



9 June: Bernhard Staresina
Measures of power-power, within/across freq coupling, power-phase, phase-phase, etc using intracranial EEG data

Cross-frequency coupling

Bernhard Staresina

CONIG 09/06/11

Talk Outline

I. What is CFC?

Definition and functional significance

II. How is CFC calculated?

PLV-MI, KL-MI

III. Example

CFC during sleep

Terminology

Terminology

Cross Frequency Coupling (*CFC*)

Terminology

Cross Frequency Coupling (*CFC*)

Phase Amplitude Coupling (*PAC*)

Terminology

Cross Frequency Coupling (*CFC*)

Phase Amplitude Coupling (*PAC*)

Cross Frequency Phase Amplitude Coupling (*CFPAC*)

Terminology

Cross Frequency Coupling (*CFC*)

Phase Amplitude Coupling (*PAC*)

Cross Frequency Phase Amplitude Coupling (*CFPAC*)

I. What



Cross-frequency coupling between neuronal oscillations

Ole Jensen¹ and Laura L. Colgin²

¹ F.C. Donders Centre for Cognitive Neuroimaging
² Centre for the Biology of Memory

Review



The functional role of cross-frequency coupling

Ryan T. Canolty^{1,2} and Robert T. Knight^{1,3}

¹ Helen Wills Neuroscience Institute
² Department of Electrical and Computer Engineering
³ Department of Psychology

REVIEWS

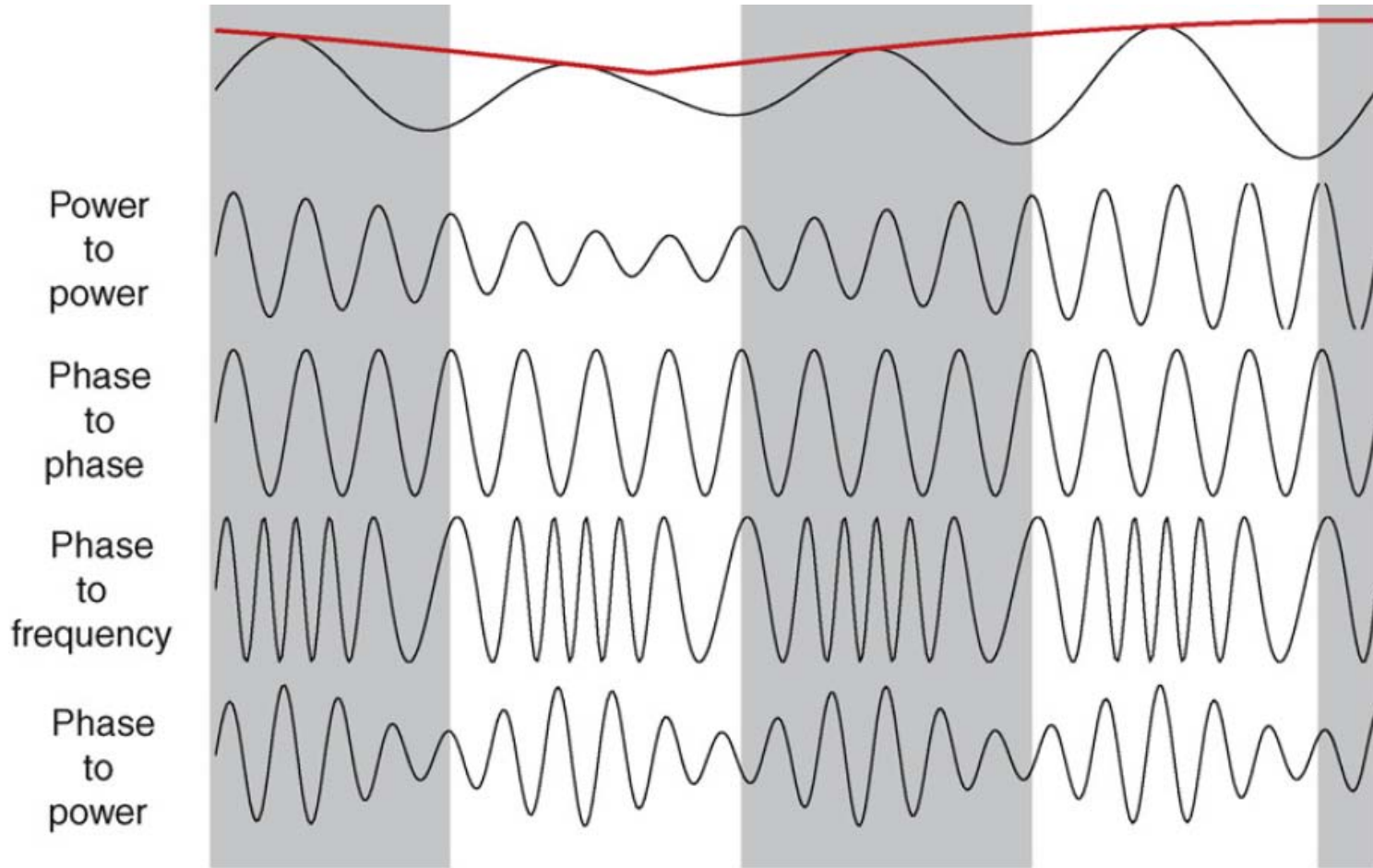
The role of phase synchronization in memory processes

Juergen Fell and Nikolai Axmacher

Oscillatory interactions of two signals

I. What

Oscillatory interactions of two signals



Definition

(Canolty and Knight, 2010)

Definition

(i) an observed statistical dependence between filtered signals derived from electrical brain activity.

(Canolty and Knight, 2010)

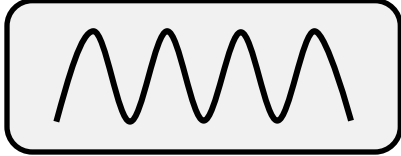
Definition

(i) an observed statistical dependence between filtered signals derived from electrical brain activity.

(ii) a transient but mechanistic coupling (mediated by spikes and synaptic activity) between the functionally distinct neuronal subpopulations that give rise to recorded electrical activity.

(Canolty and Knight, 2010)

low frequencies



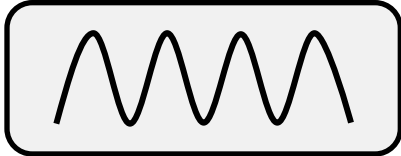
coordination of cortical excitability
(global states, sensory input)

high frequencies



coordination of local information
processing

low frequencies



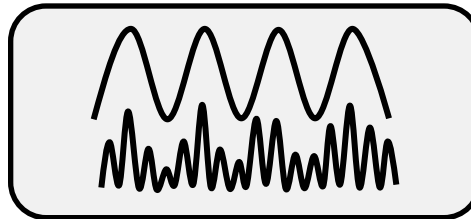
coordination of cortical excitability
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coordination of local information
processing

CFC



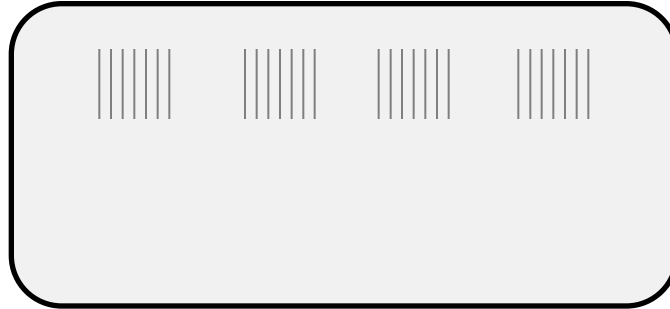
transfer of information from large-scale brain networks to local processing
required for effective computation and synaptic modification

Example

Effective LTP induction - high frequency bursts, repeated at a $\sim 3\text{-}5$ Hz inter-burst interval

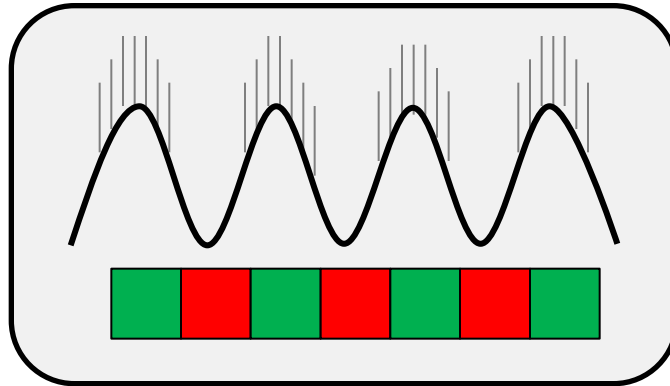
Example

Effective LTP induction - high frequency bursts, repeated at a $\sim 3-5$ Hz inter-burst interval



Example

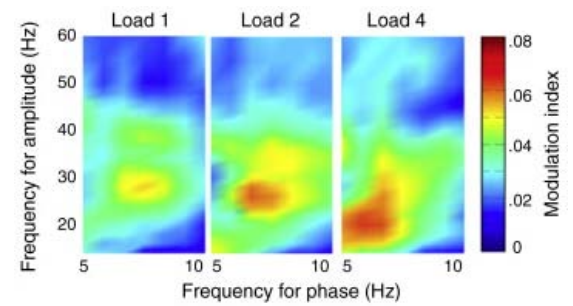
Effective LTP induction - high frequency bursts, repeated at a $\sim 3-5$ Hz inter-burst interval



Links with behaviour

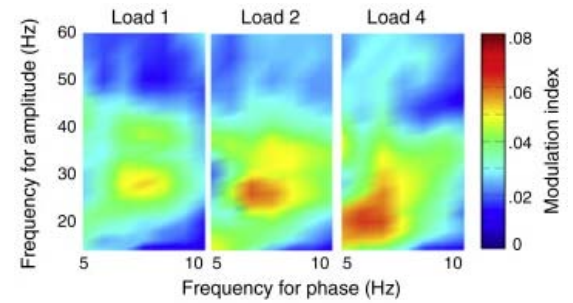
Links with behaviour

theta:gamma CFC increases with
working memory load in humans
(Axmacher et al., 2010)

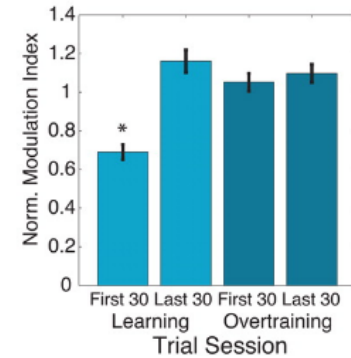


Links with behaviour

theta:gamma CFC increases with working memory load in humans
(Axmacher et al., 2010)



theta:gamma CFC increases with navigation task performance in rodents
(Tort et al., 2009)



II. How



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II. How

Testing for nested oscillation

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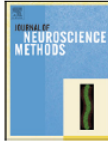
Short communication

Assessing transient cross-frequency coupling in EEG data

Michael X Cohen^{*}

Department of Epileptology and Center for Life and Brain, University of Bonn, Germany

Received 22 September 2007; received in revised form 23 October 2007; accepted 23 October 2007



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Assessing transient cross-frequency coupling in EEG data

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De
Receive

J Neurophysiol 104: 1195–1210, 2010.
First published May 12, 2010; doi:10.1152/jn.00106.2010.

Innovative Methodology

Measuring Phase-Amplitude Coupling Between Neuronal Oscillations
of Different Frequencies

Adriano B. L. Tort,¹ Robert Komorowski,² Howard Eichenbaum,² and Nancy Kopell³

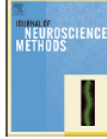

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Boston, Massachusetts

II. How

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Boston, Massachusetts



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Original Research

Quantifying phase–amplitude coupling in neuronal network oscillations

Angela C.E. Onslow^{a,b,c}, Rafal Bogacz^{b,**}, Matthew W. Jones^{c,*}

^aBristol Centre for Complexity Sciences, University of Bristol, UK

^bDepartment of Computer Science, University of Bristol, UK

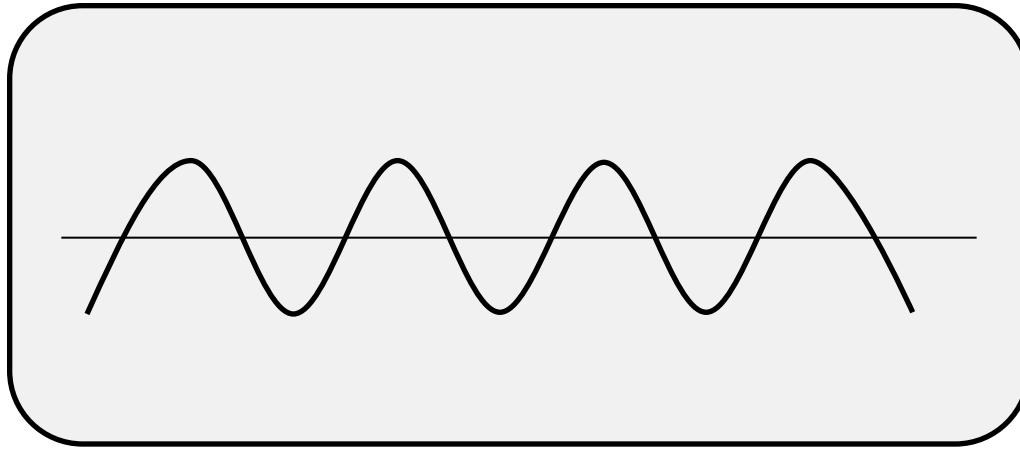
^cSchool of Physiology & Pharmacology, University of Bristol, UK

Interlude: different ways of representing phases

II. How

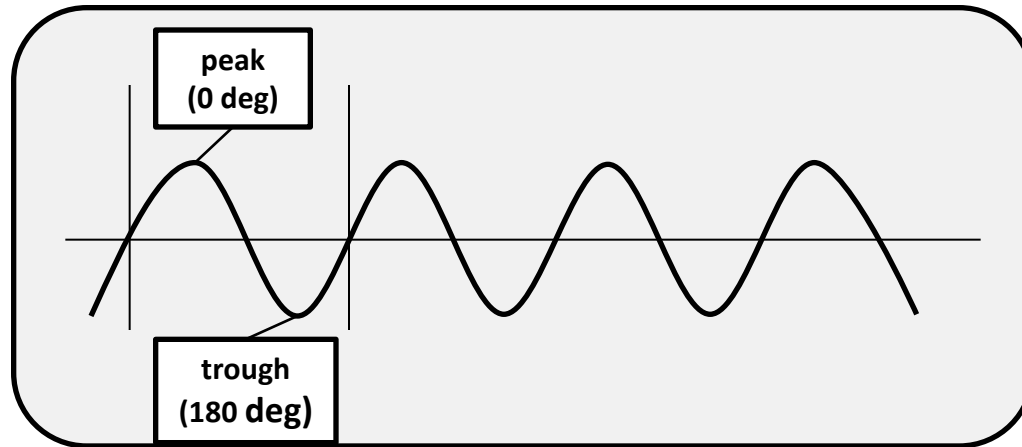
Interlude: different ways of representing phases

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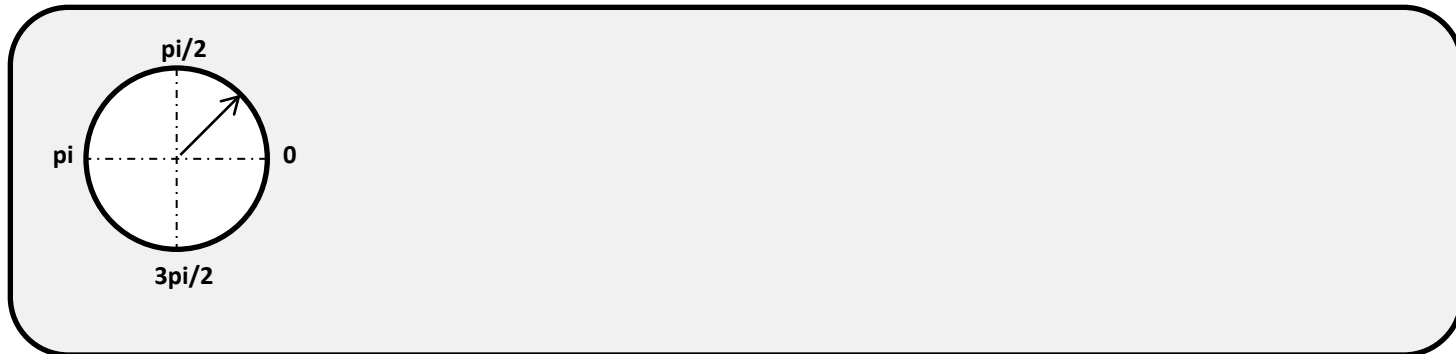
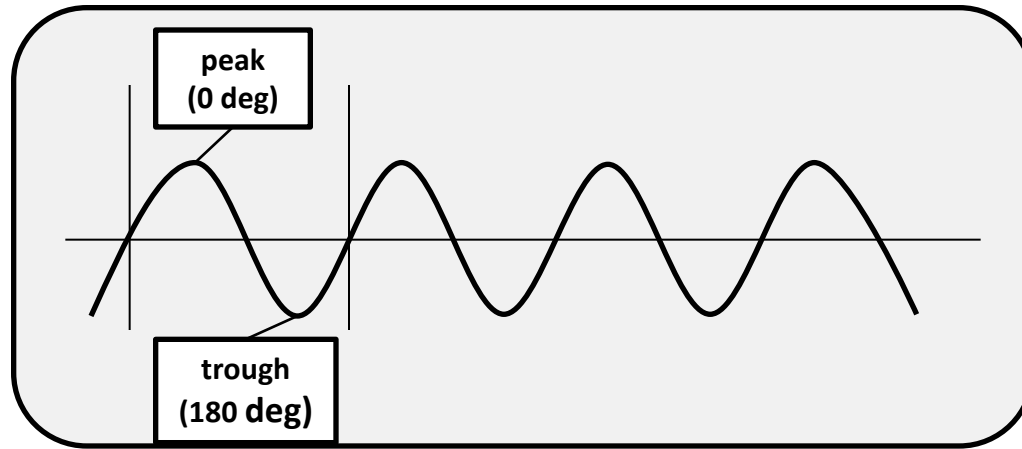
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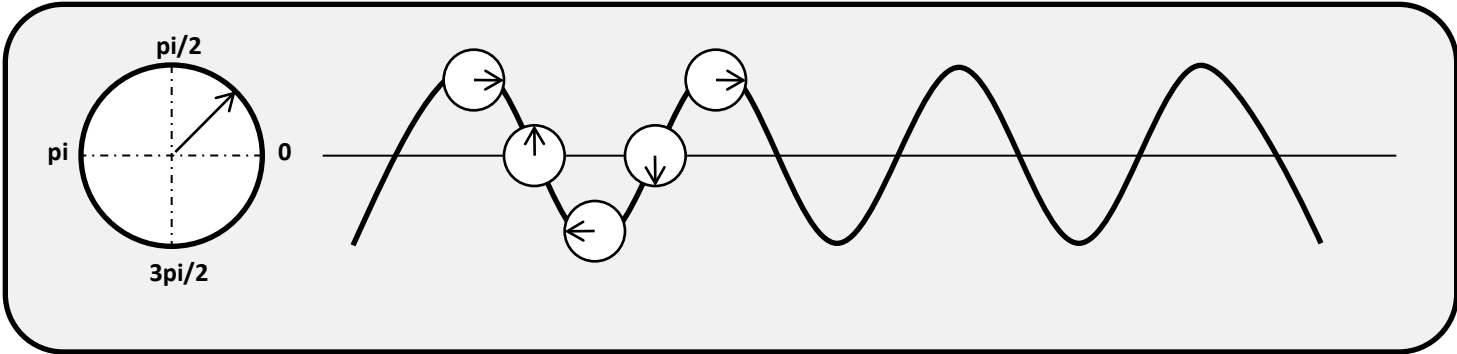
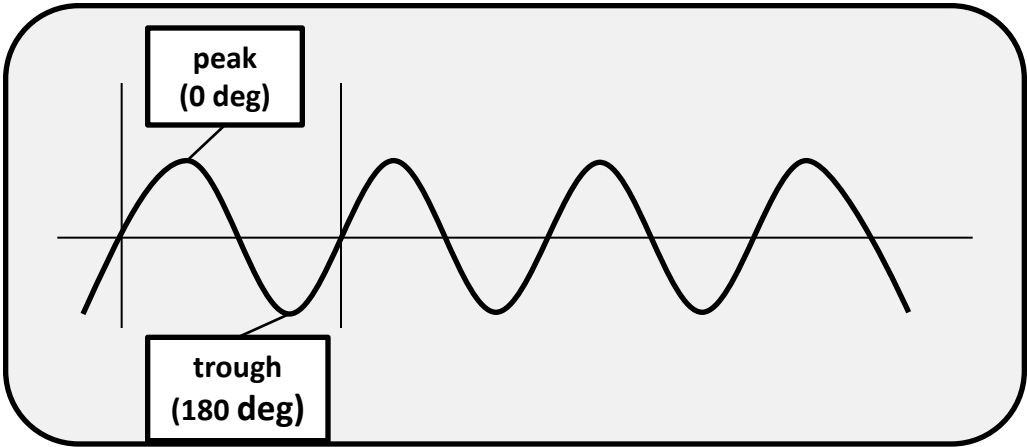


Interlude: different ways of representing phases

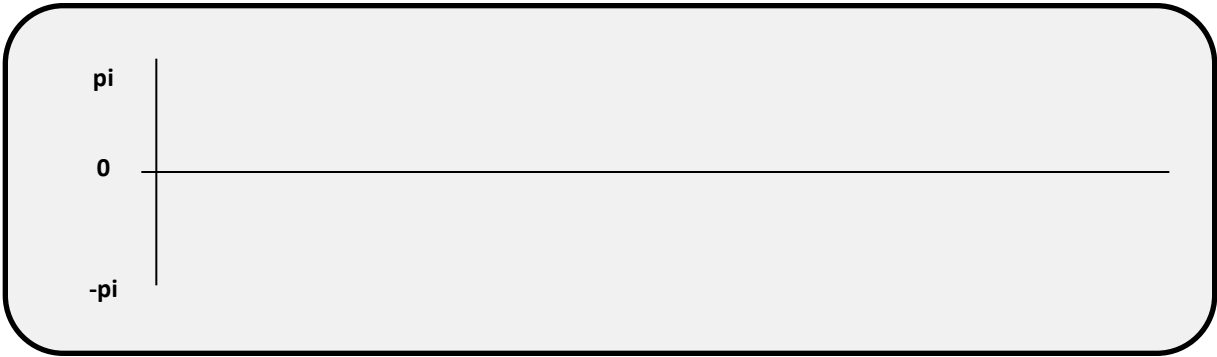
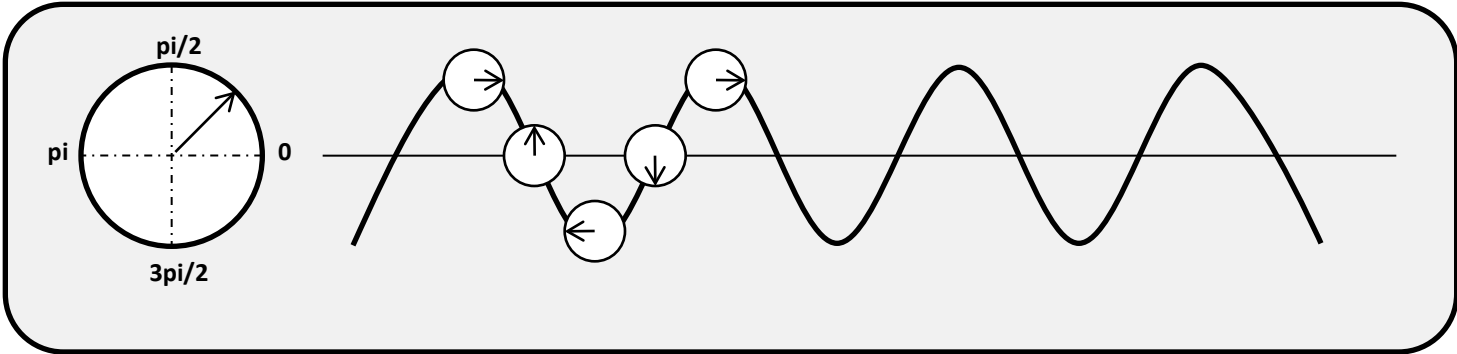
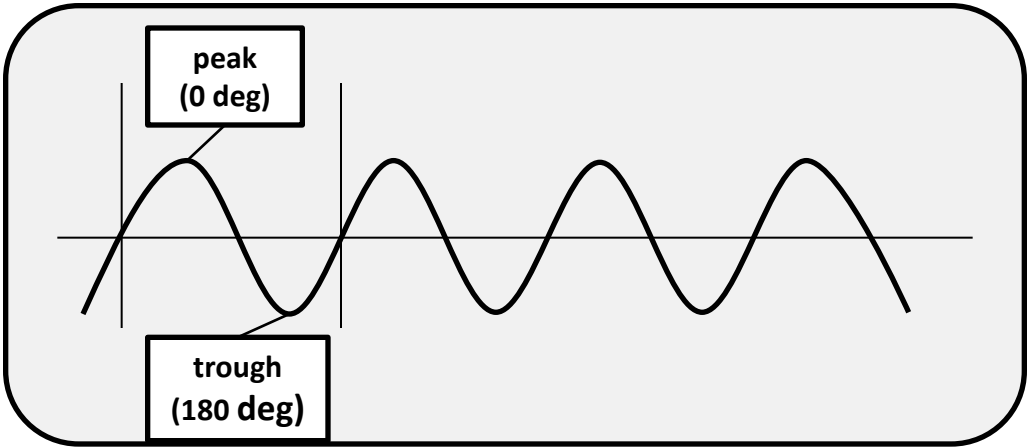
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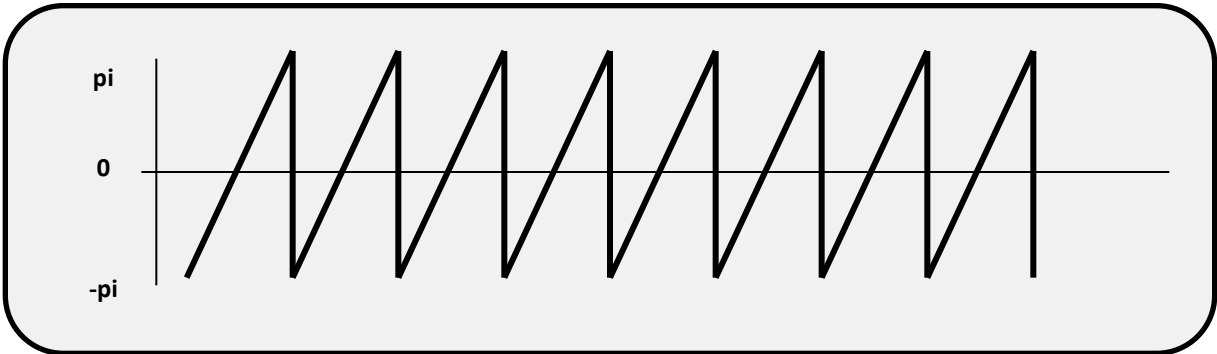
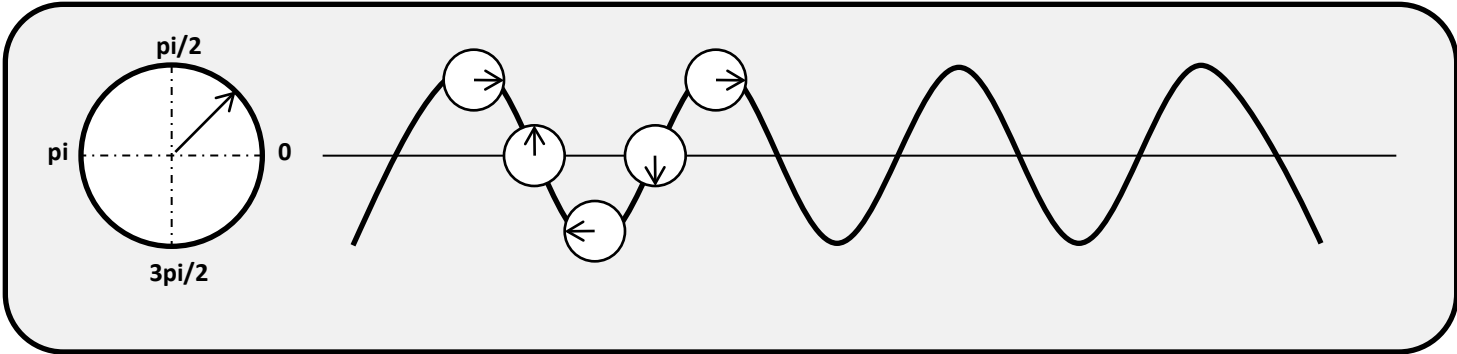
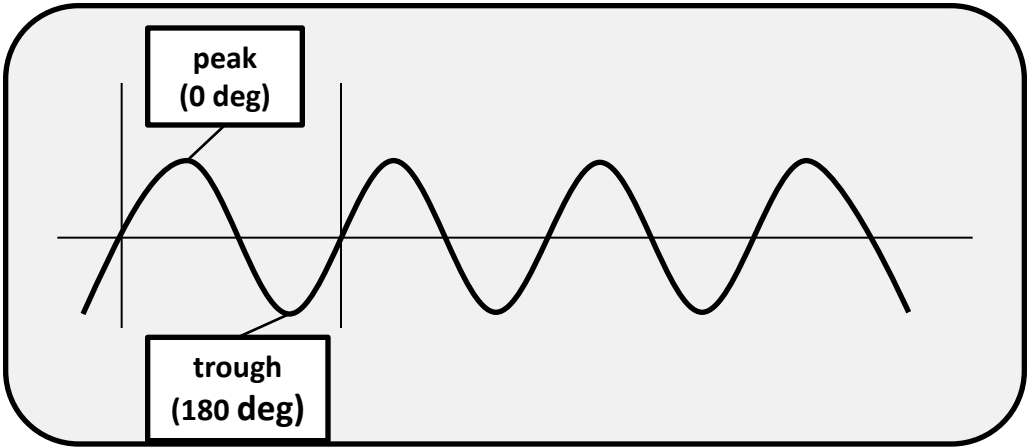
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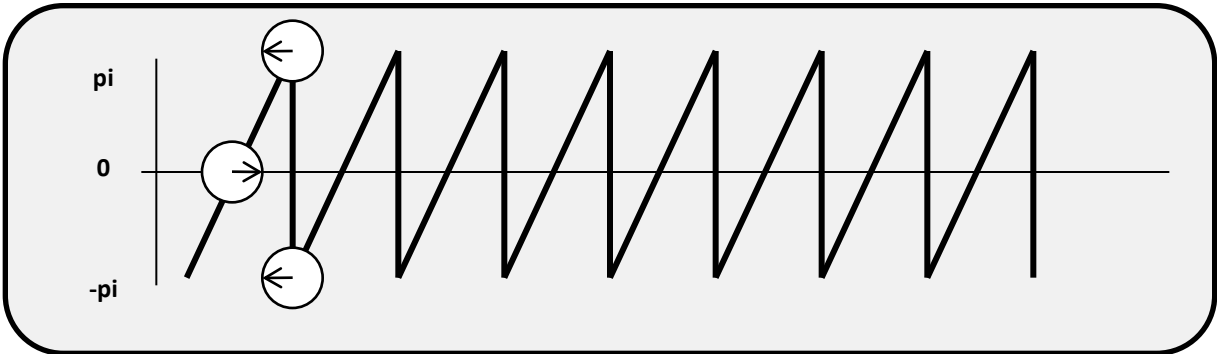
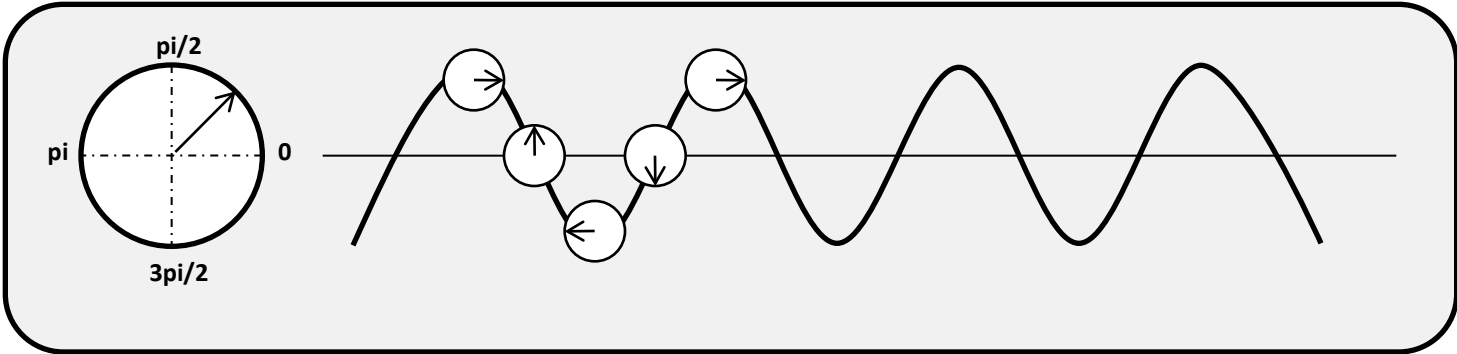
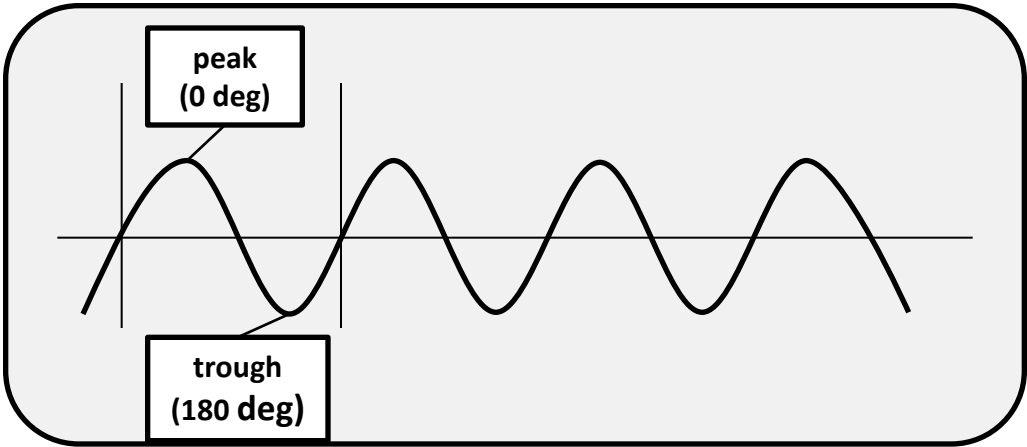
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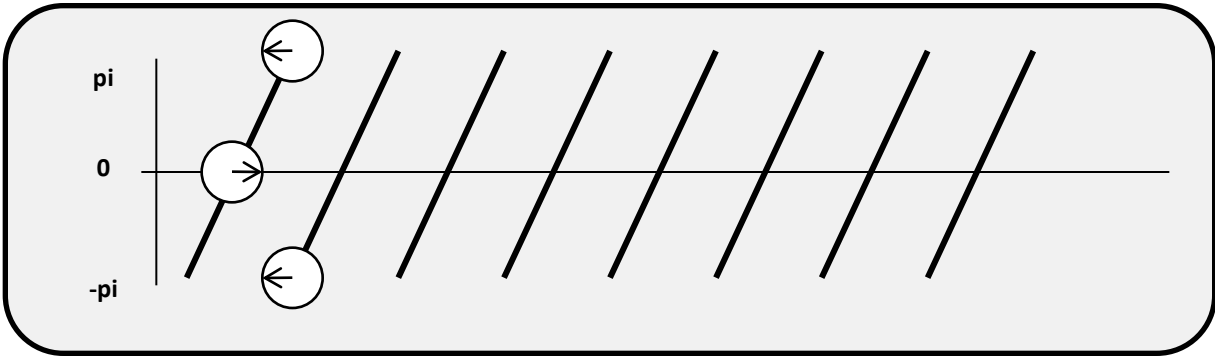
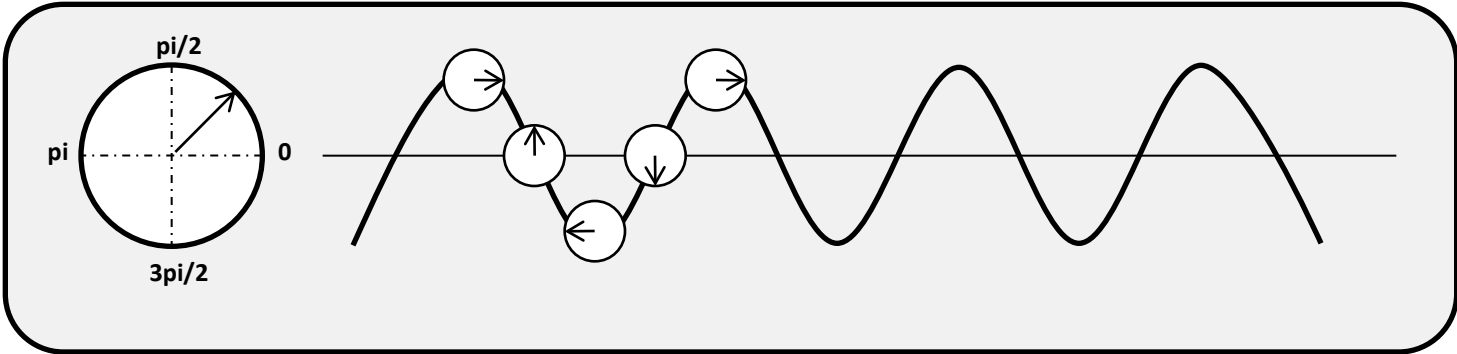
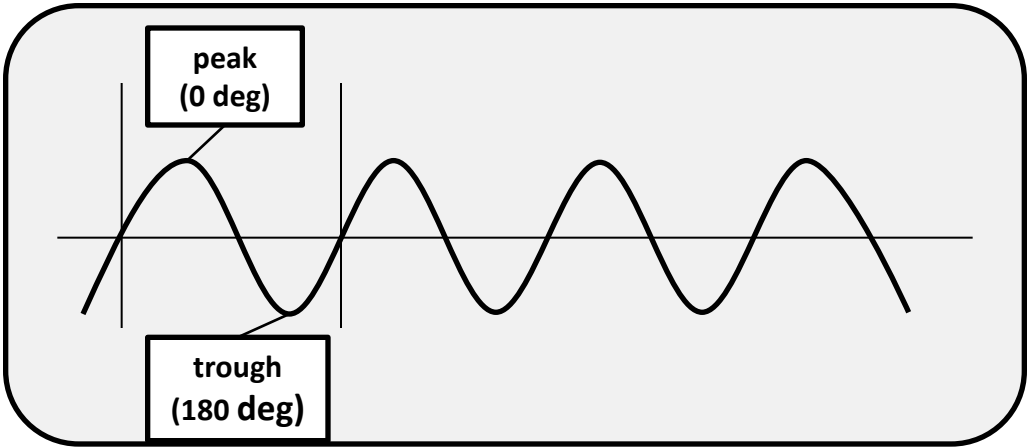
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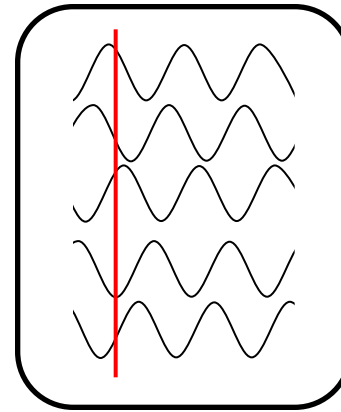
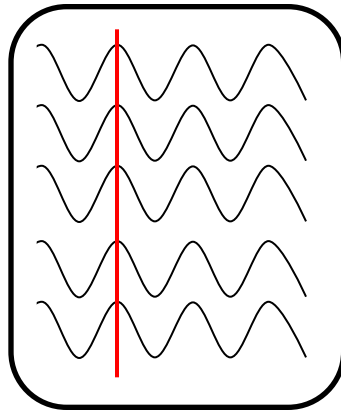


Phase locking and some of its applications

II. How

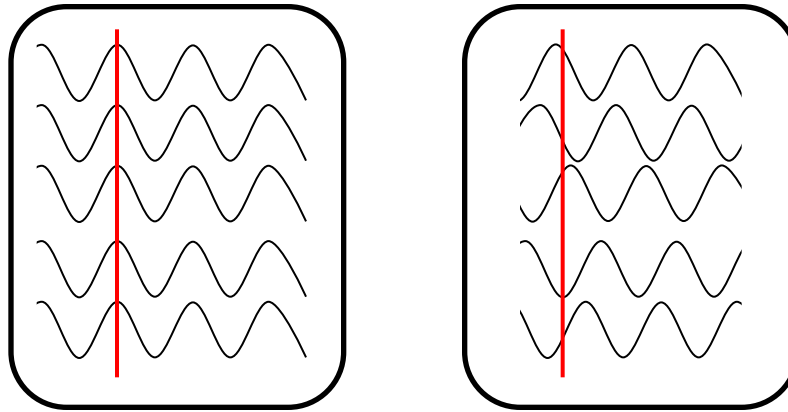
Phase locking and some of its applications

II. How



Phase locking and some of its applications

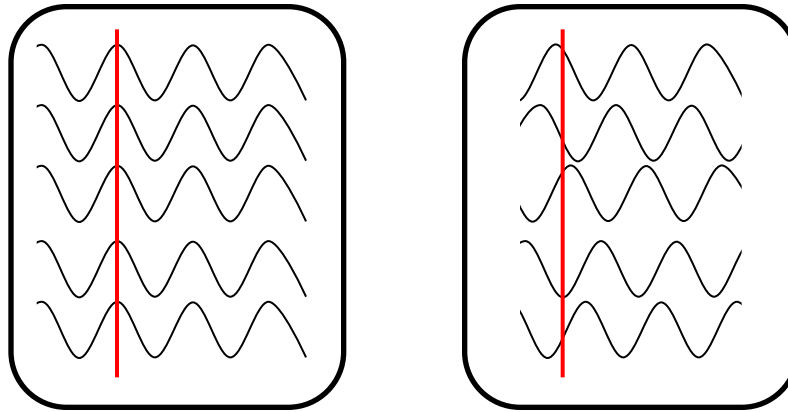
II. How



1. Alignment of phase values at time t across trials
→ inter-trial phase locking [Phase Locking Index (PLI)]

Phase locking and some of its applications

II. How

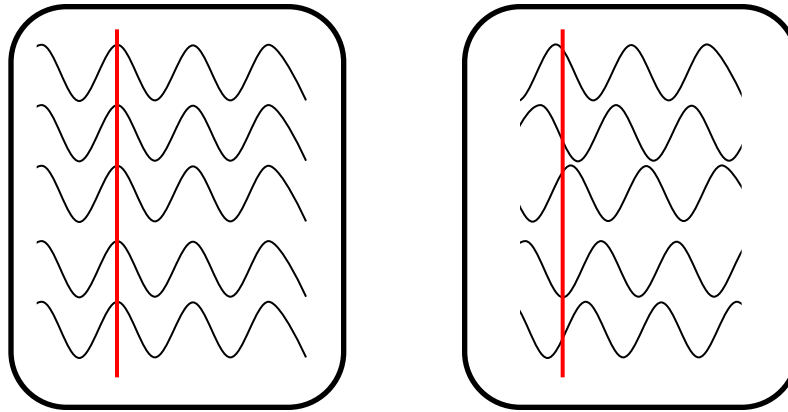


1. Alignment of phase values at time t across trials
→ inter-trial phase locking [Phase Locking Index (PLI)]

2. Alignment of phase difference values between two regions at time t across trials
→ inter-region inter-trial phase locking [Phase Locking Value (PLV)]

Phase locking and some of its applications

II. How



1. Alignment of phase values at time t across trials
→ inter-trial phase locking [Phase Locking Index (PLI)]

2. Alignment of phase difference values between two regions at time t across trials
→ inter-region inter-trial phase locking [Phase Locking Value (PLV)]

3. Alignment of phase difference values between (i) low frequency phase and (ii) high frequency envelope/power at time t across trials
→ inter-frequency inter-trial phase locking [Cross-Frequency Coupling (CFC)]

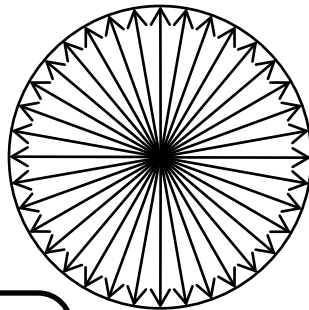
Calculation of phase locking

II. How

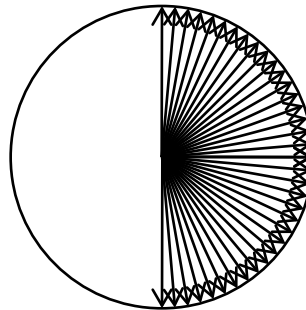
$$\text{PLI}_{(f, t)} = \frac{1}{N} \left| \sum_{x=1}^N e^{i\varphi(x, f, t)} \right|$$

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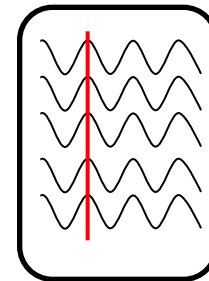
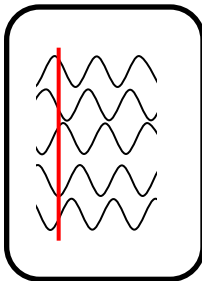
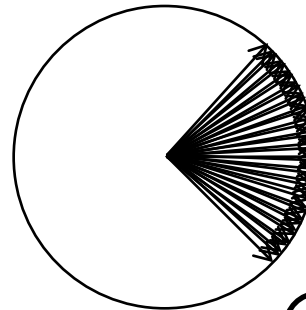
PLI = 0



PLI = .5

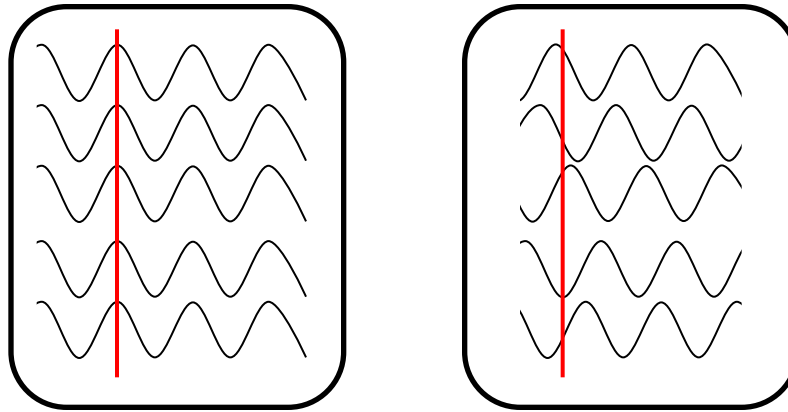


PLI = .75



Phase locking and some of its applications

II. How



1. Alignment of phase values at time t across trials
→ inter-trial phase locking [Phase Locking Index (PLI)]

2. Alignment of phase difference values between two regions at time t across trials
→ inter-region inter-trial phase locking [Phase Locking Value (PLV)]

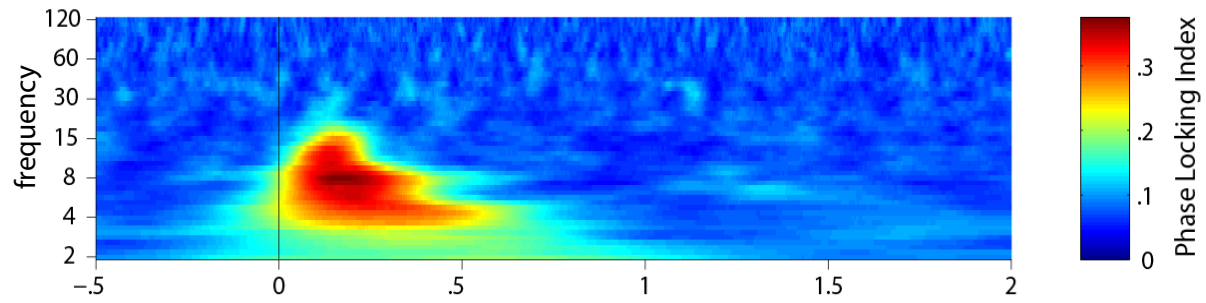
3. Alignment of phase difference values between (i) low frequency phase and (ii) high frequency envelope/power at time t across trials
→ inter-frequency inter-trial phase locking [Cross-Frequency Coupling (CFC)]

1. Phase Locking Index (inter-trial coupling)

II. How

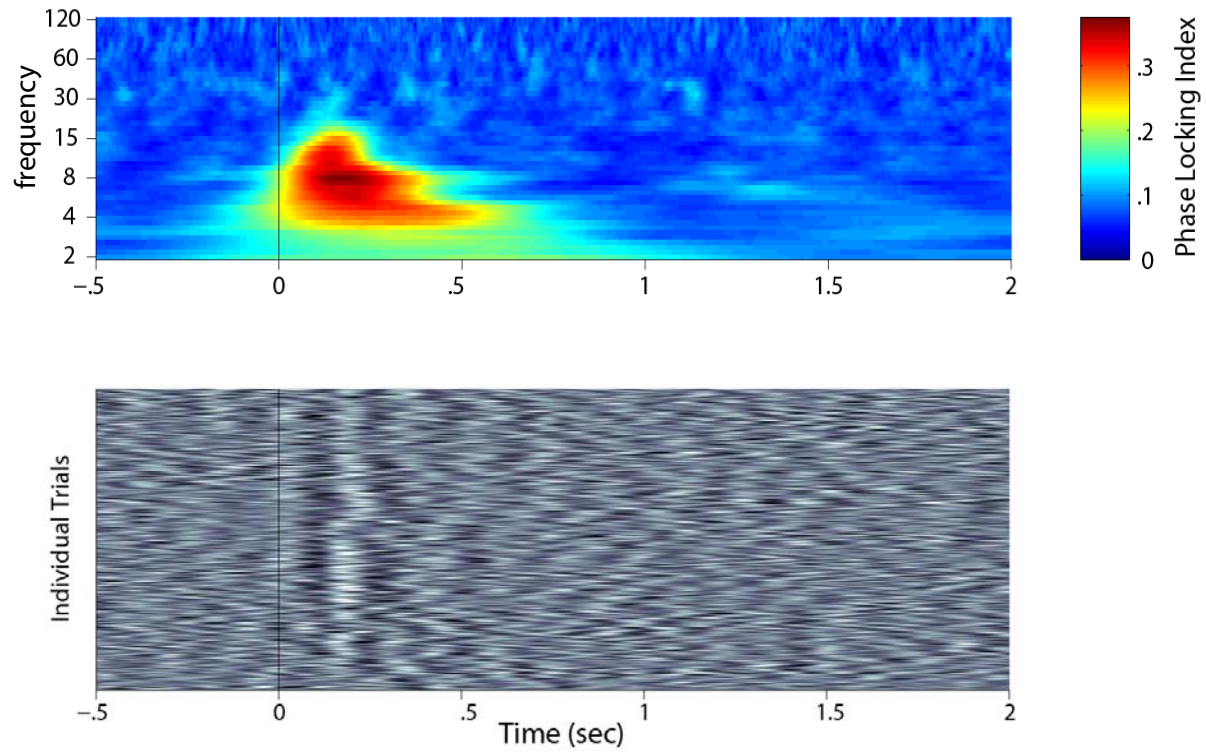
1. Phase Locking Index (inter-trial coupling)

II. How



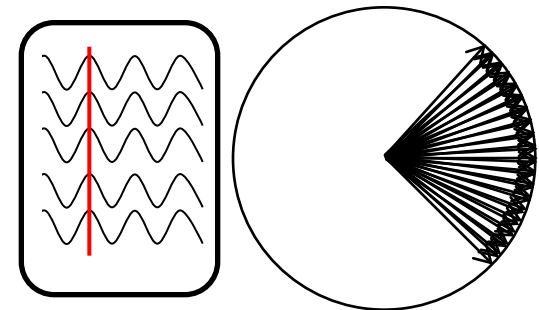
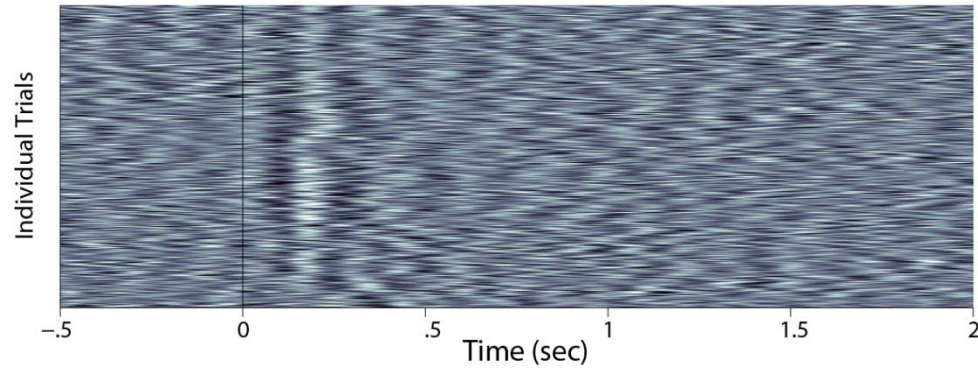
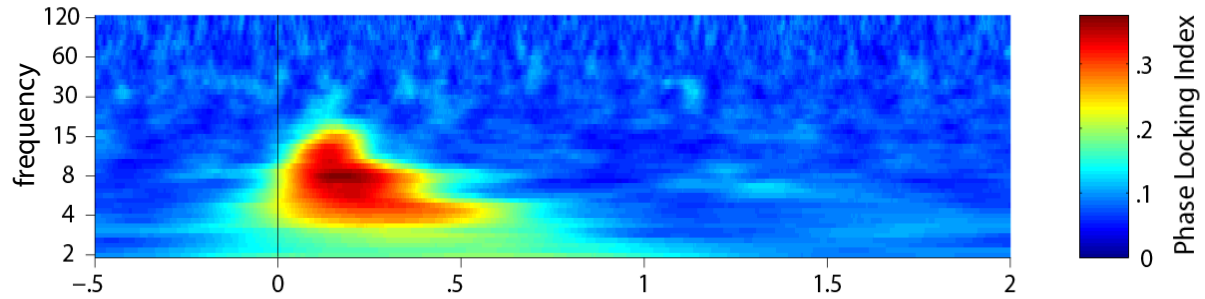
1. Phase Locking Index (inter-trial coupling)

II. How



1. Phase Locking Index (inter-trial coupling)

II. How

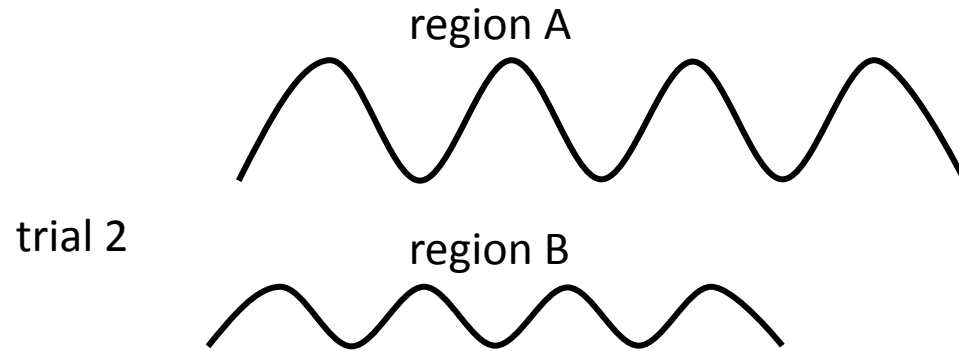
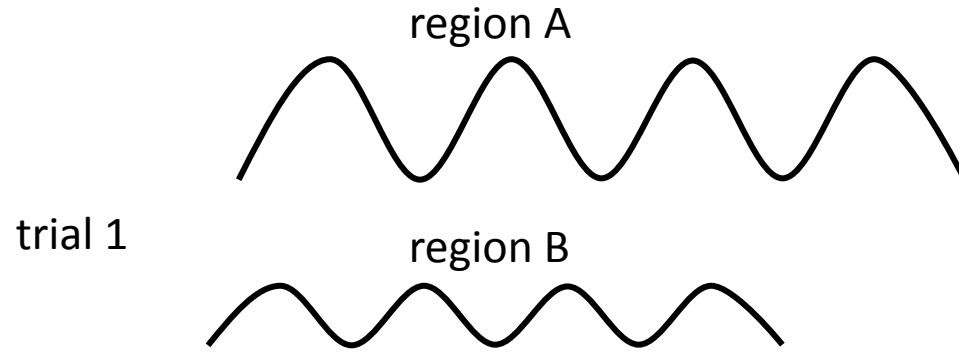


2. Phase Locking Factor (inter-region inter-trial coupling)

II. How

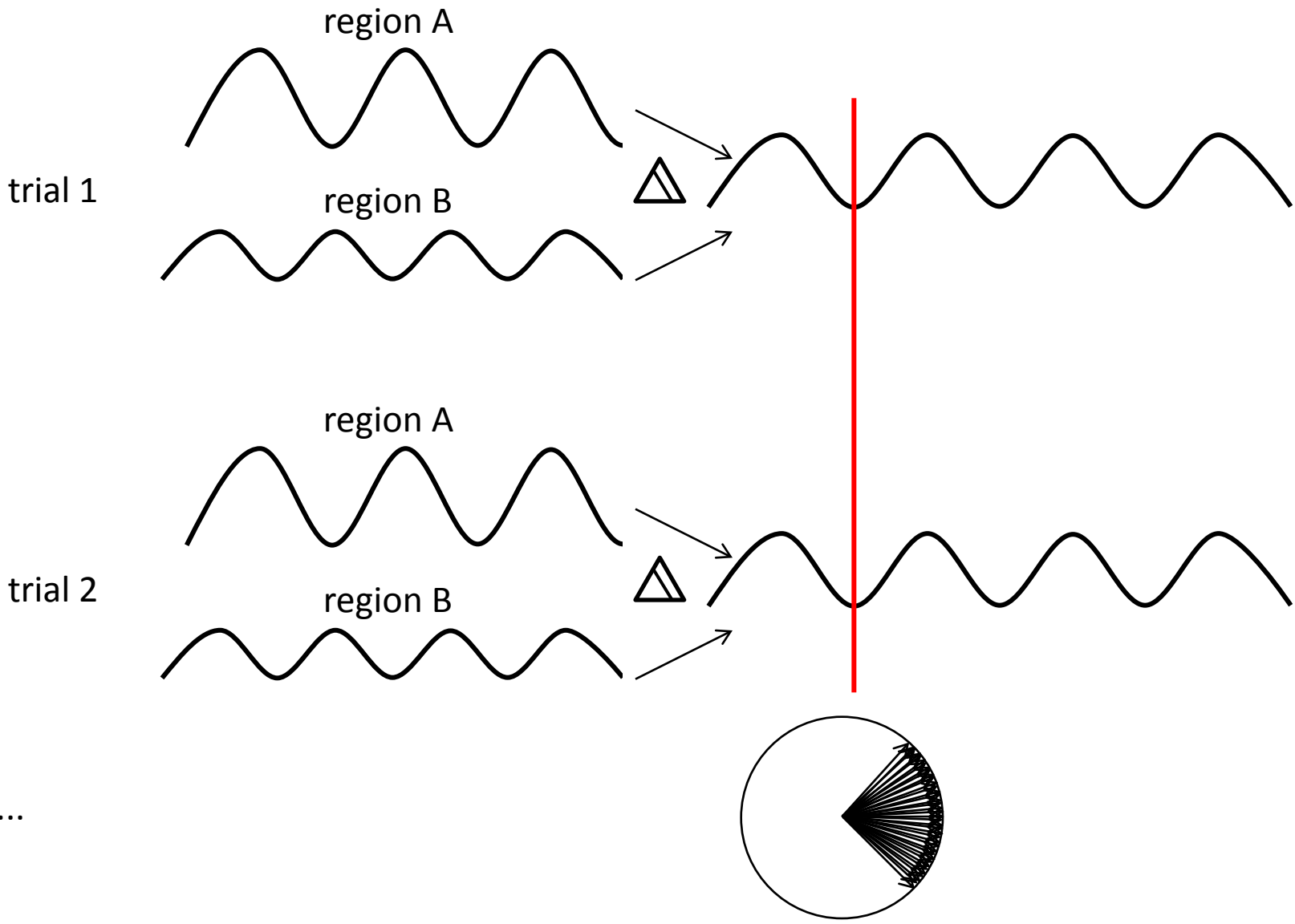
2. Phase Locking Factor (inter-region inter-trial coupling)

II. How



...

2. Phase Locking Factor (inter-region inter-trial coupling)



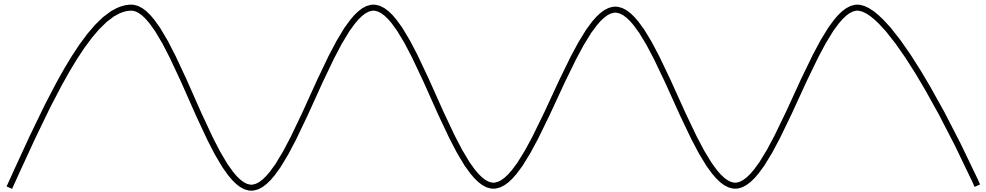
3. CFC α (inter-frequency inter-trial coupling)

II. How

3. CFC _{α} (inter-frequency inter-trial coupling)

II. How

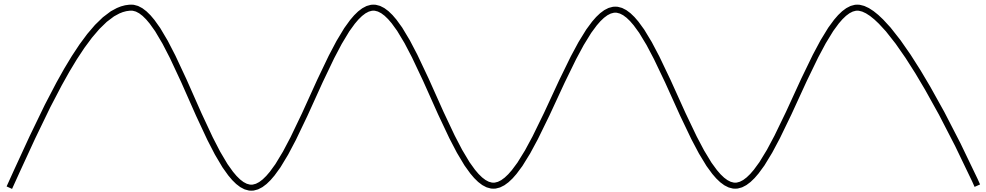
low frequency signal
"phase-providing"



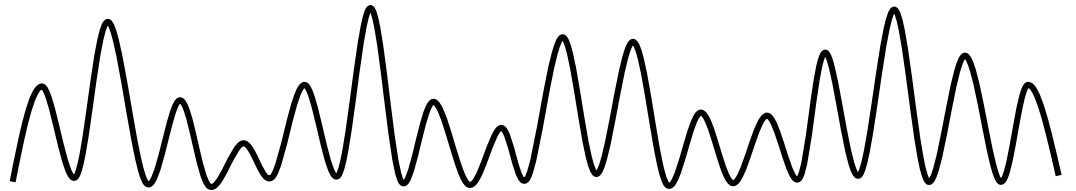
3. CFC _{α} (inter-frequency inter-trial coupling)

II. How

low frequency signal
"phase-providing"



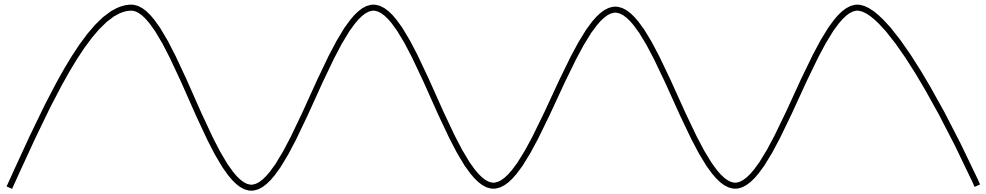
high frequency signal
"amplitude (power)-providing"



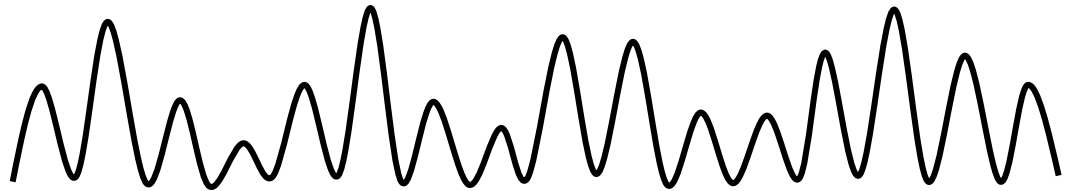
3. CFC_α (inter-frequency inter-trial coupling)

II. How

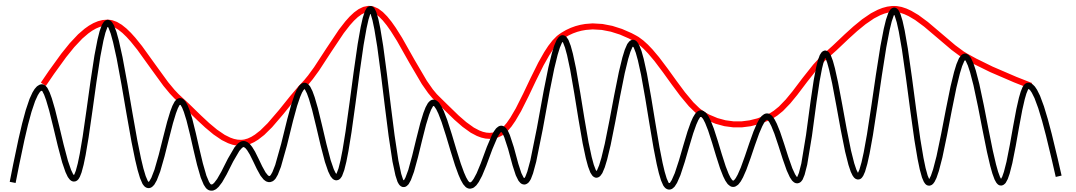
low frequency signal
“phase-providing”



high frequency signal
“amplitude (power)-providing”



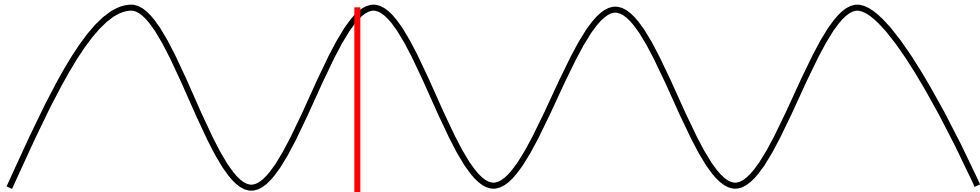
Envelope of high frequency signal



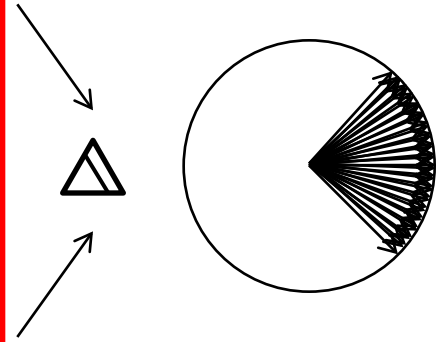
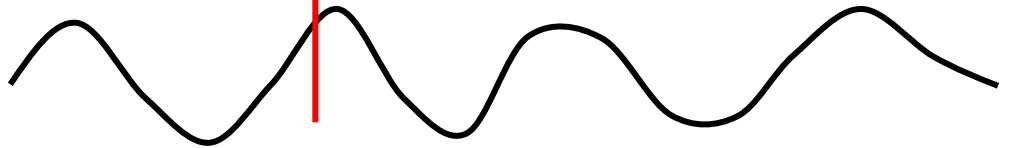
3. CFC $_{\alpha}$ (inter-frequency inter-trial coupling)

II. How

low frequency signal
"phase-providing"



Envelope of high frequency signal



CFC_b – II. Based on ‘Kullback-Leibler Distance’

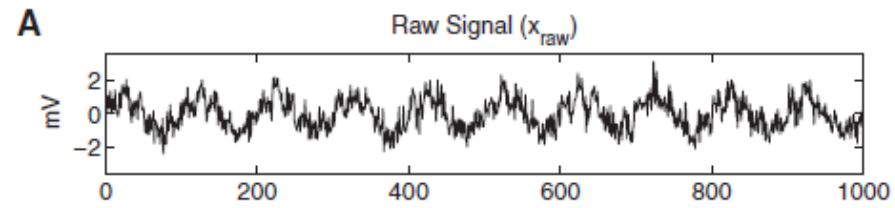
Tort et al., 2010

II. How

CFC_b – II. Based on ‘Kullback-Leibler Distance’

Tort et al., 2010

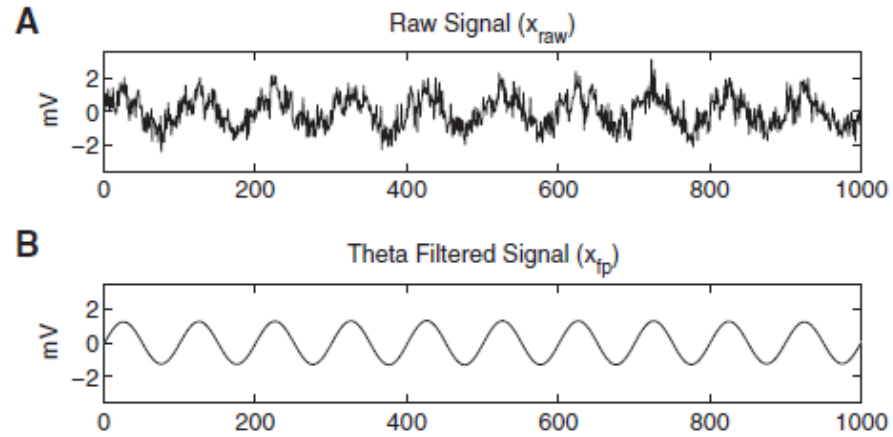
II. How



CFC_b – II. Based on ‘Kullback-Leibler Distance’

Tort et al., 2010

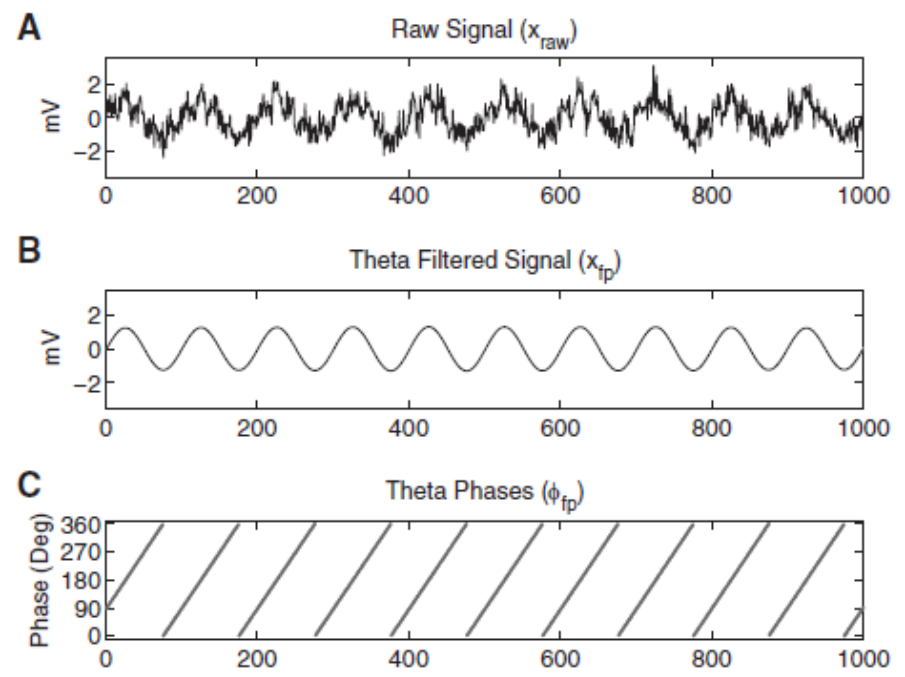
II. How



CFC_b – II. Based on ‘Kullback-Leibler Distance’

Tort et al., 2010

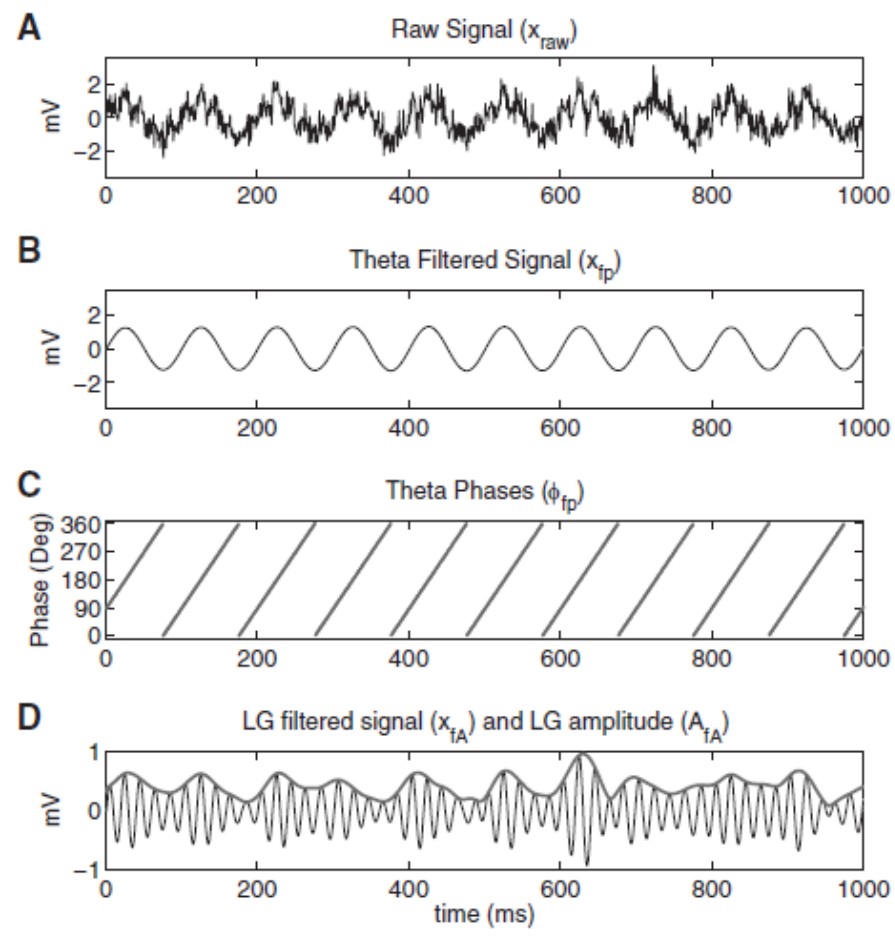
II. How



CFC_b – II. Based on ‘Kullback-Leibler Distance’

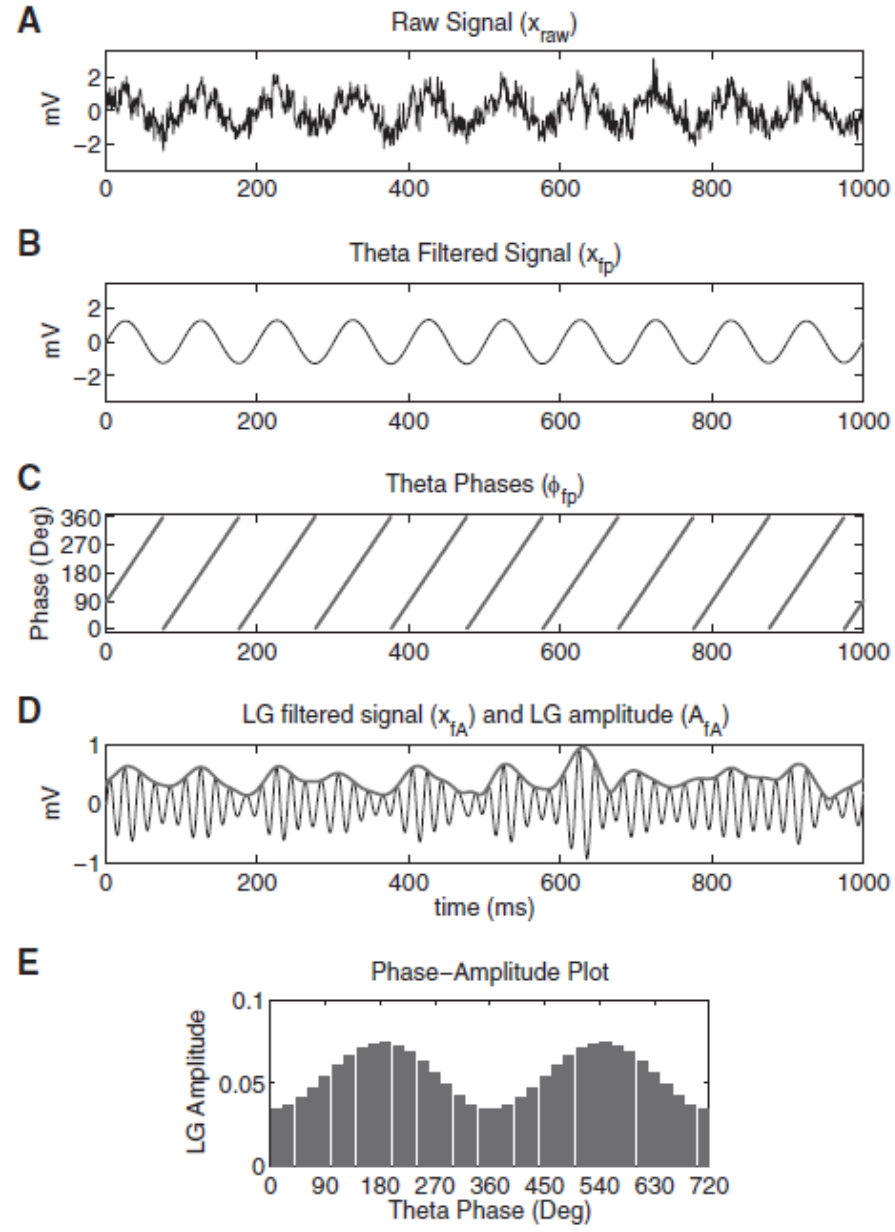
Tort et al., 2010

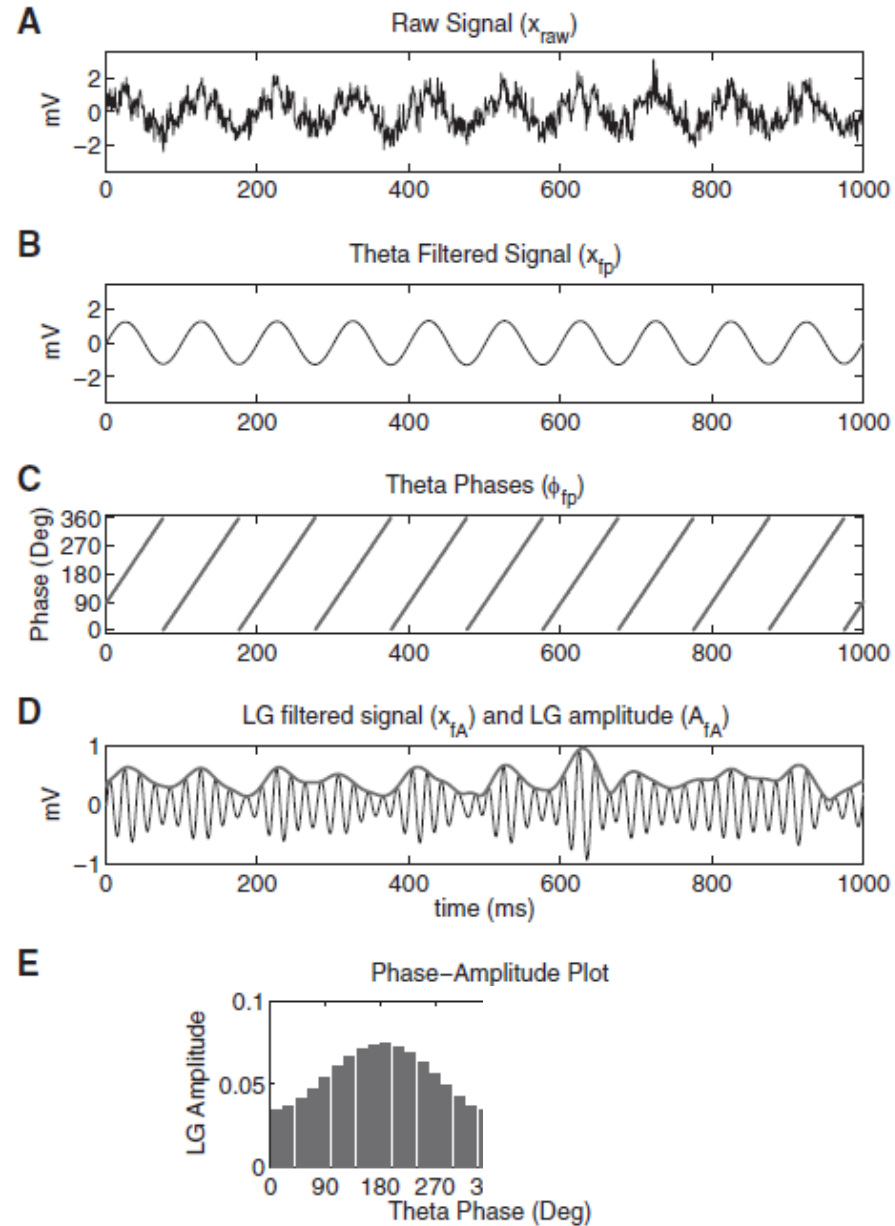
II. How



CFC_b – II. Based on ‘Kullback-Leibler Distance’

Tort et al., 2010



CFC_b – II. Based on ‘Kullback-Leibler Distance’*Tort et al., 2010*

III. Example

Background

III. Example

Background

Memories are initially stored in the hippocampus.



III. Example

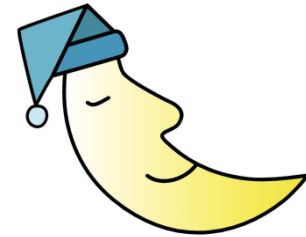
Background

III. Example

Memories are initially stored in the hippocampus.



Slow-wave sleep (SWS) facilitates memory consolidation.



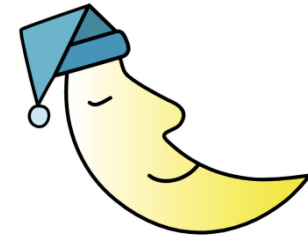
Background

III. Example

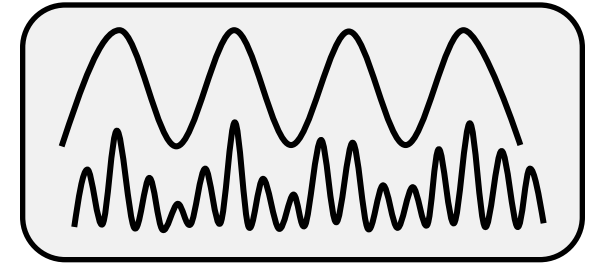
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Cross-frequency-coupling (CFC) has been related to synaptic plasticity and memory.



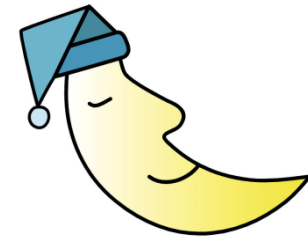
Background

III. Example

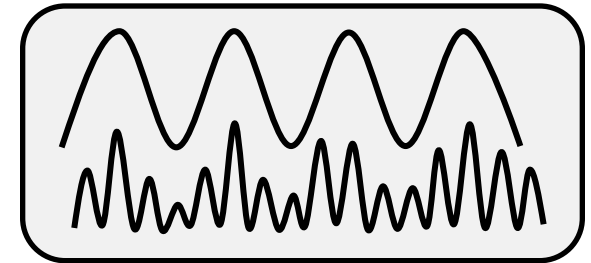
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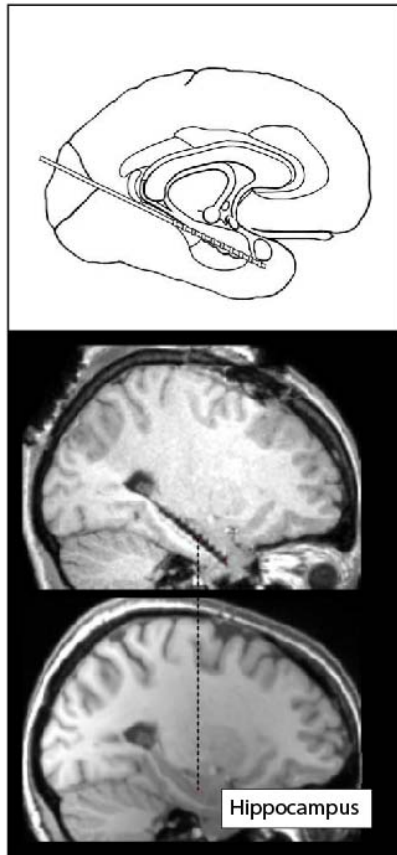


Cross-frequency-coupling (CFC) has been related to synaptic plasticity and memory.



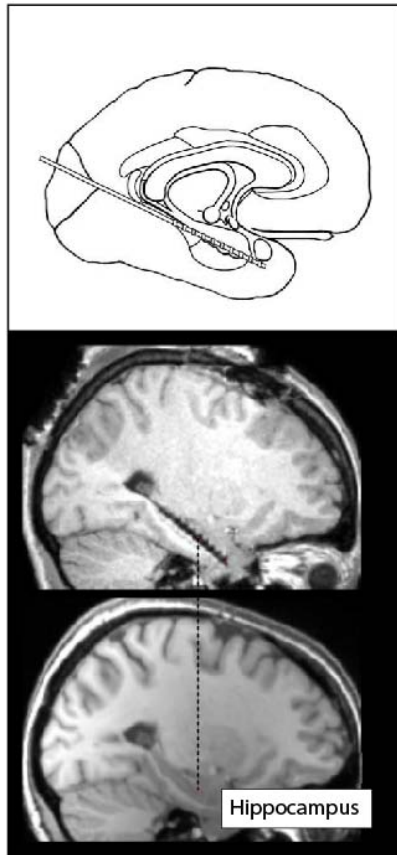
Is there evidence for hippocampal cross-frequency-coupling during SWS in humans?

iEEG recordings from MTL contralateral
to the epileptic focus (n=10)



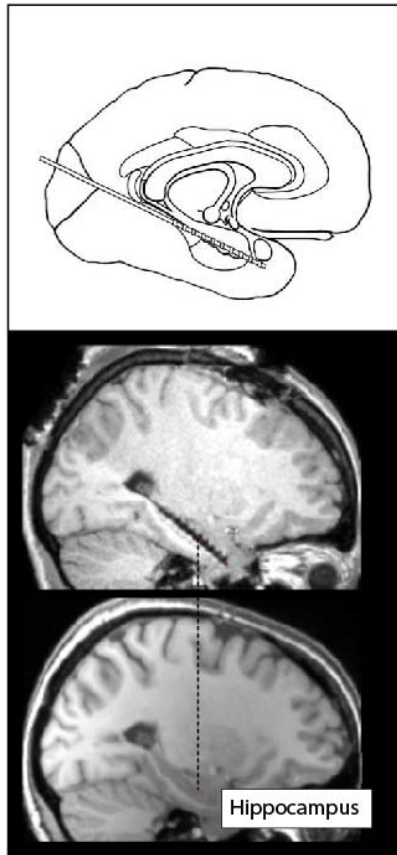
iEEG recordings from MTL contralateral
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classification of sleep stages based on Cz
scalp electrode, EOG and EMG

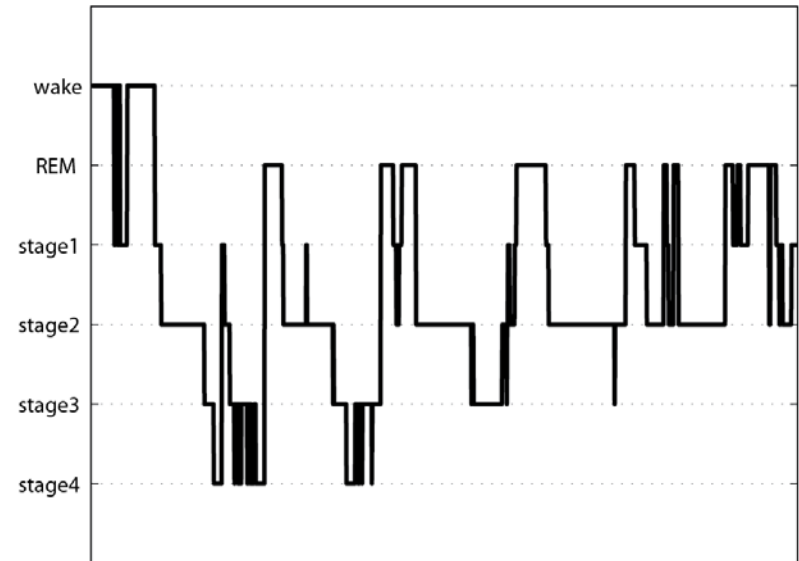


iEEG recordings from MTL contralateral to the epileptic focus (n=10)

classification of sleep stages based on Cz scalp electrode, EOG and EMG

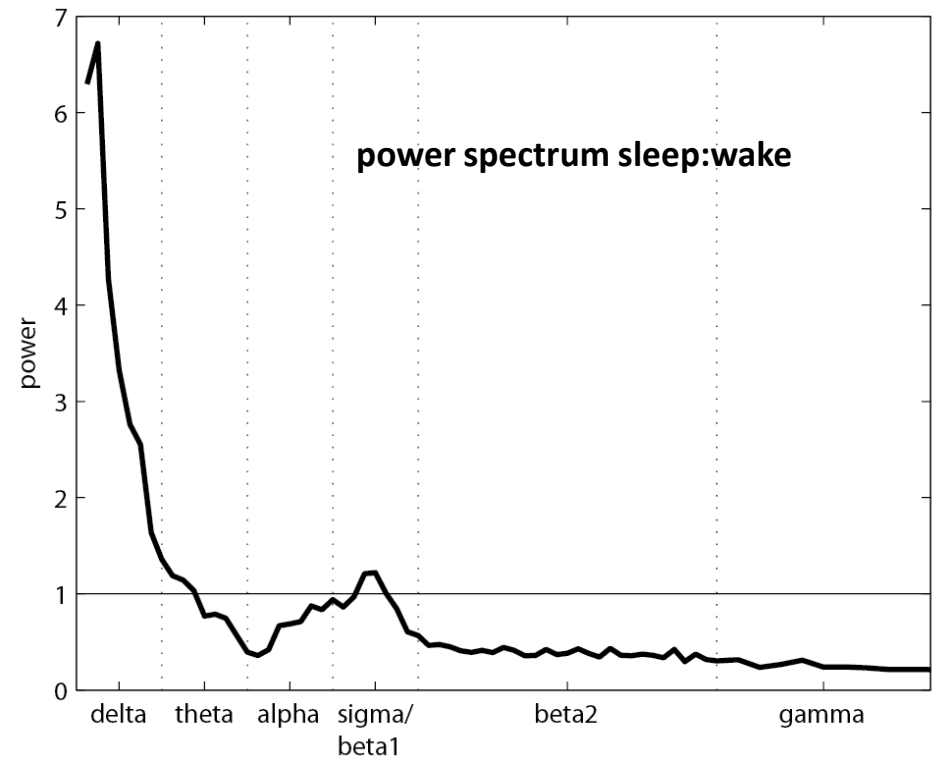
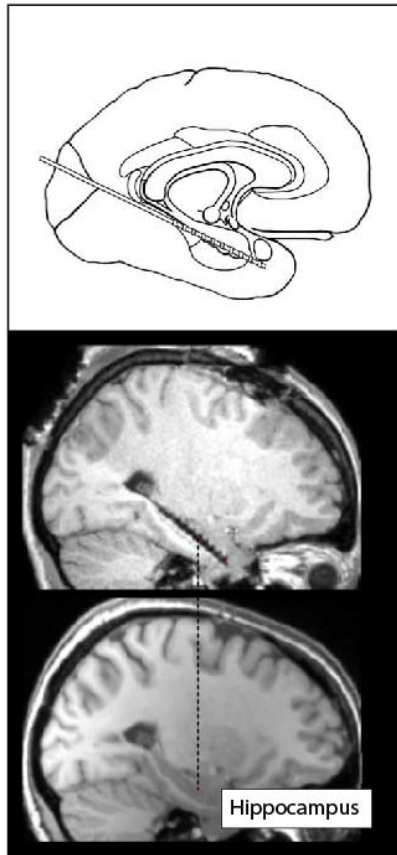


sleep architecture

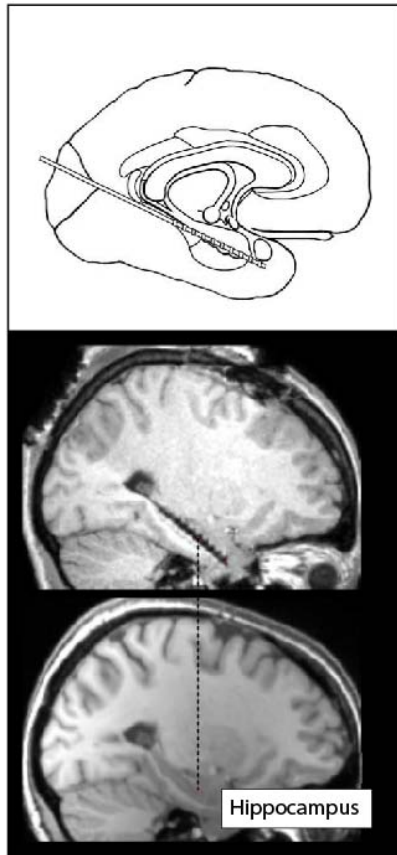


iEEG recordings from MTL contralateral to the epileptic focus (n=10)

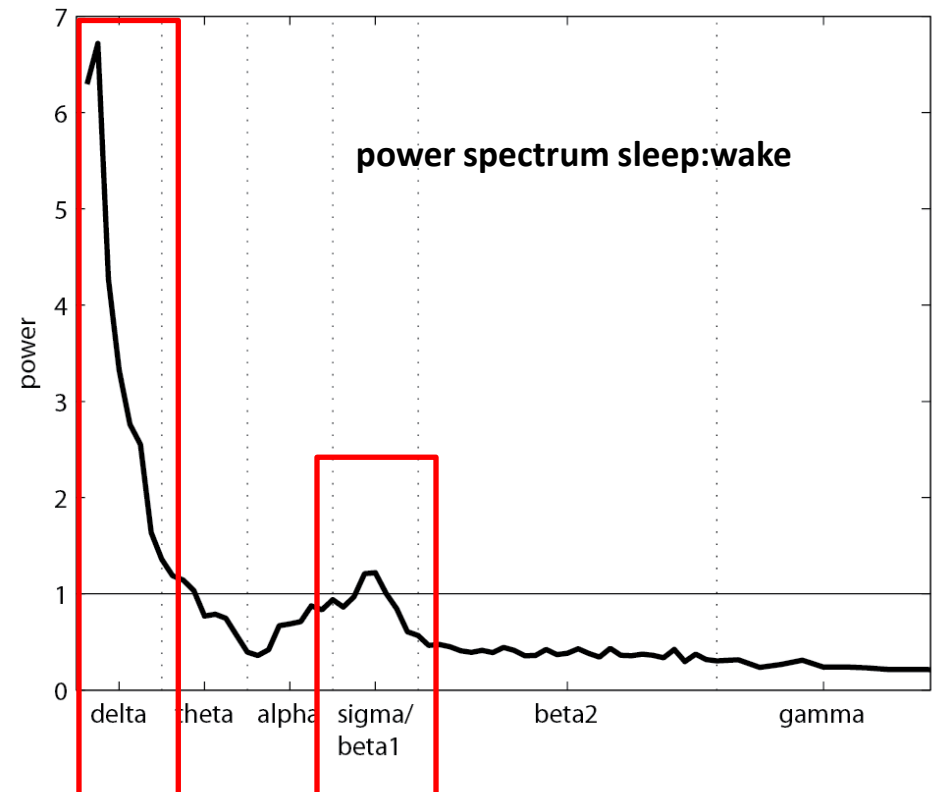
classification of sleep stages based on Cz scalp electrode, EOG and EMG



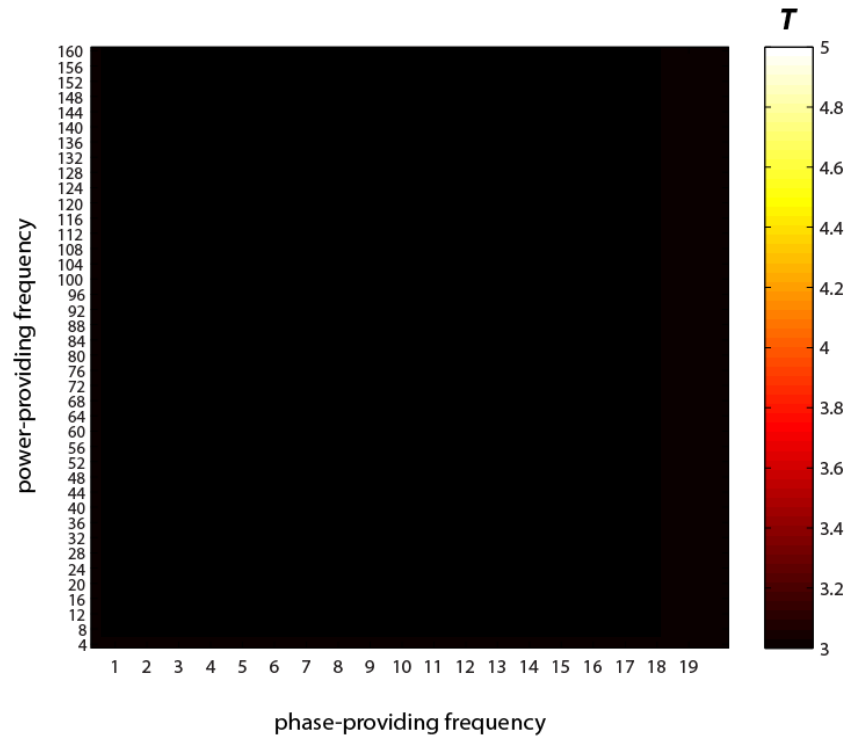
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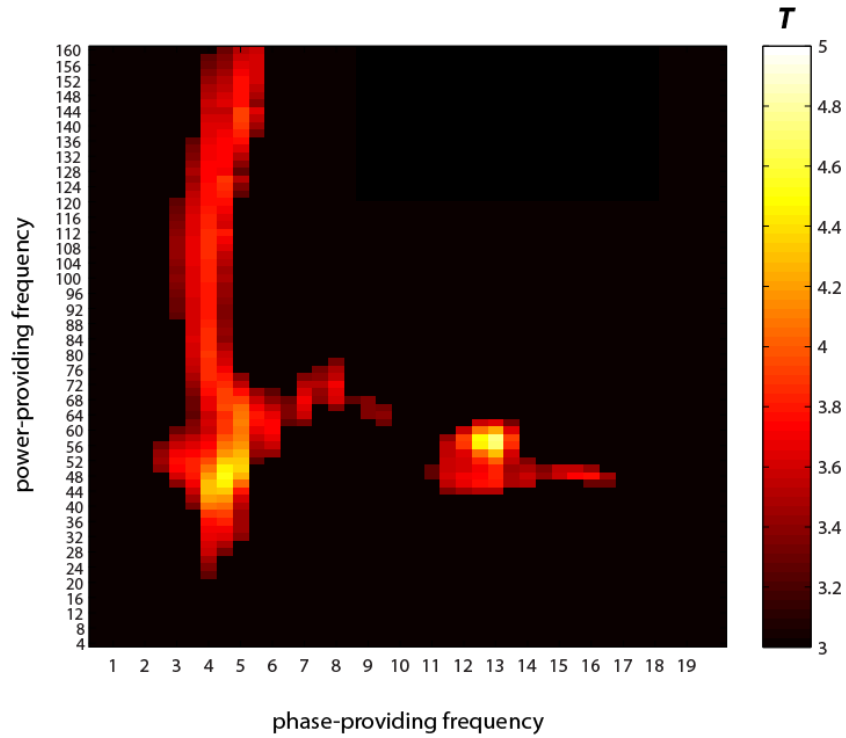
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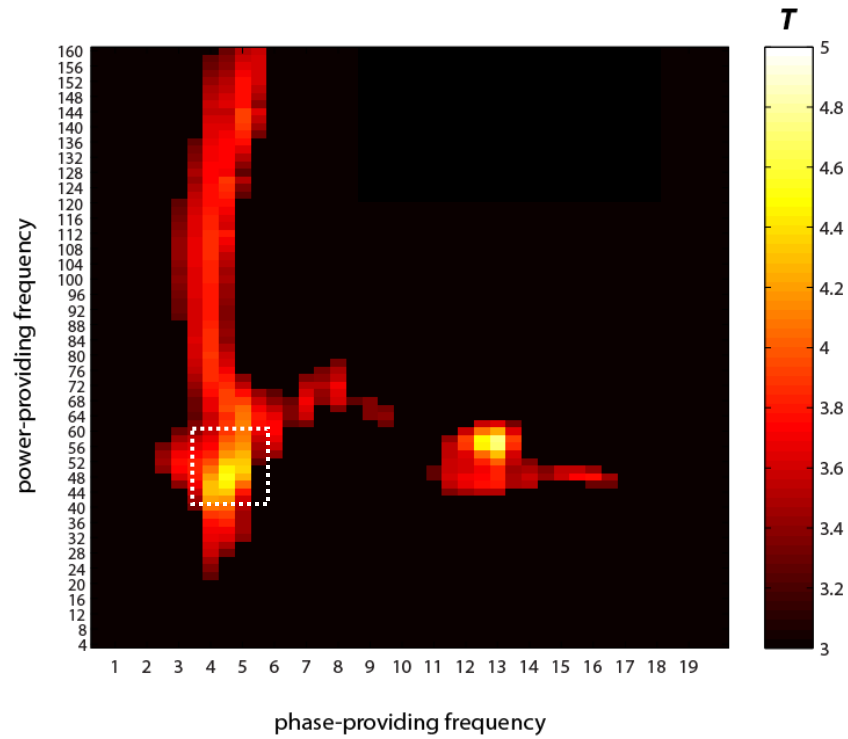
CFC in hippocampus, SWS vs. wake



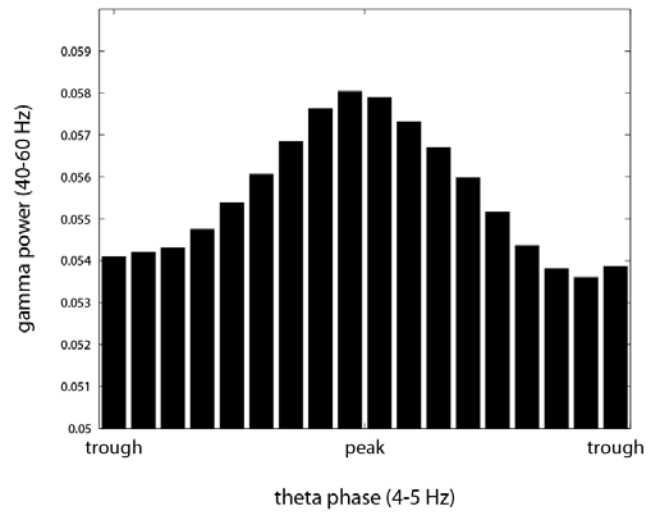
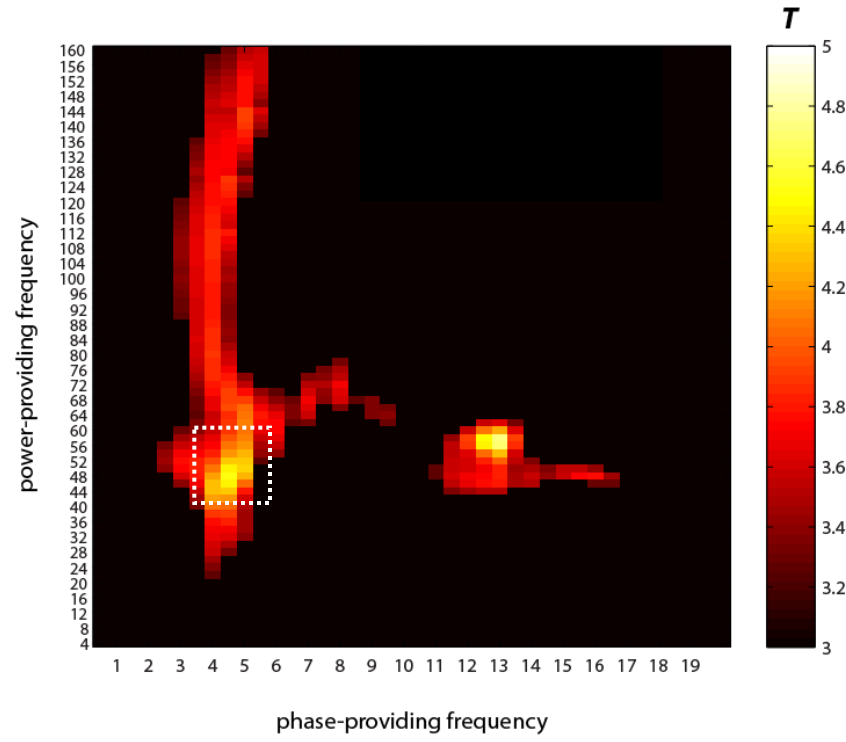
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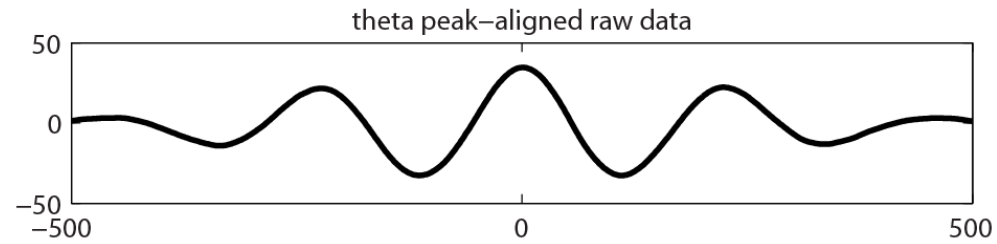


CFC in hippocampus, SWS vs. wake

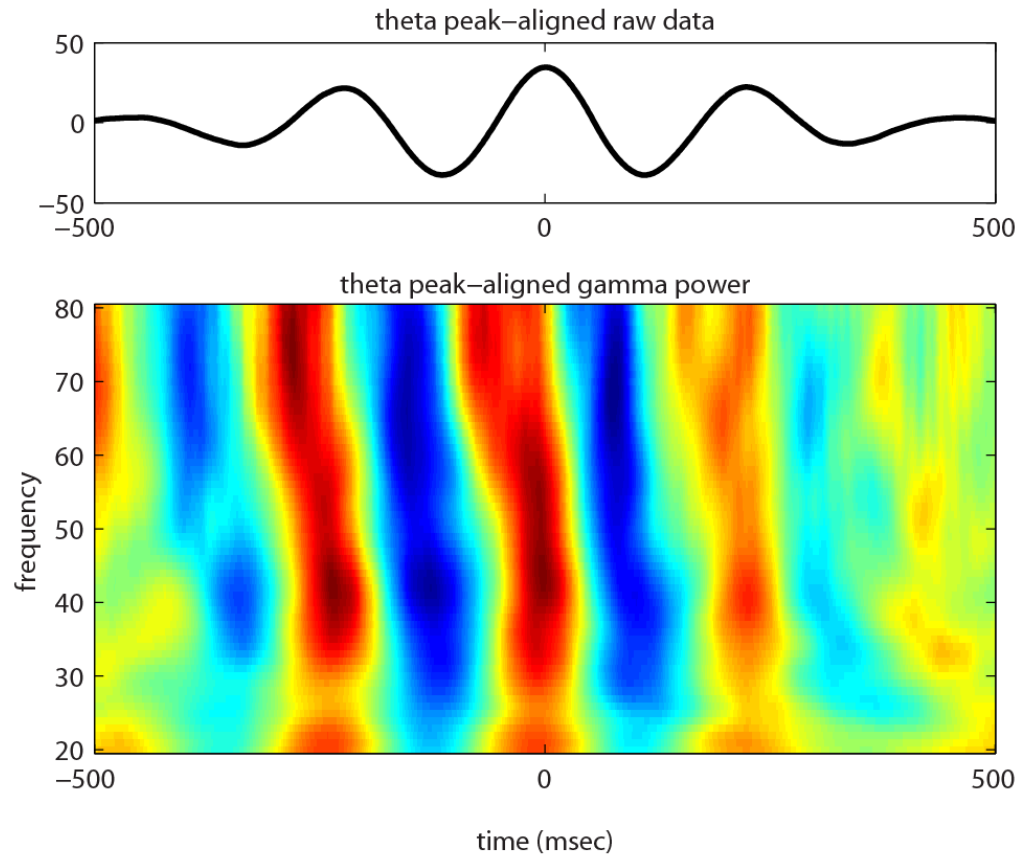


complementary analysis: display of gamma power locked to theta peak

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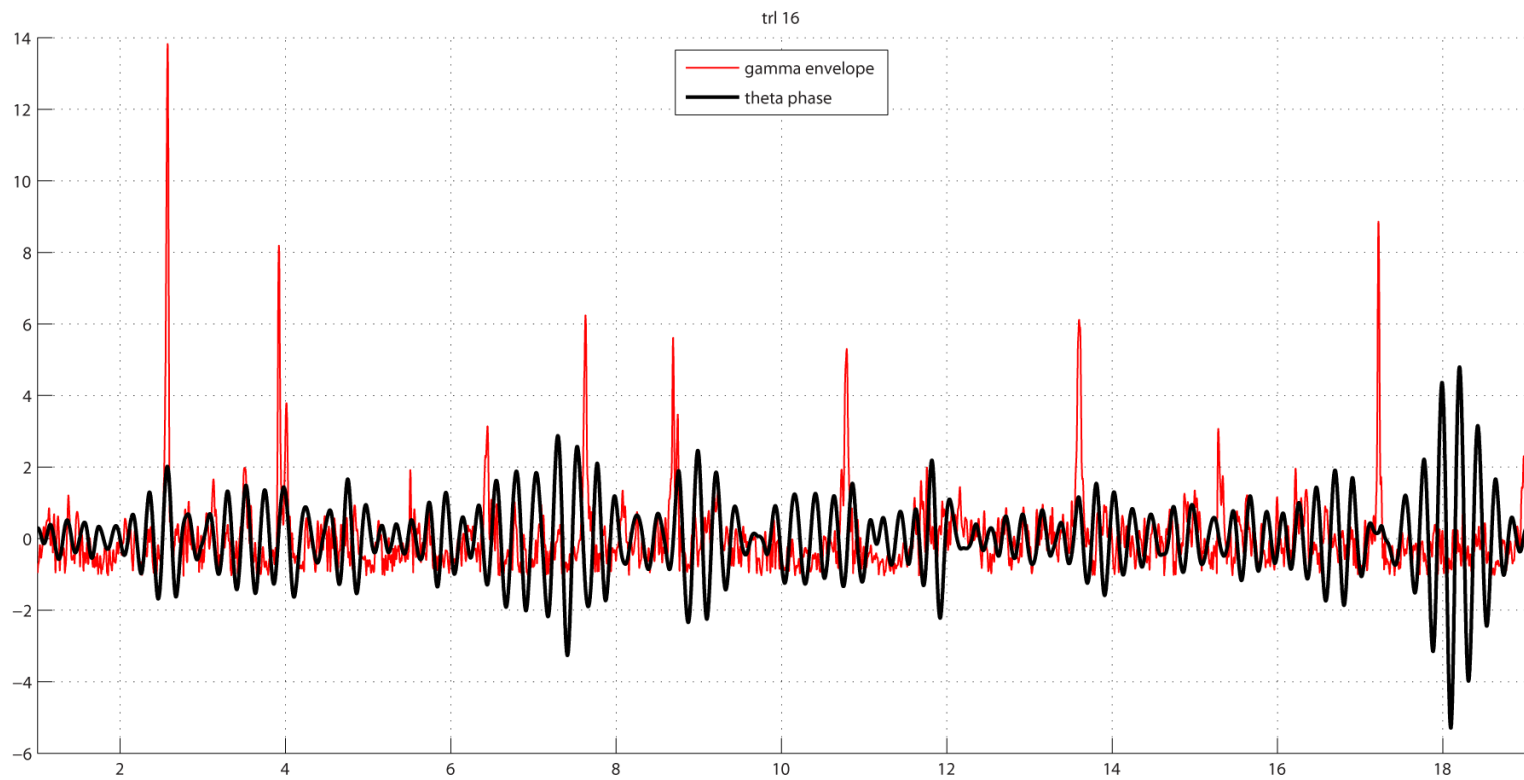


complementary analysis: display of gamma power locked to theta peak

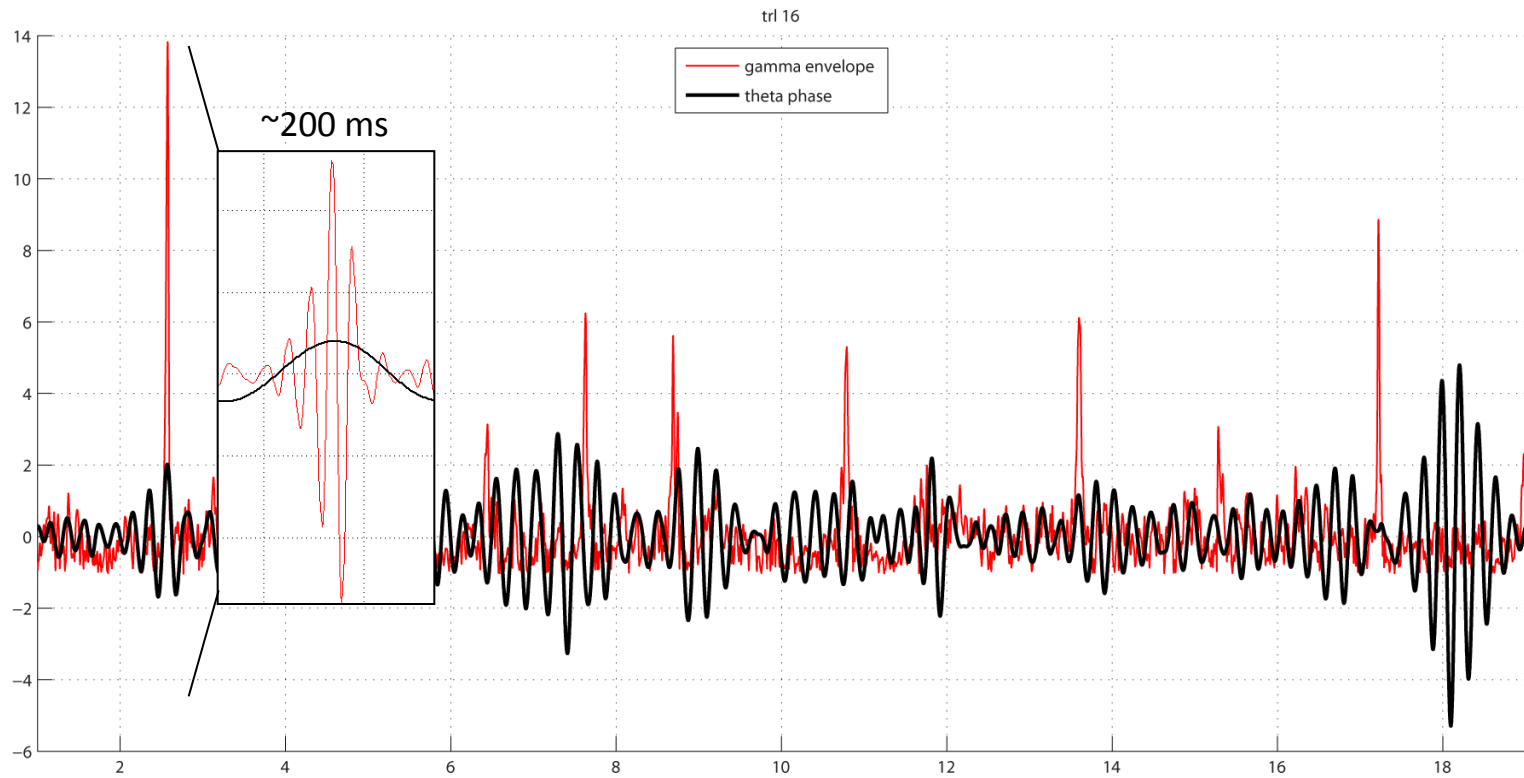


raw data example

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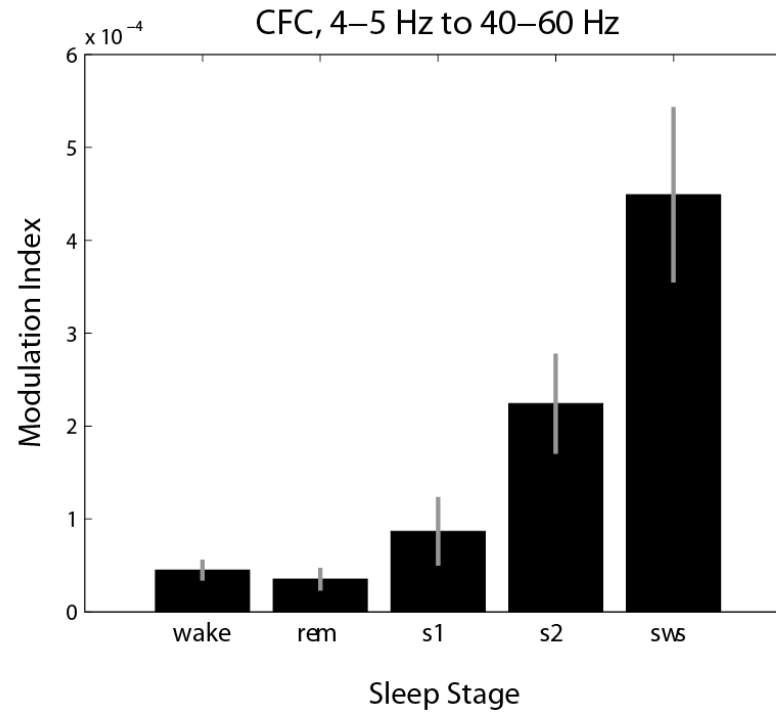


raw data example



theta:gamma CFC across sleep stages

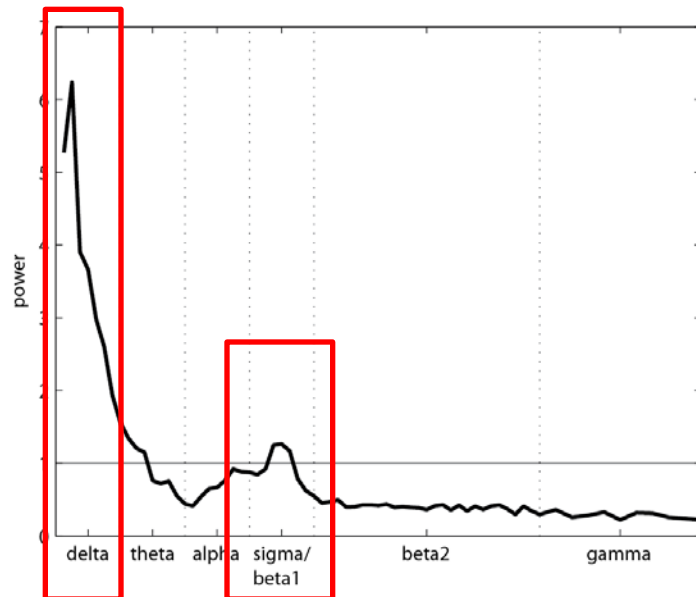
theta:gamma CFC across sleep stages



control: phase-scrambled surrogate data

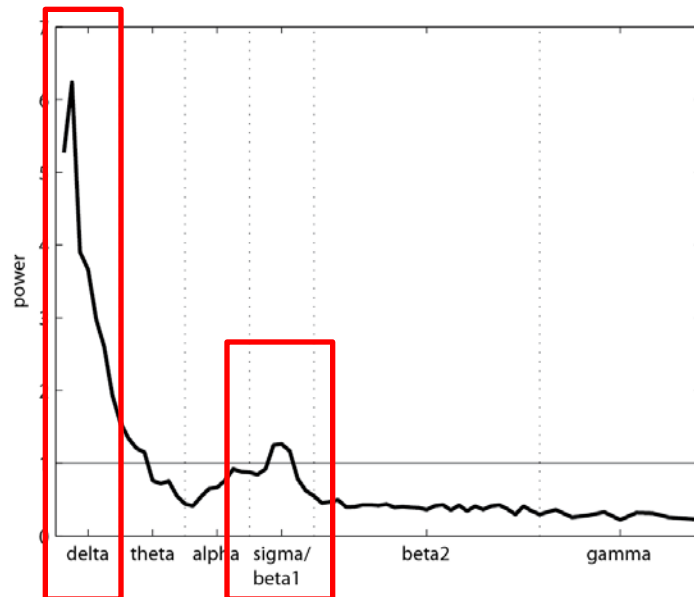
control: phase-scrambled surrogate data

power spectrum sleep:wake

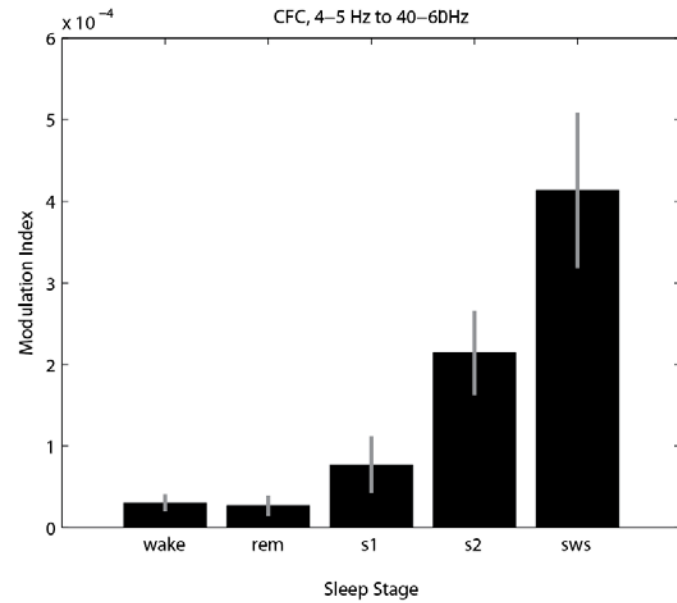


control: phase-scrambled surrogate data

power spectrum sleep:wake



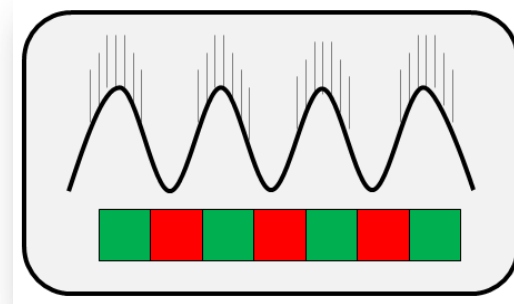
theta:gamma CFC across sleep stages



Strong theta:gamma CFC in hippocampus during SWS

Strong theta:gamma CFC in hippocampus during SWS

Evidence for effective LTP during SWS?



Thank You!