

Applicazioni cliniche dell'elaborazione del segnale EEG e dei potenziali evento-relati

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ANALISI EEG: elaborazione *numerica* dell'EEG

Pre-elaborazione del segnale (rimozione artefatti, filtraggio,...)

- evidenziare specifiche componenti
- estrarre misure quantitative oggettive
 - supporto alla diagnosi
 - supporto al trattamento farmacologico
 - confronto tra successive registrazioni
- avanzamento delle conoscenze: comprensione meccanismi di base

Applicazione di metodi di elaborazione dei segnali e di modelli matematici all'analisi dell'EEG e delle risposte evento-correlate o evocate da stimoli somatosensoriali

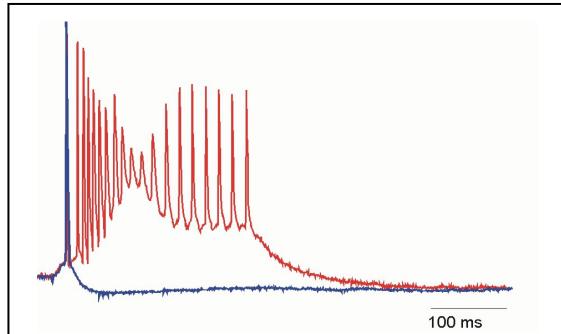
Studio della relazione tra attività corticale e ipercinesie muscolari

Studio della connettività/sincronizzazione

Studio dei meccanismi neurofisiologici che precedono e preparano la scarica epilettica EEG

Studio della sincronizzazione/desincronizzazione evento correlata

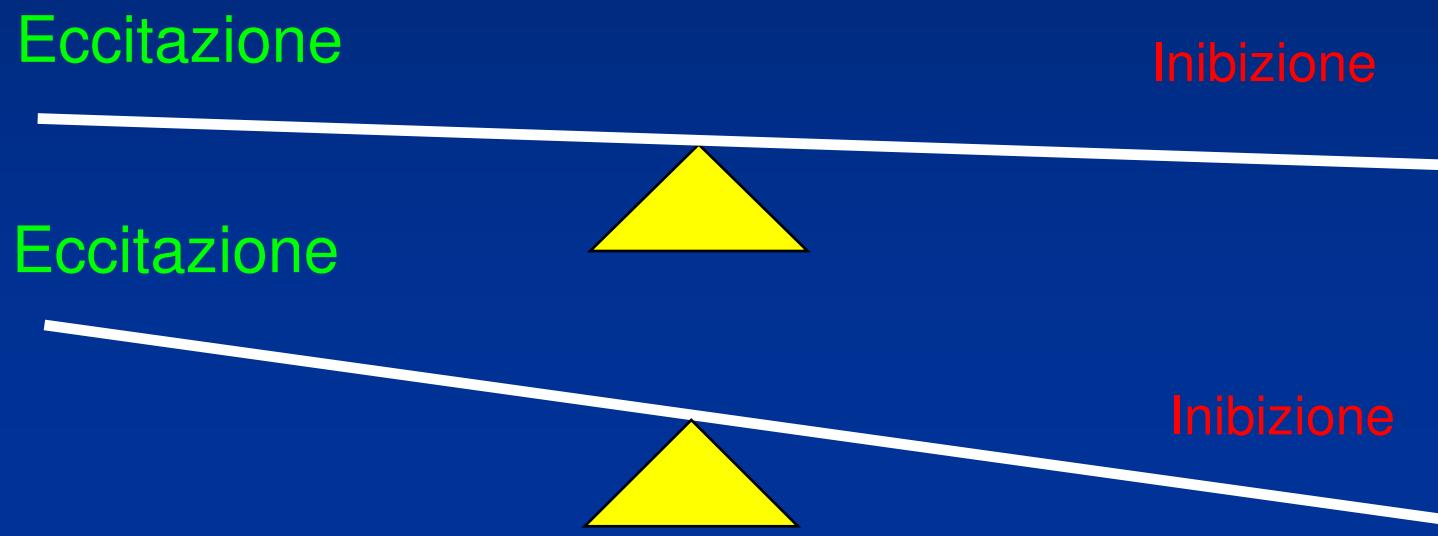
- Analisi delle proprietà di membrana dei neuroni corticali
- Sviluppo e gestione di database per lo studio delle epilessie
- Coregistrazione di segnali neurofisiologici e funzionali (EEG-fMRI-NIRS)



- ♦ Crisi: manifestazione clinica di una anormale ed eccessiva sincronizzazione di una popolazione di neuroni corticali
- ♦ Epilessia: tendenza verso la ricorrenza di crisi non provocate da un danno neurologico o sistematico acuto
- ♦ Epilettogenesi: sequenza di eventi che porta alla conversione di una normale rete di neuroni in una rete ipereccitabile

Epileptogenic Mechanisms

- Sbilancio tra meccanismi sinaptici inibitori ed eccitatori (insufficiente trasmissione GABA?)
- Canalopatie (mutazione genetica con conseguente malfunzionamento dei canali voltaggio dipendenti della membrana)
- Modificazioni della geometria dei neuroni, presenza neuroni immaturi o distorti (malformazioni corticali)



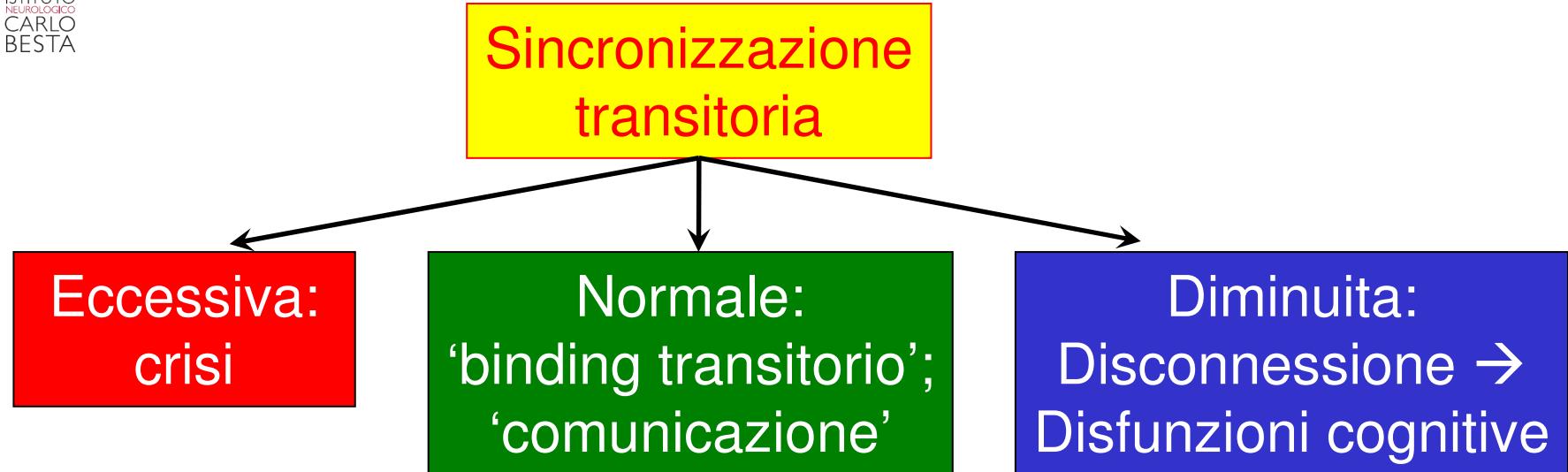
Per generare attività **ritmiche** fisiologiche o patologiche

- E' necessaria la sincronizzazione di una popolazione **abbastanza ampia** di neuroni che può derivare da:
 - Un input comune remoto (talamo)
 - Un input comune locale
 - Neuroni dotati di
 - **correnti ioniche con caratteristiche di attivazione / inattivazione assembrate in modo da generare oscillazioni regolari**
 - **connessioni sinaptiche permissive che permettano cioè la formazione di reti neurali (locali o a relativa distanza)**

- Aree cerebrali diverse hanno una specifica specializzazione
- Compiti complessi richiedono cooperazione tra diverse aree cerebrali
- La sincronizzazione *in diverse bande di frequenza, con una definita, ma transitoria, struttura temporale e spaziale,* sembra essere un meccanismo chiave per l'integrazione delle informazioni elaborate in specifiche aree (connettività)

CONNETTIVITÀ'

- Connettività anatomica: insieme delle connessioni strutturali
- Connettività funzionale: misura (statistica) del grado di interazione tra attività rilevate in differenti aree, sottosistemi o distretti anatomici;
- Connettività effettiva: stima delle interazioni causali e dei flussi di propagazione trà attività presenti in aree diverse (modello).



Sincronizzazione di attività oscillatorie in diverse bande di frequenza appare essere uno dei meccanismi chiari per:

1. *Integrazione dinamica (binding) di un distribuito set di neuroni in un insieme funzionalmente coerente, per l'elaborazione di processi cognitivi, compiti motori e/o sensoriali*
2. *Comunicazione tra aree/regioni differenti.*

Evidenze che un'alterata sincronizzazione sia associata a diverse malattie neurologiche o disfunzioni cognitive (schizofrenia, epilessia, Alzheimer, Parkinson,...)

Esistenza di specifiche reti corticali e/o sottocorticali coinvolte nella genesi e nell'evoluzione delle crisi epilettiche.

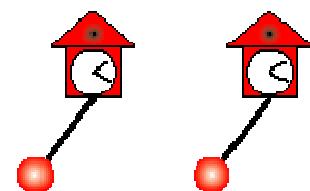
Studio della connettività e delle relazioni causali può essere uno strumento utile per:

- Comprensione dei meccanismi fisiopatologici di patologie legate a un'alterata eccitabilità neuronale (e.g. epilessia, Parkinson, disordini del movimento, schizofrenia)
- Comprensione della relazione complessa tra strutture e dinamica delle reti epilettiche coinvolte nella generazione e nell'evoluzione delle crisi epilettiche
- Supporto alla diagnosi e valutazione efficacia intervento terapeutico (riabilitazione??), attraverso l'individuazione di specifici pattern di alterazione o di indici quantitativi
- Supporto per lo sviluppo di nuove strategie terapeutiche ??

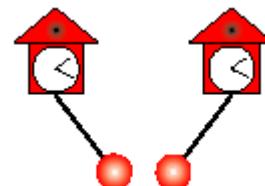
Sincronizzazione

- Due segnali sono sincroni se i loro ritmi coincidono
- Sincronizzazione: aggiustamento dei ritmi di due o più segnali dovuta a deboli interazioni tra gli stessi

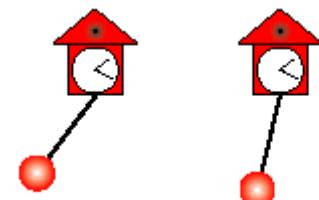
In fase



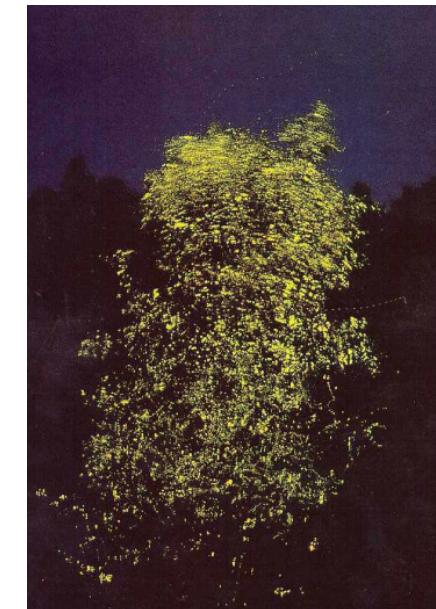
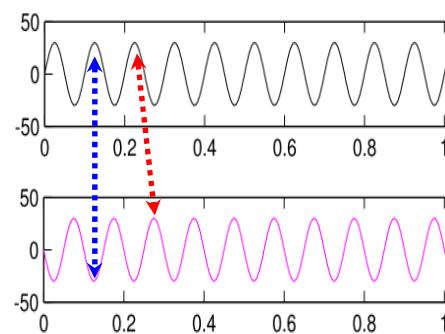
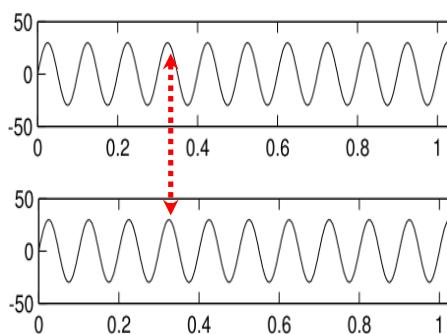
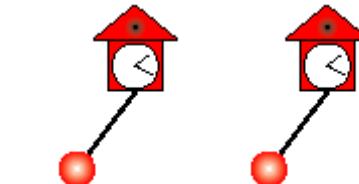
Opposizione di fase



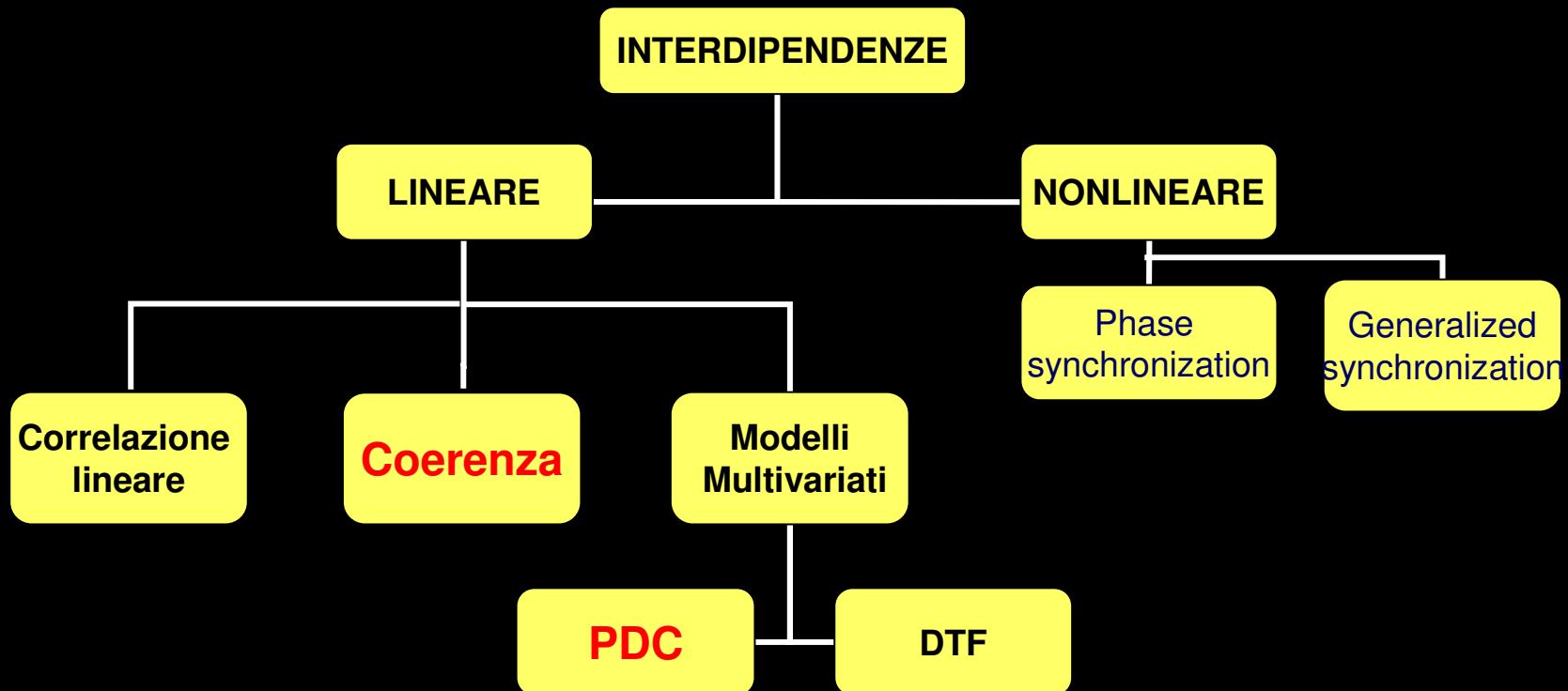
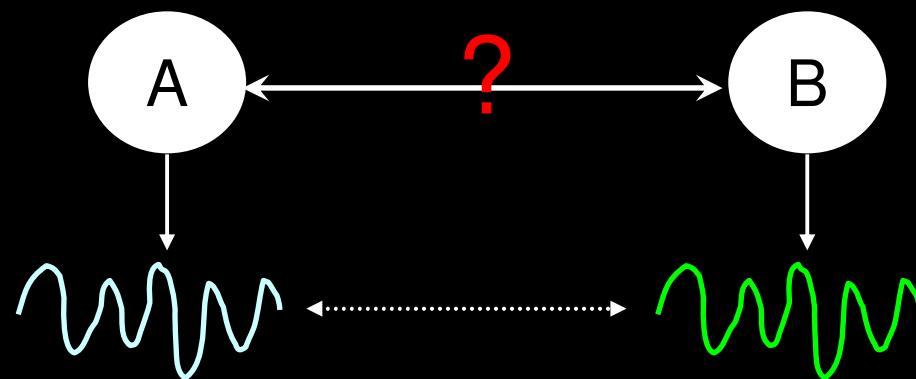
Differenza di fase



Nessuna sincronizzazione



Sincronizzazione: Come valutarla?





Clinical Neurophysiology 114 (2003) 1041–1052



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Movement-activated myoclonus in genetically defined progressive myoclonic epilepsies: EEG–EMG relationship estimated using autoregressive models

F. Panzica, L. Canafoglia, S. Franceschetti*, S. Binelli, C. Ciano, E. Visani, G. Avanzini

MIOCLONO EPILESSIE PROGRESSIVE

malattie a carattere primitivamente progressivo che si presentano nella **seconda infanzia, adolescenza con crisi epilettiche, miocloni, sindrome cerebellare, (deterioramento psichico)**

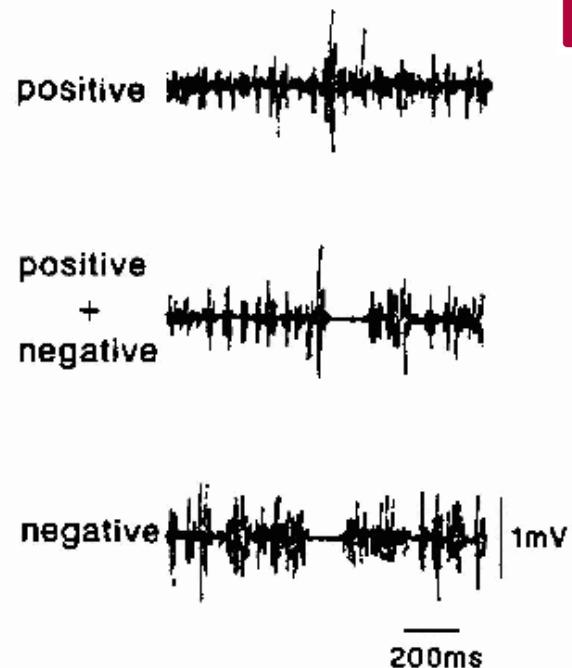
Unverricht-Lundborg disease, Lafora body disease, MERRF, sialidosis, Kuf's disease, Gaucher, Niemann-Pick type C

- Hanno diversa genetica
- Hanno diversa patogenesi
- Sono diverse per gravità, segni associati, pattern EEG

Possono essere distinte sul piano elettrofisiologico?

Mioclono: movimento involontario, di breve durata, improvviso (Shock-like), causato da un'attivazione (mioclono positivo) o una inibizione (mioclono negativo) muscolare

- Isolato, irregolare, periodico, ritmico
- A riposo o correlato all'attività motoria (mioclono d'azione o intenzione)
- Spontaneo o stimolo indotto (luce, rumori, improvvise stimolazioni sensoriali)
- Focale, multifocale, segmentale, unilaterale, generalizzato
- Massima eterogeneità per:
 - Eziologia
 - Contesto clinico (da condizioni fisiologiche fino a malattie severe e progressive)
 - Fisiopatologia e generatori (dalla neocorteccia al nervo)



Unverricht-Lundborg disease (ULD)

Unverricht–Lundborg disease (ULD) is an autosomal recessively inherited neurodegenerative disorder and the most common single cause of progressive myoclonus epilepsy worldwide. Mutations in the gene encoding cystatin B (CSTB), a cysteine protease inhibitor, are responsible for the primary defect underlying

- *Lenta progressione*
- *Mioclono d'azione multifocale*
- *Mioclono massivo, crisi “miocloniche” e tonico cloniche*
- *Moderata o nulla regressione mentale*
- *Moderata atassia*
- *Nessun altro segno*
- *Trasmissione recessiva*
- *Diagnosi genetica*

EEG-EMG: ULD

ULD: No Gi., M

F4-C4



C4-P4



P4-O2



F3-C3



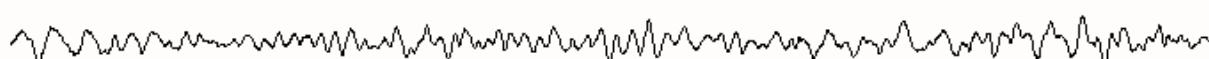
C3-P3



P3-O1



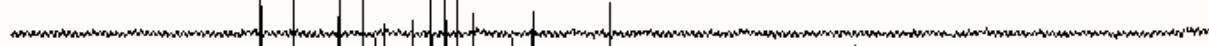
Fz-Cz



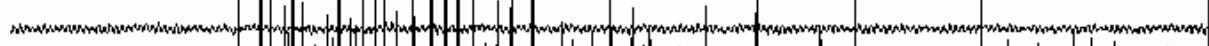
Cz-Pz



EMG flex c dx



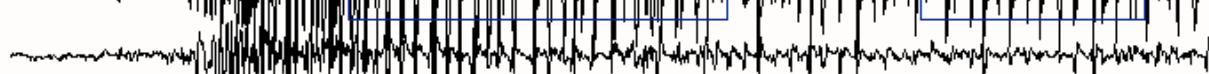
EMG ext c dx



EMG flex c sx

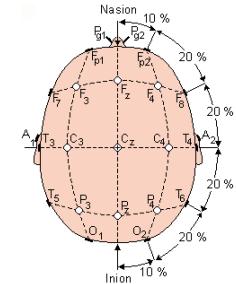


EMG ext c sx



100 μ V

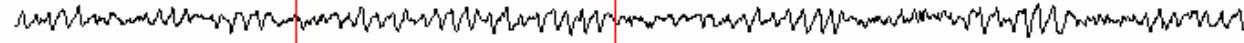
1 sec



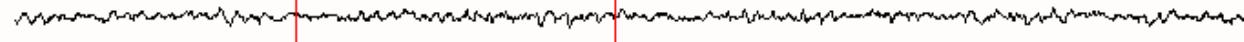
EEG-EMG: sialidosi

Fr. Ma., f

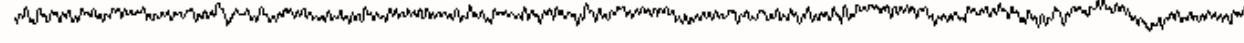
F4-C4



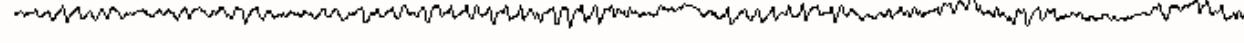
C4-P4



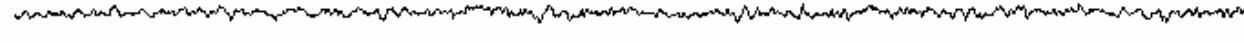
P4-O2



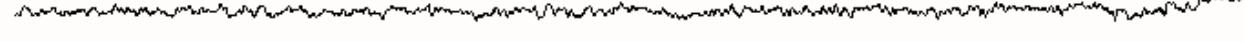
F3-C3



C3-P3



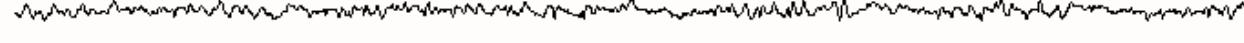
P3-O1



Fz-Cz



Cz-Pz



EMG flex c dx

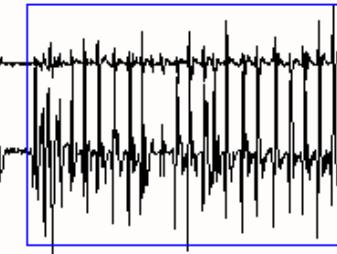
100 μ V

EMG ext c dx

1 sec

EMG flex c sx

EMG ext c sx



Modelli parametrici autoregressivi (AR)

FORMULAZIONE MONOVARIATA (1 CANALE)

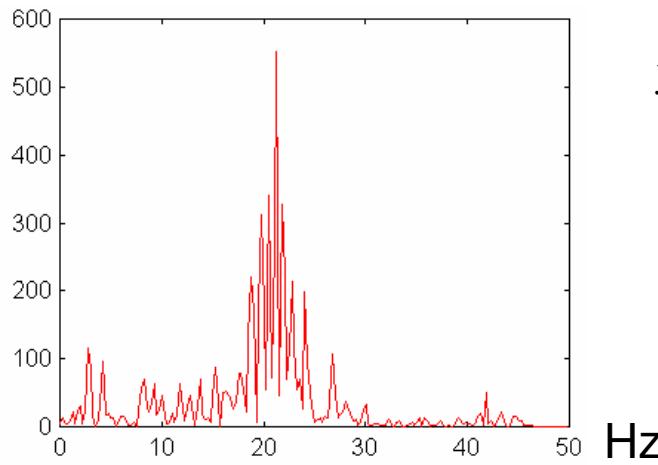
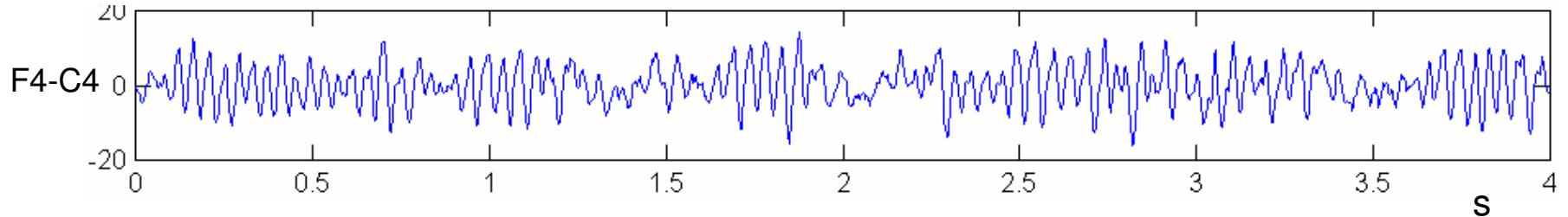
Un segnale (serie temporale) è descritto in termini di un modello matematico caratterizzato da un insieme di coefficienti

$$\hat{x}(n) = a_1x(n-1) + a_2x(n-2) + \dots + a_p x(n-p) = \sum_{i=1}^p a_i x(n-i)$$

Predizione lineare: il campione al passo n-esimo è stimato a partire dai campioni ai passi precedenti

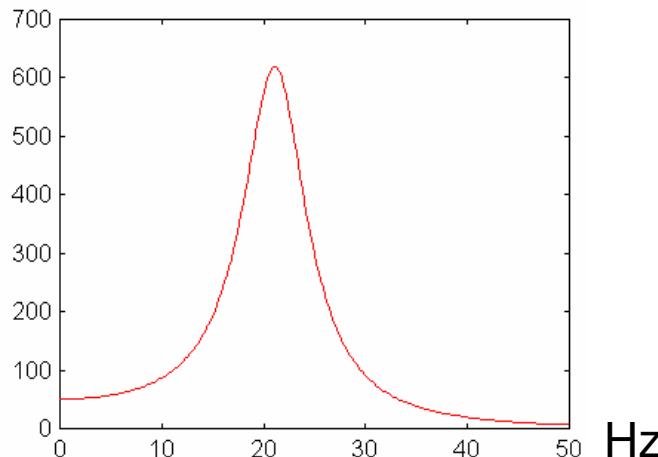
$$e_{pn} = x(n) - \hat{x}(n) = \text{errore di predizione}$$

$$E_p = \frac{1}{N} \sum_{n=1}^N (e_{pn})^2 = \sum_{n=1}^N (x(n) - \hat{x}(n))^2$$



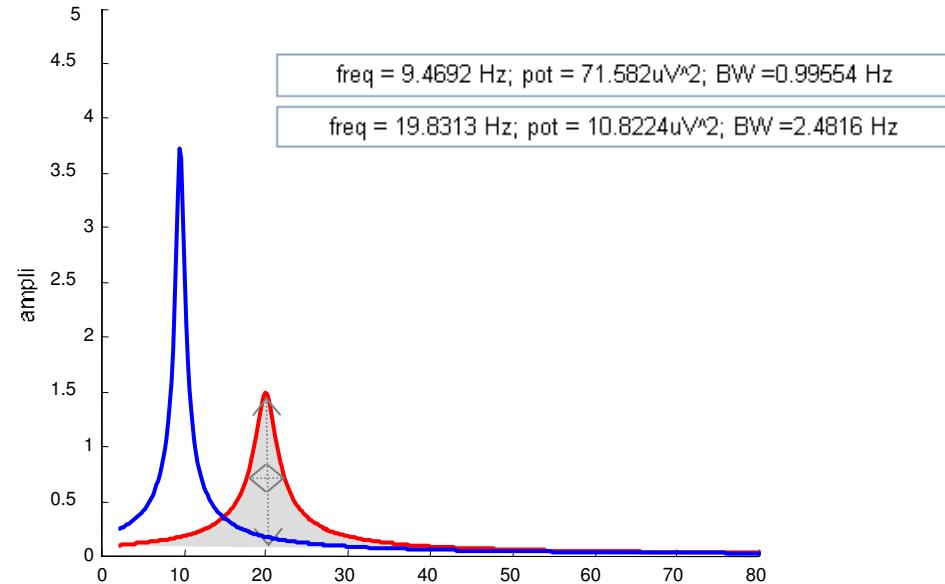
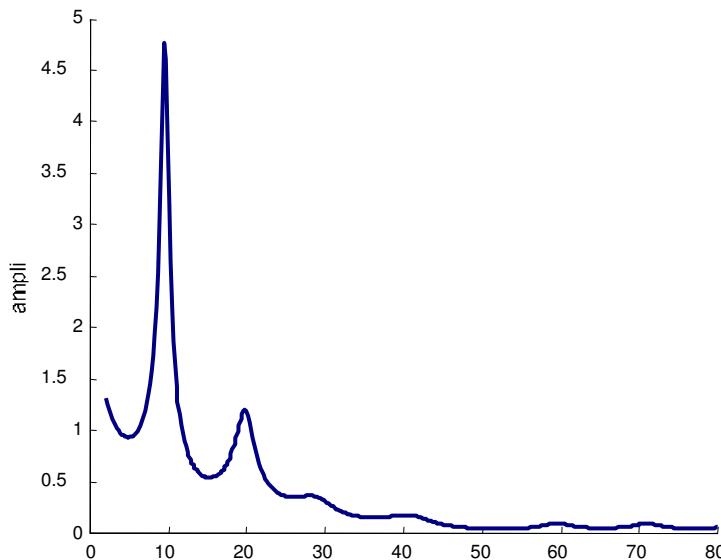
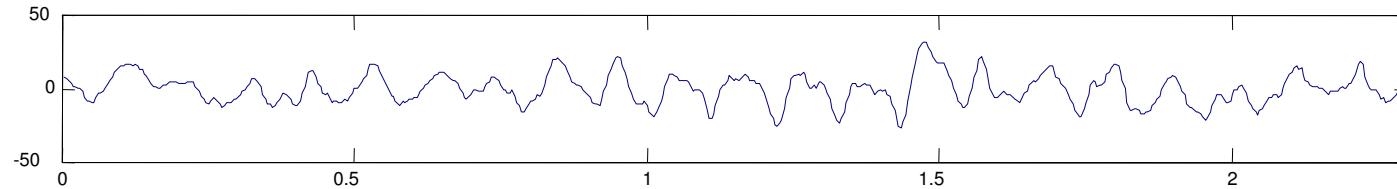
$$\hat{y}(n) = a_1 y(n-1) + a_2 y(n-2) + \dots + a_p y(n-p) = \sum_{i=1}^p a_i y(n-i)$$

$$PSD(f) = \frac{\sigma^2 T}{\left| 1 - \sum_{i=1}^p a_i z^{-i} \right|^2}_{z=\exp(j2\pi fT)}$$



- ◆ Improvement in frequency resolution
- ◆ AR spectra can be obtained without windowing the data
- ◆ AR spectrum is smooth, its shape depends only on the values of the coefficients → No averaging
- ♠ Choice of model order

F4-A2



Power spectra were divided into components relevant to poles in the z-domain using the residue method (Johnsen and Andersen, 1978, Zetterberg 1979, Baselli *et al.*, 1987).

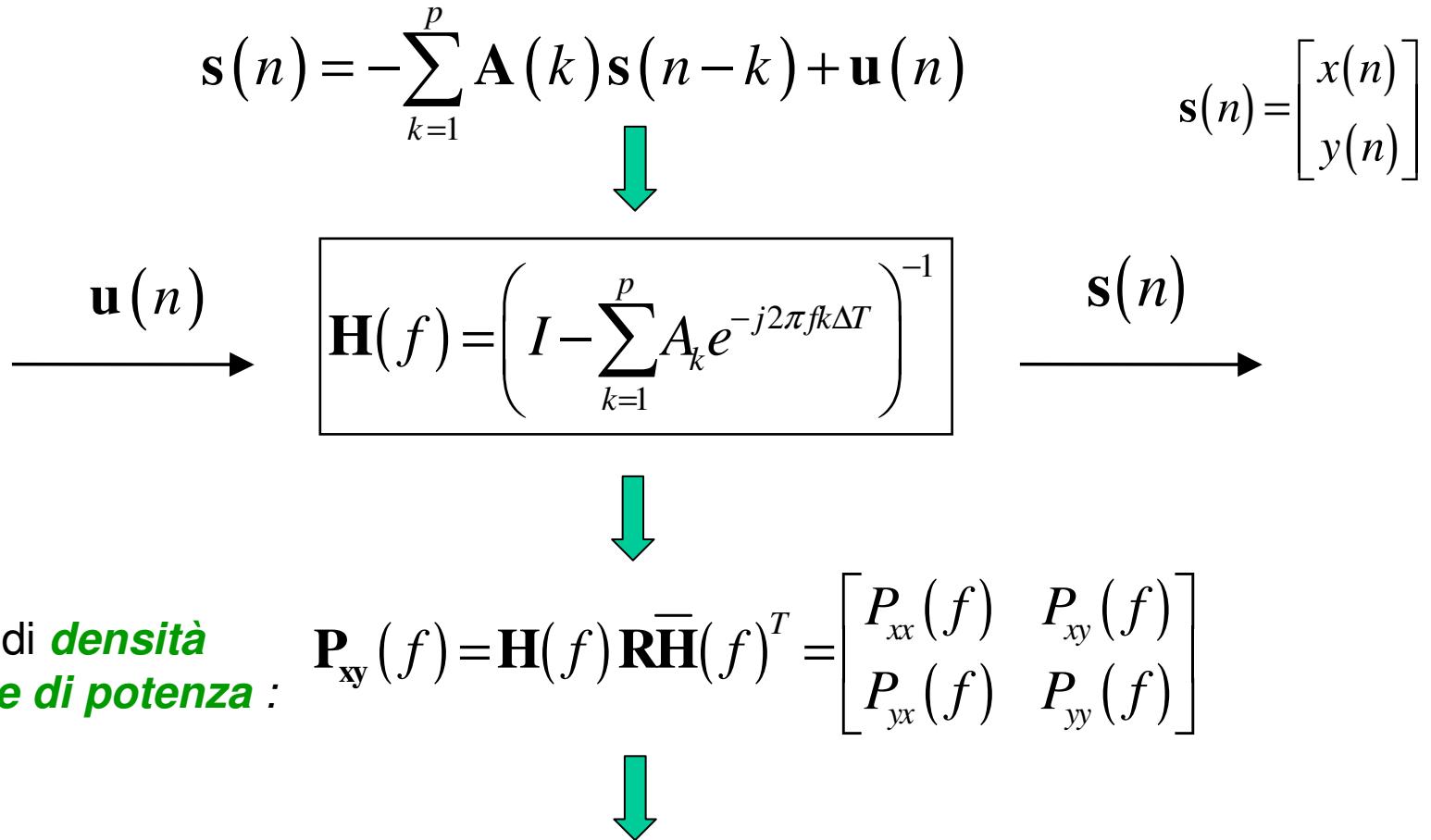
$$S(f) = \Delta t H(z) \sigma^2 H(z^{-1}) \Big|_{z=\exp(j2\pi f \Delta t)}$$

$$H(z) = \frac{1}{A(z)} = \frac{1}{1 + \sum_{k=1}^n a_k z^{k-1}} = \frac{z^n}{\prod_{k=1}^n (z - \lambda_k)}$$

$$\gamma_k = \text{res} \left[\frac{S(z)}{z} \right]_{\lambda_k} = \frac{\sigma^2}{z \cdot \prod_{\substack{h=1; \\ h \neq k}}^n (z - \lambda_h) \cdot \prod_{h=1}^n (z^{-1} - \lambda_h)} \Bigg|_{z=\lambda_k}$$

ANALISI SPETTRALE BIVARIATA PARAMETRICA

Modelli Autoregressivi Bivariati:



Matrice di densità spettrale di potenza :

- Autospettri di potenza $(P_{xx}(f), P_{yy}(f))$

$$\bullet \text{ Coerenza } C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f) P_{yy}(f)}$$

Coerenza: identificazione di attività oscillatorie sincrone tra due canali

Coerenza funzione che permette di valutare il grado di relazione **lineare** tra due segnali in funzione della frequenza.

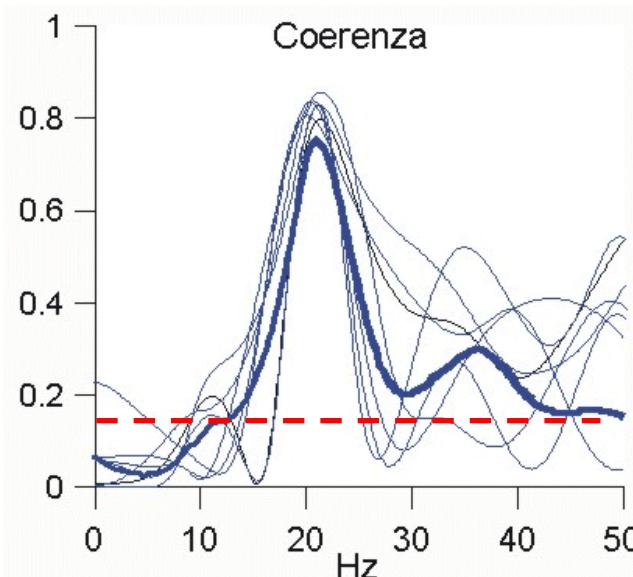
Valori sono compresi tra 0 e 1

Un elevato valore suggerisce:

- ◆ comune origine dell'attività in banda di frequenza
- ◆ esistenza connessione funzionale

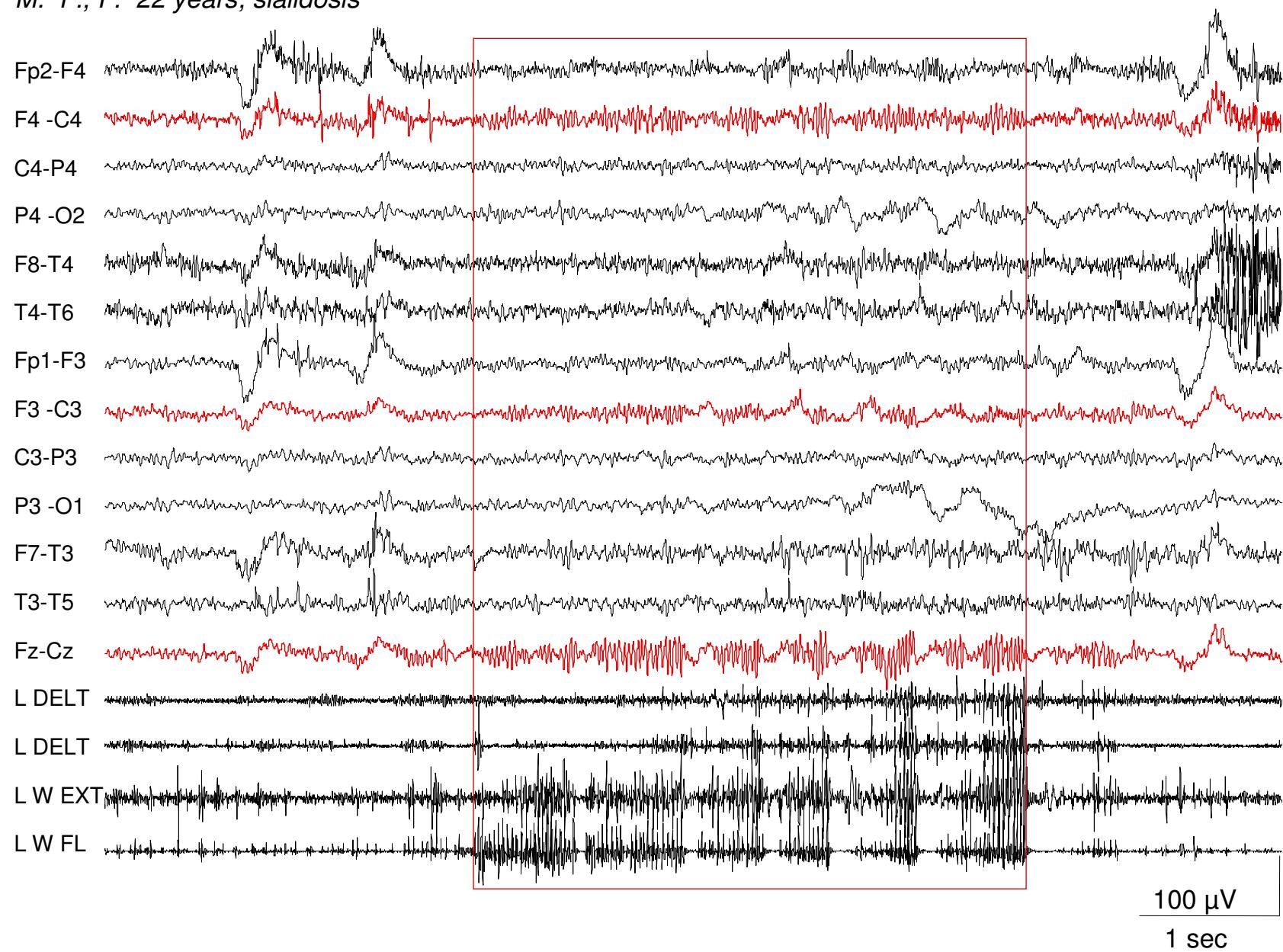
$$Coh_{xy}(f) = \frac{|C_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

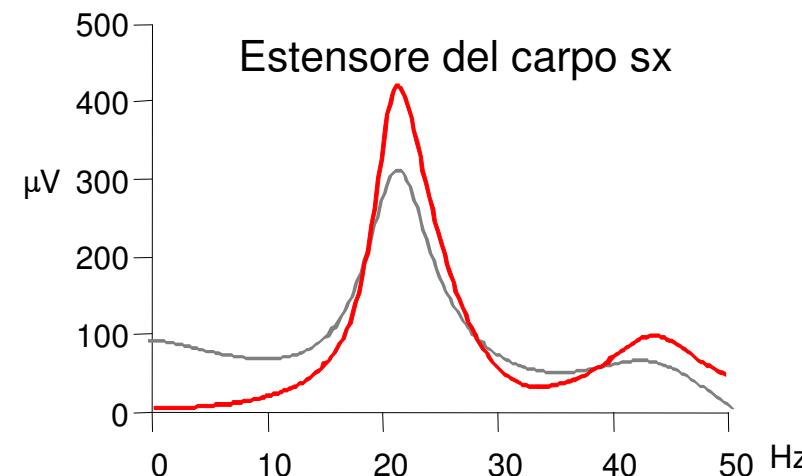
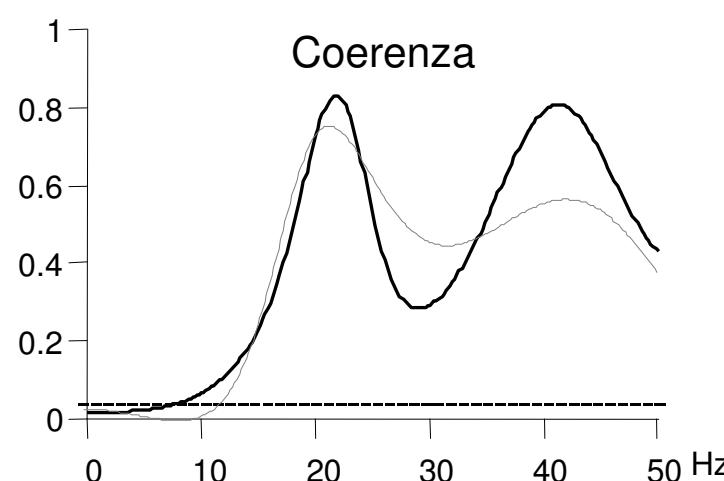
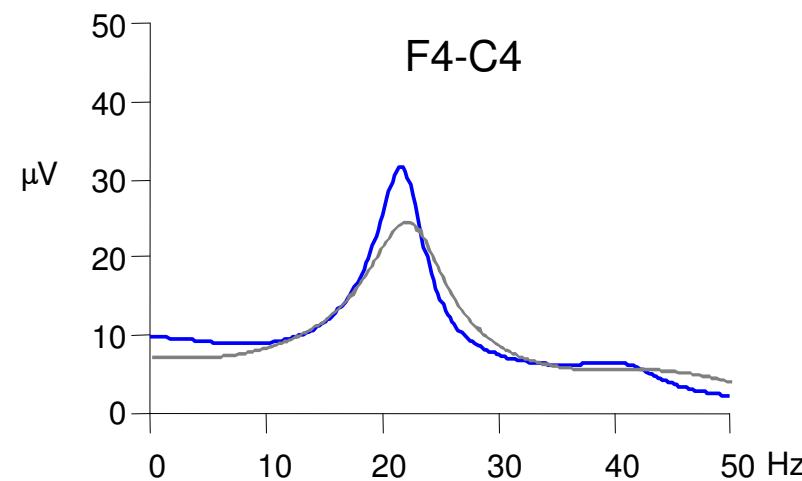
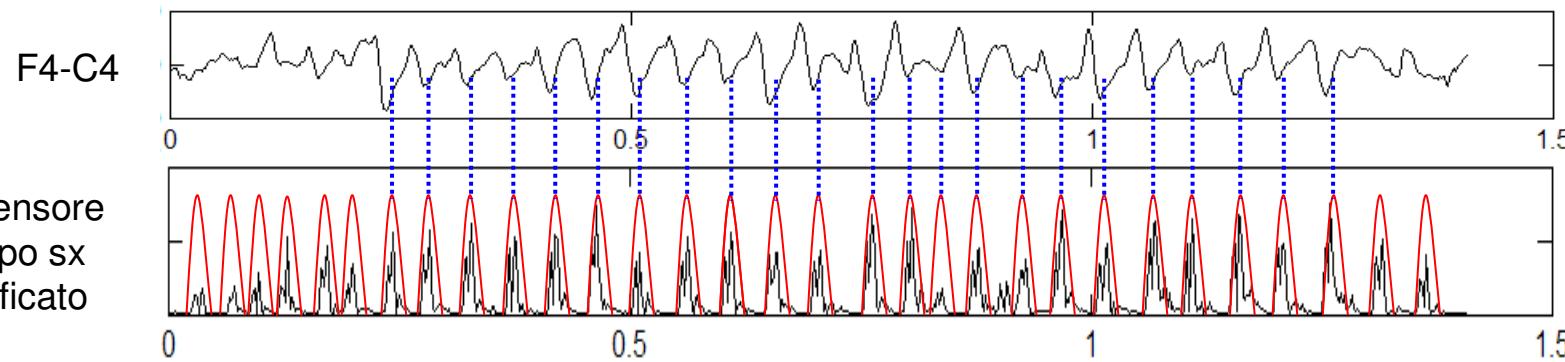
$$IC = \text{Tanh}^{-1}|Coh(f)| \mp \frac{1.96}{\sqrt{2L}}$$



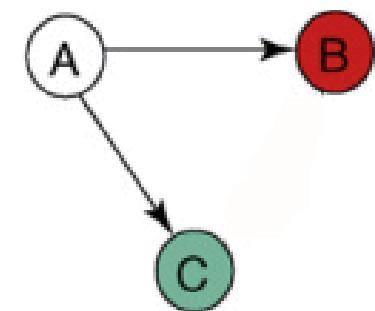
$$1 - (1 - \alpha)^{\frac{1}{L-1}}$$

M. F., F. 22 years; sialidosis





- Sincronizzazione → causalità = influenza che un sistema esercita su un altro ("chi guida chi")
- Un'area può essere connessa contemporaneamente con diverse regioni e influenzarle (sorgente comune)



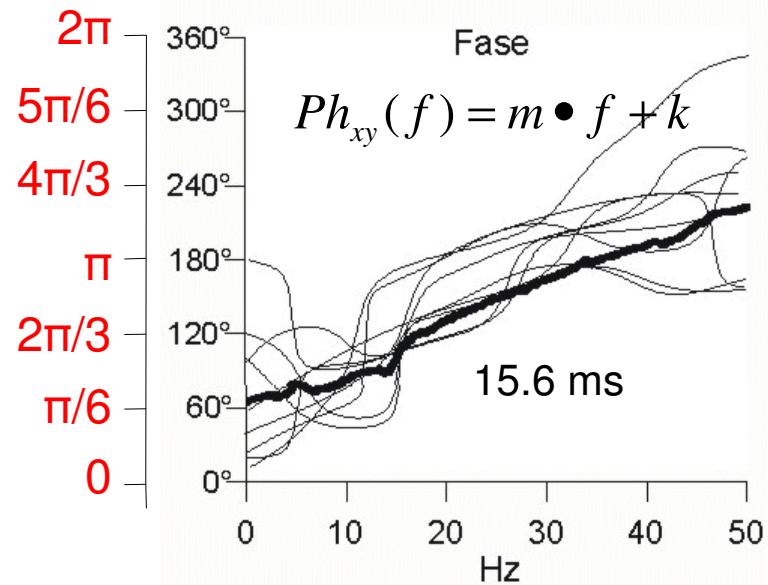
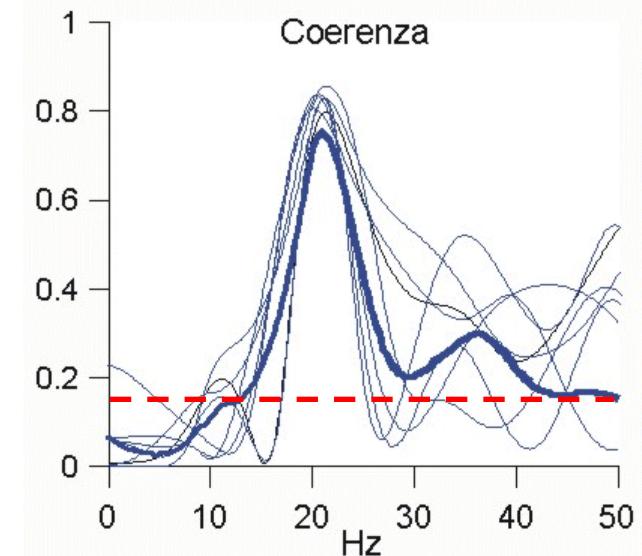
Fase: relazione causale e direzione flusso informazioni

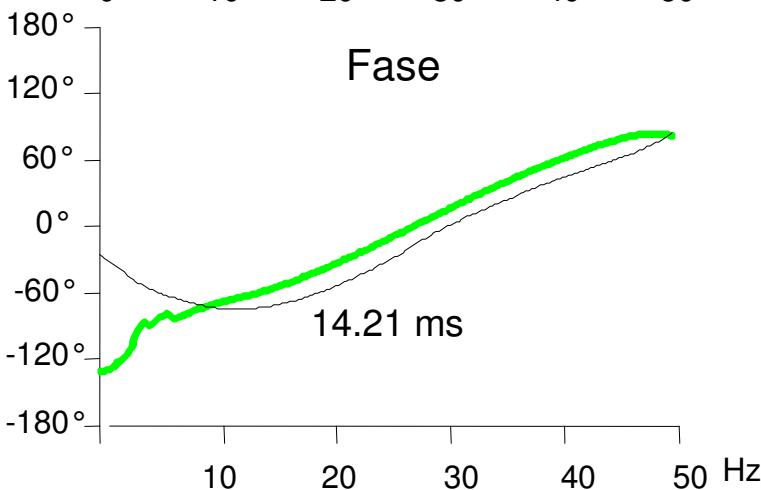
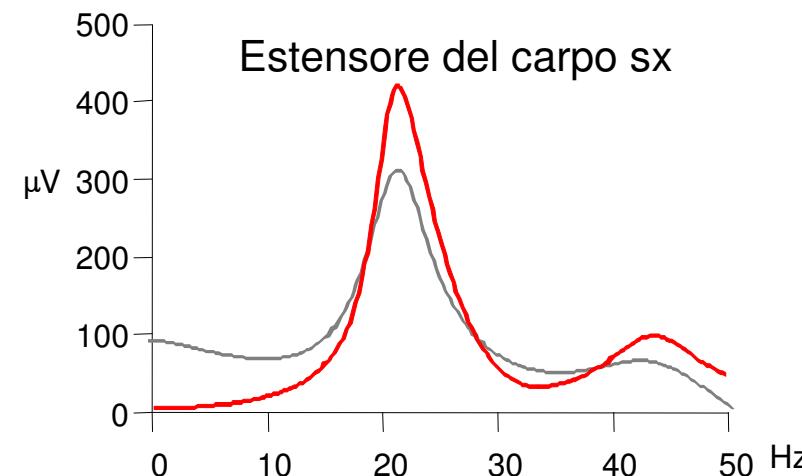
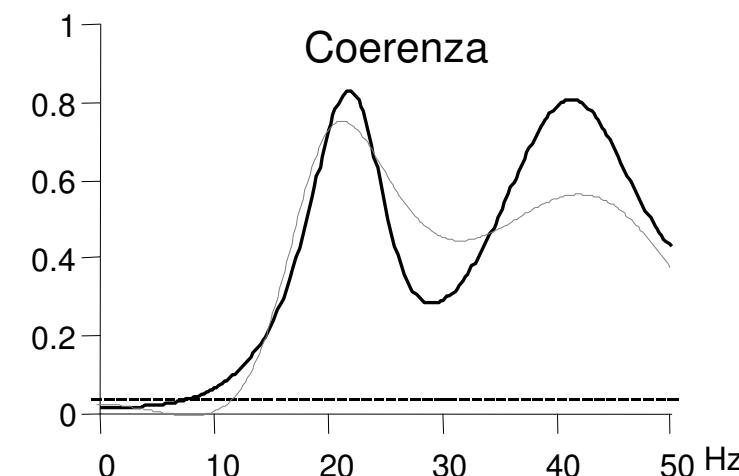
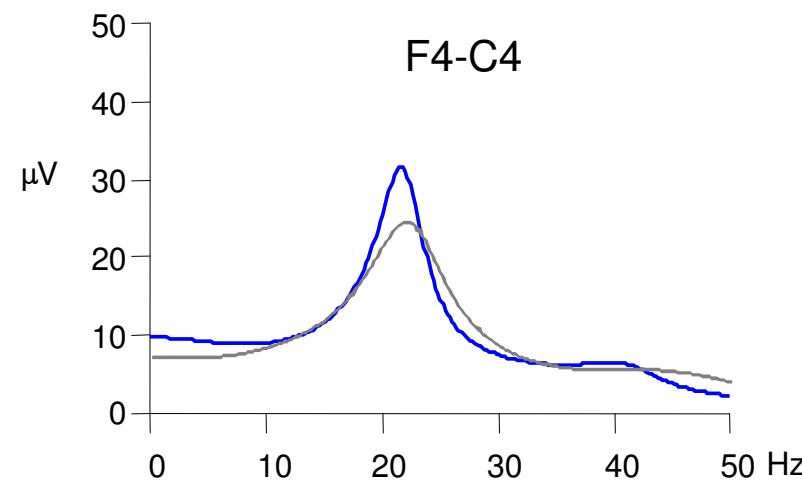
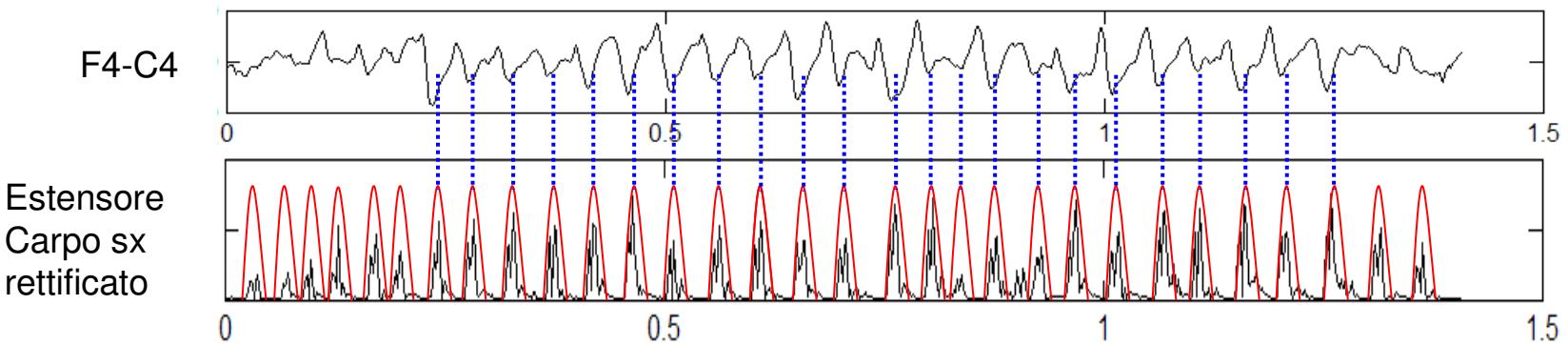
Differenza temporale valutabile se:

- coerenza significativamente $\neq 0$ in un range di frequenze
- correlazione lineare tra fase e frequenza nella stessa banda

$$m = \frac{\Delta\Phi}{\Delta f}; \Rightarrow t[ms] = \frac{\Delta\Phi}{\Delta f \cdot 2\pi} \cdot 1000 = \frac{m}{2\pi} \cdot 1000$$

$$IC = Ph_{xy}(f) \pm 1.96 \left[\frac{1}{2L} \left(\frac{1}{Coh_{xy}(f)} - 1 \right) \right]^{\frac{1}{2}}$$





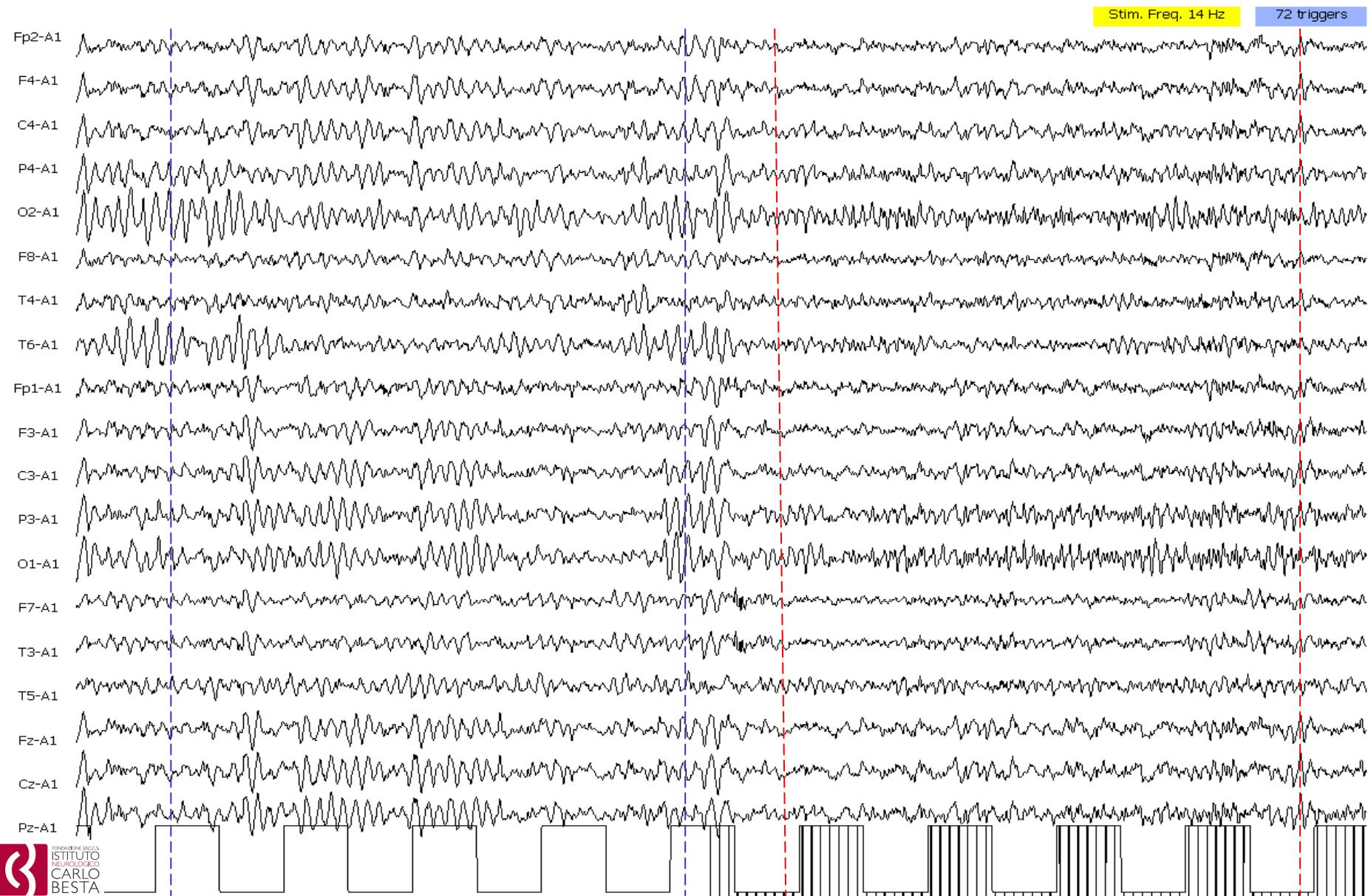


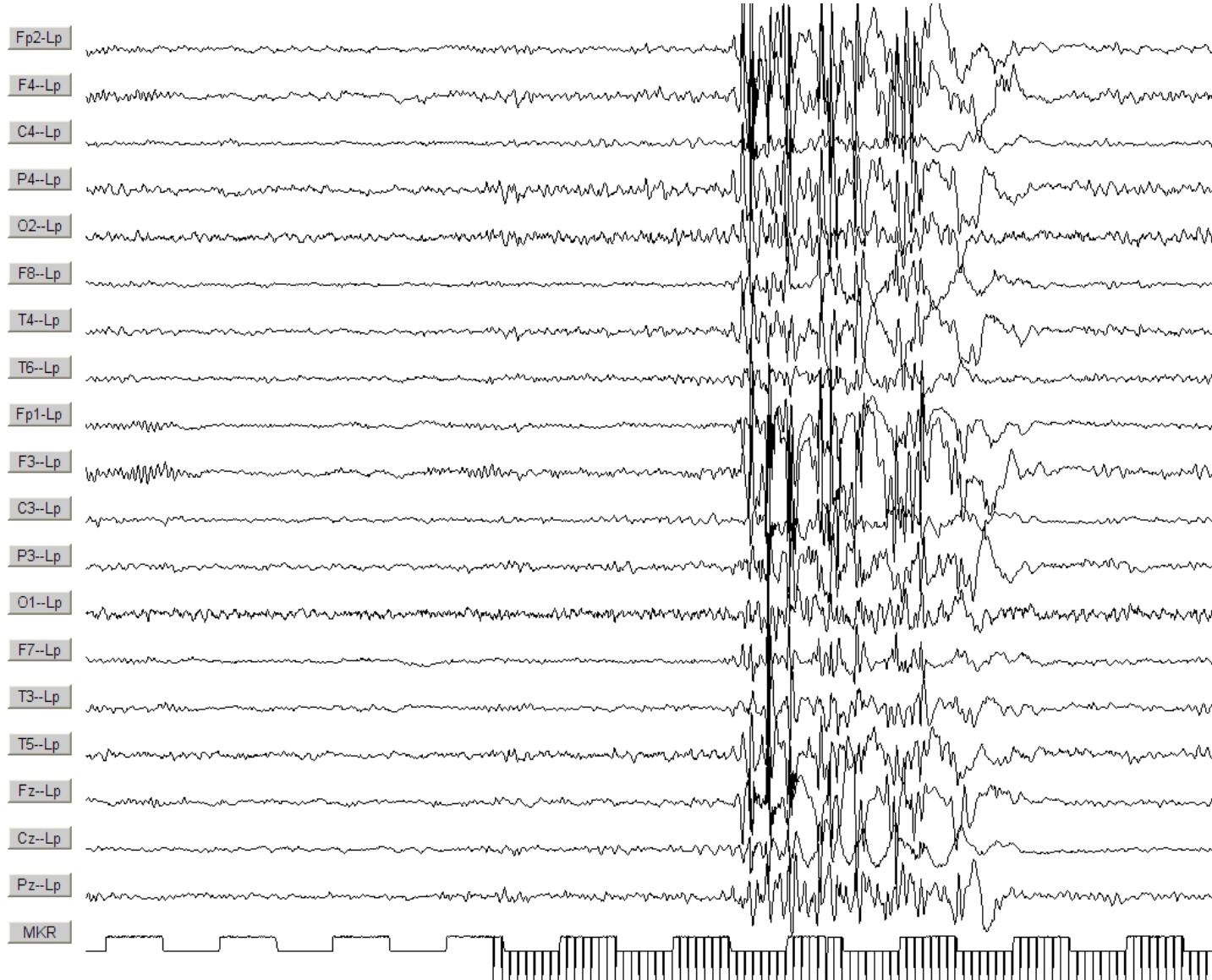
Photosensitive epilepsy: Spectral and coherence analyses of EEG using 14 Hz intermittent photic stimulation

E. Visani, G. Varotto, S. Binelli, L. Fratello, S. Franceschetti *, G. Avanzini, F. Panzica

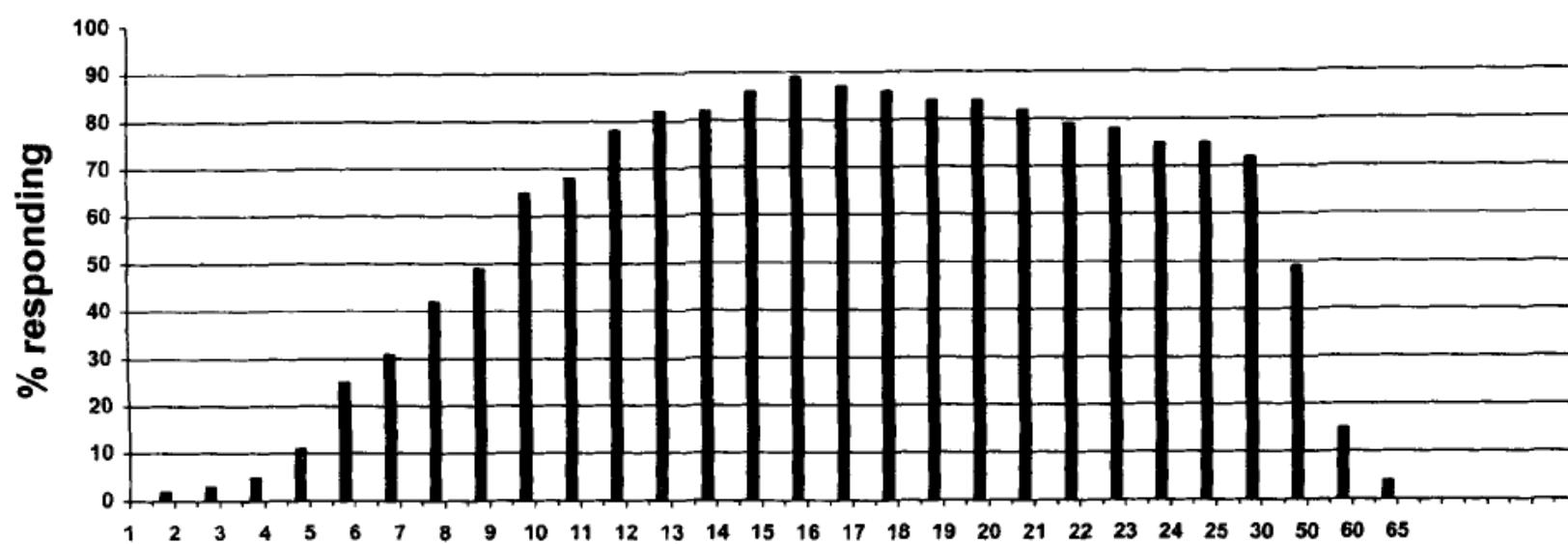
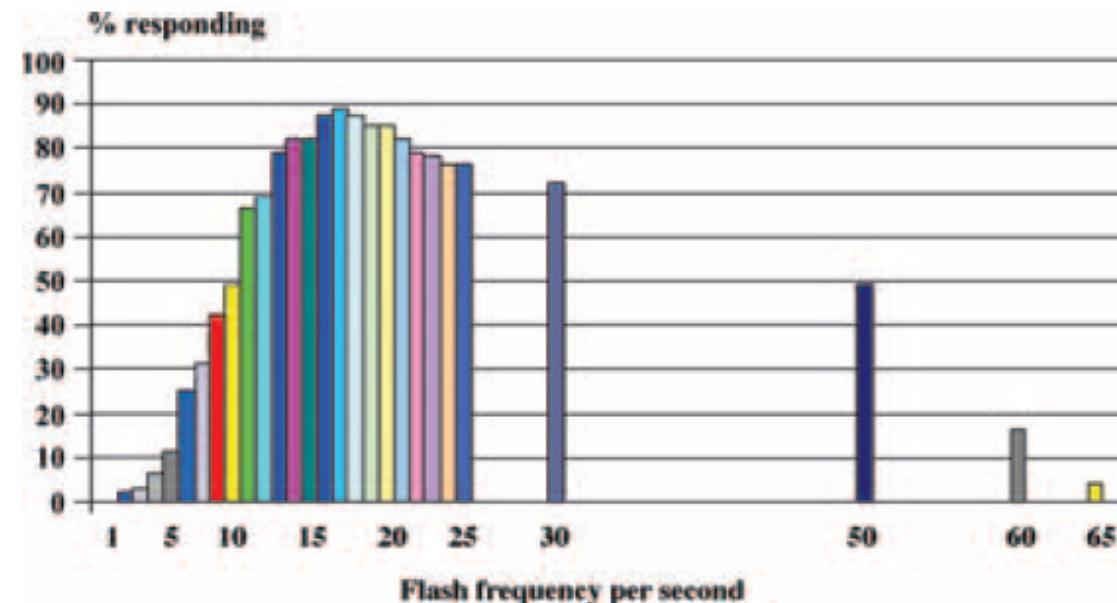
Unit of Neurophysiopathology – Epilepsy Centre, Fondazione IRCCS Istituto Neurologico Carlo Besta, Via Celoria 11, 20133 Milano, Italy

Trascinamento fotico → risposta fisiologica più evidente sulle regioni posteriori caratterizzata dalla comparsa di un ritmo con frequenza pari a quella della SLI.





Risposta fotoparossistica. Modificazione patologica dell'EEG indotta dalla SLI. E' caratterizzata da parossismi di punta o polipunta-onda a proiezione bilaterale e sincrona. Può comportare una fenomenologia clinica caratterizzata in genere da mioclonie palpebrali, agli arti o massive e a volte può verificarsi una crisi convulsiva.



Photosensitive epilepsy: Spectral and coherence analyses of EEG using 14 Hz intermittent photic stimulation

E. Visani, G. Varotto, S. Binelli, L. Fratello, S. Franceschetti *, G. Avanzini, F. Panzica

Unit of Neurophysiopathology – Epilepsy Centre, Fondazione IRCCS Istituto Neurologico Carlo Besta, Via Celoria 11, 20133 Milano, Italy

***Identificazione dei
meccanismi fisiopatologici
alla base della fotosensibilità***

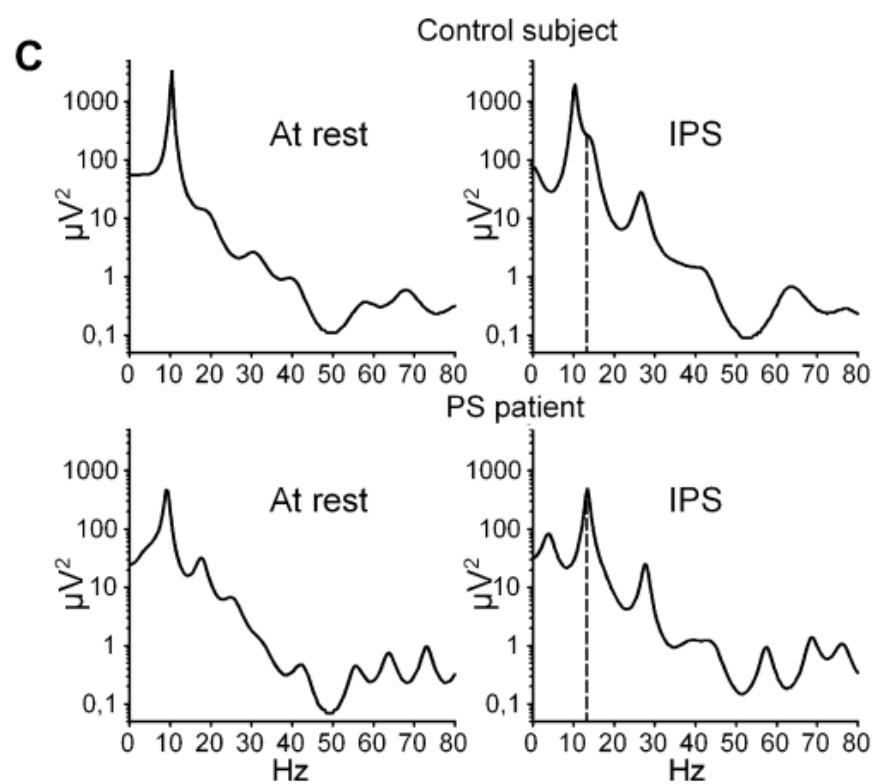
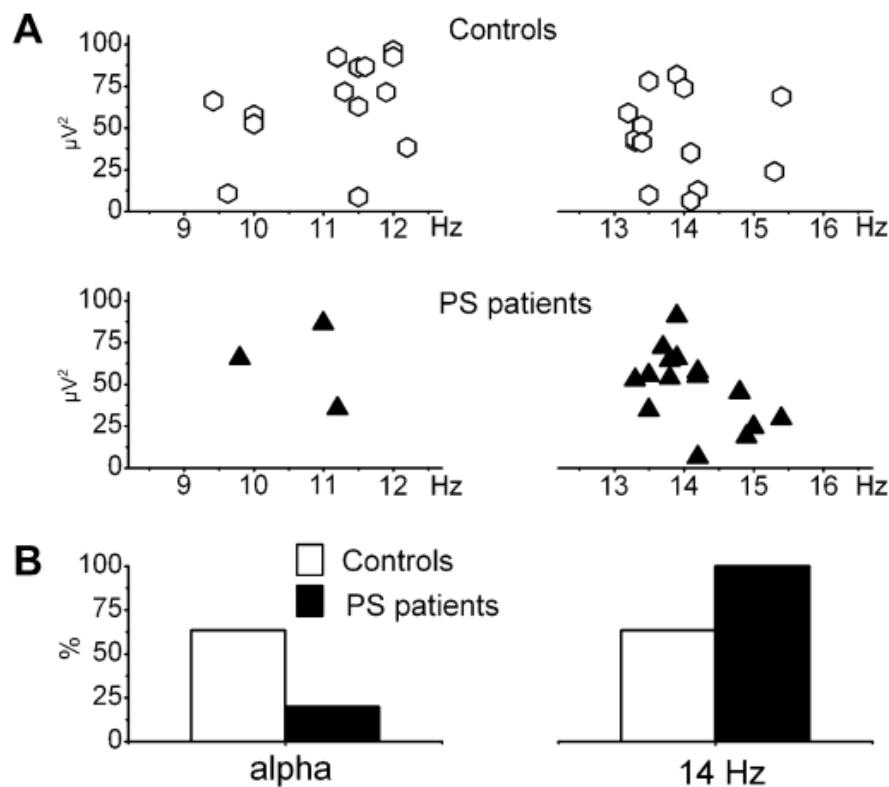
***Studio, in ambiente di
laboratorio controllato e
riproducibile, delle alterazioni
elettroencefalografiche durante
crisi epilettiche***



Analisi Spettrale Parametrica del segnale EEG

- Identificare le caratteristiche fondamentali che distinguono soggetti sani da soggetti fotosensibili a riposo.
- Individuare le diverse caratteristiche del segnale EEG durante SLI quando questa induce o meno una risposta parossistica.

Spectral changes during 14 Hz IPS



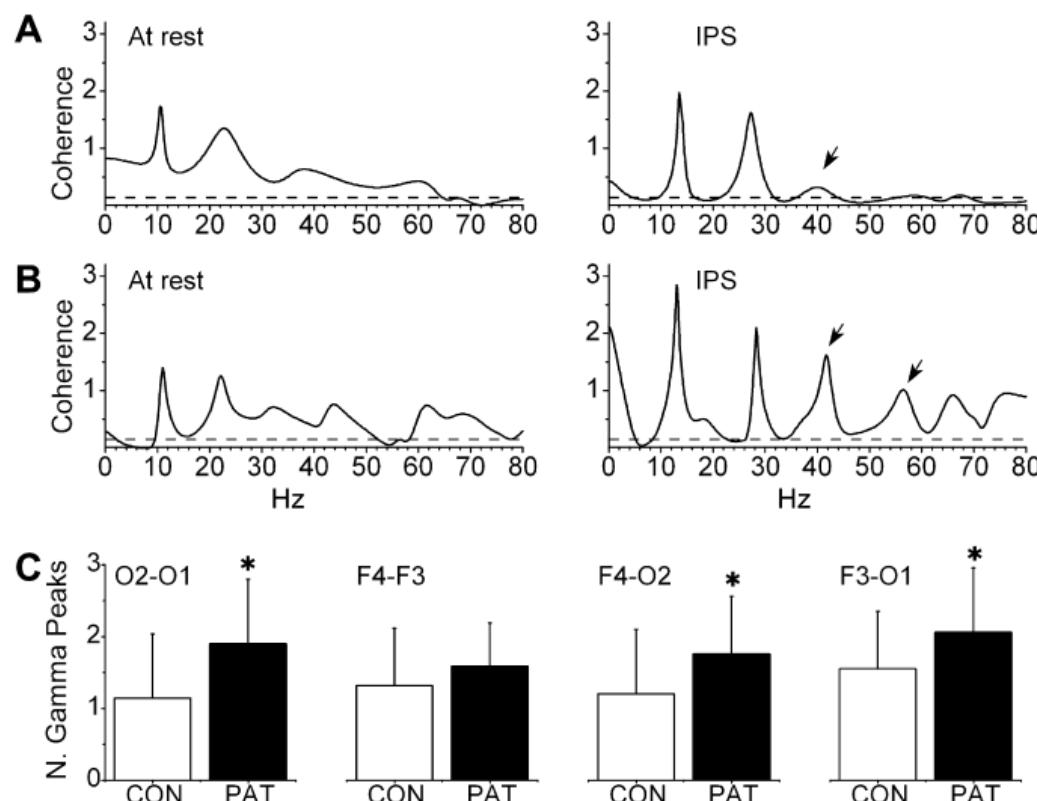
Coherent peaks in gamma band

Table 1

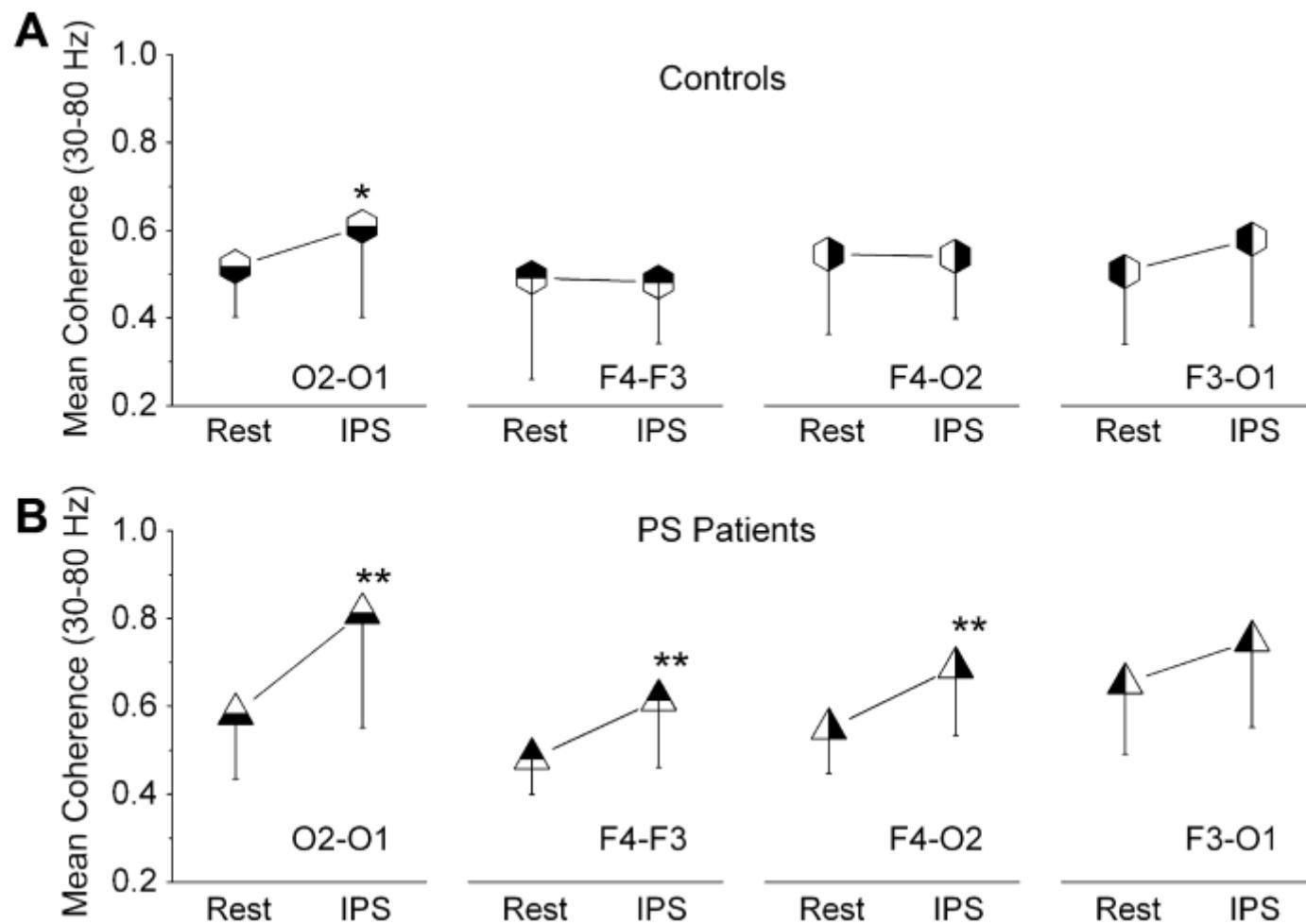
Coherence analysis: number of coherence peaks.

		At rest		During 14 Hz IPS	
		PS patients [p]	Controls	PS group A [p]	Controls
0–30 Hz	F4–F3	2.5 ± 0.7 [0.025]	2.0 ± 0.7	2.8 ± 1.1	2.3 ± 0.8
	O2–O1	2.5 ± 0.5 [0.001]	2.0 ± 0.4	2.5 ± 0.5	2.3 ± 0.8
	F4–O2	2.6 ± 0.7 [0.027]	2.1 ± 0.6	2.6 ± 0.6	2.5 ± 0.7
	F3–O1	2.6 ± 0.7 [0.039]	2.2 ± 0.7	2.5 ± 0.8	3.0 ± 1.3
30–80 Hz	F4–F3	4.3 ± 0.9 [0.009]	3.4 ± 1.2	4.2 ± 1.1	3.8 ± 1.2
	O2–O1	3.8 ± 1.1 [0.002]	2.7 ± 1.3	4.1 ± 1 [0.001]	2.9 ± 1.0
	F4–O2	3.9 ± 1.2 [0.048]	3.1 ± 1.4	4.6 ± 0.9 [0.0002]	3.1 ± 1.2
	F3–O1	3.8 ± 0.7 [0.010]	3.2 ± 1.1	4.5 ± 1.1 [0.001]	3.0 ± 1.3
IPS harmonics in gamma band (30–80 Hz)	F4–F3			1.6 ± 0.6	1.3 ± 0.8
	O2–O1			2.0 ± 0.9 [0.006]	1.1 ± 0.9
	F4–O2			1.8 ± 0.8 [0.048]	1.2 ± 0.9
	F3–O1			2.1 ± 0.9 [0.022]	1.5 ± 0.9

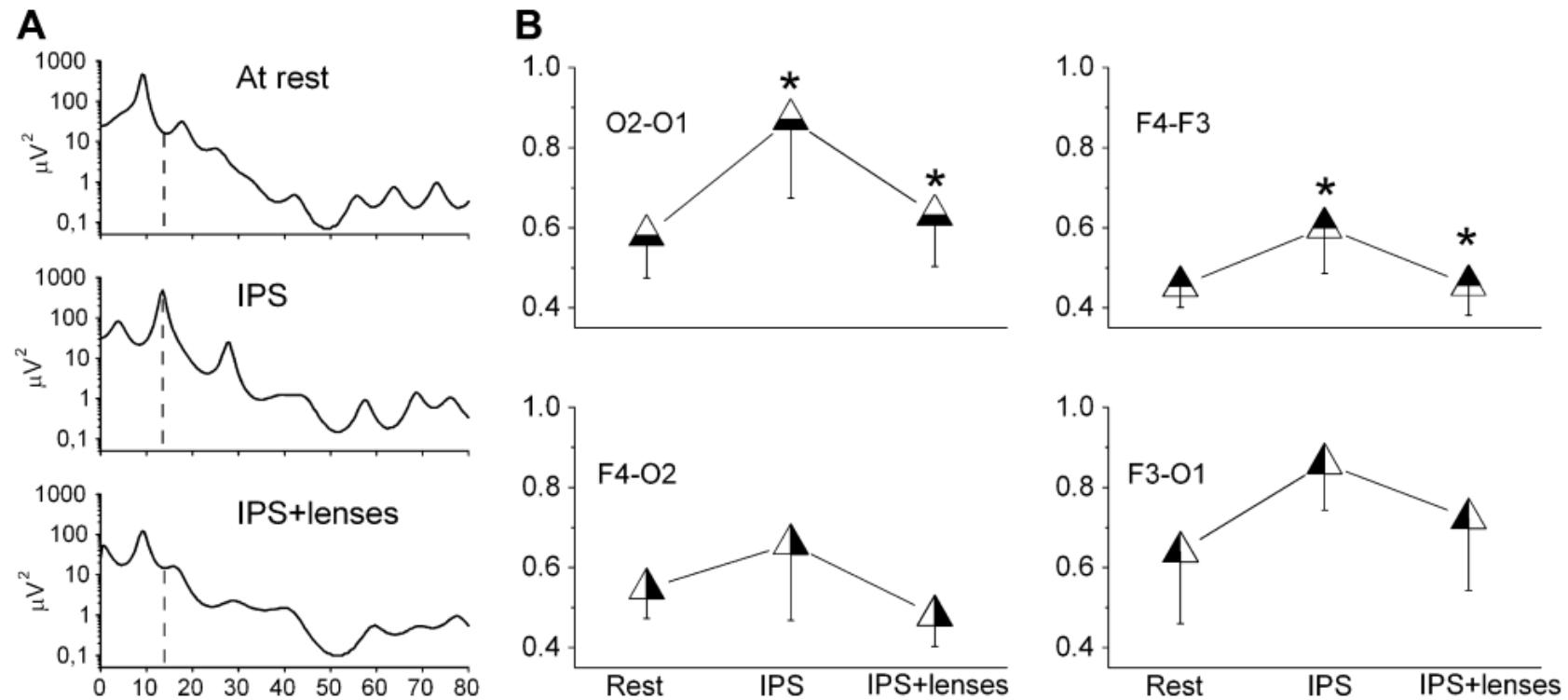
Significant values [p] refer to the comparison between group A PS patients and controls.



Mean gamma coherence



Mean gamma coherence without and with blue lenses



At rest, the intra- and inter-hemispheric coherence spectra showed a significantly larger number of coherence peaks in patients.

During IPS coherent gamma activity is mainly presented as IPS frequency harmonics; the patients' intra- and inter-hemispheric mean coherence values significantly increased in gamma band.

Alpha peaks persisted during IPS in most controls but not in patients

In six patients re-evaluated with IPS after putting on glasses with Z1 blue lens the spectral and coherence profiles tended to return to the resting ones.

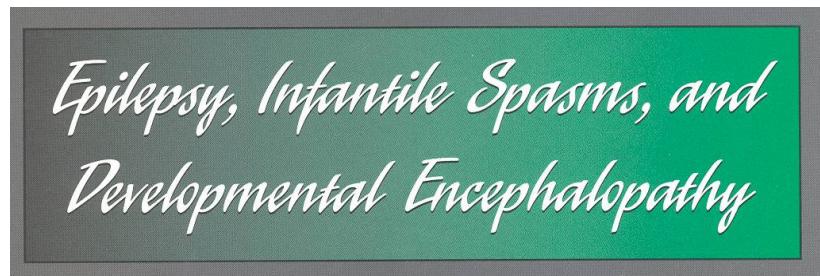
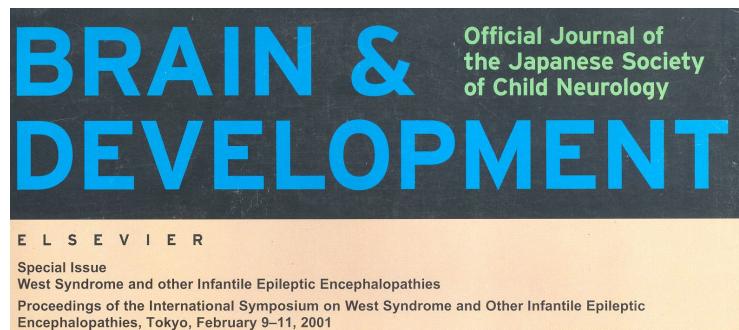
Patients are endowed with inherited EEG hyper-synchrony as shown by the large number of coherence peaks detectable under resting conditions

The persistence of alpha activity peaks during IPS in most controls but not in patients suggests that the alpha generating network plays a significant role in counteracting PPR.

Both gamma and alpha EEG generators are involved in the PPR generation and in the widespread synchronisation characterising the IGE-associated photosensitivity.

Spectral properties of EEG fast activity ictal discharges associated with infantile spasms

F. Panzica^{a,*}, S. Franceschetti^a, S. Binelli^a, L. Canafoglia^a, T. Granata^b, G. Avanzini^a



**26th International Epilepsy Congress
Paris, France, August 28th - September 1st, 2005**

**28th International Congress of Clinical Neurophysiology
Edinburgh, September 11st-14st, 2006**

Ictal EEG Fast Activity in West Syndrome: From Onset to Outcome

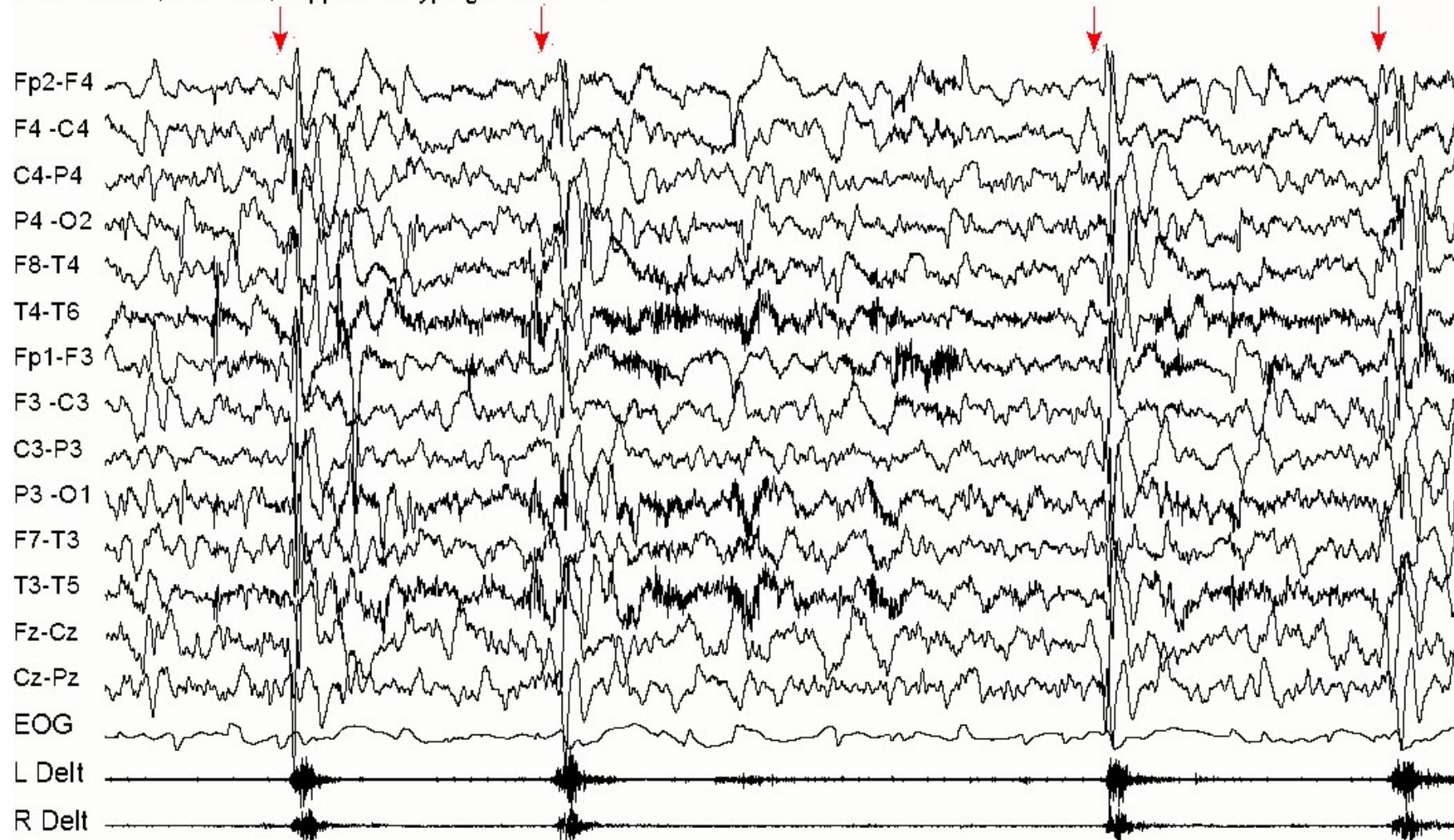
**Ferruccio Panzica, Simona Binelli, Laura Canafoglia, Marina Casazza, Elena Freri,
Tiziana Granata, Giuliano Avanzini, and Silvana Franceschetti**

"C. Besta" Foundation Neurological Institute, Milan, Italy

Epilepsia, 48(11):2101–2110, 2007

Infantile spasms are characterized by a short tonic contraction involving the axial muscles and proximal limb segments. The association of infantile spasms with 'chaotic' asynchronous interictal EEG discharges (the so-called hypsarrhythmia) and impairment of psychomotor development, constitutes the distinctive presentation of the relatively common infantile epileptic encephalopathy known as West syndrome (West, 1841)

M.V F. 8 mth, 28.04.91, supposed cryptogenic West S

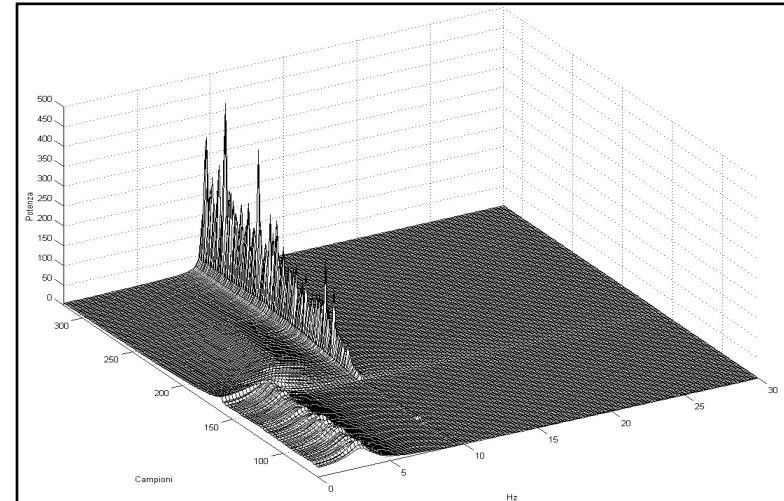
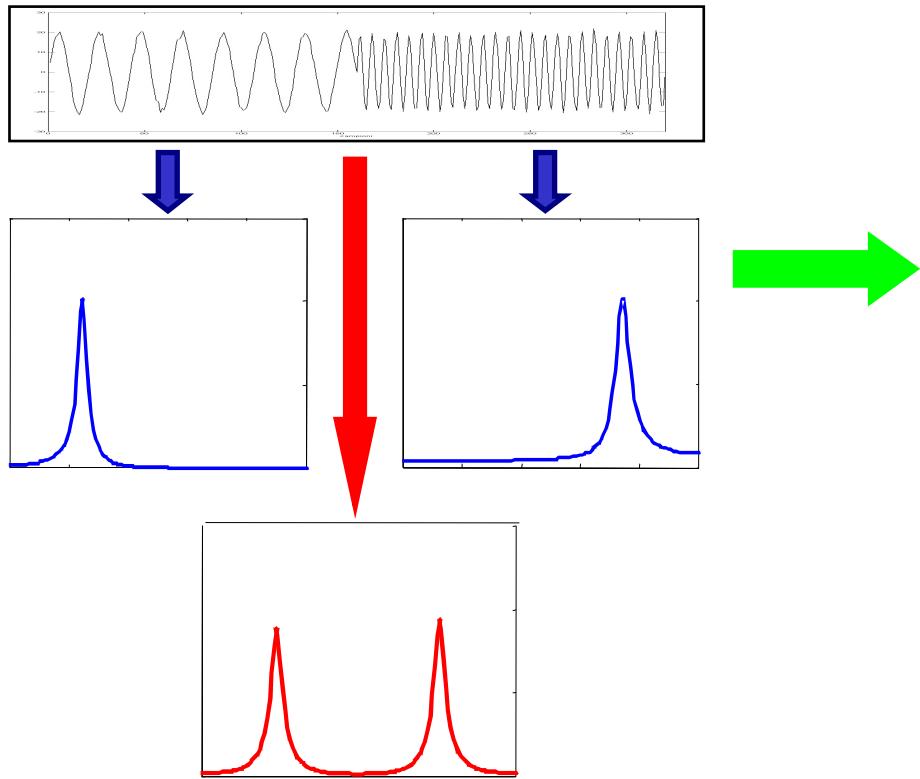


Ictal events associated with spasms: complex and variable waveform including slow and/or sharp transients, variably associated with attenuation and/or short discharges of fast activity. (Kellaway et al., 1979)

Could the ictal EEG help to predict seizure outcome following West syndrome ?

Could location of the ictal fast activity at the moment of early spasm presentation predict the location/lateralization of the following seizures ?

$$f_1 = 3 \text{ Hz}; \quad f_2 = 10 \text{ Hz}$$



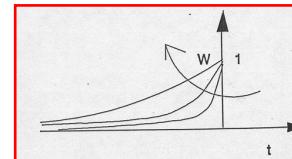
$$\varphi(t) = [y(t-1), y(t-2), \dots, y(t-p)]^T$$

$$\mathbf{a}(t) = \mathbf{a}(t-1) + \mathbf{K}(t)e(t) \quad e(t) = y(t) - \hat{y}(t)$$

$$\hat{y}(t) = \varphi^T(t)\mathbf{a}(t-1)$$

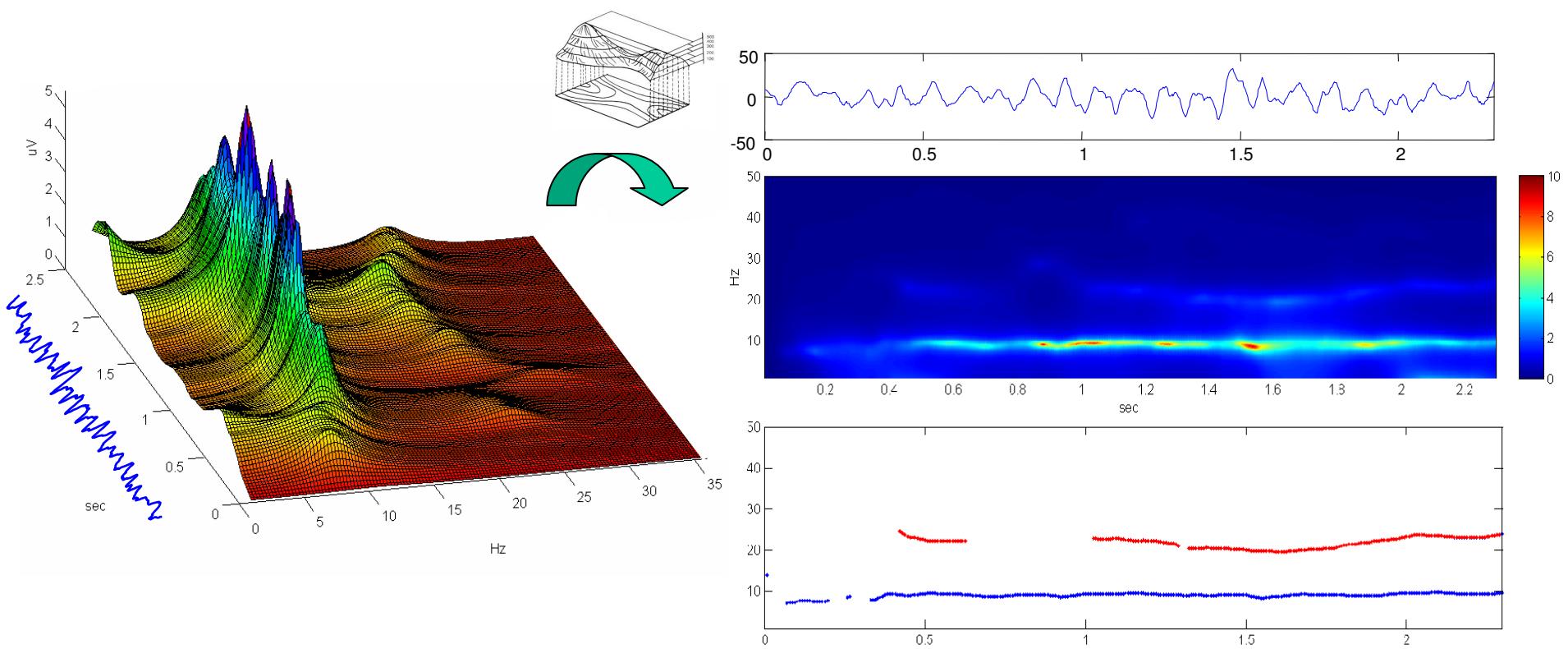
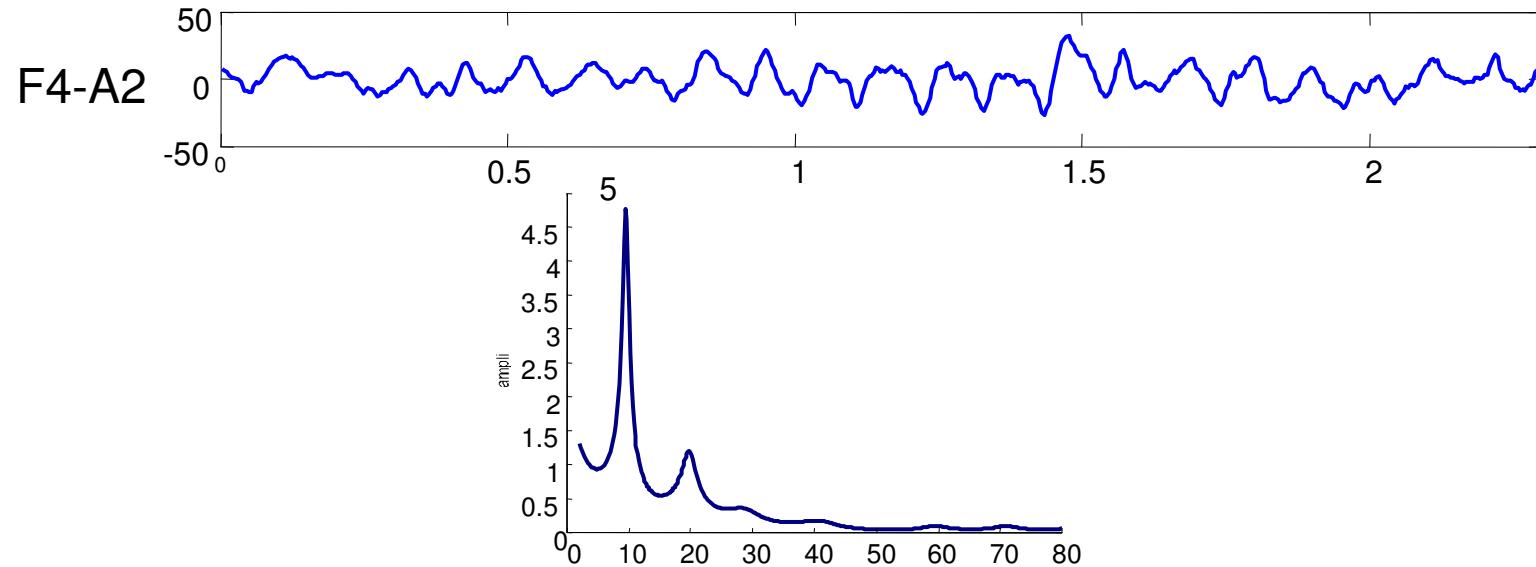
$$\mathbf{K}(t) = \frac{\mathbf{P}(t-1)\varphi(t)}{w + \varphi(t)^T\mathbf{P}(t-1)\varphi(t)}$$

$$\mathbf{P}(t) = \frac{1}{w} \left[\mathbf{P}(t-1) - \frac{\mathbf{P}(t-1)\varphi(t)\varphi(t)^T\mathbf{P}(t-1)}{w + \varphi(t)^T\mathbf{P}(t-1)\varphi(t)} \right]$$



$N = \frac{1}{1-w}$	$w = 1 \quad \text{all samples}$
	$w = 0.99 \quad 100 \text{ samples}$
	$w = 0.98 \quad 50 \text{ samples}$

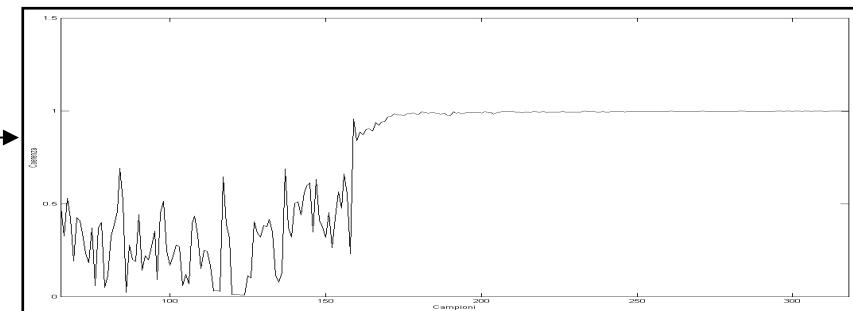
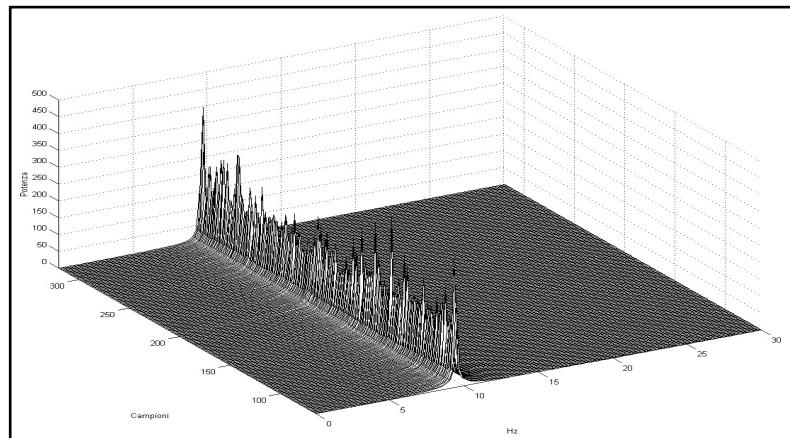
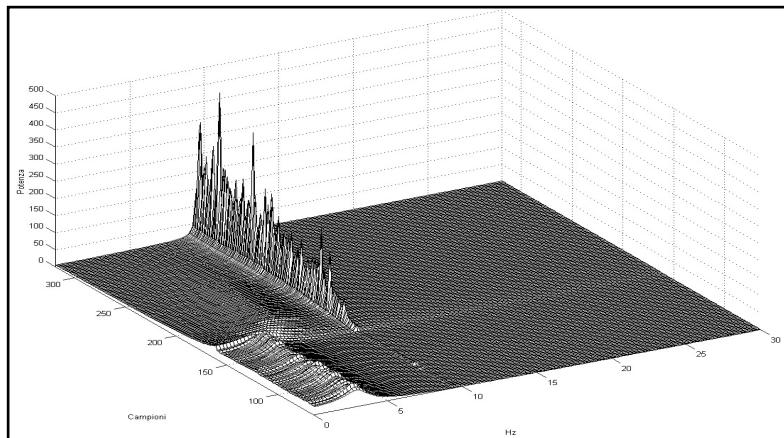
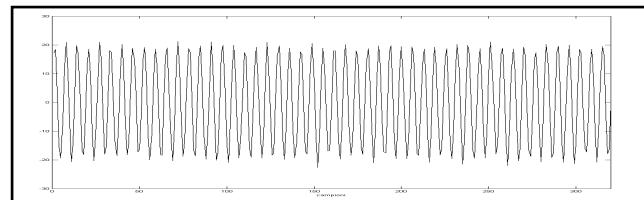
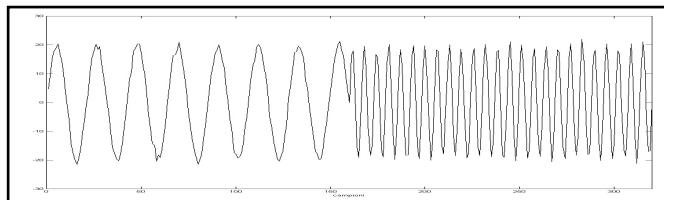
- Stationarity of the signal
- No information about the time at which a frequency pattern occurs

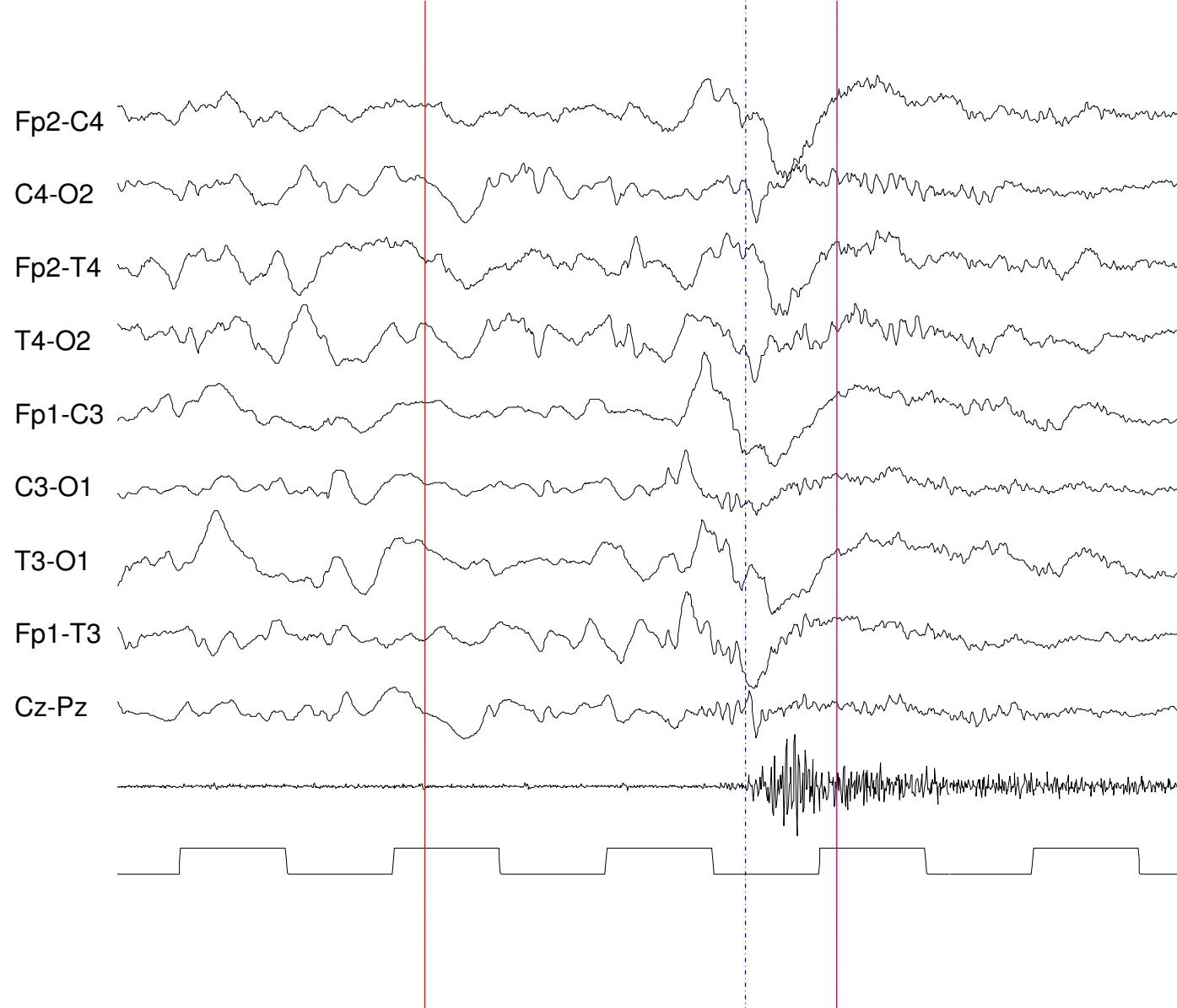


TVAR ANALYSIS

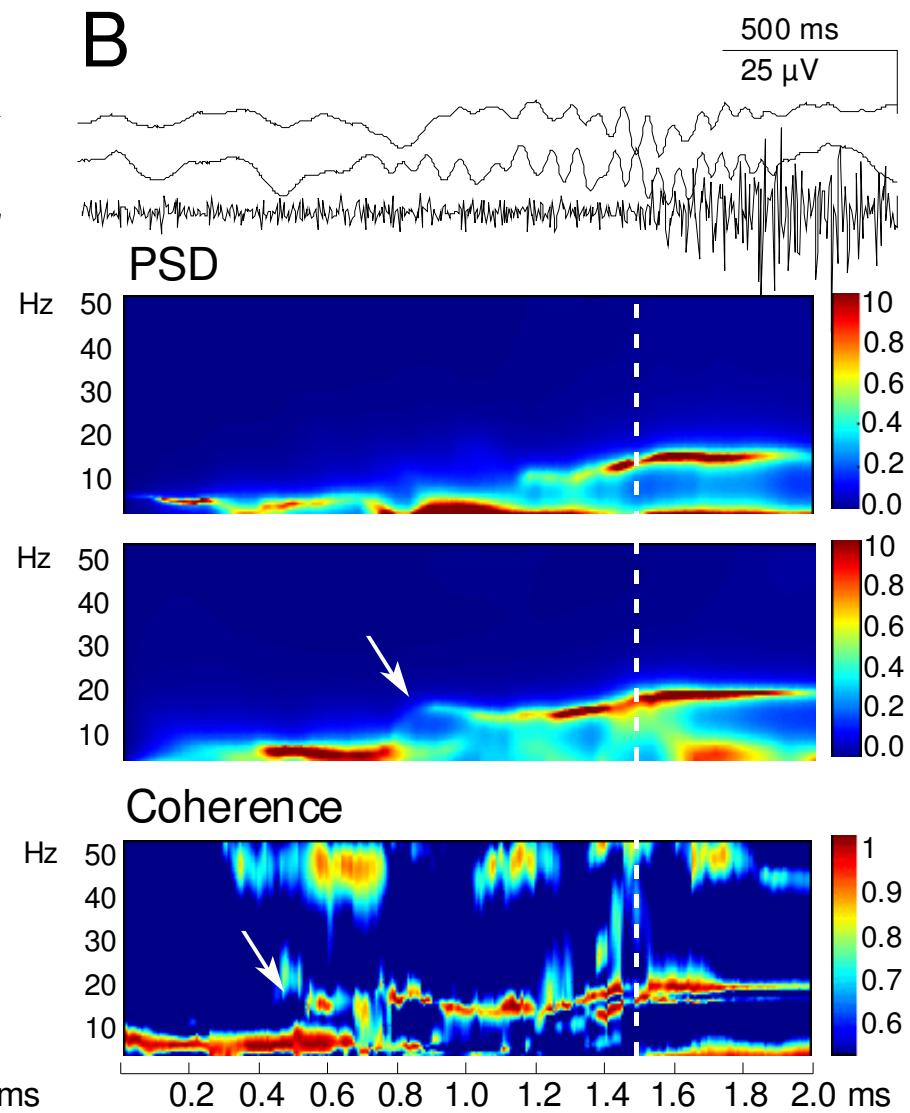
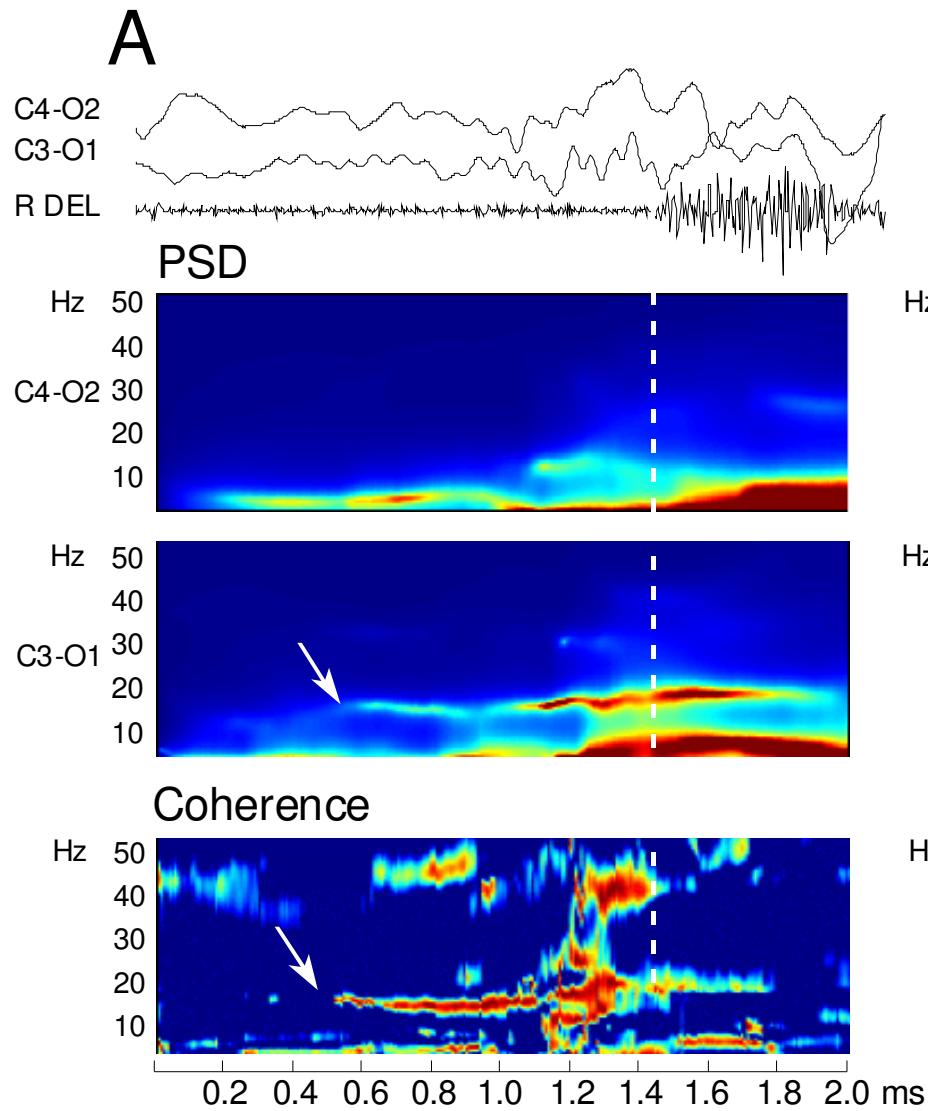
$$y_1(t) = \begin{cases} 20 \cdot \sin \varphi \cdot \pi \cdot f_1 \cdot t + d(t); & t \leq 160 \\ 20 \cdot \sin \varphi \cdot \pi \cdot f_2 \cdot t + d(t); & t > 160 \end{cases} \quad \begin{array}{l} f_1 = 3 \text{ Hz} \\ f_2 = 10 \text{ Hz} \end{array}$$

$$C(f,n) = \frac{S_{y_1 y_2}(f,n)}{\sqrt{S_{y_1 y_1}(f,n) \cdot S_{y_2 y_2}(f,n)}}$$



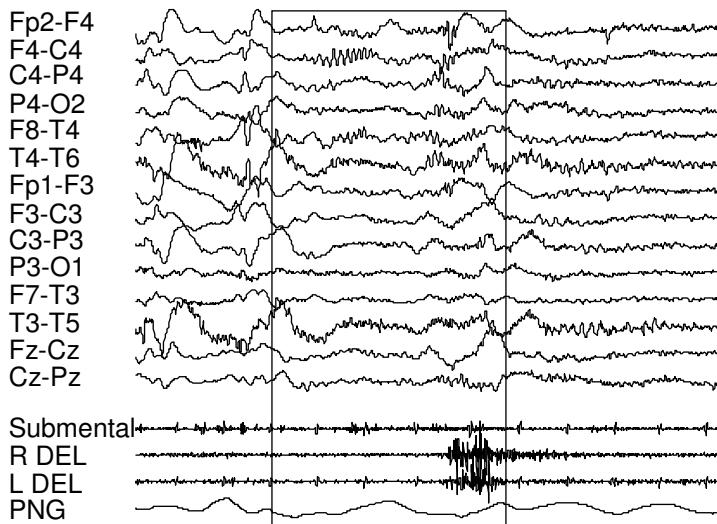


ZG, 4 months . Cryptogenic west syndrome

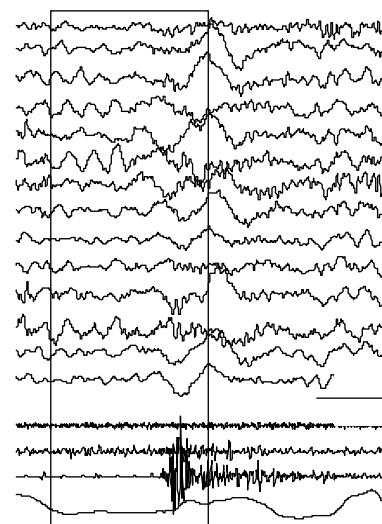


Panzica et al., Epilepsia, 2007

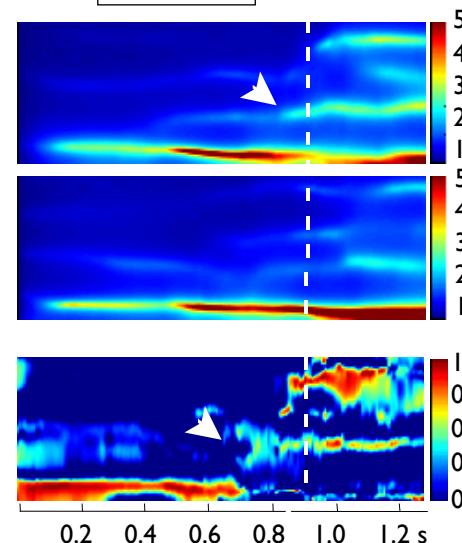
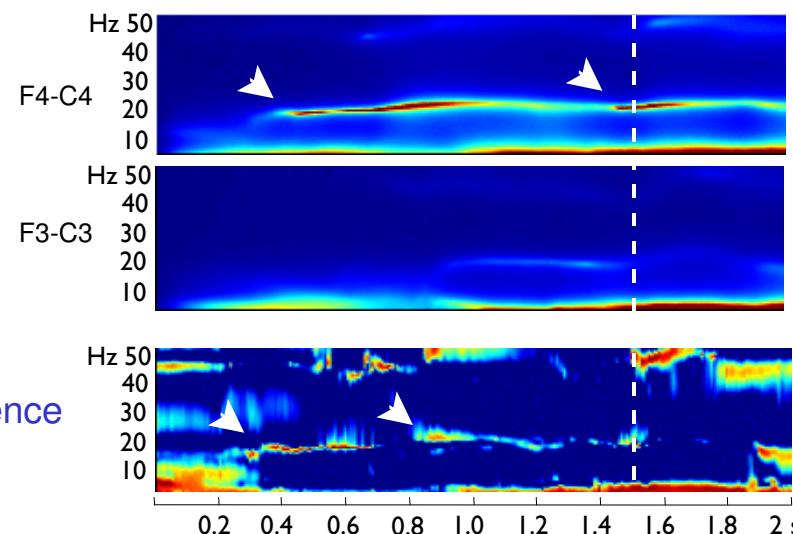
ZR, F, 8 mth, West syndrome



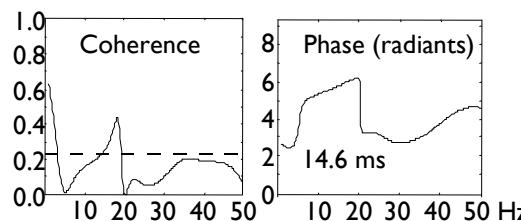
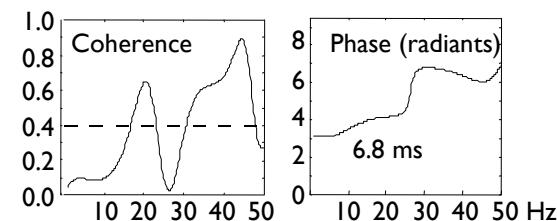
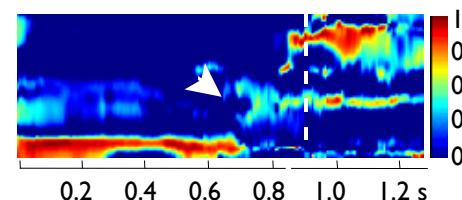
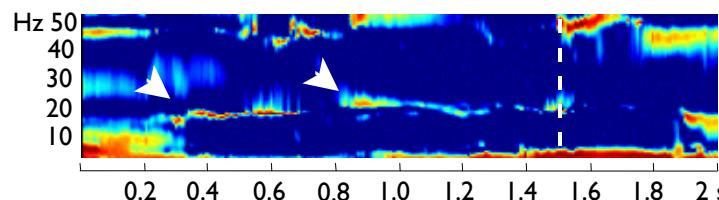
7 years old (follow-up)



PSD



Coherence



CONCLUSIONS

- *Lateralized fast activity is part of the ictal events in most infant with cryptogenic or symptomatic West syndrome*
- *Coherence and phase analysis indicate a transfer from the generating hemisphere to the contralateral one.*
- *Ictal beta activity is significantly associated with a poor outcome, but it is not a definite marker of seizure recurrence*
- *In patients with seizure recurrence, late seizure origin showed a lateralization similar to that of the ictal events associated with early spasms. This suggests that the EEG beta activity should be considered as indicating local cortical lesion/dysfunction in infants who fail to respond to early treatment and often progress toward severe epilepsy*

Partial Directed Coherence estimated on Stereo-EEG signals in patients with Taylor's type focal cortical dysplasia

Giulia Varotto, Silvana Franceschetti, Roberto Spreafico,
Laura Tassi, Ferruccio Panzica

Focal Cortical Dysplasia

Subtype of malformation of cortical development

Focal abnormalities of cortical structures.

Can be histopathologically classified into different types.

Type II (Taylor') FCDs

Spatially circumscribed

- **Intrinsic epileptogenic**
- **Peculiar cortical organization**
- **Typical and peculiar EEG interictal activity**

Goal of resective epilepsy surgery

Complete resection of the **epileptogenic zone**
(the area of cortex that is required to
generate clinical seizures)

Its location and boundaries are defined by:

- seizure semiology
- electrophysiologic recordings
- functional testing
- neuroimaging techniques

Strategia diagnostica pre-chirurgica

- Anamnesi dettagliata;
- EEG intercritico (+/- EEG critico);
- Diagnostica per immagini (TC; RM)
- Valutazione Neuropsicologica;

Monitoraggio VEEG

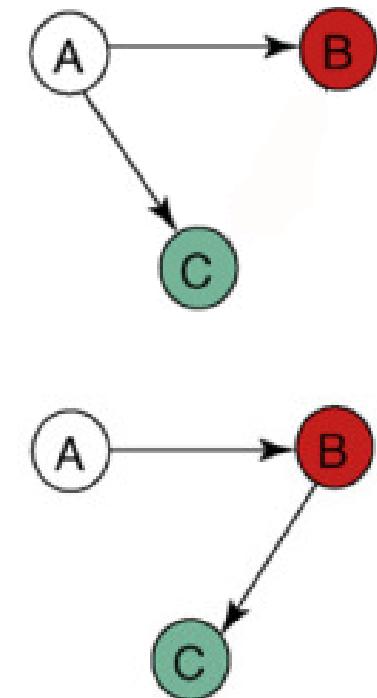
Esplorazione Stereo-EEG

Chirurgia: lesionectomia,
lesionectomia + corticectomia

Analysis of dynamic brain oscillations: TINS 30(7): 365-373,2007 methodological advances

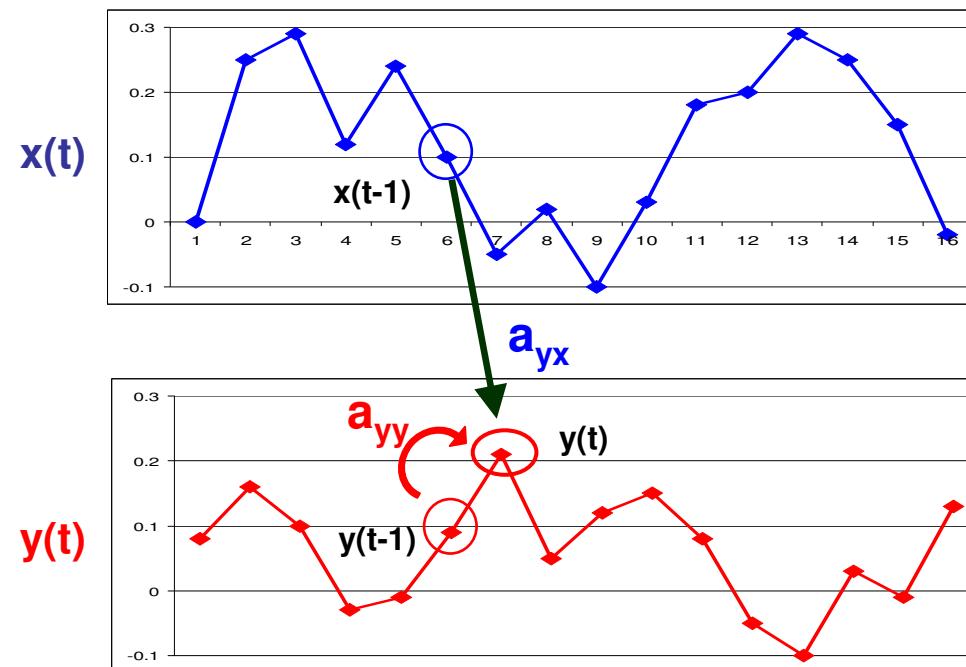
Michel Le Van Quyen¹ and Anatol Bragin²

- Sincronizzazione → causalità = influenza che un sistema esercita su un altro ("chi guida chi")
- Un'area può essere connessa contemporaneamente con diverse regioni e influenzarle (sorgente comune)
- Due strutture possono non interagire direttamente. L'analisi a coppie delle attività di interesse può non essere sufficiente per rivelare la corretta rete di interazioni (dirette e/o indirette) → **analisi multicanale (multivariate)**



Norbert Wiener (1956) Dati due segnali, misurati simultaneamente, se la predizione del primo è migliorata dall'aver incorporato le informazioni relative al passato del secondo segnale, piuttosto che usando solo l'informazione relativa al passato del primo, allora si può dire che il secondo segnale è causa (in senso statistico) del primo.

Clive Granger (Premio Nobel economia, 2003), 1969: Formulazione matematica del concetto espresso da Wiener. Dati due segnali X e Y, si può dire che X influenza Y se includendo i valori passati della prima variabile nella stima regressiva della seconda, questo migliora la qualità della stima, cioè riduce l'errore di predizione.



Autoregressive Models (AR)

MULTIVARIATE AR

$$\begin{bmatrix} x_1(t) \\ \vdots \\ x_Q(t) \end{bmatrix} = \sum_{k=1}^p A_k \begin{bmatrix} x_1(t-k) \\ \vdots \\ x_Q(t-k) \end{bmatrix} + \begin{bmatrix} w_1(t) \\ \vdots \\ w_Q(t) \end{bmatrix}$$

$$A_k = \begin{bmatrix} a_{1,1}(k) & a_{1,2}(k) & \cdots & \cdots & a_{1,Q}(k) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & a_{n,m}(k) & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{Q,1}(k) & \cdots & \cdots & \cdots & a_{Q,Q}(k) \end{bmatrix}$$



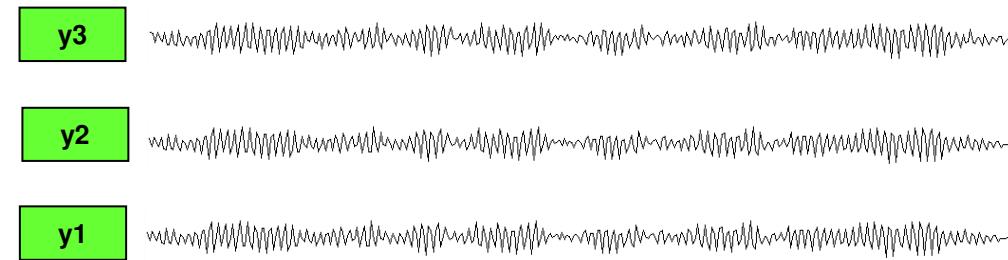
PDC

$$Pdc_{ij}(f) = \frac{\bar{a}_{ij}}{\sqrt{\bar{a}_j^H(f) \cdot \bar{a}_j(f)}}$$

$$\bar{A}(f) = I - A(f) \quad A(f) = \sum_{k=1}^p A_k e^{-2i\pi fk},$$

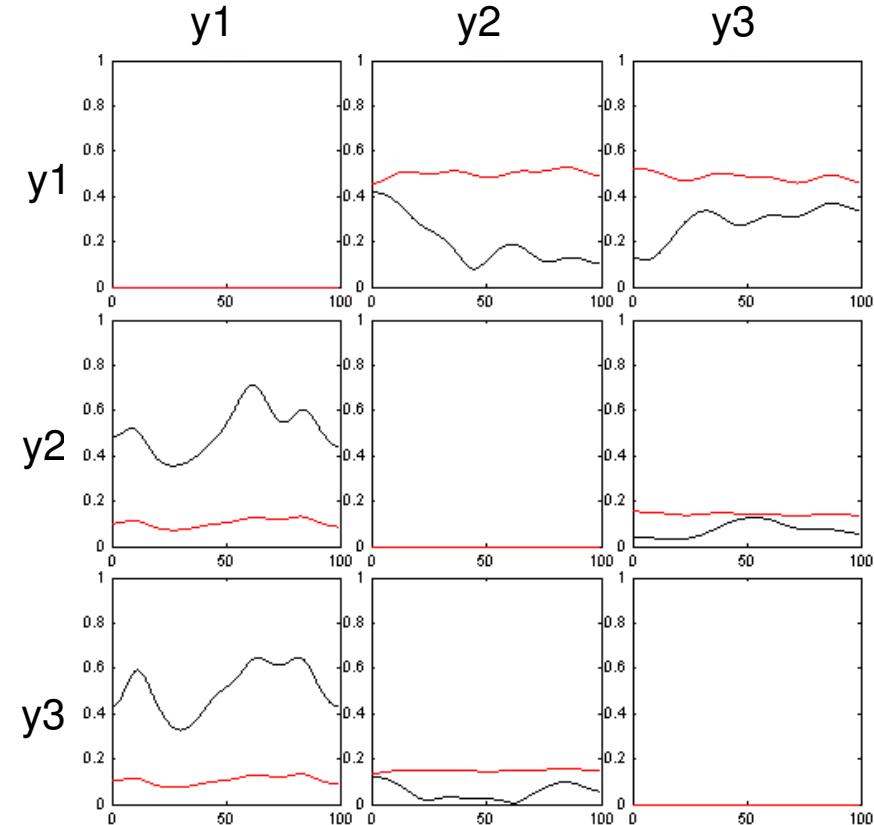
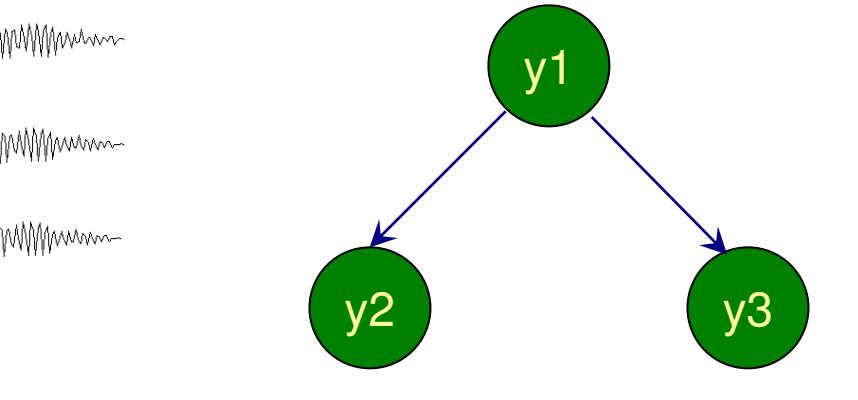
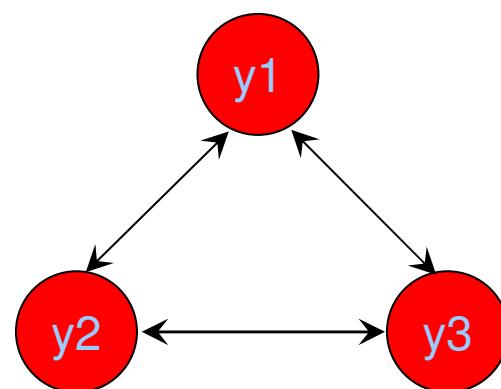
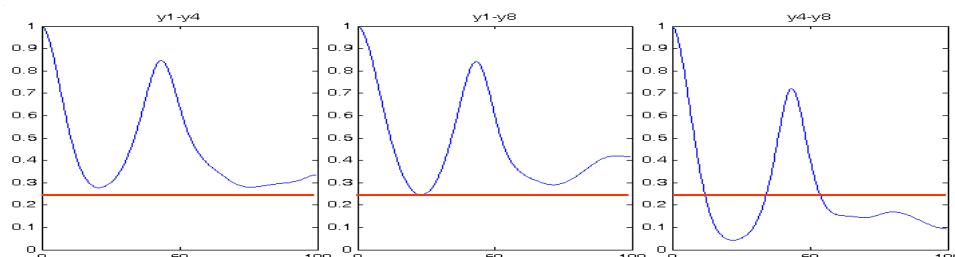
$$\bar{\mathbf{A}}(f) = \begin{bmatrix} \bar{a}_{11}(f) & \cdots & \bar{a}_{1j}(f) & \cdots & \bar{a}_{1m}(f) \\ \bar{a}_{21}(f) & \ddots & \vdots & & \vdots \\ \vdots & & \bar{a}_{jj}(f) & & \vdots \\ \vdots & & \vdots & \ddots & \vdots \\ \bar{a}_{m1}(f) & \cdots & \bar{a}_{mj}(f) & \cdots & \bar{a}_{mm}(f) \end{bmatrix}$$

Indici di direzionalità



Coerenza

y_1-y_2 y_1-y_3 y_2-y_3



PDC

Experimental Protocol

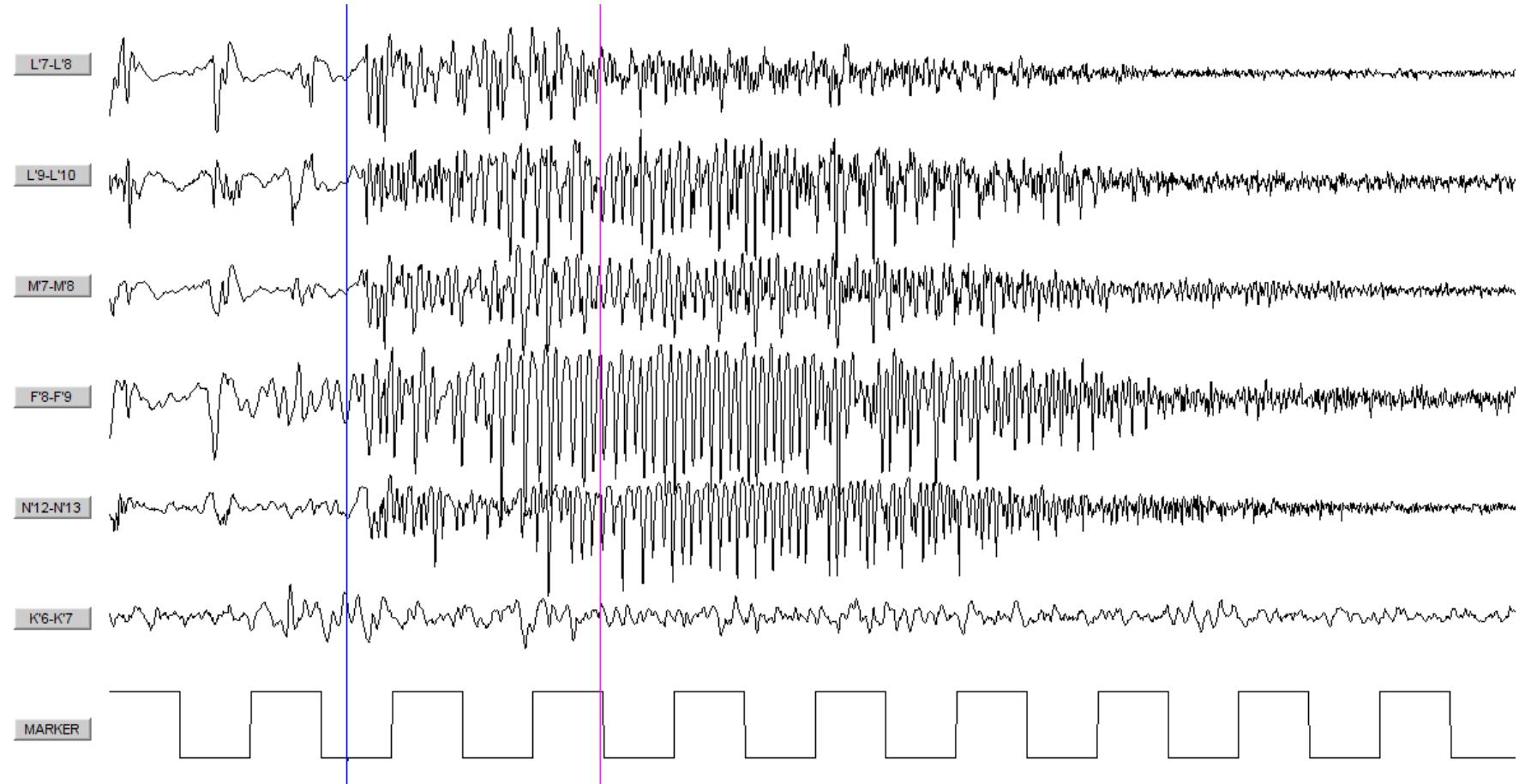
Four subjects with *Focal Cortical Dysplasia - Taylor Type.*

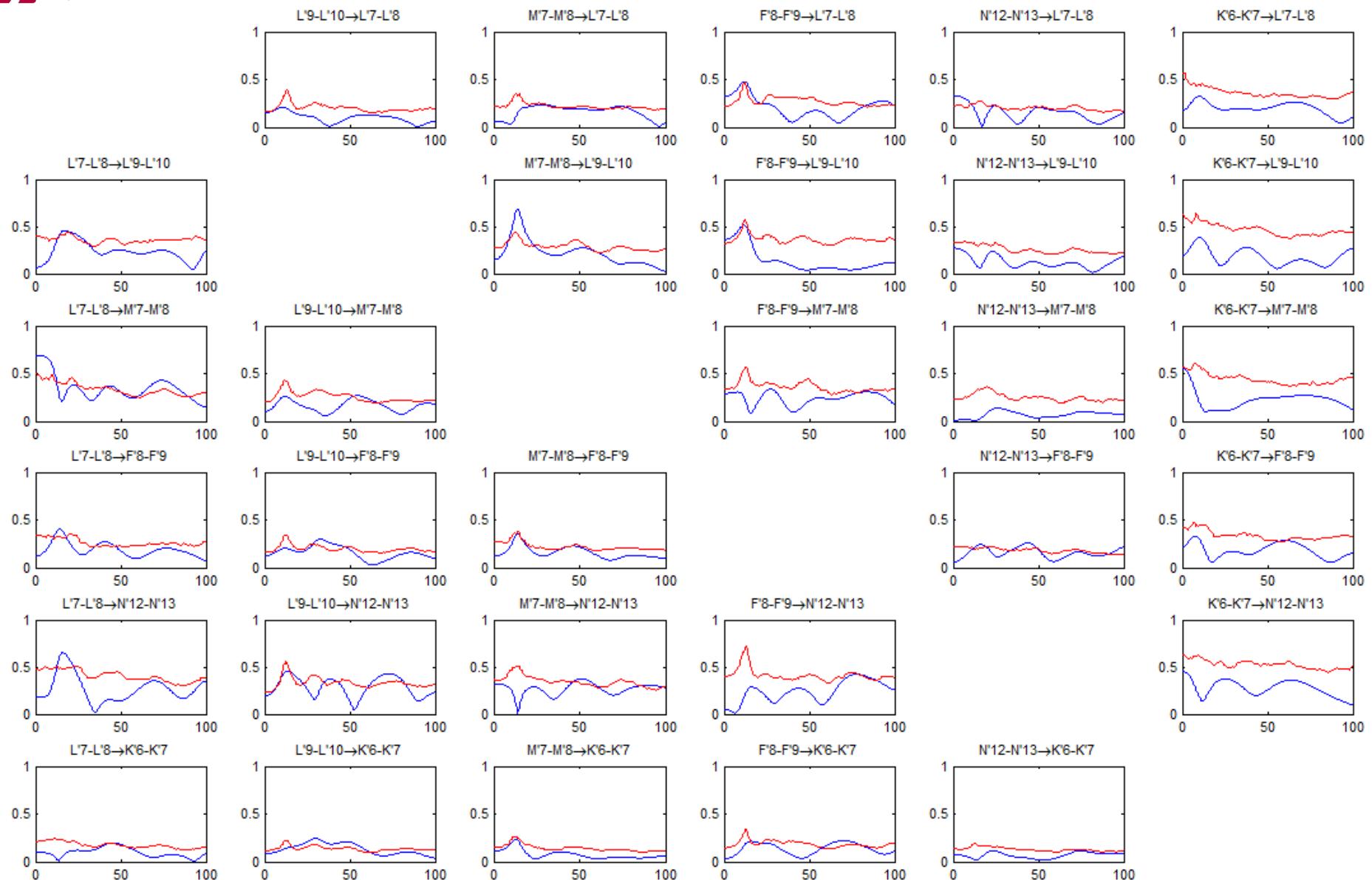


- Intra-lesional;
- Peri-lesional involved in the seizure;
- Peri-lesional not involved;
- Far from lesion involved;
- Far from lesion not involved;

- Inter-ictal
- Pre-ictal
- Ictal

20 epochs - 1 sec length

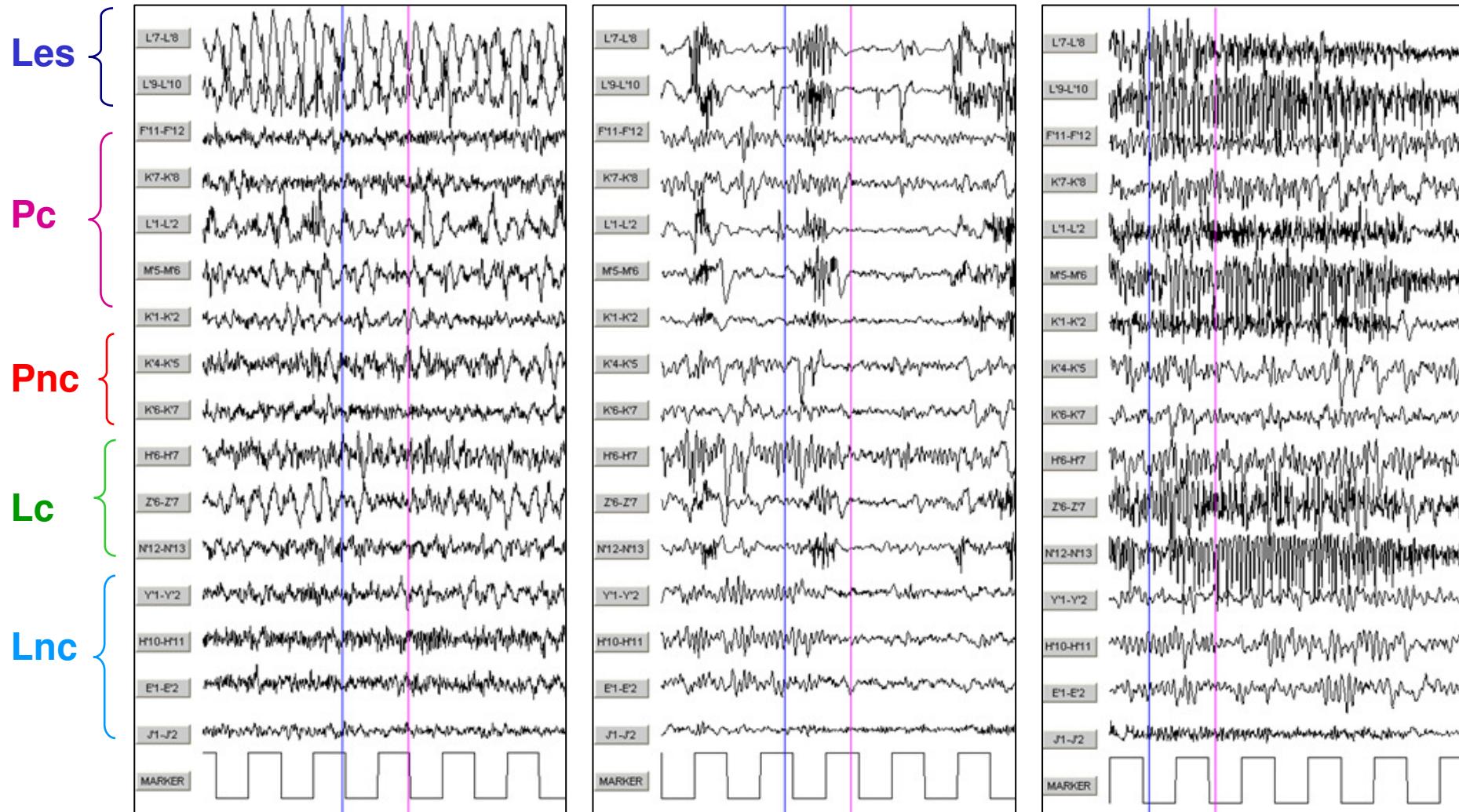




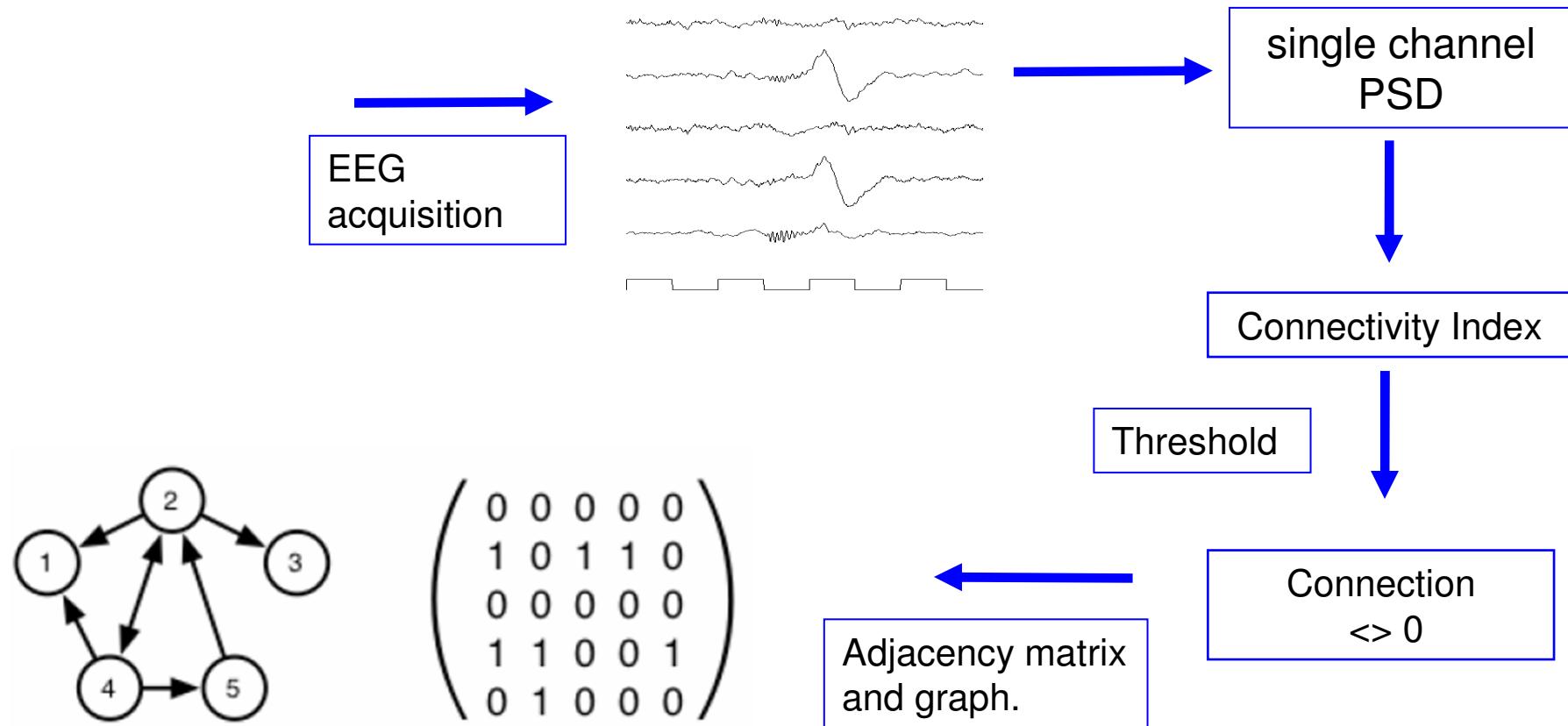
INTERCRITICO

PRECRITICO

CRITICO



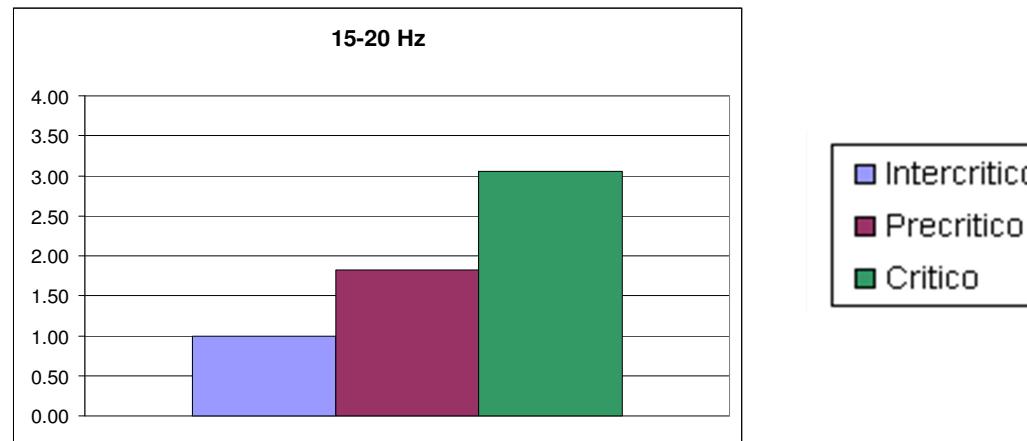
Methodological procedure



- Estimation of :
 - Power spectra density and main frequency components.
 - Directionality indexes (PDC) and associated parameters.
- Identification and graphical representation of links connecting different leads.

Densità Globale

Rapporto densità pre-critica e critica vs intercritica



- Aumento della sincronizzazione della rete tra intercritico, pre-critico e critico.

TESI

Possibilità di svolgere presso il nostro istituto
tesi di laurea sui diversi argomenti presentati.

In particolare:

- Approfondimento di aspetti teorico-matematici dei modelli multivariati e della PDC.

Studio su data set di segnali simulati e su segnali EEG durante stimolazione luminosa intermittente.

Contatti: Ing. Ferruccio Panzica
panzica@istituto-bestta.it

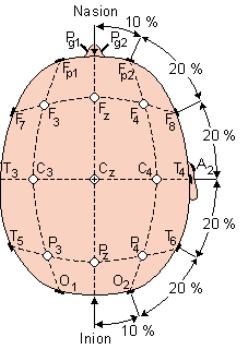
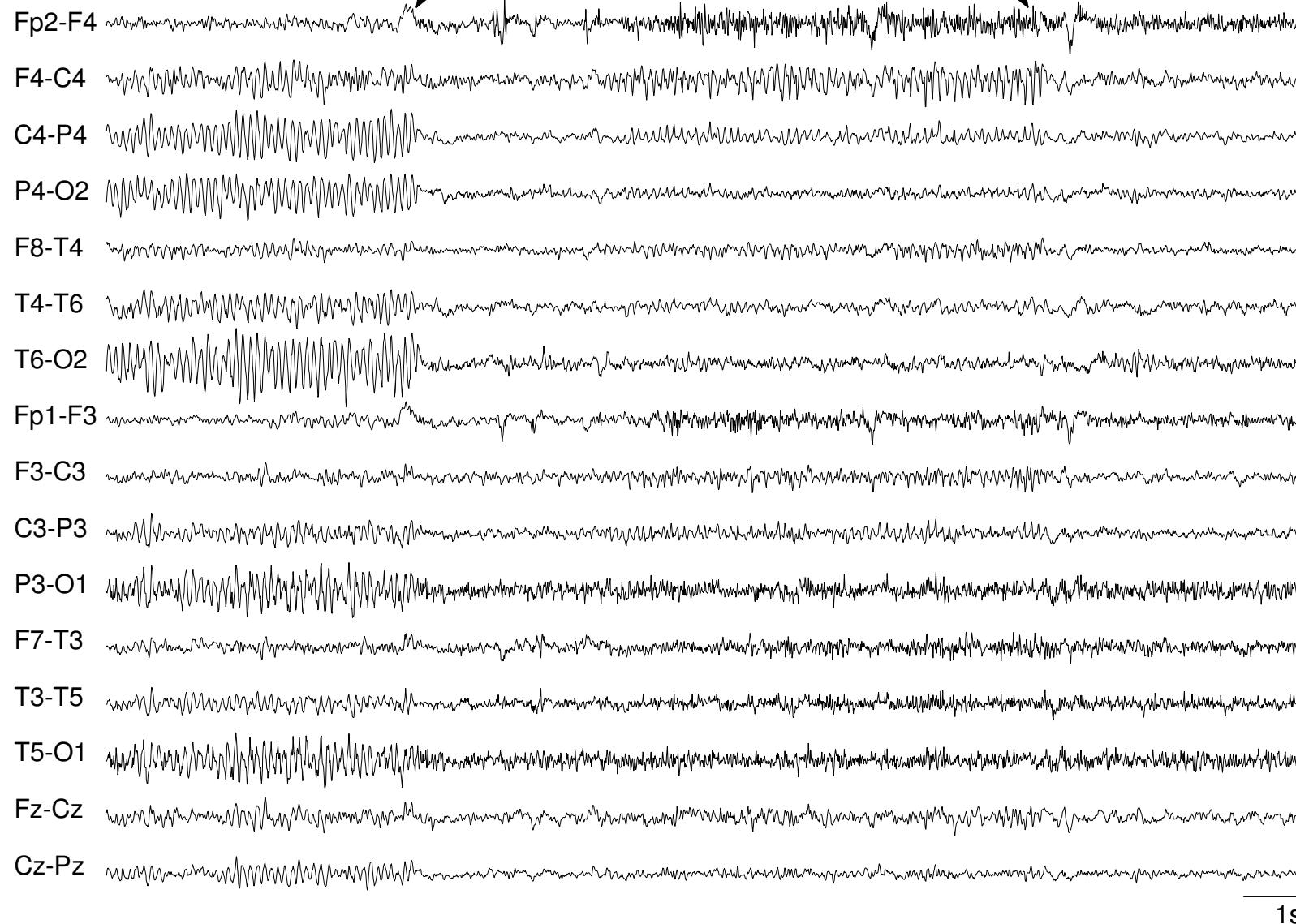


Movement-related desynchronization-synchronization (ERD/ERS) in patients with Unverricht–Lundborg disease

E. Visani, P. Agazzi, L. Canafoglia, F. Panzica,* C. Ciano, V. Scaioli,
G. Avanzini, and S. Franceschetti

Apre gli occhi

Stringe i pugni

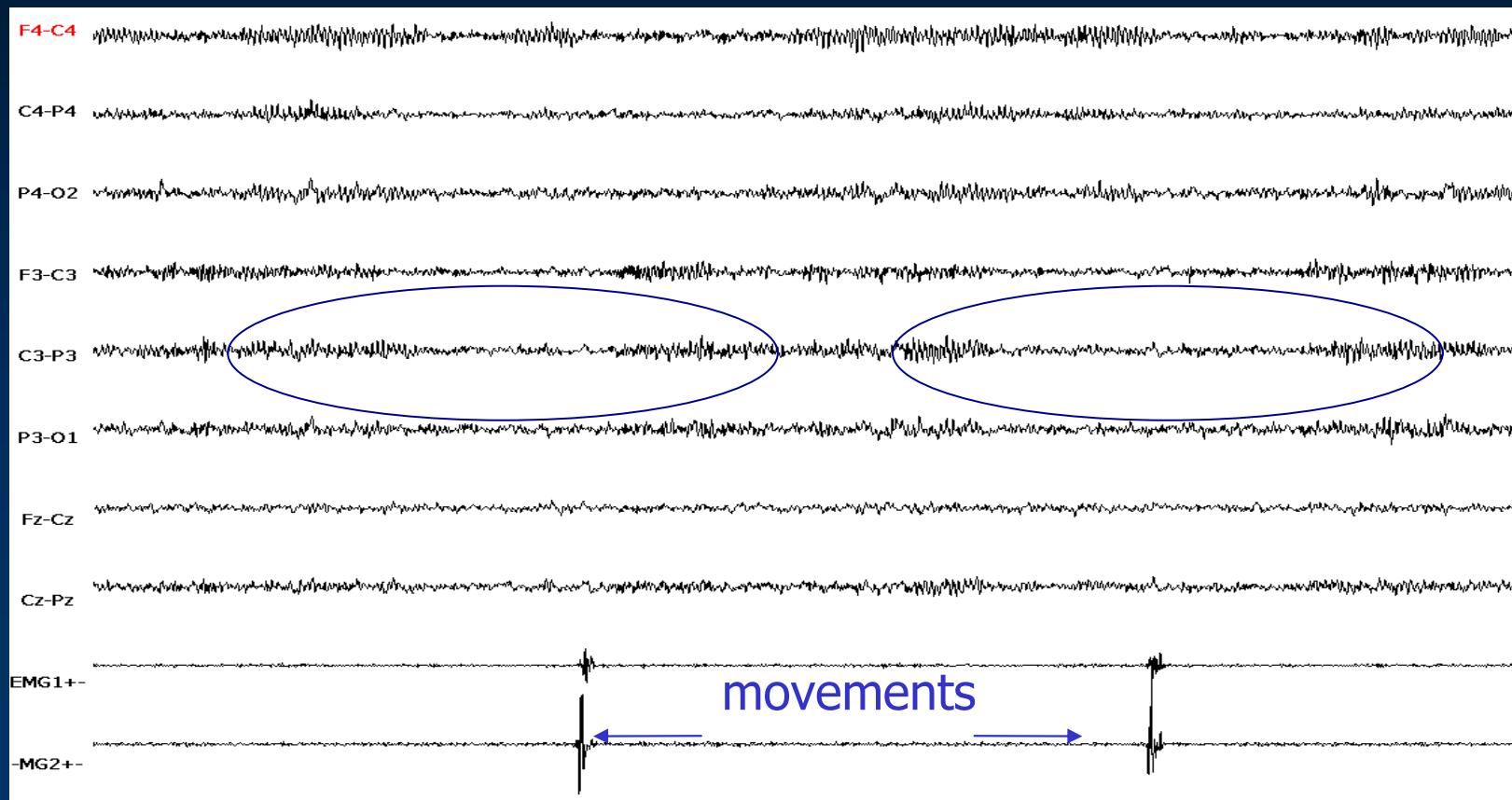


Presenza di ritmo mu in sede centrale bilaterale, che persiste a occhi aperti, e viene bloccato dall'attività motoria

Event-related EEG analysis: ERD/ERS

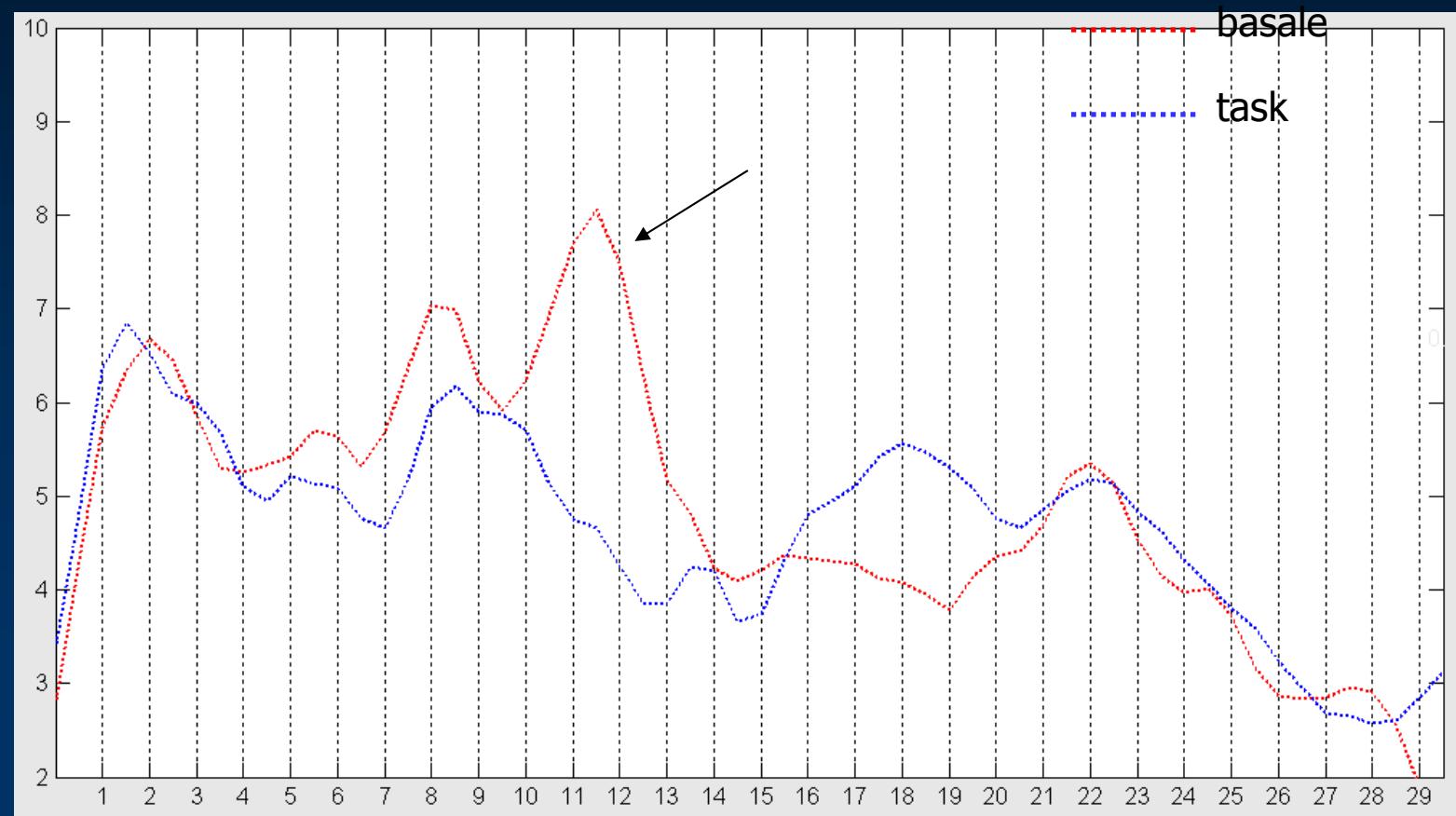
to study dynamic changes in EEG activity in selected frequency bands during movement and cognitive tasks

- ❖ Short duration
- ❖ Localized topography
- ❖ Frequency specificity



One of the most important questions is how to determine the upper and the lower limits of the band pass filter

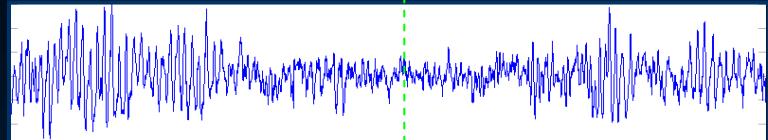
Detection of the most reactive frequency band based on the comparison of two short-term power spectra



ERD/ERS

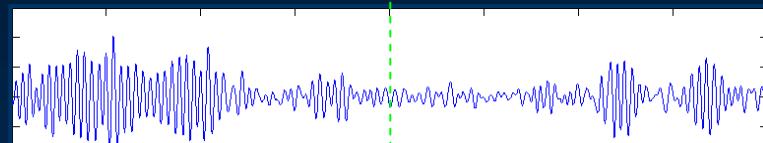
1. EEG epoch selection

1
...
N



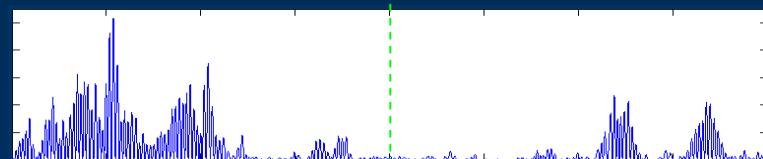
2. Digital band-pass filtering

1
...
N



3. Squaring

1
...
N



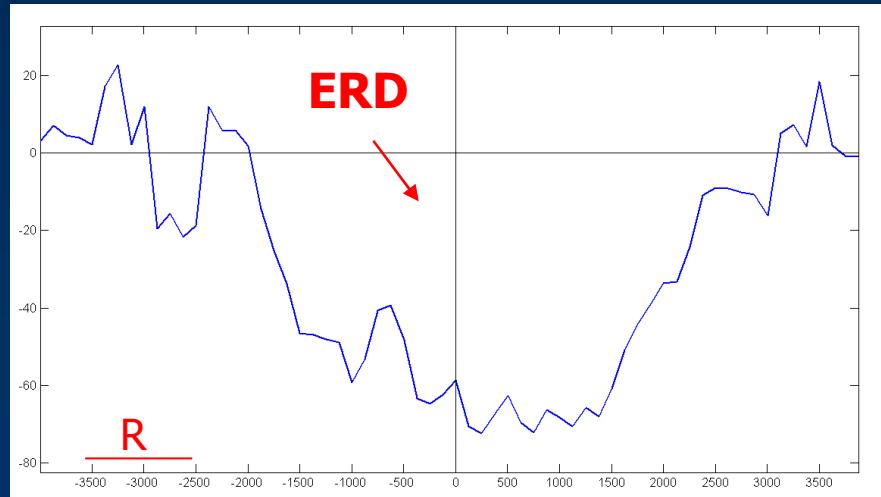
4. Averaging over N trials

5. Computation of time course ERD/ERS

$$\% \text{ ERD/S(t)} = \frac{(A(t)-R)}{R} \times 100$$

EEG/MEG power within identified frequency bands is displayed relative as percentage to the power of the same EEG/MEG derivations recorded during the reference or baseline period a few seconds before the event occurs

ERD decrease of band power



ERS increase of band power

