# EEG Data: Phase-Locking Analysis

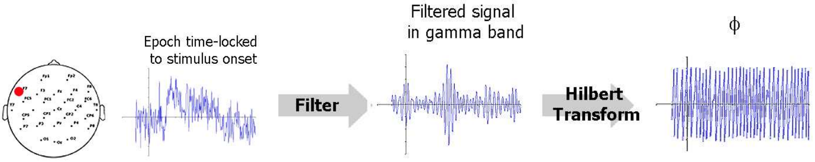
Nils Rosjat

Heisenberg Research Group
University of Cologne

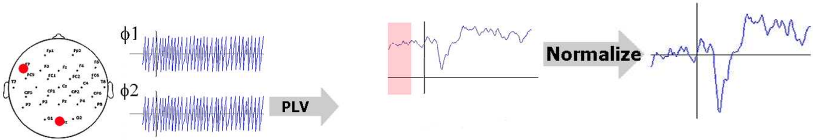
28.01.2015

# Outline

## Phase-Locking Value (PLV)

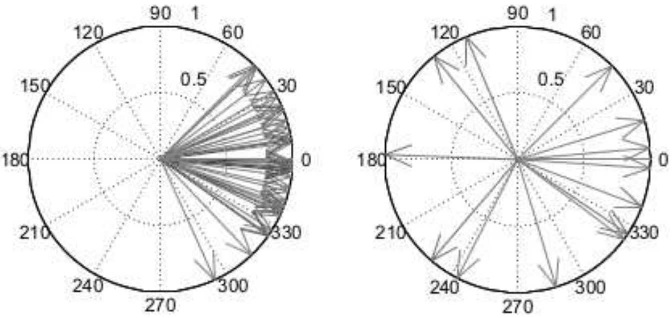


# Phase-Locking Value (PLV)




Phase-Locking Value (Lachaux 1999) for electrodes k and $\ell$ calculated by:

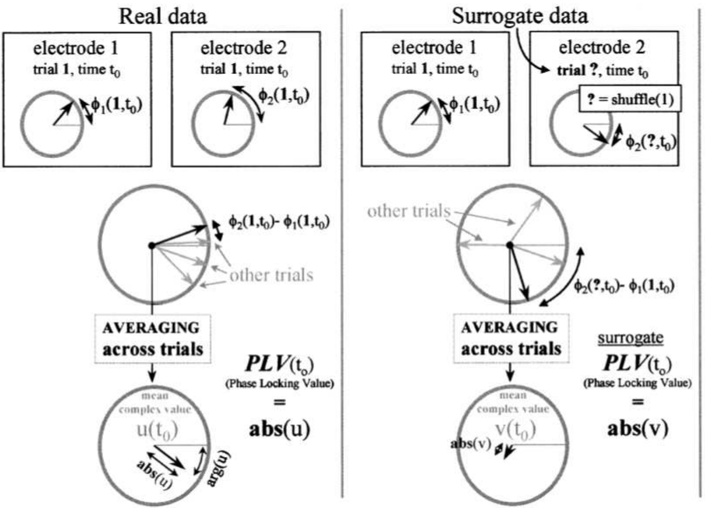
$PLV_{k,\ell}(t) = \frac{1}{N} \left| \sum_{n=1}^{N} e^{i(\varphi_k(t,n) - \varphi_\ell(t,n))} \right|$, with $\varphi_x(t,n)$ phase of electrode x at time t and trial number n.




Phase differences: Left high PLV value, Right low PLV value.

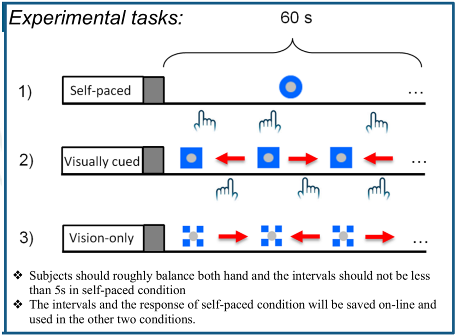
## Phase-Locking Statistics (PLS)

- Build a statistical test based on surrgogate data to differentiate between significant PLVs and background fluctuations.
- Statistical test based on randomization.
- This approach does not require any a priori hypothesis on the signals.
- Generate 200 new time-series, creatd by shuffling the trials within the measures of the second electrode.
- The proportion of surrogate values higher than the original PLV is called Phase-Locking Statistics (Lachaux 1999).

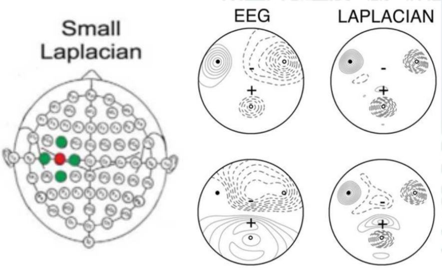

Real data
electrode 1
trial 1, time t0
ϕ1(1,t0)
electrode 2
trial 1, time t0
ϕ2(1,t0)
ϕ2(1,t0)- ϕ1(1,t0)
other trials
AVERAGING across trials
mean complex value
u(t0)
abs(u)
arg(u)
PLV(t0)
(Phase Locking Value)
=
abs(u)
Surrogate data
electrode 1
trial 1, time t0
ϕ1(1,t0)
electrode 2
trial ?, time t0
? = shuffle(1)
ϕ2(?,t0)
other trials
ϕ2(?,t0)- ϕ1(1,t0)
AVERAGING across trials
mean complex value
v(t0)
abs(v)
surrogate
PLV(t0)
(Phase Locking Value)
=
abs(v)

# Experimental design

- Participants: 17 healthy young subjects
- Data aquisition: 64-channel EEG system
- Data prepocessing: Artifact rejection, segmentation to epochs and re-referencing to small Laplacian reference (McFarland 1997).



# Experimental design




- Data prepocessing: Artifact rejection, segmentation to epochs and re-referencing to small Laplacian reference (McFarland 1997).
- $V_i^{LAP} = V_i - \frac{1}{4} \sum_{j \in S_i} V_j$, where $S_i$ is the set of all electrodes surrounding electrode i.

## Questions

- Which brain regions are connected on the electrode level?
- Do the obtained networks differ for self-paced and visually cued tapping?

## PLV-Pipeline

- Filtered the data to $\delta/\theta$, $\alpha$, $\beta$ and $\gamma$ frequency bands.
- Computed the PLV for all channel combinations for self-paced and visually cued left finger tapping.
- Applied a threshold for the PLS ($< 0.05$) and for the maximal PLV during the pre-movement interval [-300,0] ($> 0.45$).

# PLV-Pipeline

- Filtered the data to $\delta/\theta$, $\alpha$, $\beta$ and $\gamma$ frequency bands.
- Computed the PLV for all channel combinations for self-paced and visually cued left finger tapping.
- Applied a threshold for the PLS ($< 0.05$) and for the maximal PLV during the pre-movement interval [-300,0] ($> 0.45$).

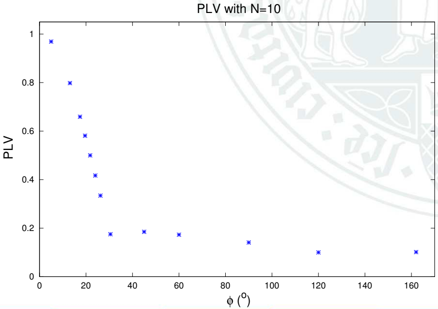


Fig : $\theta$-frequency band for self-paced (left) and visually cued tapping (right).

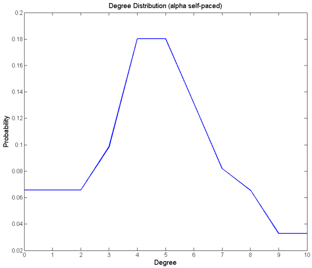
Fig : $\beta$-frequency band for self-paced (left) and visually cued tapping (right).

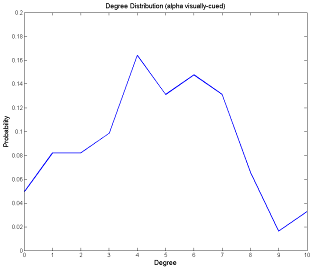
Fig : $\gamma$-frequency band for self-paced (left) and visually cued tapping (right).

Fig : $\alpha$-frequency band for self-paced (left) and visually cued tapping (right).

# Measures of resilience

- Degree distribution: complex networks with power-law degree distributions may be resilient to random deterioration, but highly vulnerable to disruptions of high-degree nodes.

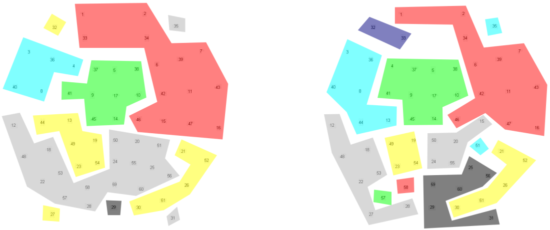



- Edge disjoint paths / Minimal Cut: Number of possible connections between two clusters. Clusters connected through hub nodes are highly vulnerable to insults.

## Functional segregation

- Clustering coefficient: Fraction of triangles around an individual node (nodes neighbors that are also neighbors of each other).
- Modularity: Subdividing the network into groups with minimal between-group links and maximum of within-group links.



Cluster for self-paced (left) and visually-cued (right) condition.

## Functional integration

- Average shortest path length (characteristic path length): primarily influenced by long paths.
- Global efficiency (inverse characteristic path length): primarily influenced by short paths.

## Further analysis

- Compare all measures for both conditions in the four frequency bands.
- Calculate the measures on single subject level to find significant differences between the conditions.