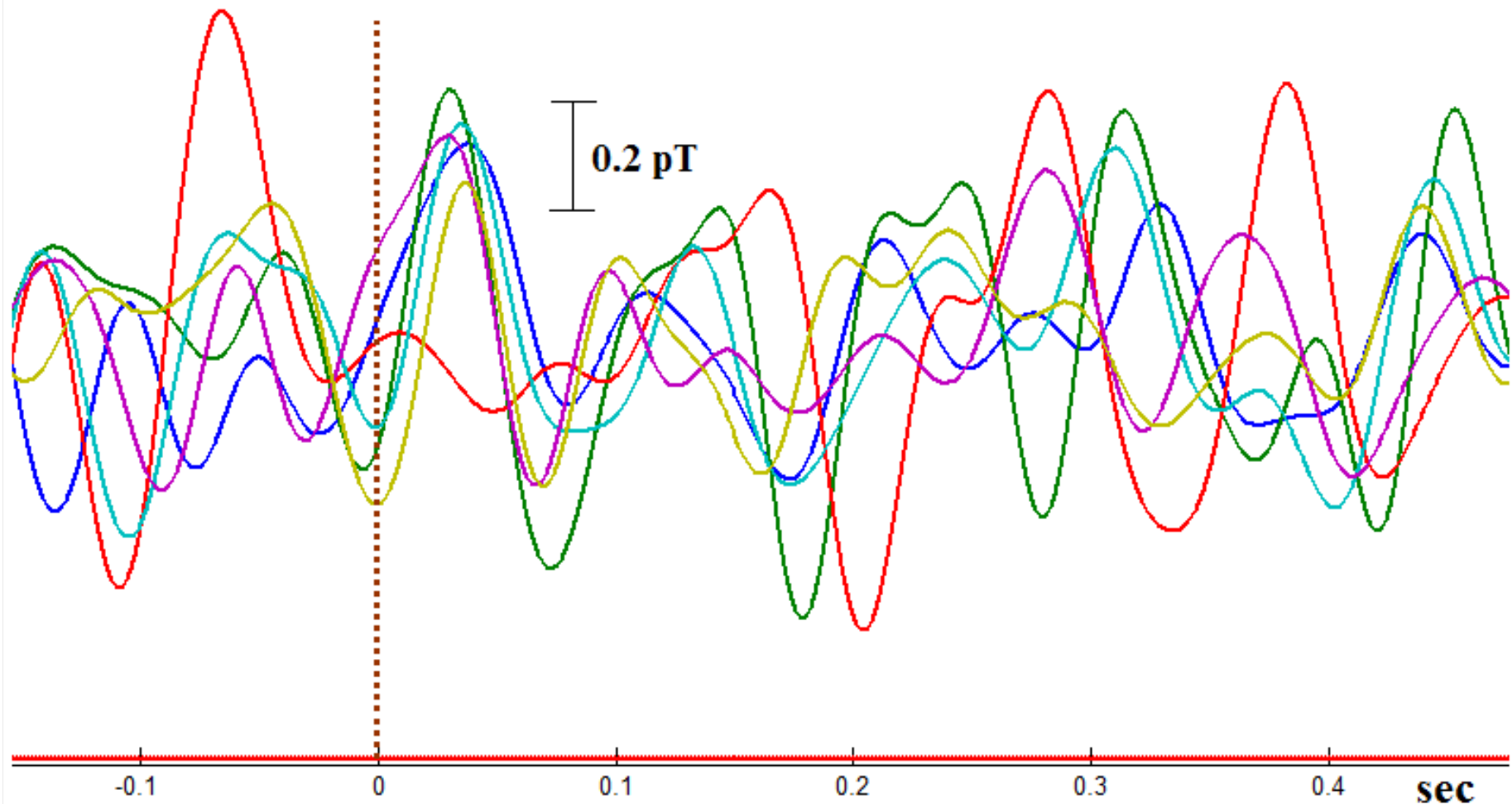


On the contrary, the *low-SNR group* of STs

$S_2$  *left - hemisphere*  
*attentive-task*

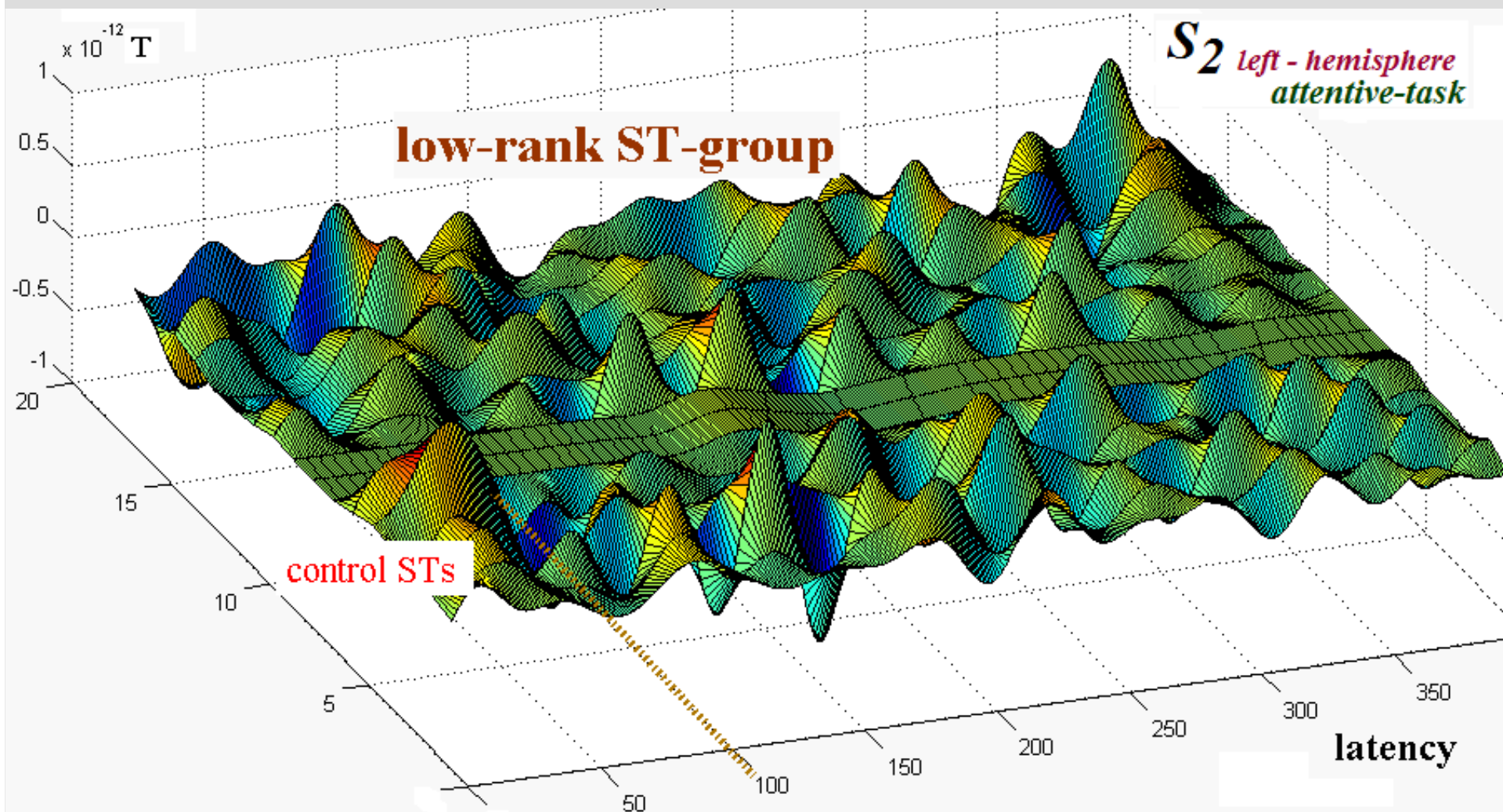
22, 49, 56, 86, 110, 120

**low-rank ST-group**



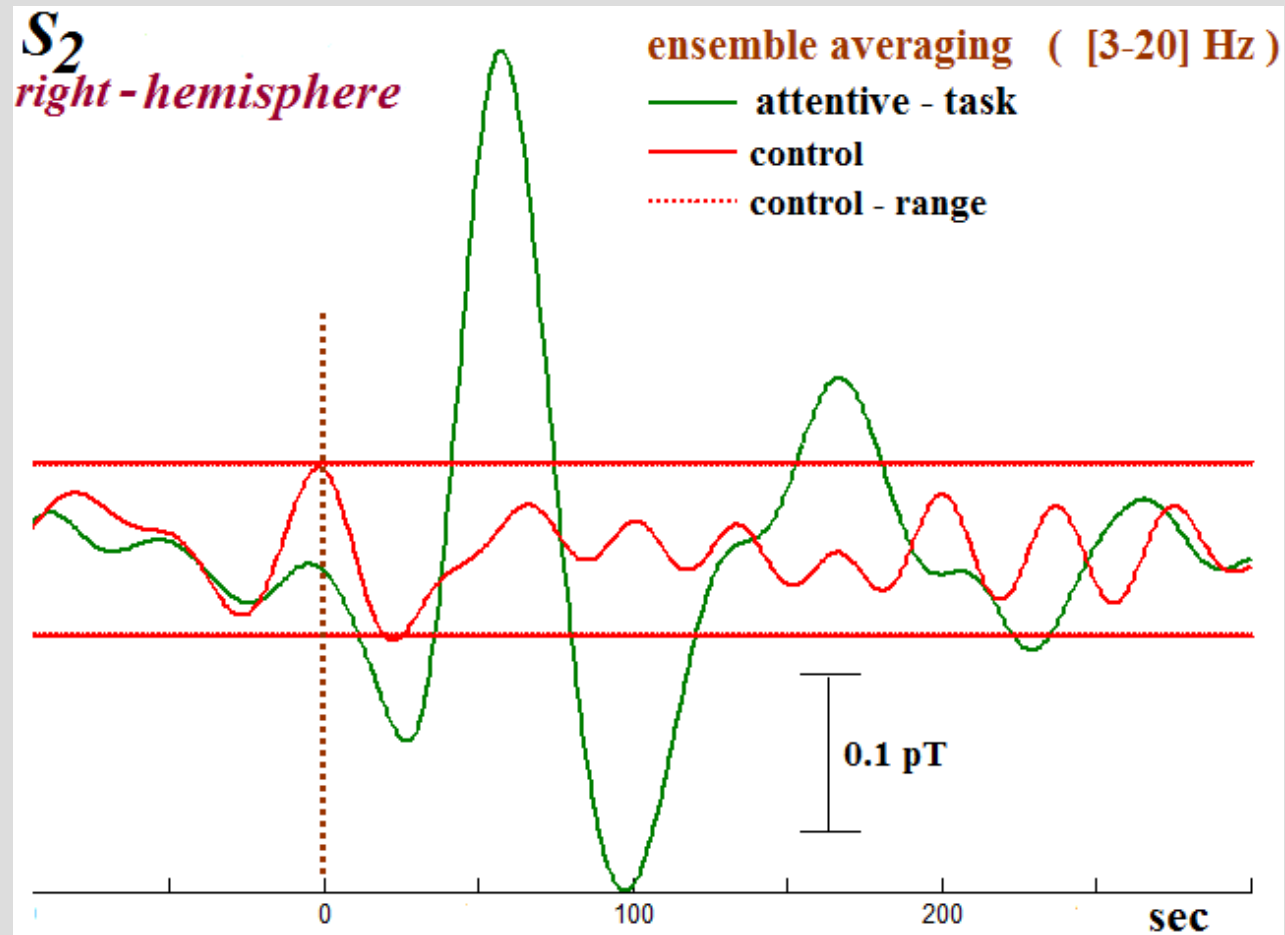


shows no prominent stimulus-induced changes

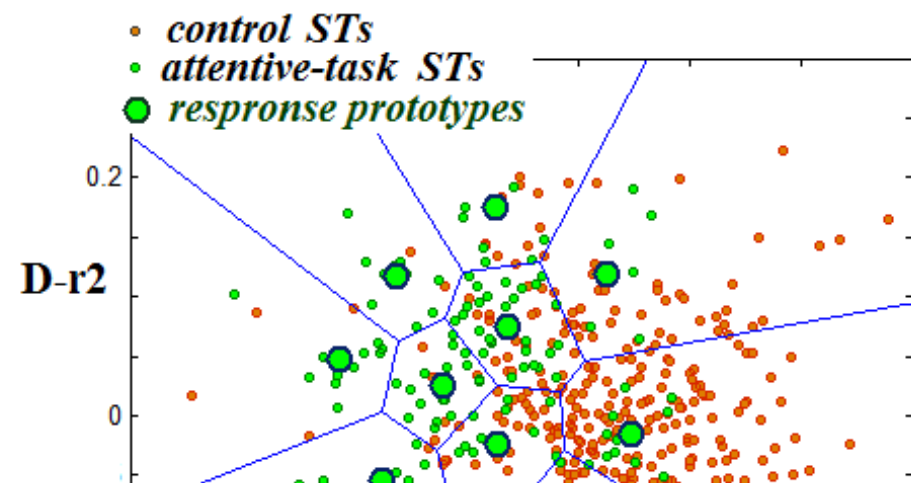
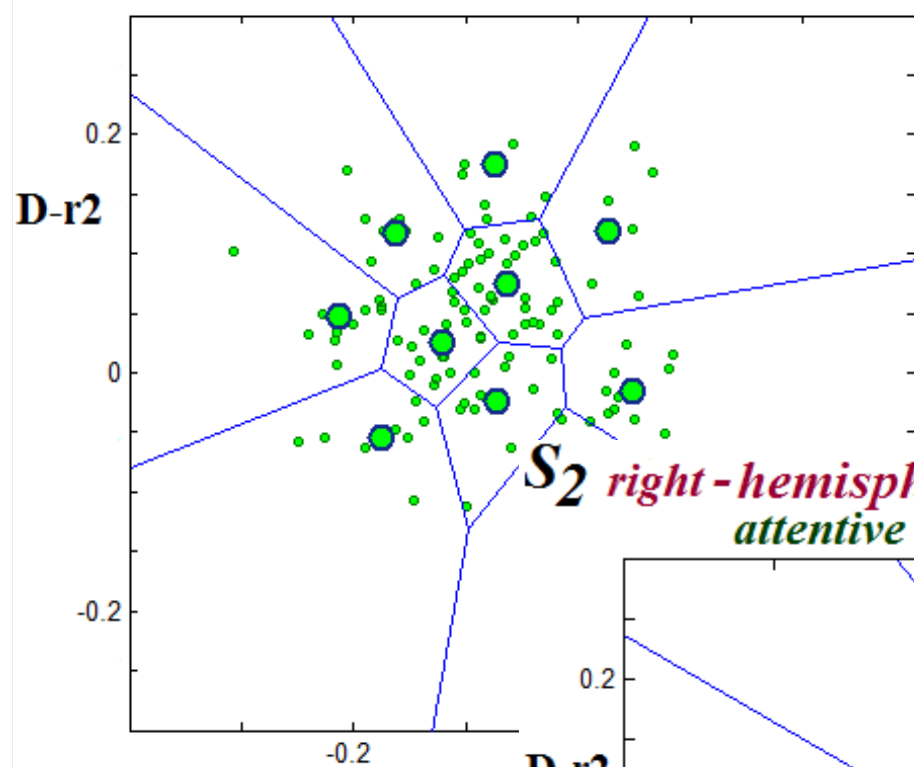




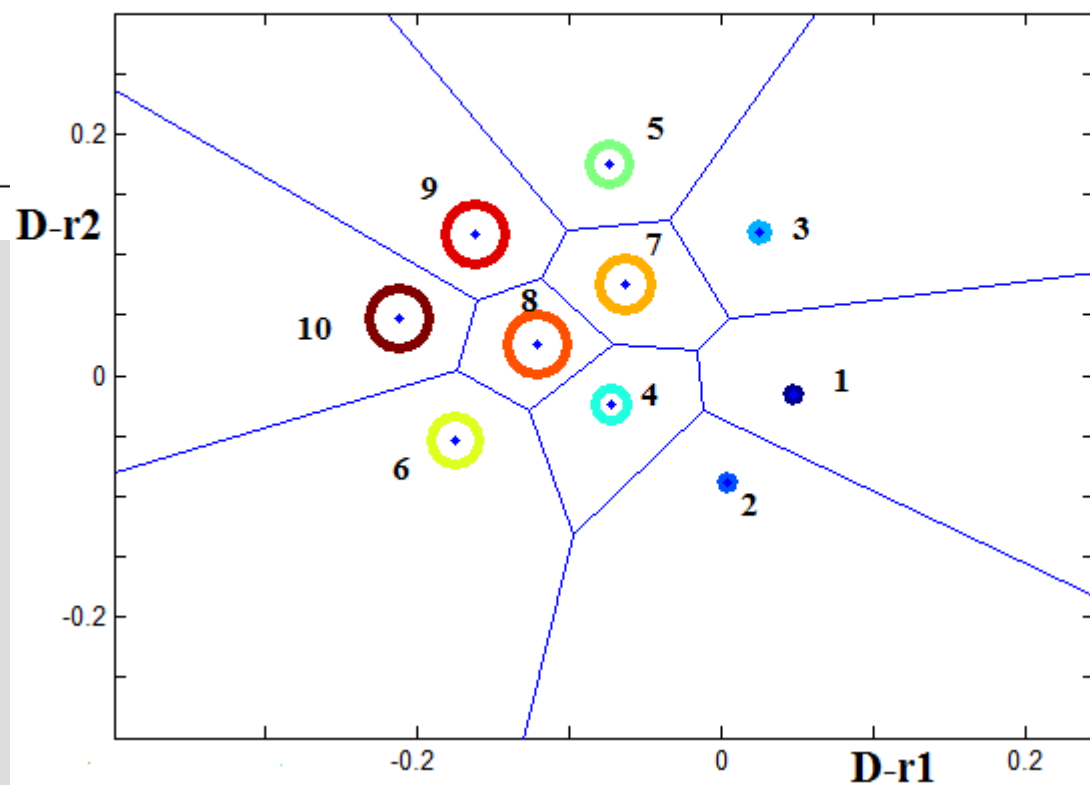
Similar observations can be made  
for the other hemisphere *of the same subject*



$S_2$  right-hemisphere  
attentive - task

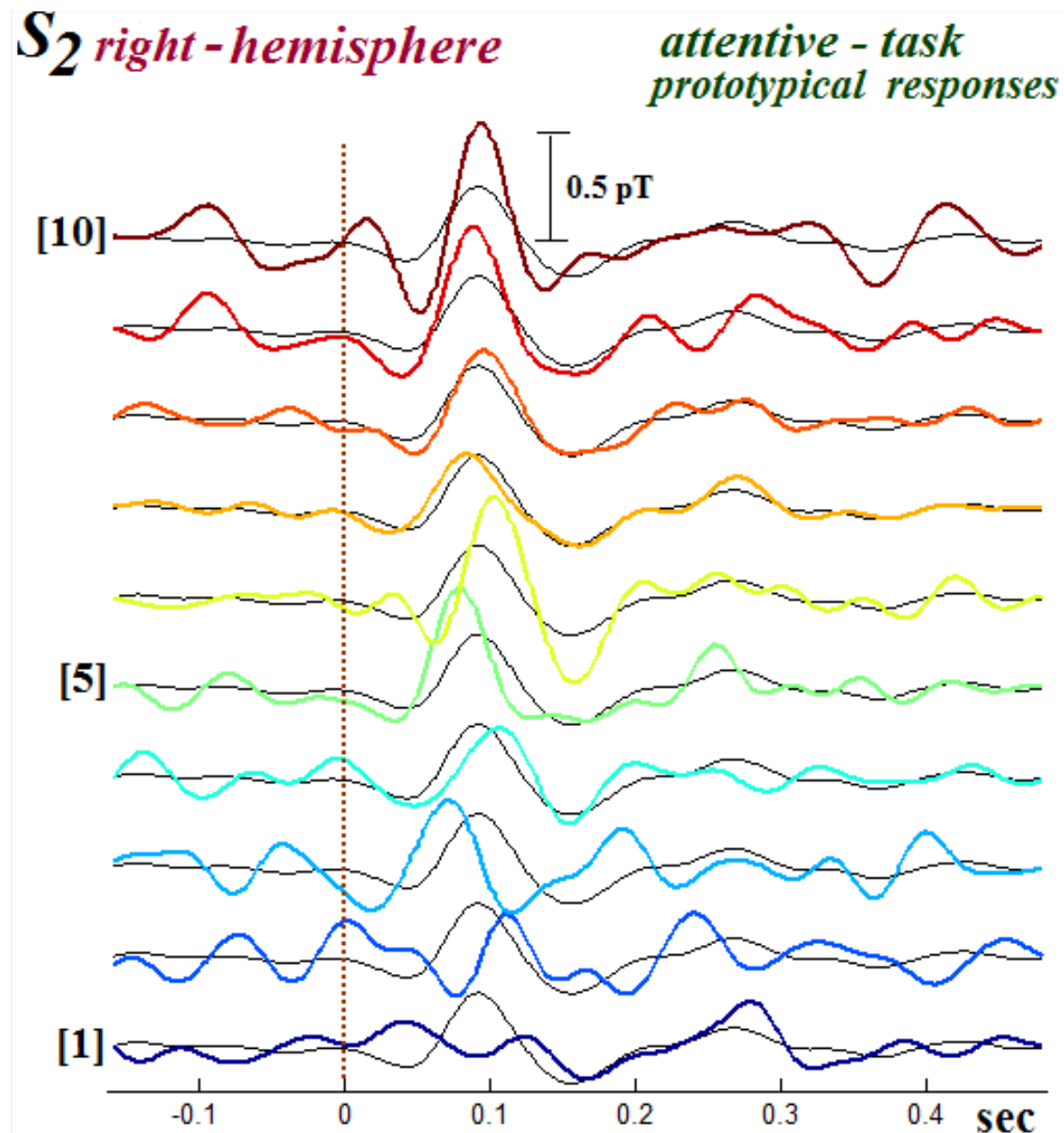


$S_2$  right-hemisphere  
attentive - task



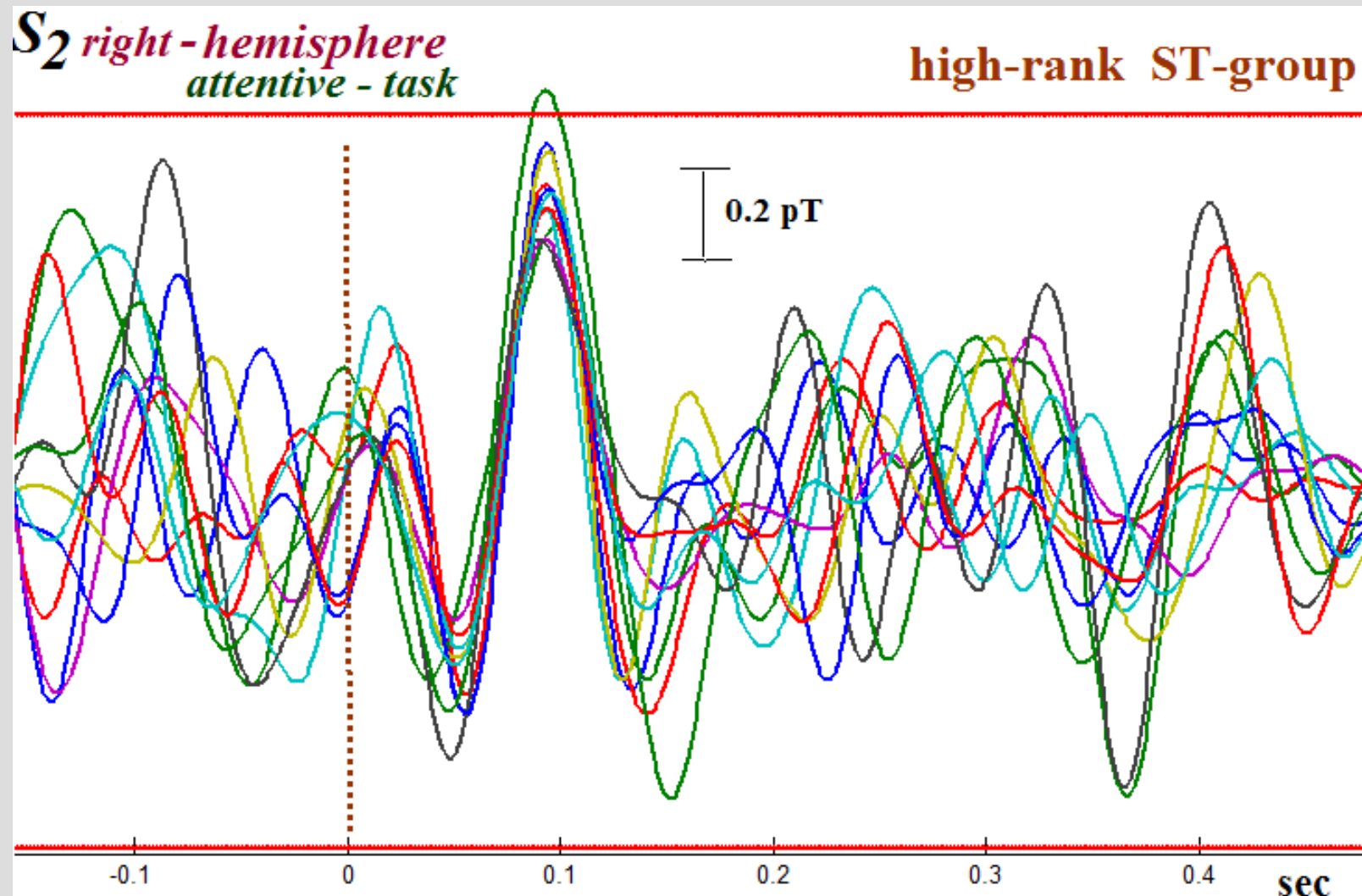
SNR-class.error

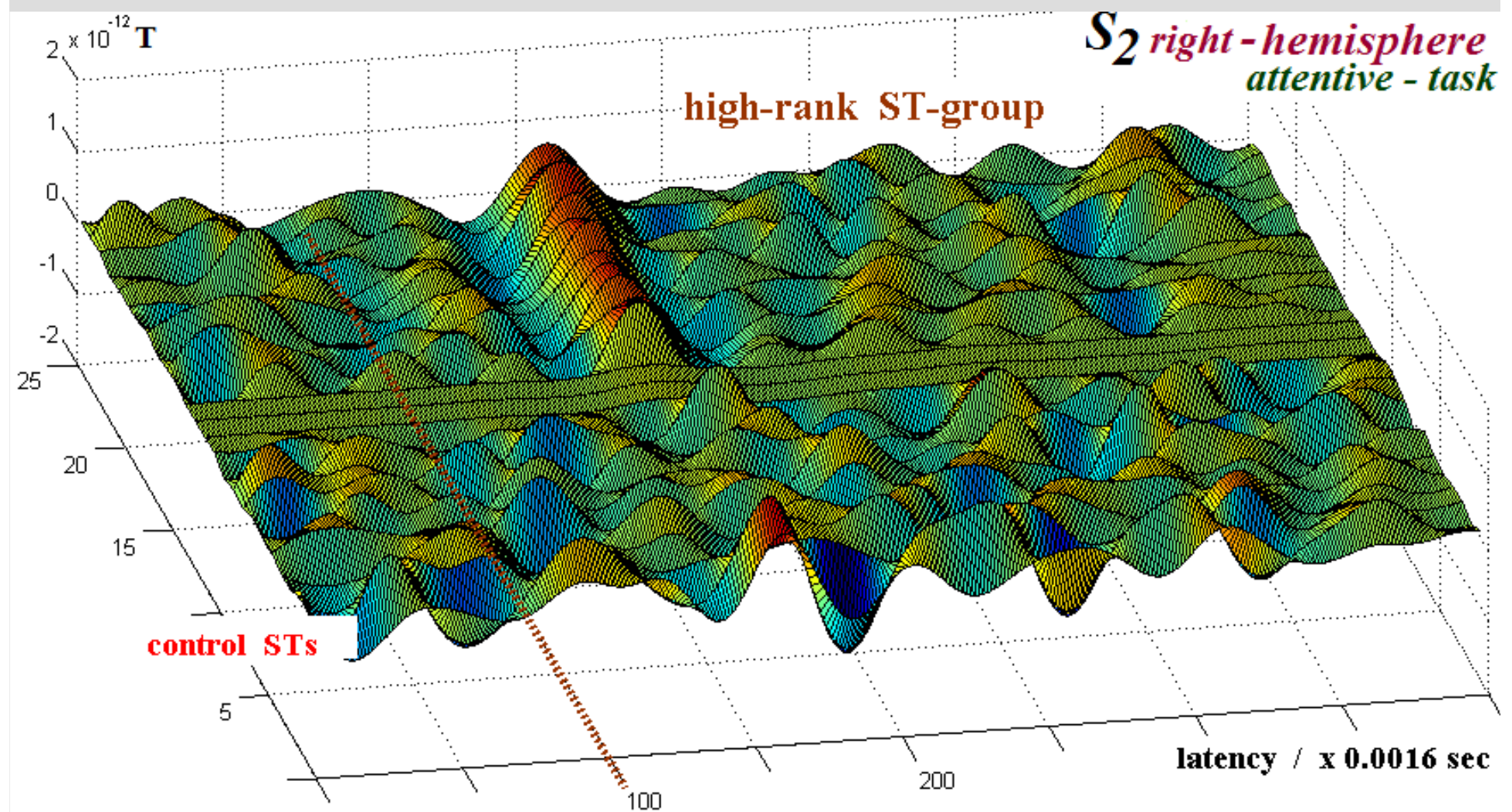
[1]	0.19
[2]	0.20
[3]	0.30
[4]	0.50
[5]	0.65
[6]	0.75
[7]	0.79
[8]	0.90
[9]	0.91
[10]	0.92



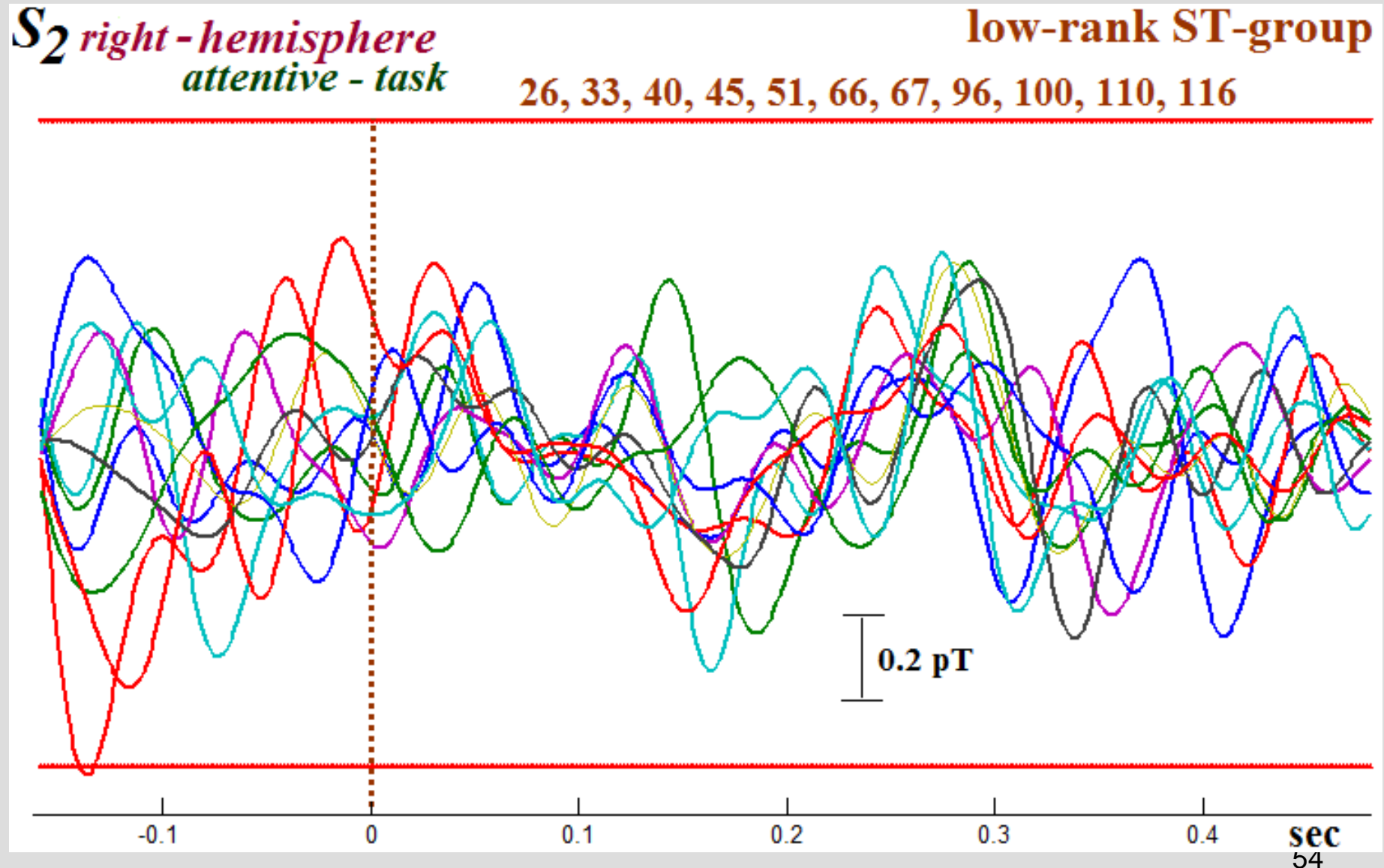
**AND for this hemisphere ( in the *attentive-task* !!! )**  
**there is a ST-group ‘void-of-M100’**

*Phase-reorganization* of brain waves is apparent in the **high-SNR STs**





While *stimulus-induced dilution* of *brain waves*  
can be seen in the *low-SNR* ST-group





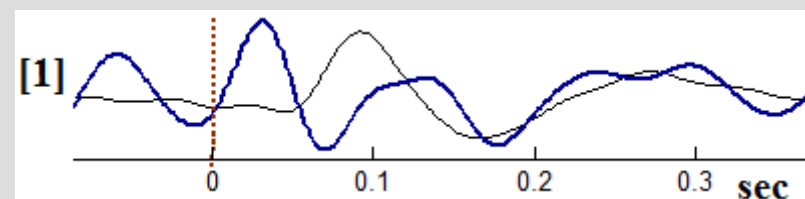
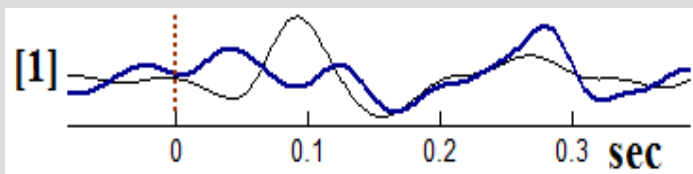
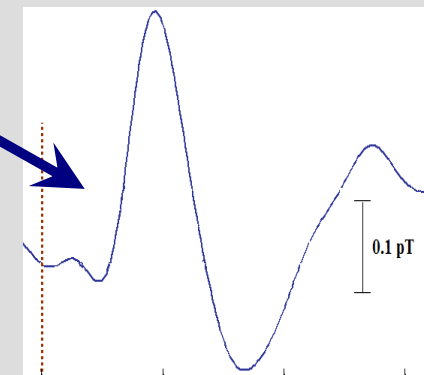
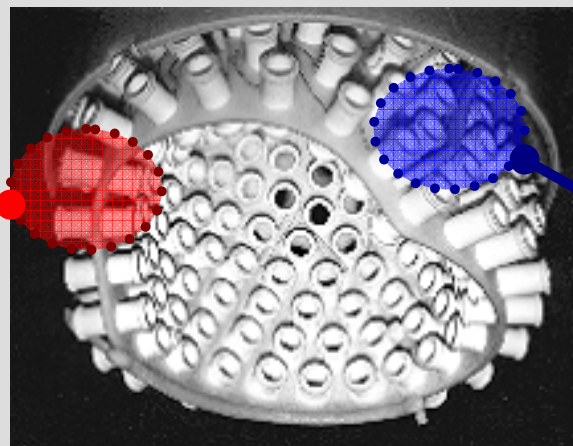
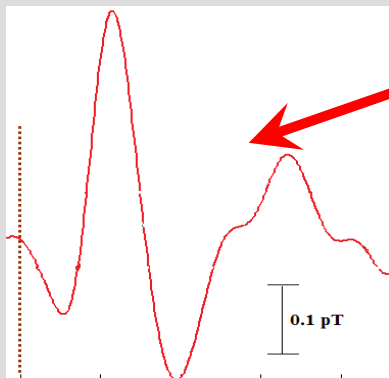
*S<sub>2</sub> right-hemisphere  
attentive - task*

low-rank ST-group

control STs

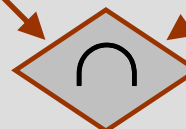
latency

Count #



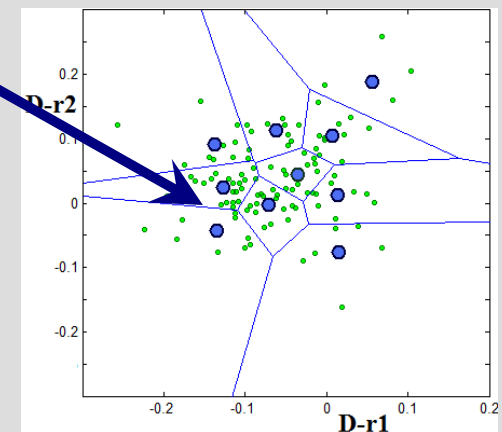
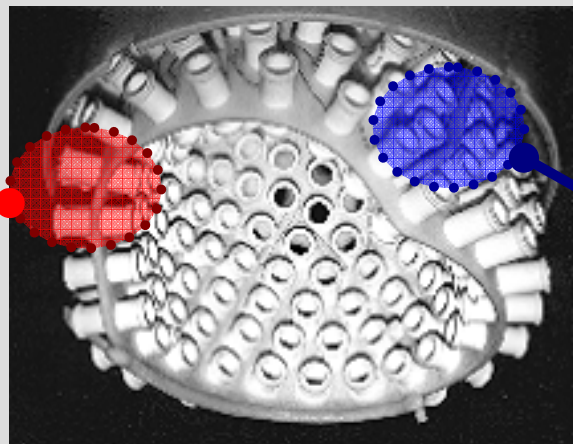
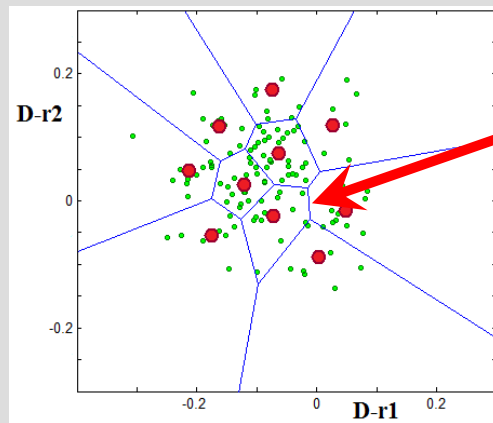
**void\_trials\_right** = {26, 33, ..., 116}

{22, 49, ..., 120} = **void\_trials\_left**



**Rare coincidence**

We further pursue any kind of systematic-relationship  
 between the two hemispheres  
 in the formation of brain-waves groups  
 by resorting to *Variational-Information (VI) measure*  
 (e.g. **low-SNR** STs in the left hemisphere  
 could coincide with **high-SNR** STs in the right hemisphere )

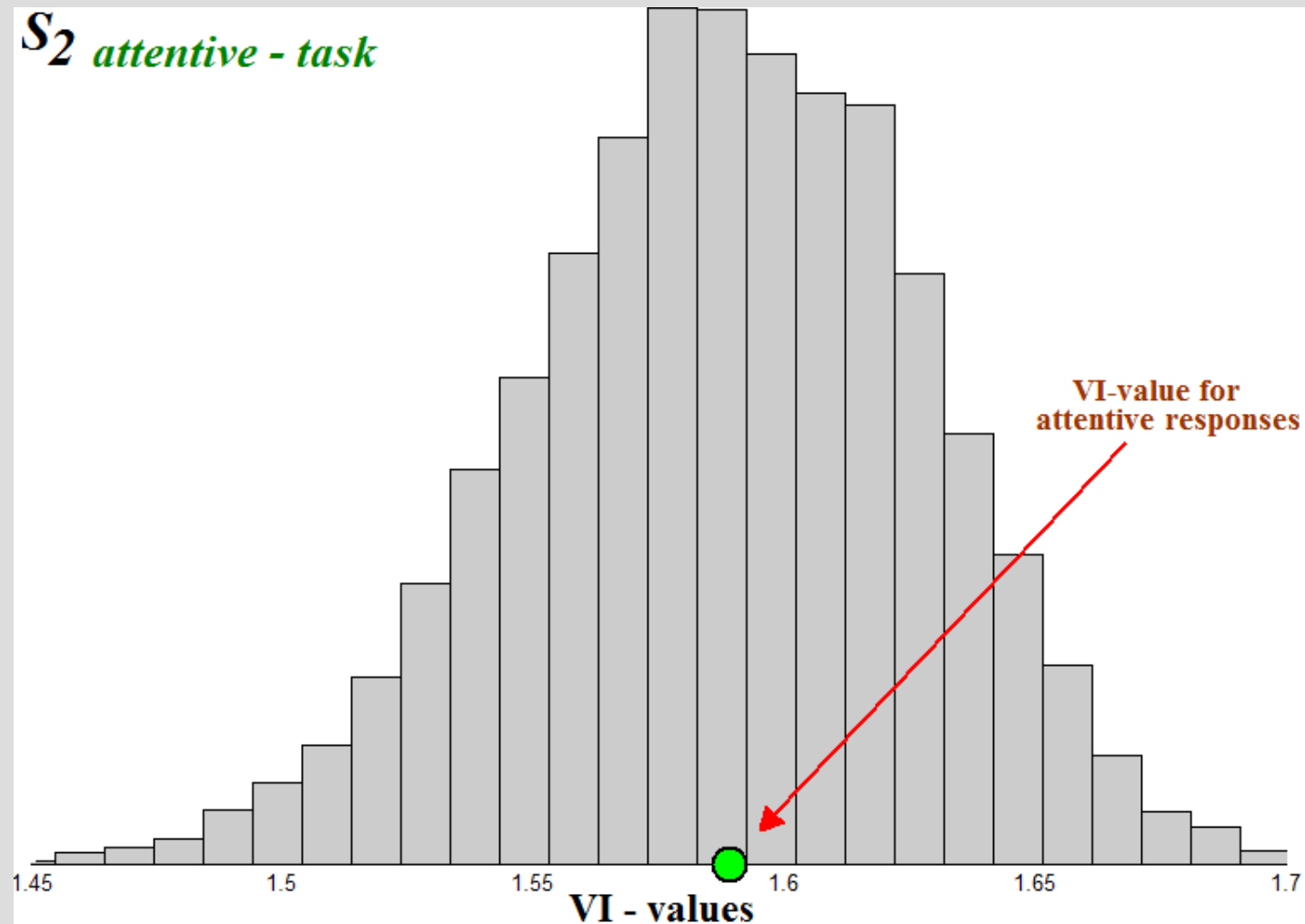


**Right\_trials\_group\_index** = {3, 2,2,1, ...,10,4 }

**Left\_trials\_group\_index** = {8, 4,3,1, ...,1,9 }

**VI** = **MI** for partitions & an adjustment for being a *true-metric*

Based on a *randomization test* (10000 permutations)



**Left** and **Right** hemisphere groups  
of (M100-related) brain waves are formed **independently**

## ***IIc. Empirical Mode Decomposition for enhancing (M100-related) brain waves***



## ***Intrinsic mode functions (IMFs)***

**Huang et al., Proc. R. Soc Lond. A, 454 (pp.903-995), 1998 :**

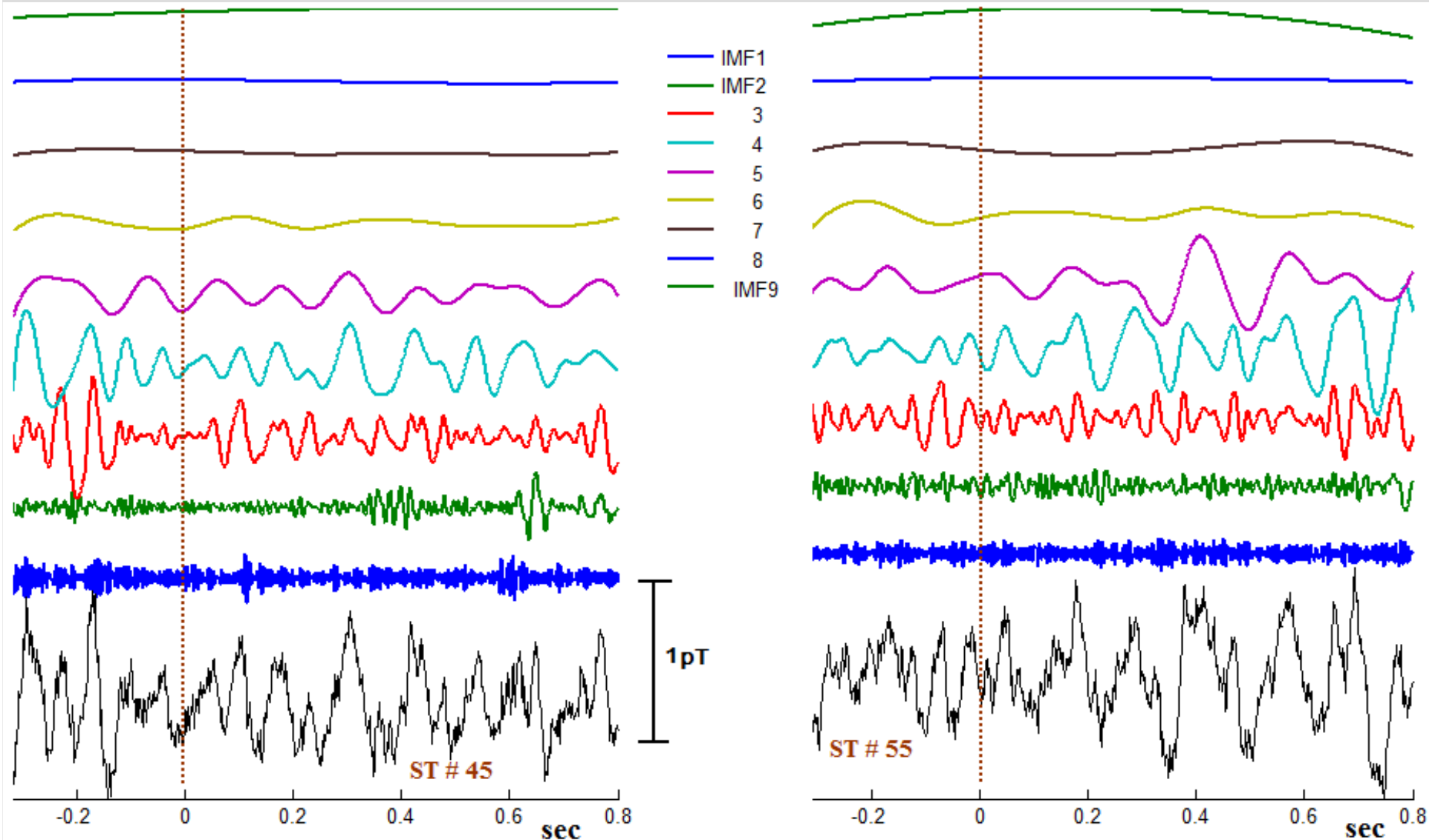
***‘‘The **EMD** and the hilbert spectrum  
for nonlinear and non-stationary time series analysis’’***

- An iterative (hierarchical ) sifting-procedure is applied**

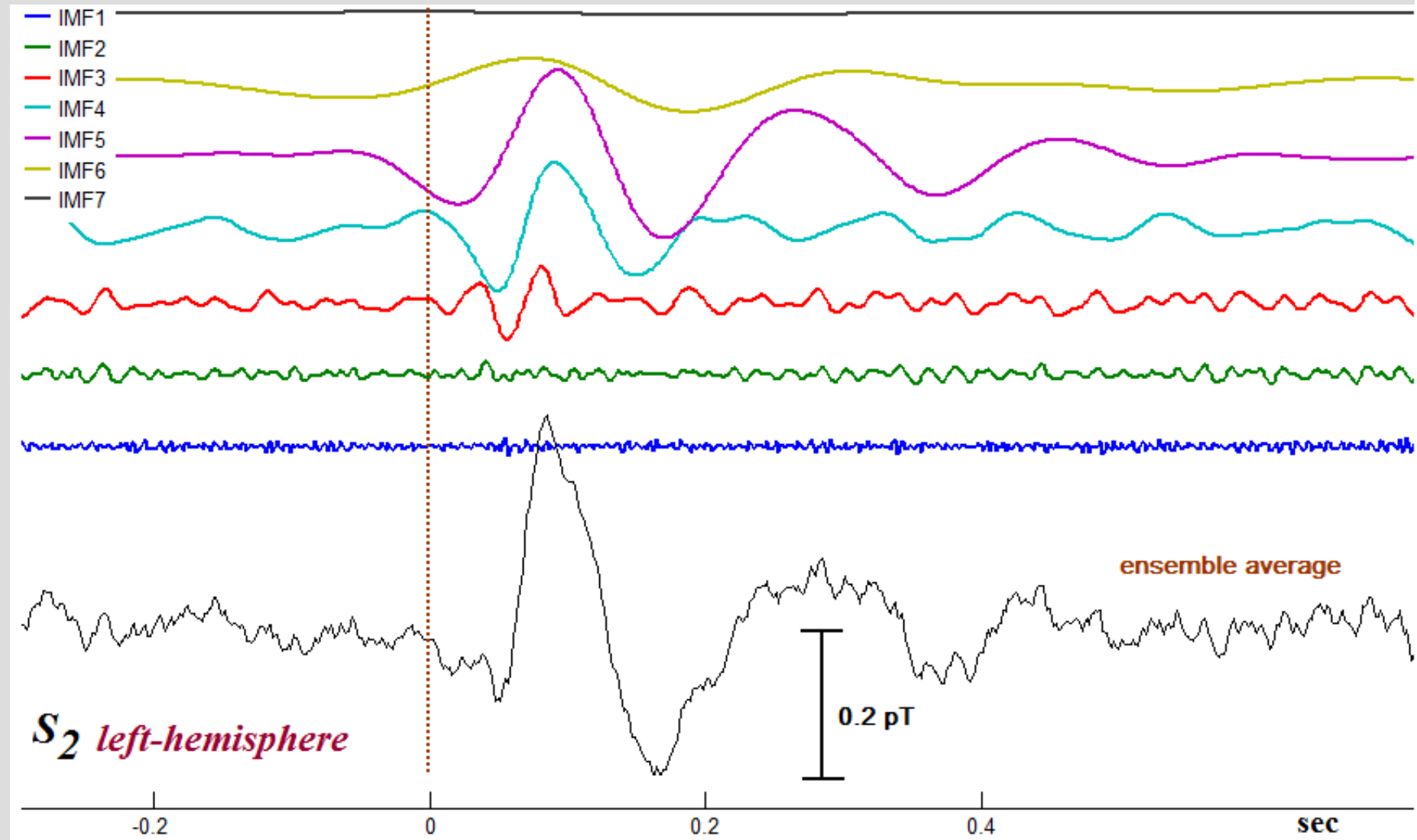
**It considers the signals at their local oscilation scale,  
subtracts the faster oscilation,  
and iterates with the residual**



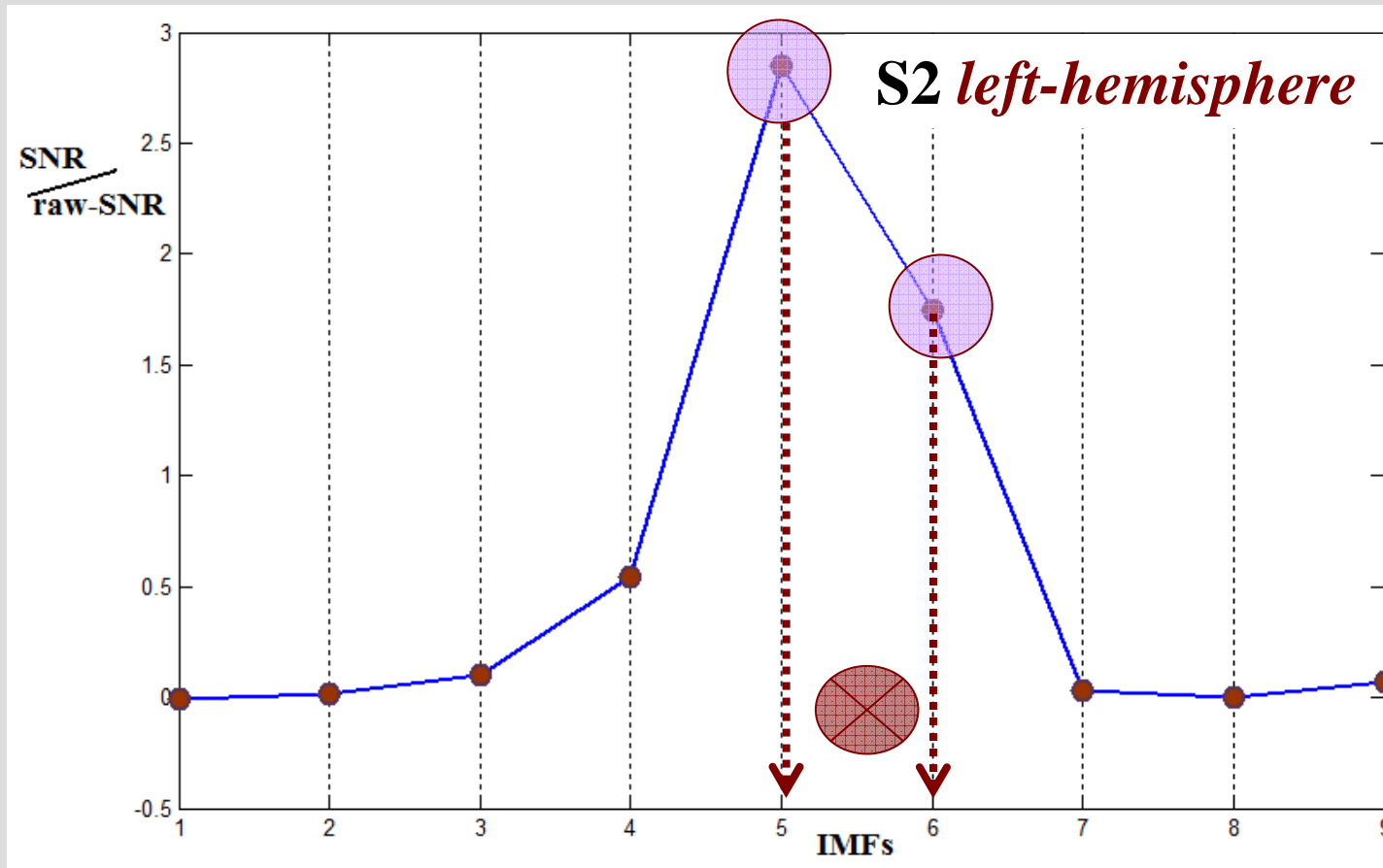
# Two examples of EMD-analysis applied to STs from S2 (passive-task)



# By ensemble averaging of all ST-IMFs

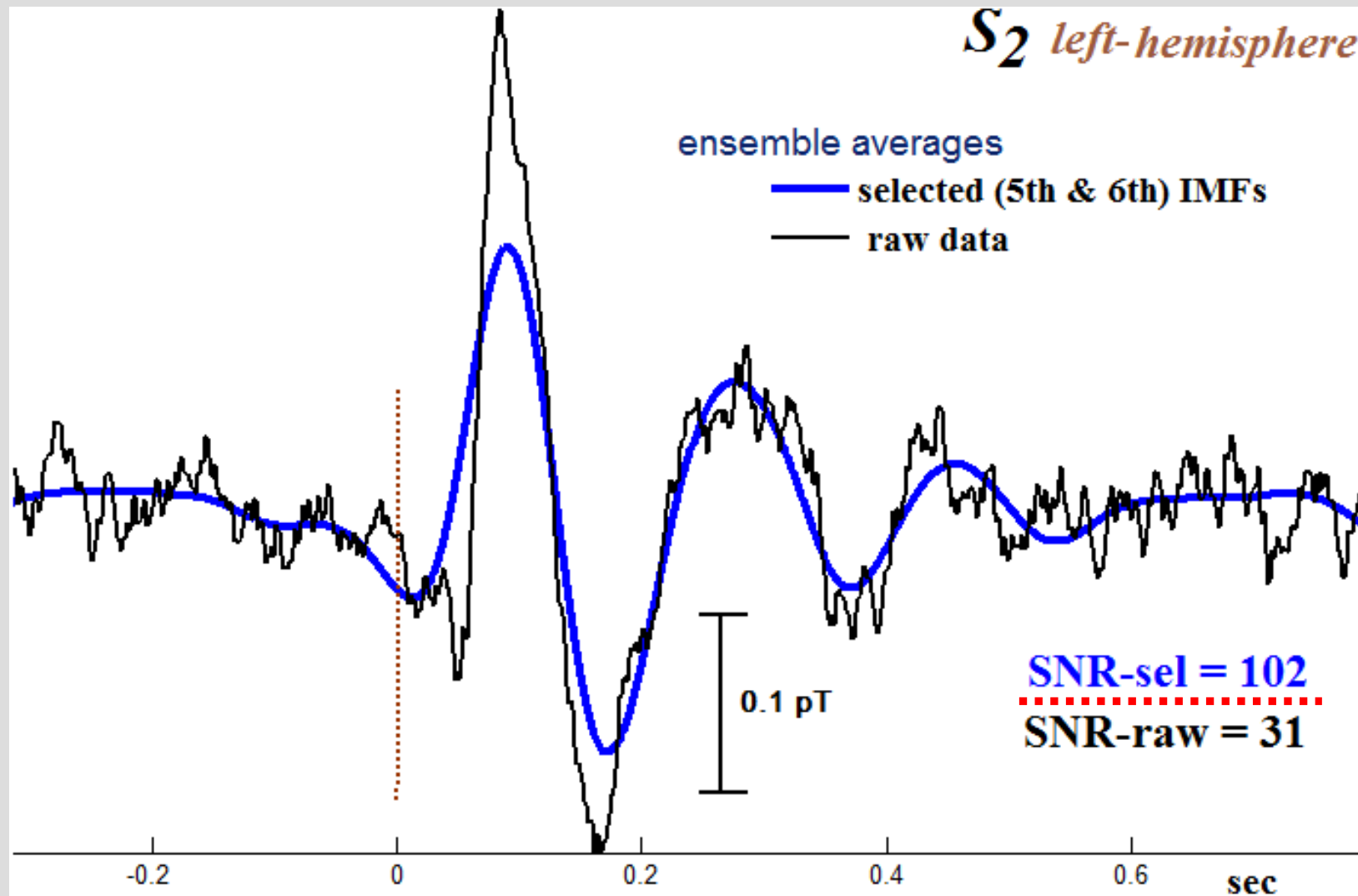


With an *ensemble characterization*  
based on a standard **SNR**-estimator  
for all IMFs (individually)

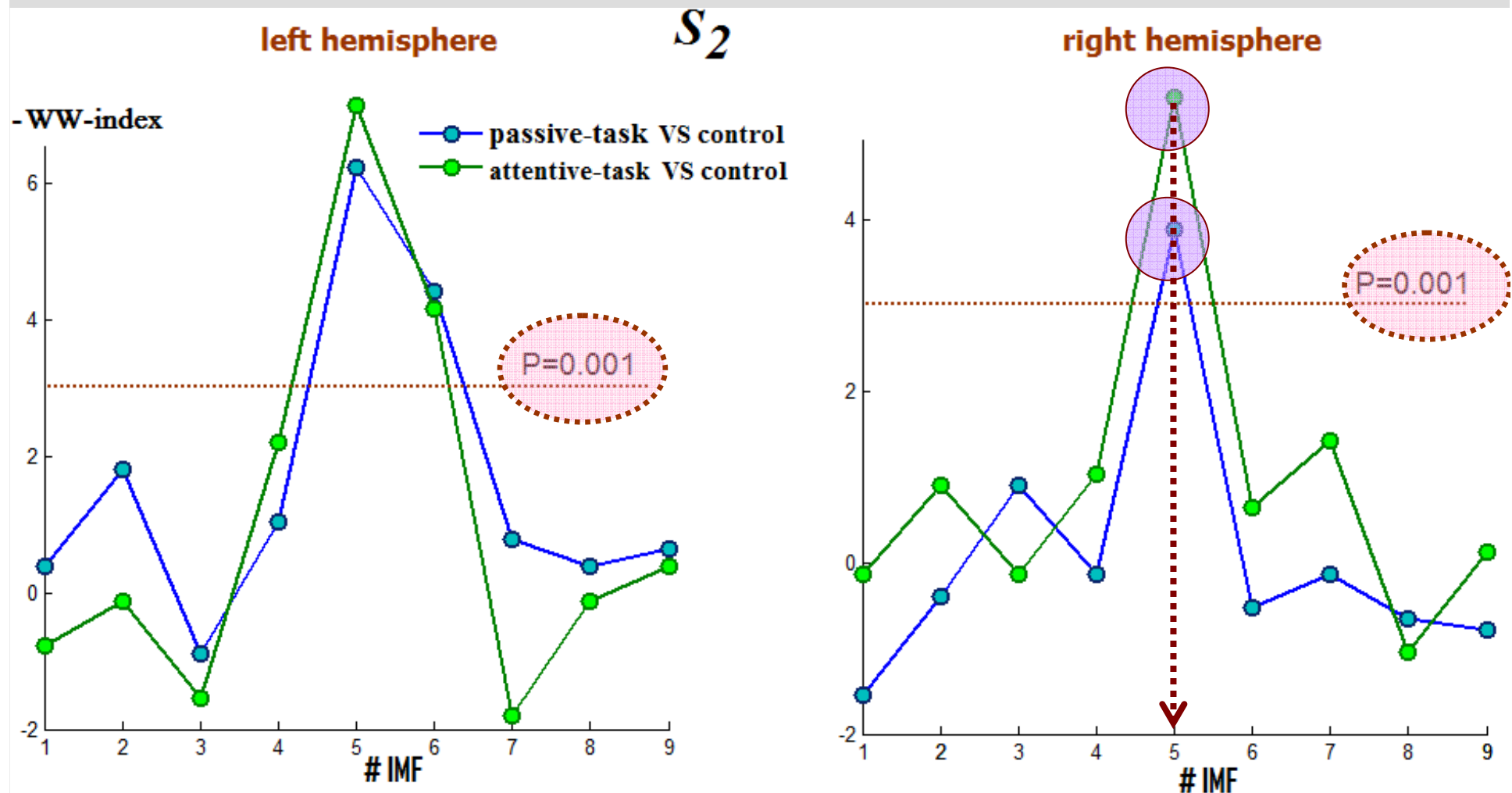


Some IMFs are information-rich, while others not

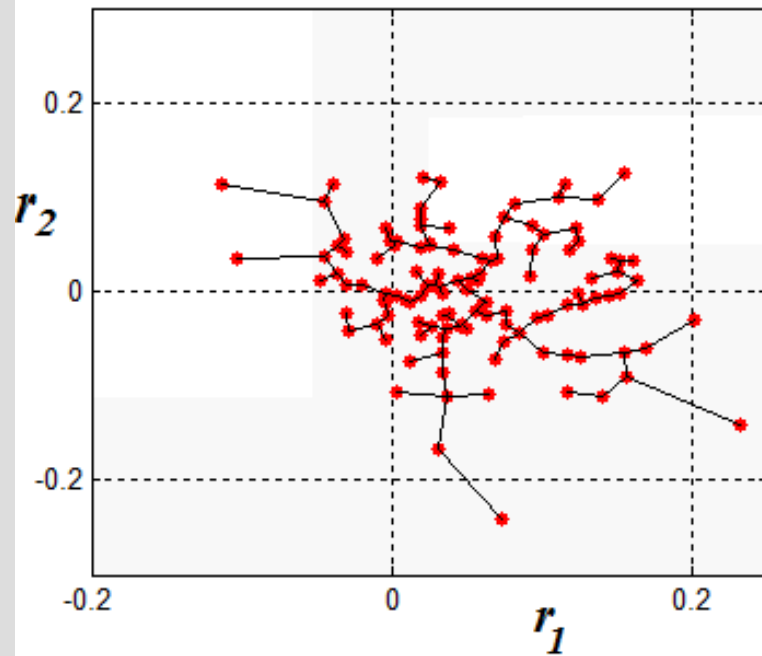
By (re)combining the more informative ones,  
an enhanced M100-response can appear



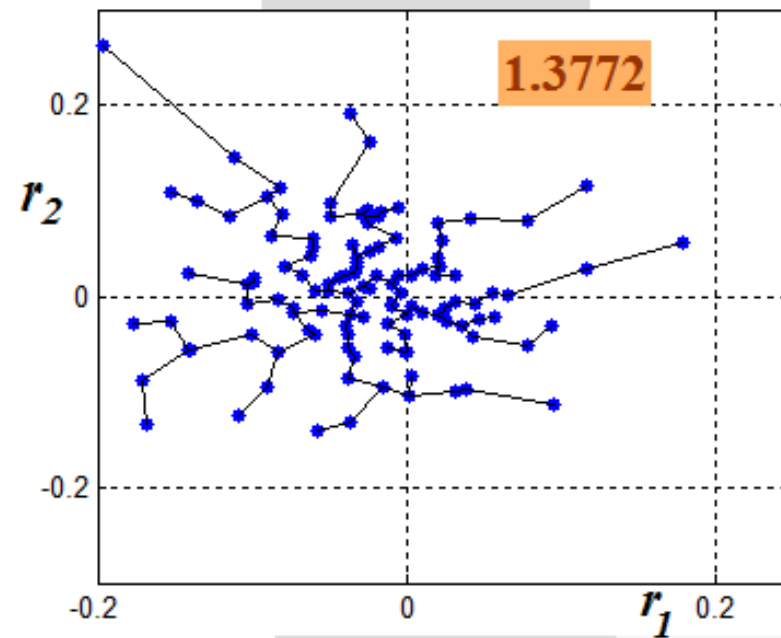
With a (*graph-based*) *ensemble characterization*  
based on WW-index  
a similar picture emerges



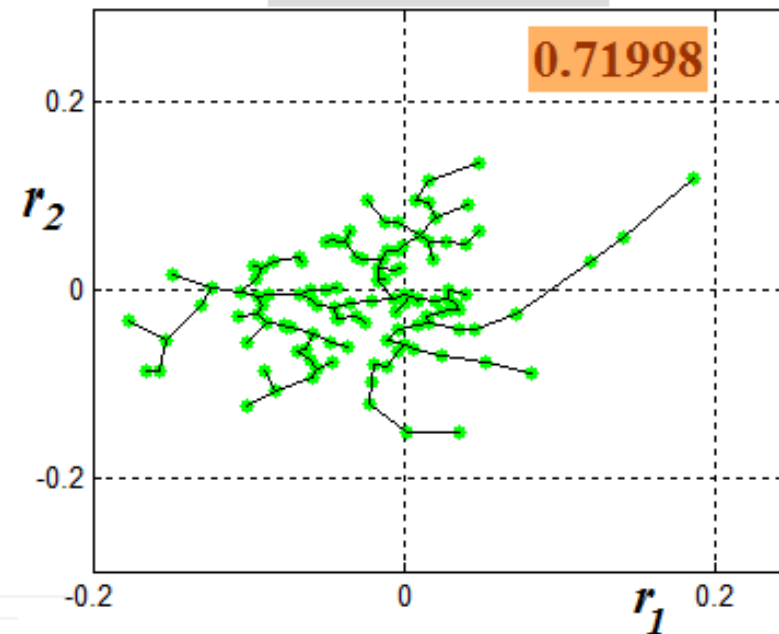
$S_2$   
*right-hemisphere*  
**5th IMF**



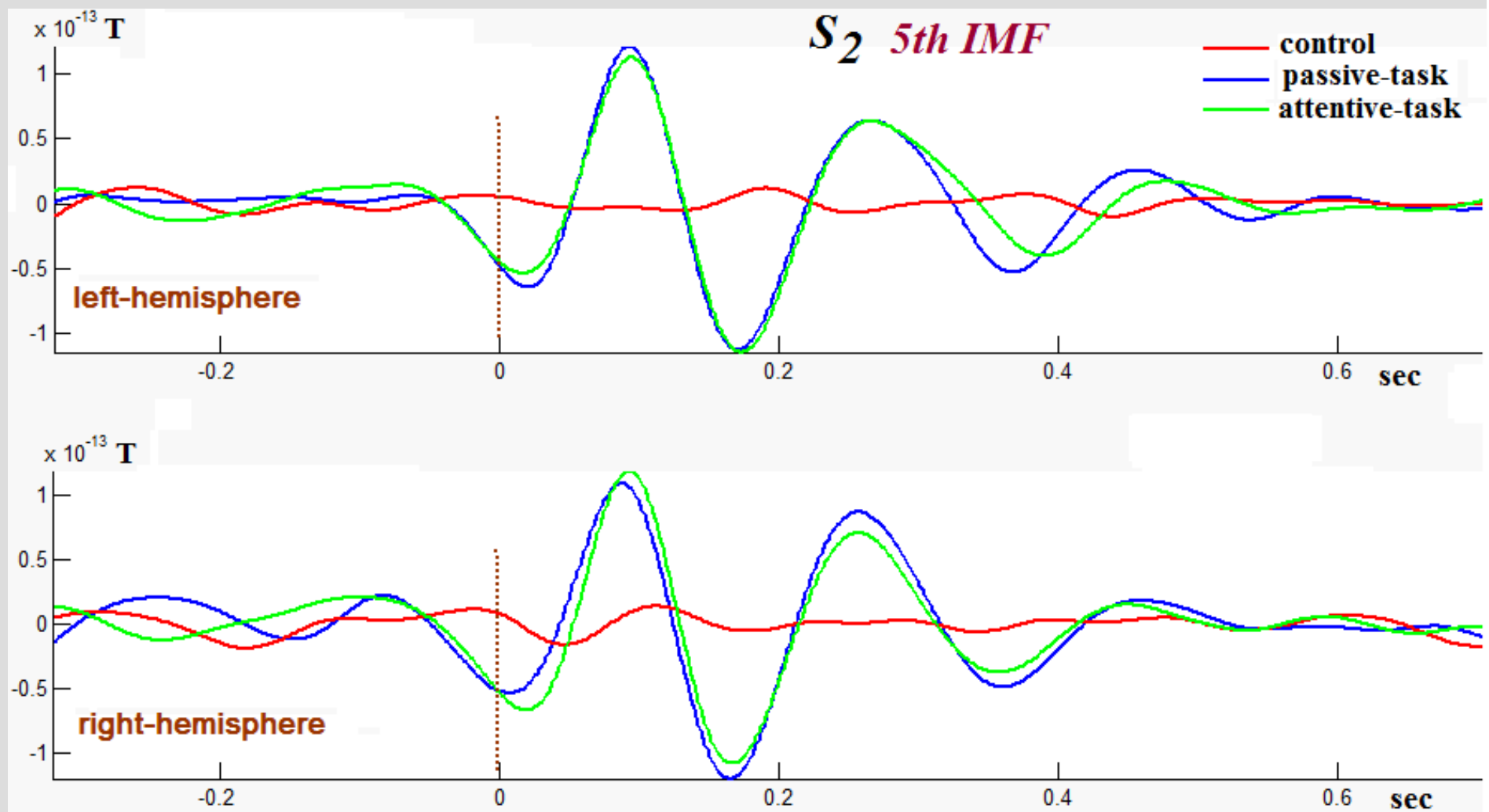
WW= -3.8846

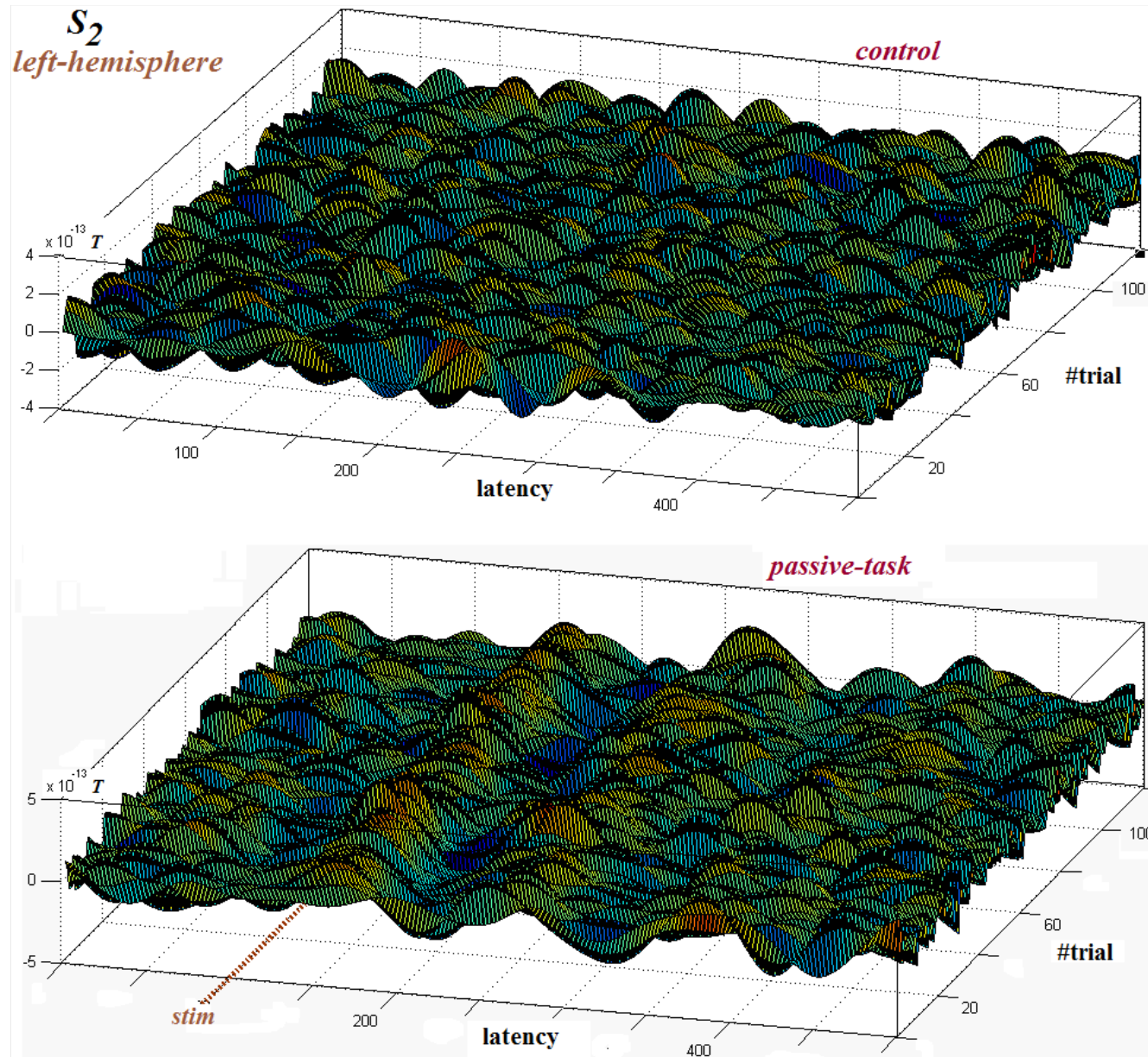


WW= -5.4391





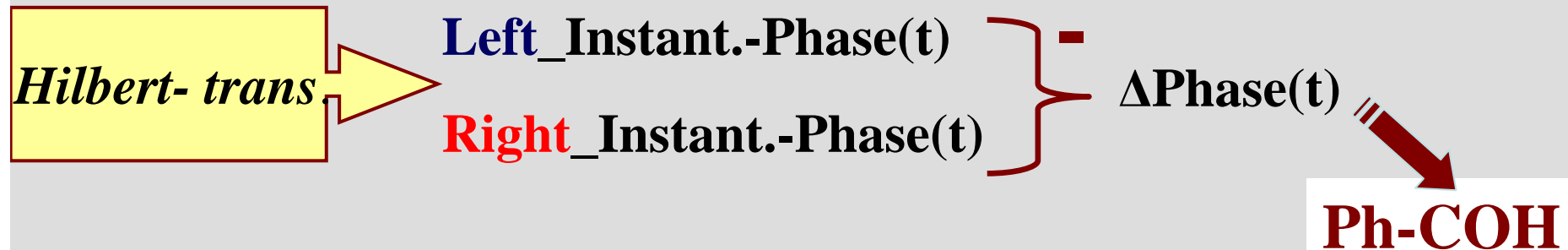
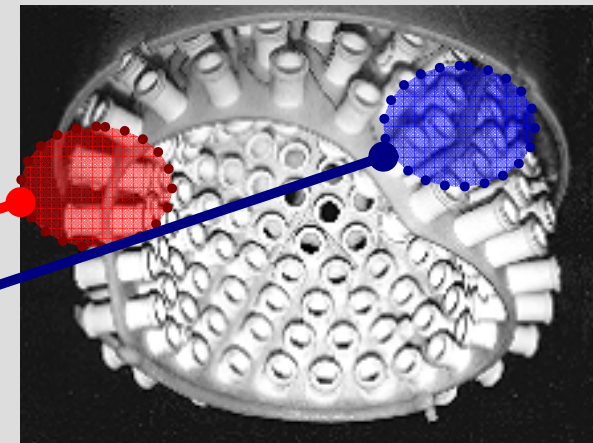
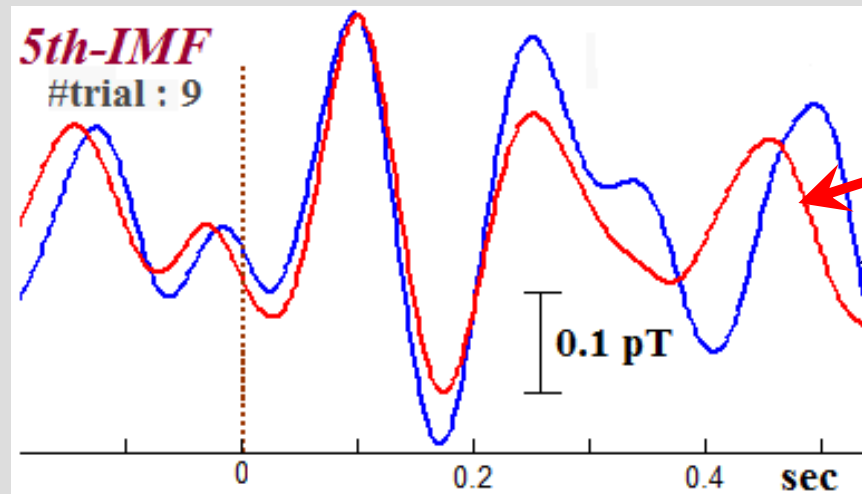




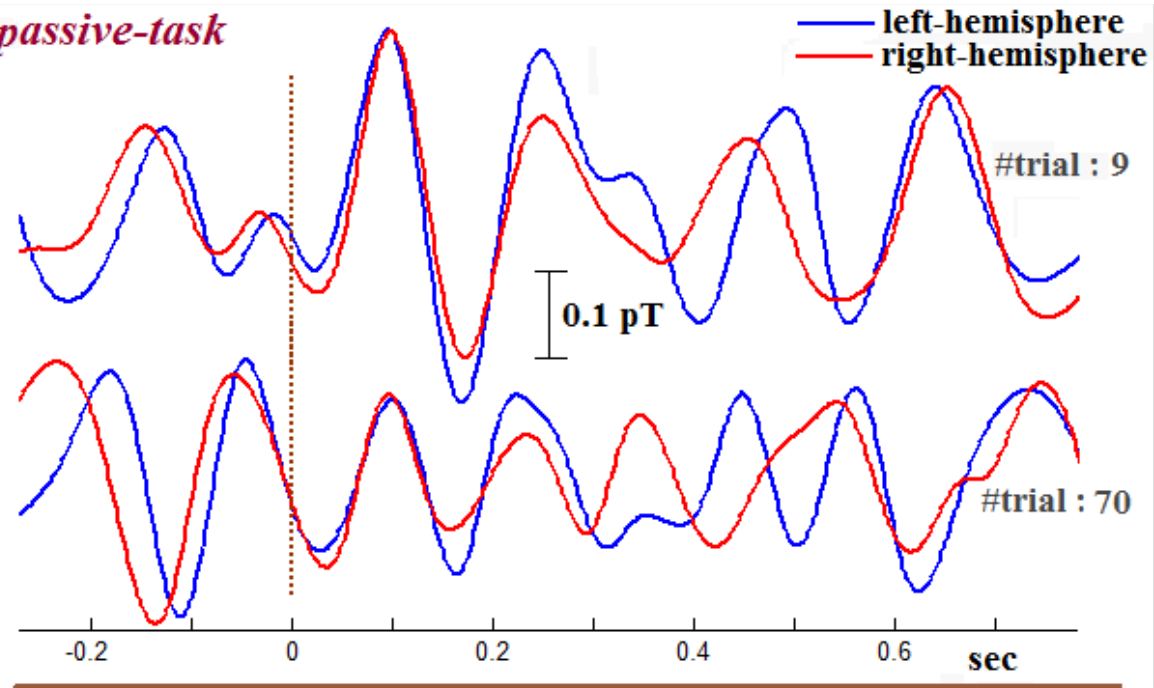
Stimulus-induced modulations of oscillatory activity has now become prominent

Since interactions between oscillatory systems are (often) best described via phase coupling,

we measured **left-right inter-hemisphere coupling** using *Phase Coherence index* (P.Tass ) for the *well discriminating* IMF(s)



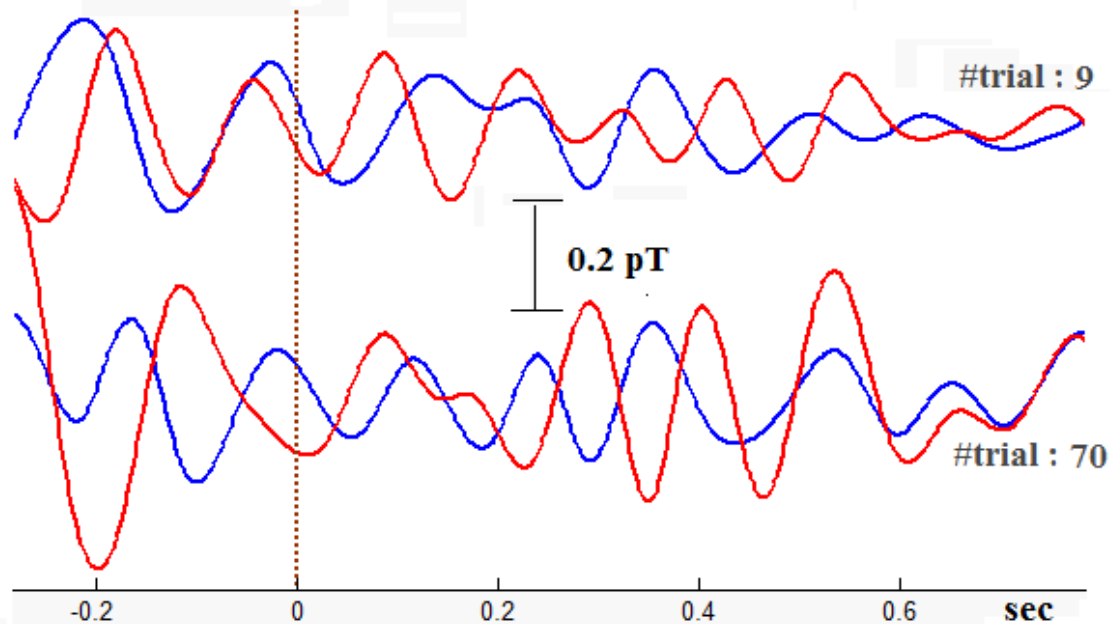
*passive-task*



Ph-COH=0.9

Ph-COH=0.93

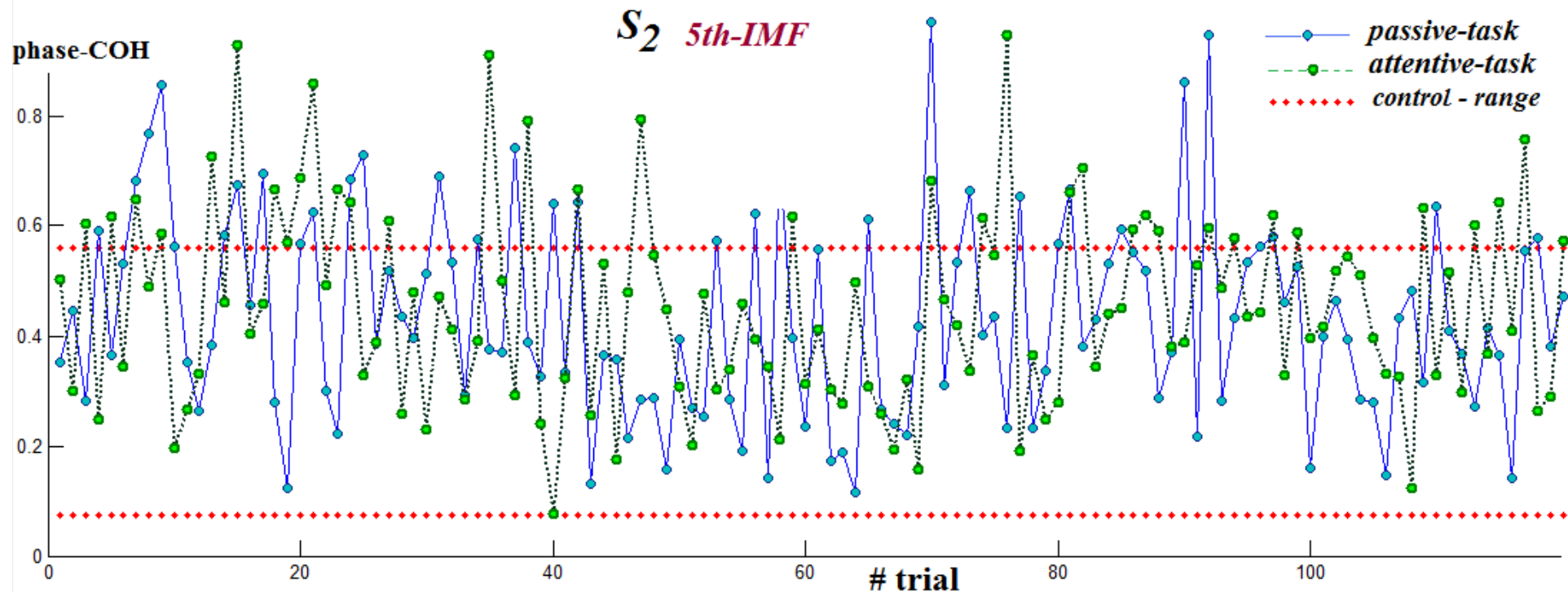
*control condition*



Ph-COH=0.13

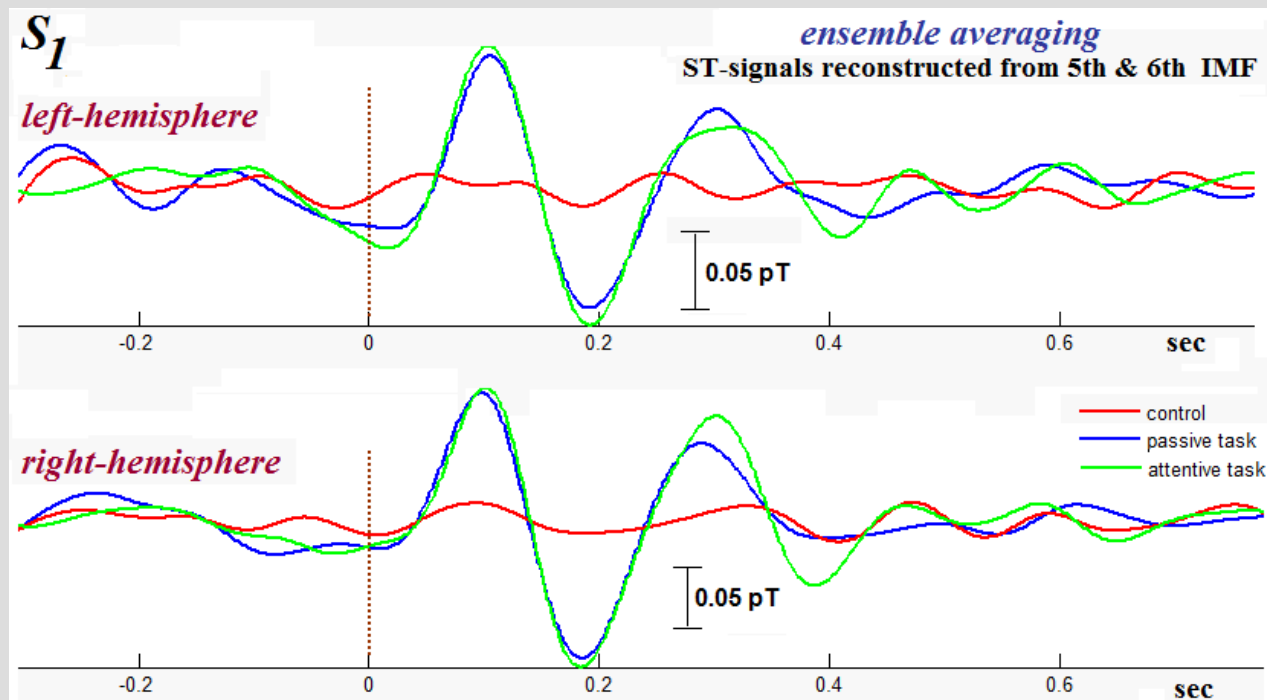
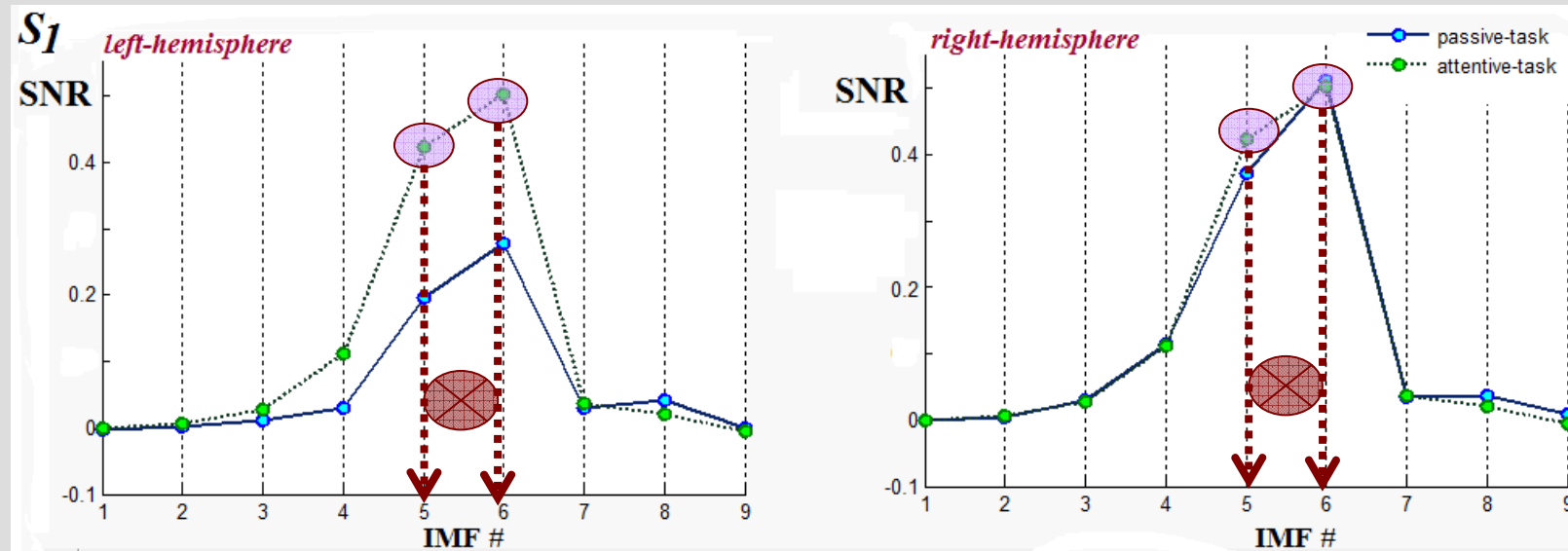
Ph-COH=0.12

# Phase Coherence, for all conditions, as a function of trial-number

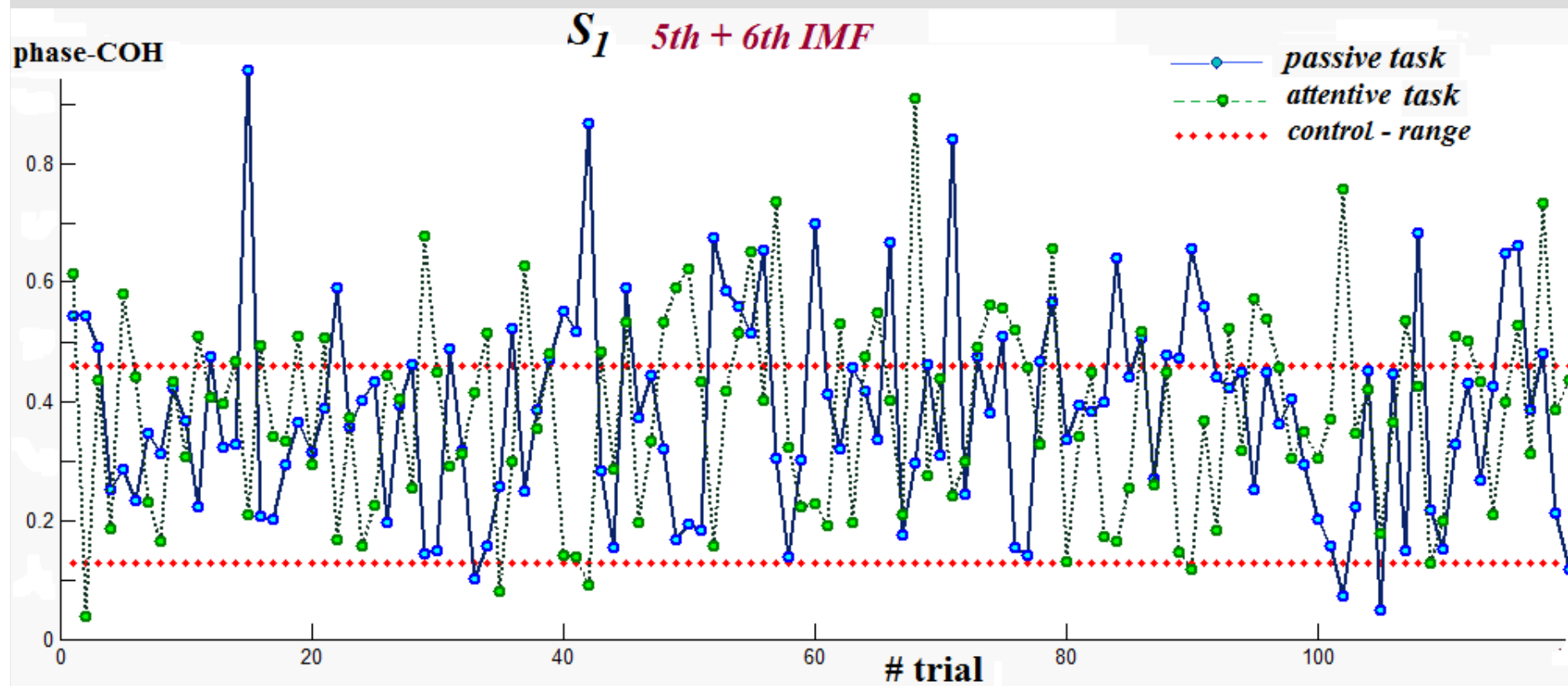


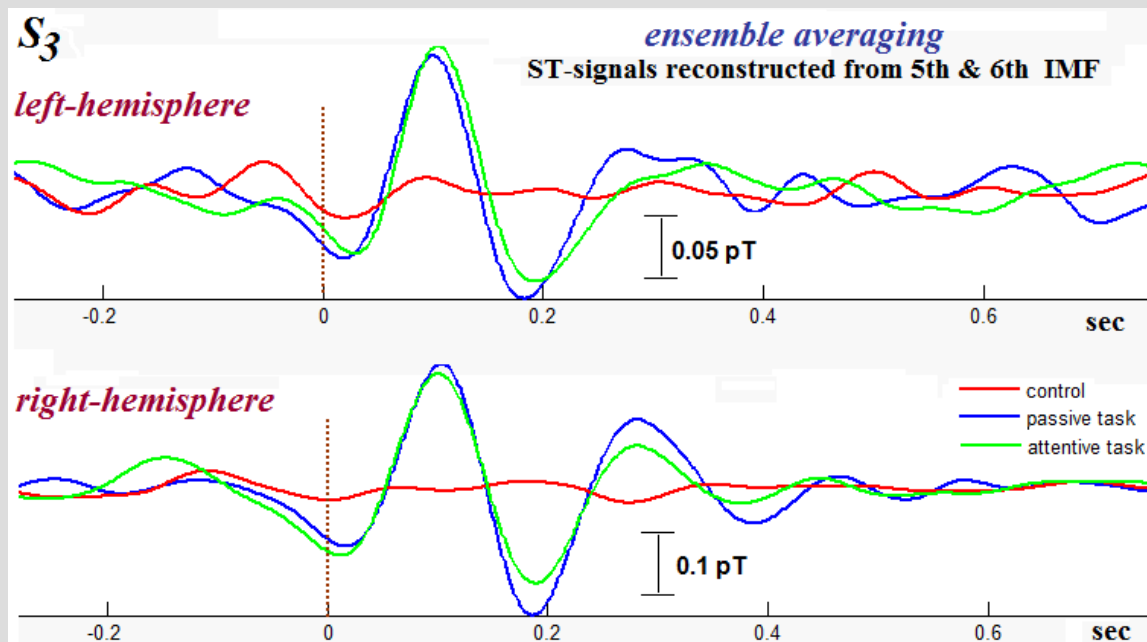
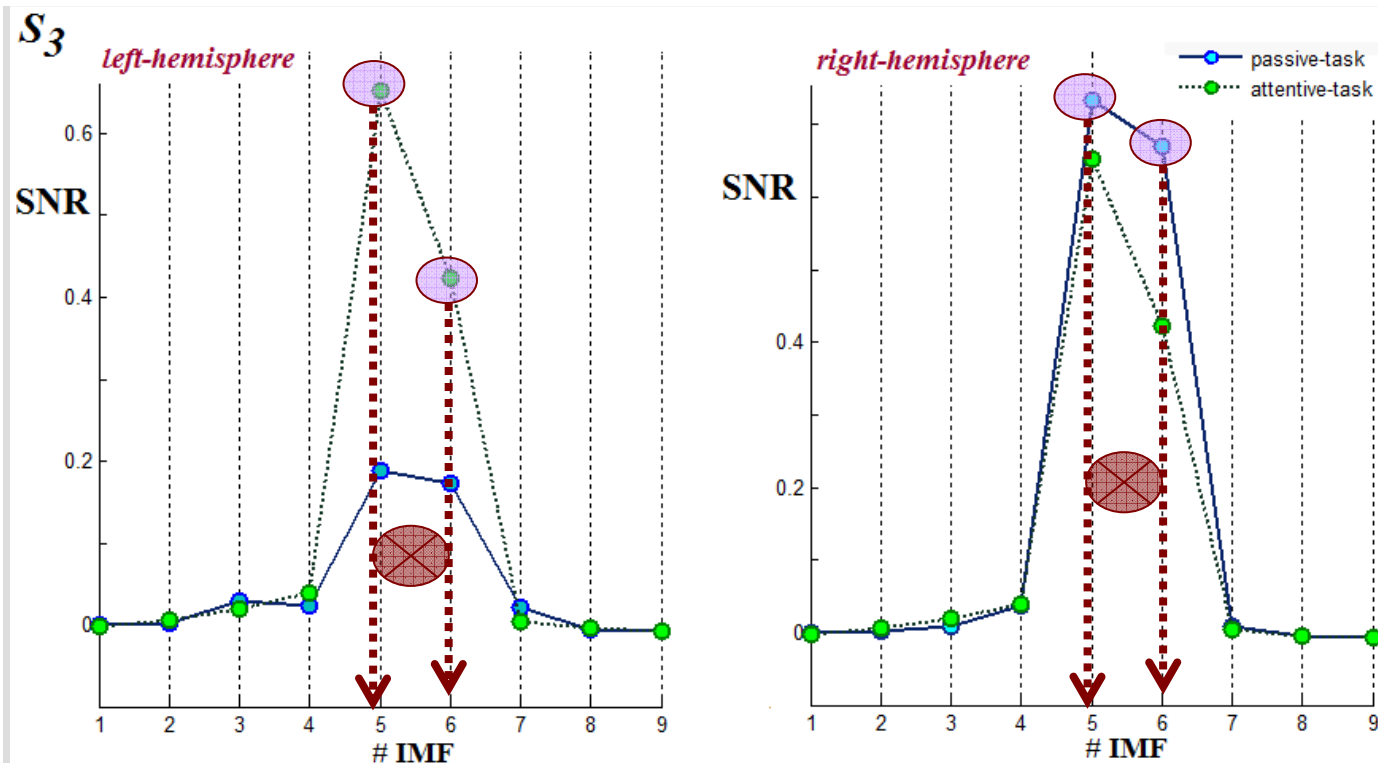
- In both tasks, the Coupling is higher than control
- Attention increases the coupling

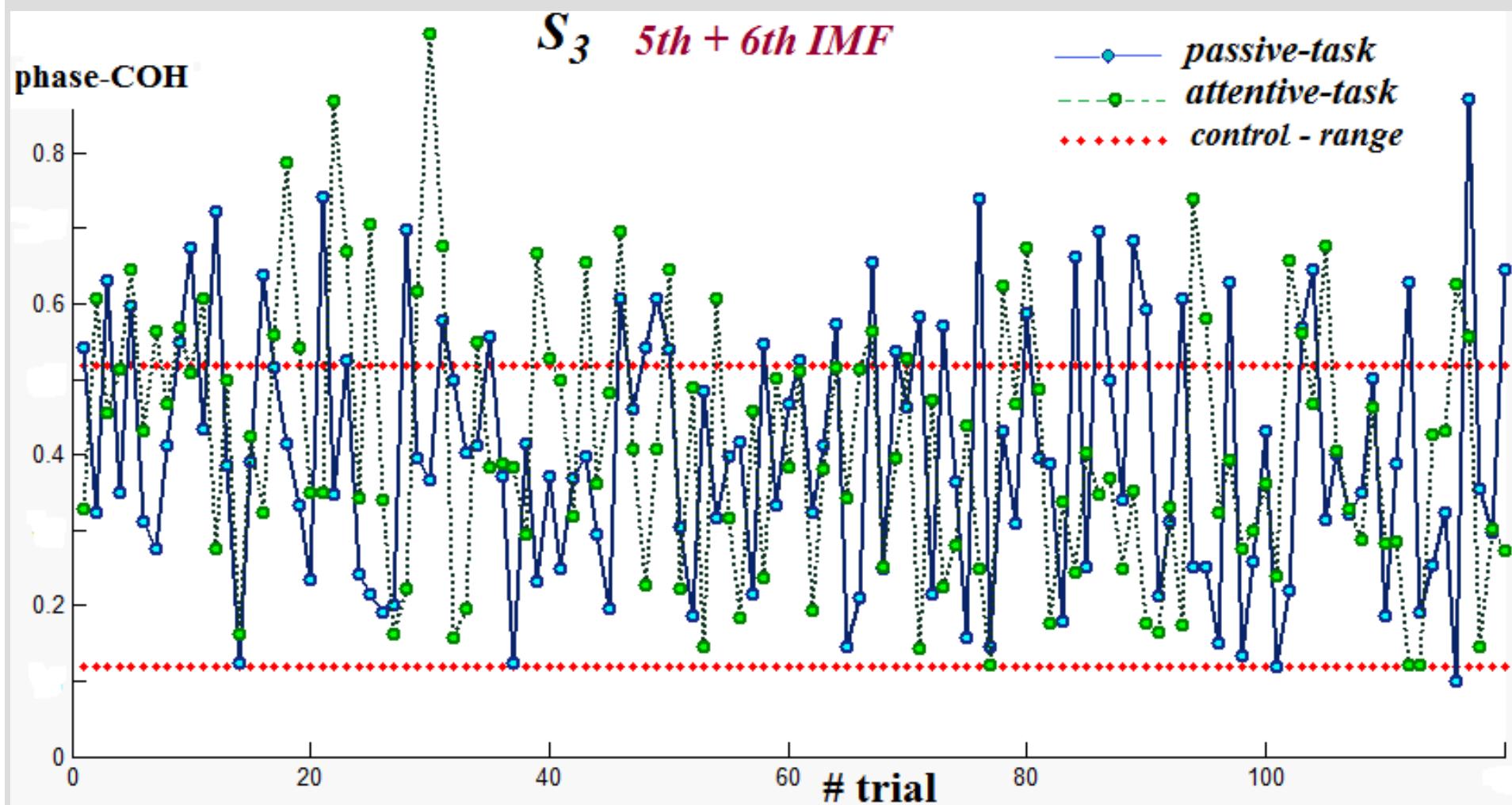
The same observations can be made for other subjects as well











# ***Conclusions***

**ST-Variability is lower in attentive task**

**Trials void of response do not appear simultaneously in both hemispheres**

**Inter-hemispheric Phase-locking is higher for attentive responses**

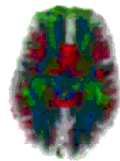


## *Future work and Perspective*



Bipartite-graphs techniques  
for biclustering ( LOIs & ST-group )

Hypergraphs for analyzing multiple traces  
at different scales (from wavelet or EMD analysis)



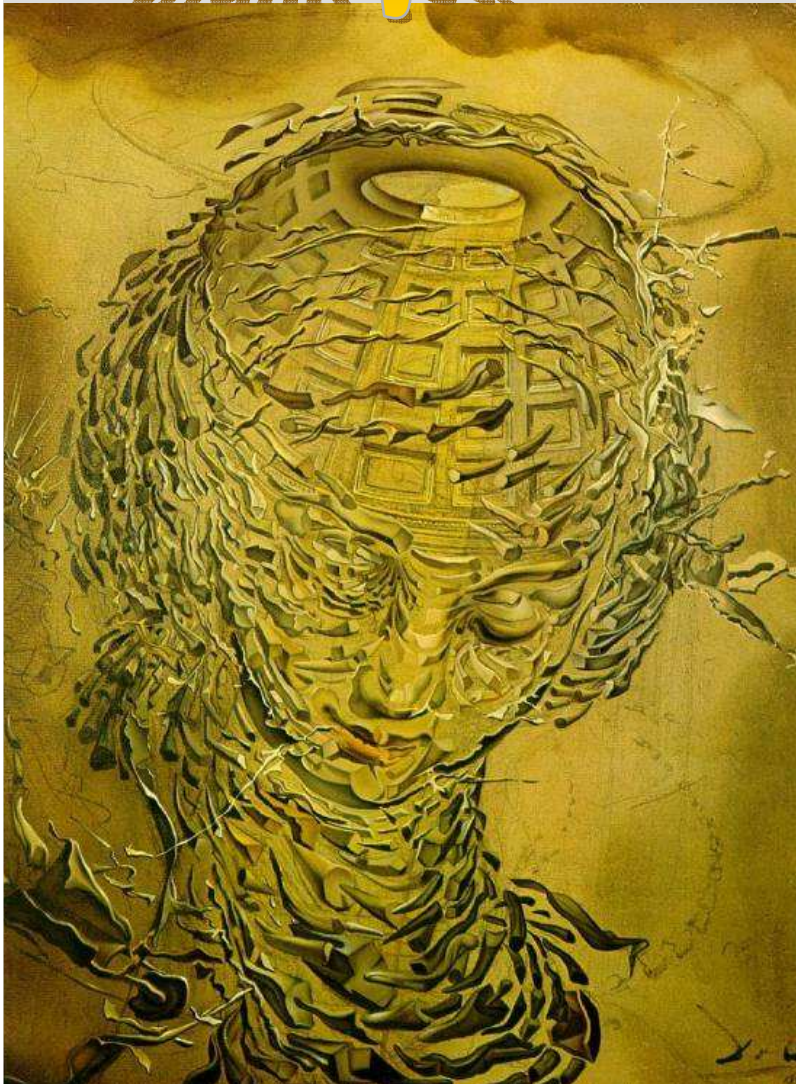
Mining Graph data



***“If you torture data sufficiently,  
it will confess to almost anything”***

***FRED MENDER***

**thank you**



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laskaris@aiia.csd.auth.gr

LHBD site :

**<http://humanbraindynamics.com/>**



**AAI Scientific  
Cultural Services**

