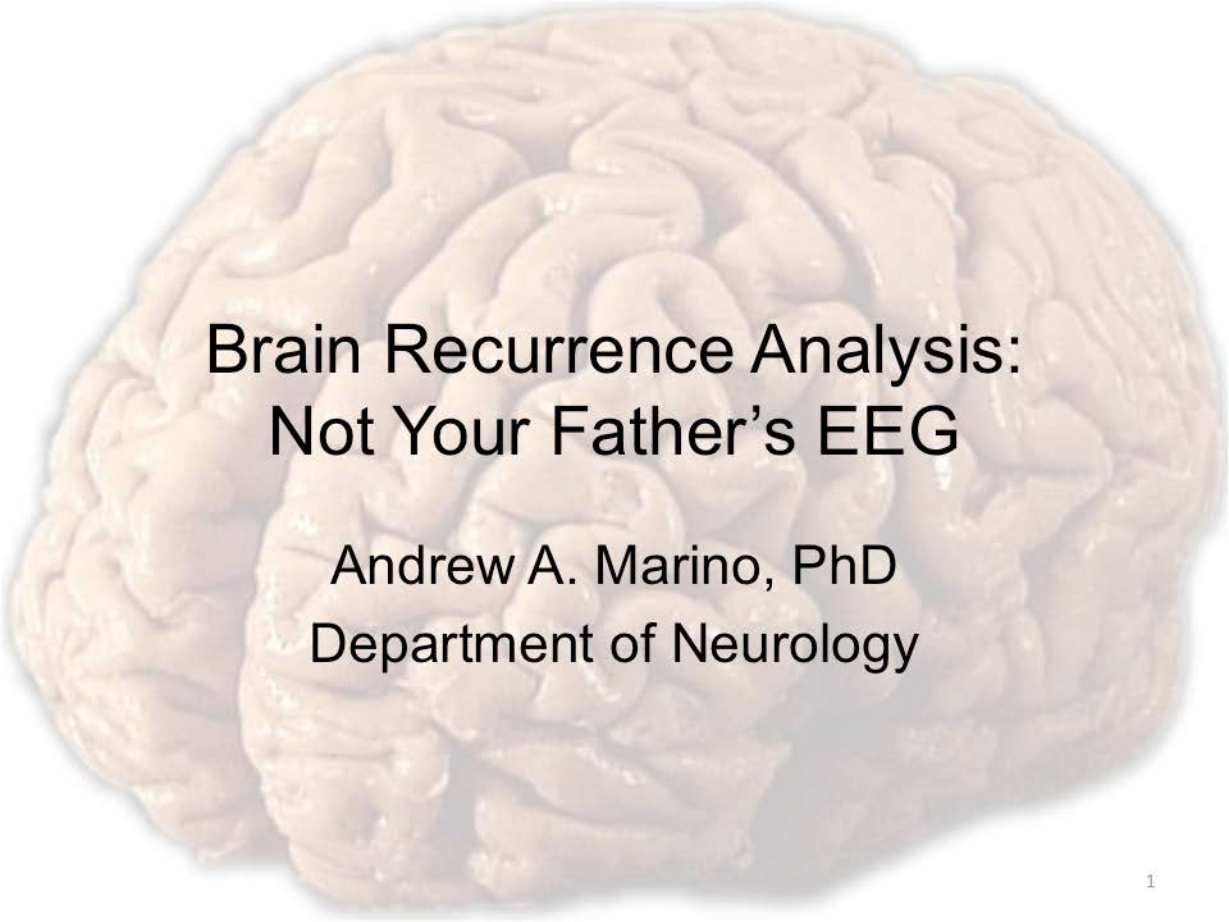
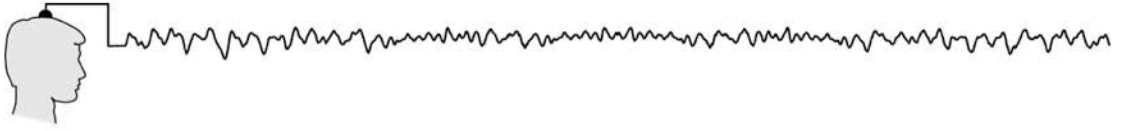


Brain Recurrence Analysis: Not Your Father's EEG

Andrew A. Marino, PhD
Department of Neurology

The EEG

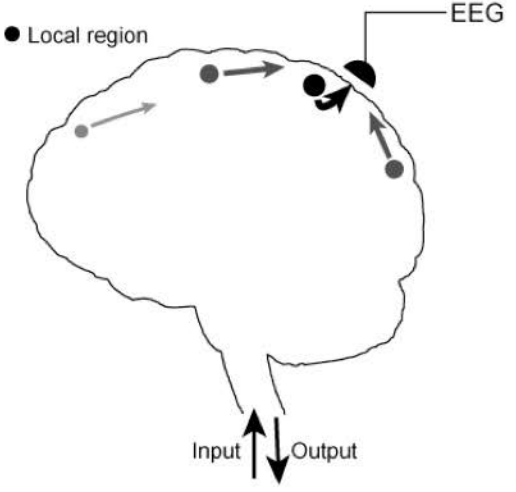


What it is: Time-dependent voltages measured between pairs of standardized locations on the scalp

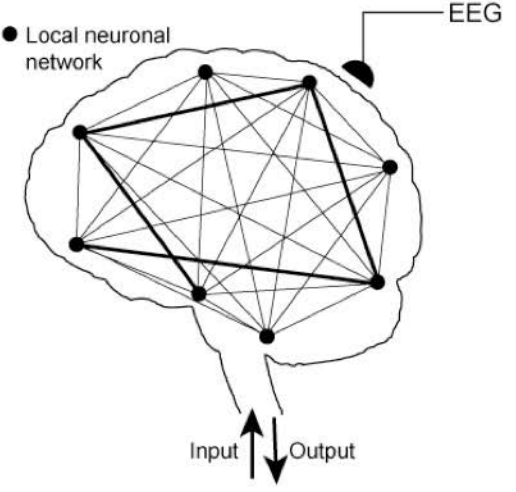
Traditional clinical use: Diagnosing brain diseases: largely supplanted by CT and MRI

Present-day uses:
- Sleep studies
- Epilepsy
- Brain death

Recent Developments: The Cognitive Perspective

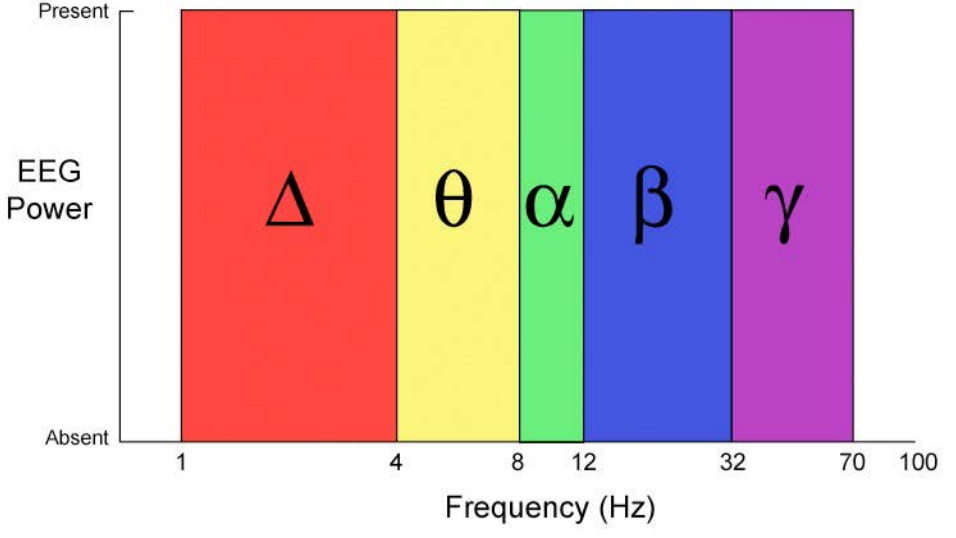


Traditional View
(linear, quasi-static)



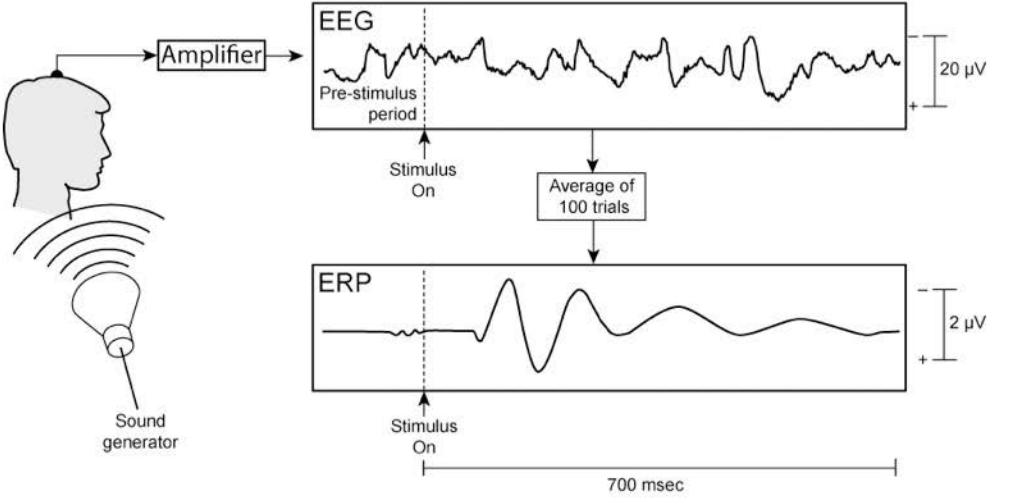
New View
(nonlinear, dynamic)

Linear Method: Spectral Analysis



Assumption: EEG is composed of parts

Linear Method: Time Averaging



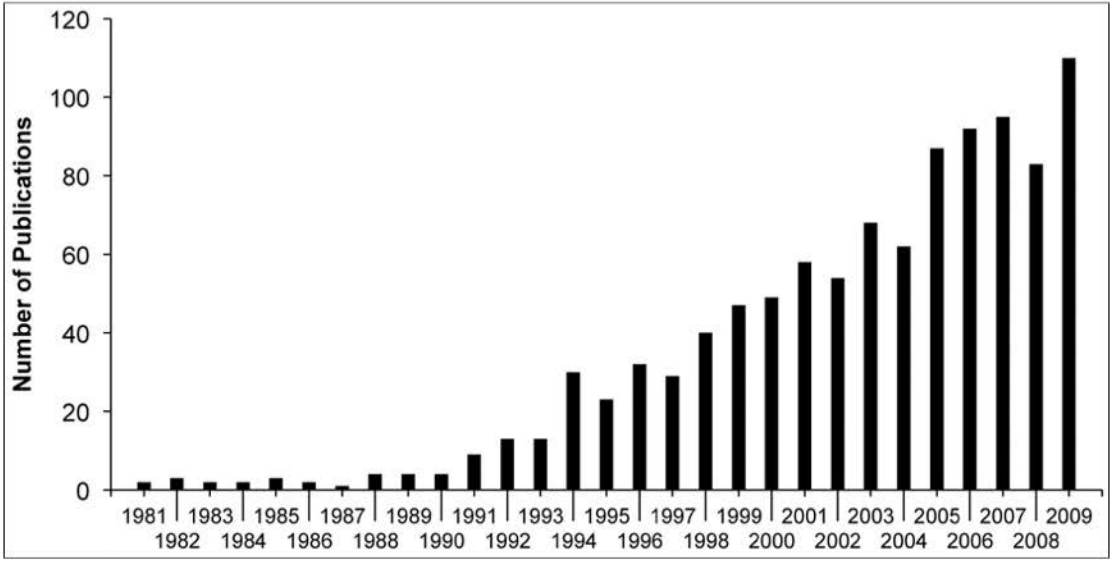
Assumption: Response is time locked

Basic Ideas Behind Nonlinear Analytical Methods

- **Sensitivity to initial conditions**

- **Recurrence: The future resembles (but is not identical to) the past**

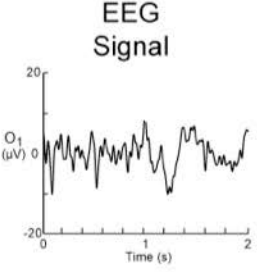
PubMed Publications on Nonlinear Analysis of EEG

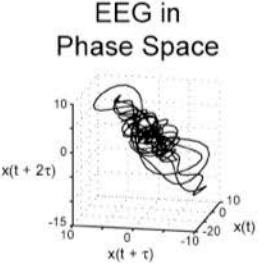


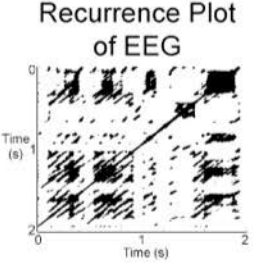
Characteristics of Nonlinear Methods

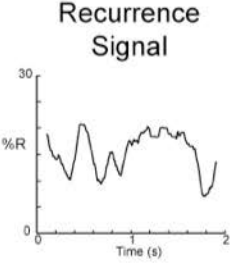
- General method (includes linear)
- Symbolic representation of dynamics
- Units are unfamiliar and nonphysiological
- ~100 specific techniques; no consensus yet

A Representative Technique: Recurrence Analysis



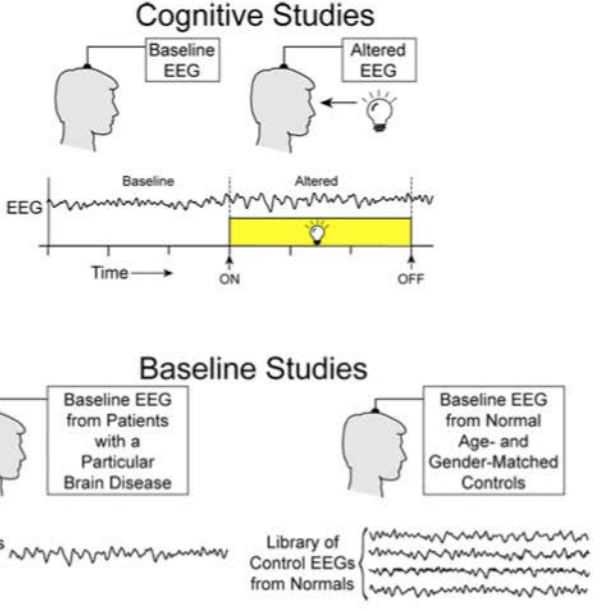




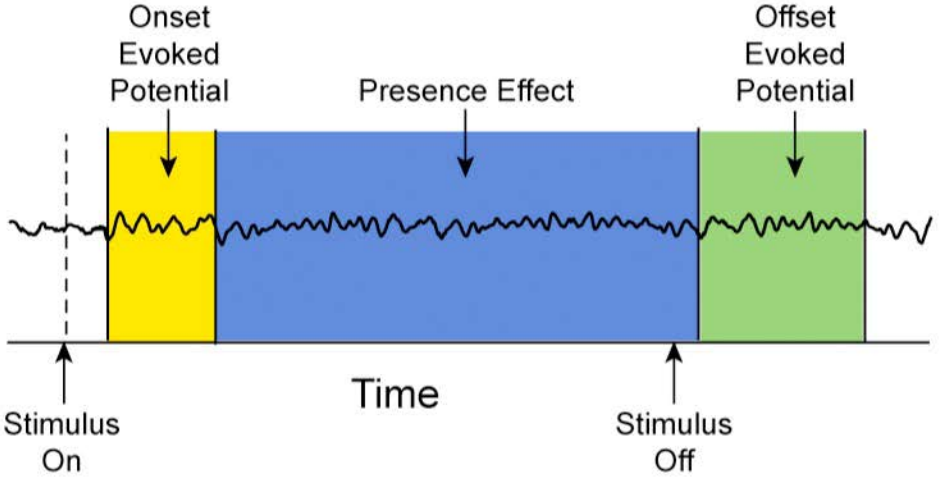


S. Carrubba, C. Frilot, A. Chesson, Jr., A.A. Marino: J. Neurosci. Meth. 157:39–47, 2006.
S. Carrubba, C. Frilot, A.L. Chesson, Jr., A.A. Marino: J. Neurosci. Meth. 173:41–46, 2008.

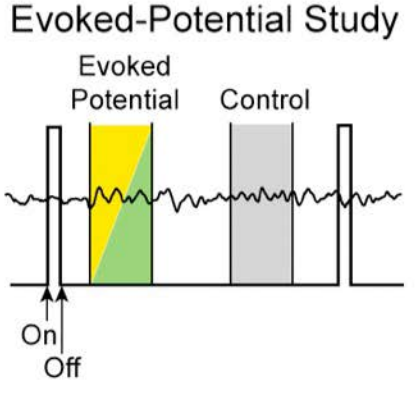
Experimental Design

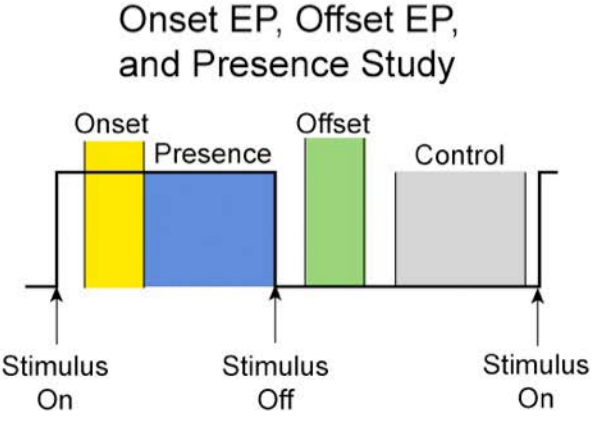


Distinct Brain Electrical Responses



Experimental Procedures

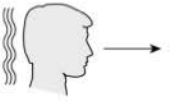




Discovery of Human Magnetic Sense

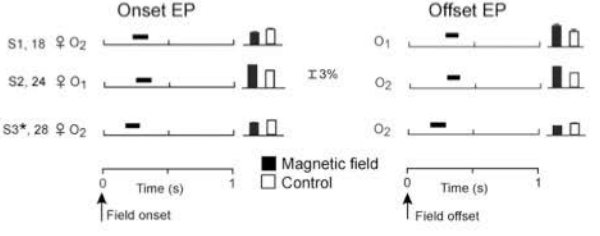
Rationale: Sensory perception entails evoked potentials

Procedure:



Analyze EEG for evoked potentials (EP)

Typical Results (N=17 subjects):



Summary:

- Each subject detected the magnetic field ($P < 0.05$)
- Latency and direction of effect (relative to control) varied with subject
- Effect not bilateral

S. Carrubba, C. Frilot, A.L. Chesson Jr., A.A. Marino: Neuroscience 144:356–367, 2007.

Basis for Functional Test for Multiple Sclerosis

Patients with Multiple Sclerosis

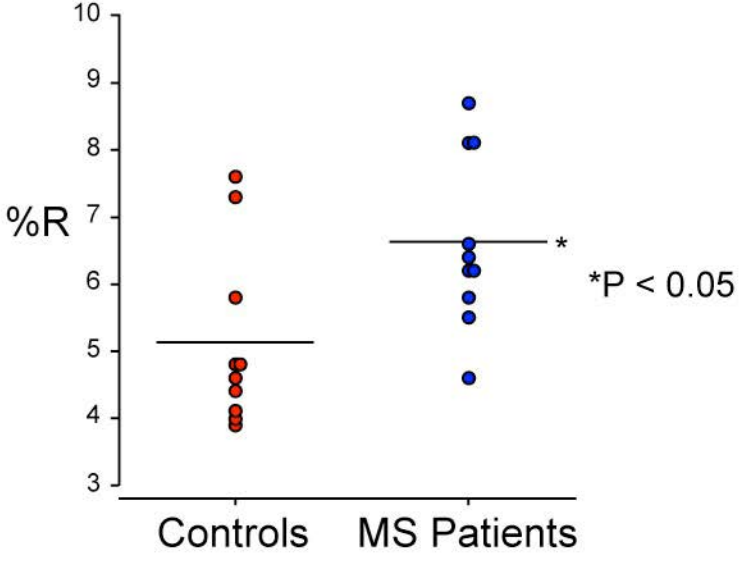
MS participant (age)	Onset Evoked Potential	Offset Evoked Potential
1 (40)	No Response	No Response
2 (34)	No Response	O_1 O_2 P_4
3 (52)	No Response	O_1 C_3
4 (32)	O_1 O_2 C_4	C_3 C_4
5 (19)	No Response	O_2 C_3 P_3
6 (30)	O_2 C_3	O_2 C_3 P_3
7 (18)	No Response	C_3 C_4 P_3 P_4
8 (27)	C_3 C_4 P_4	O_2 C_4 P_4
9 (50)	No Response	No Response
10 (31)	No Response	O_1 P_3
11 (38)	No Response	O_2 C_4

Normal Controls

Normal participant (age)	Onset Evoked Potential	Offset Evoked Potential
1 (51)	O2	C_3 C_4 P_3
2 (66)	O_2 C_3 P_4	C_4 P_4
3 (22)	No Response	O_2 P_3
4 (26)	C_3 C_4 P_3	No Response
5 (23)	C_3 C_4 P_4	O_2 C_4 P_3
6 (23)	C_3 C_4	C_4 P_4
7 (23)	O_1 C_3 P_3	O_1 O_2 C_3 P_3 P_4
8 (46)	O_1 C_3	O_1 C_3 P_3
9 (23)	O_1 O_2 C_4 P_3 P_4	C_3 P_3
10 (25)	P_3 P_4	C_3 P_3 P_4

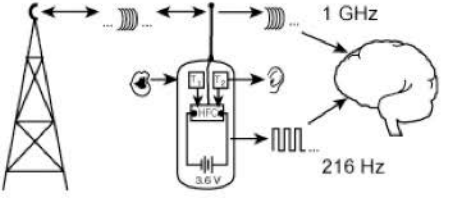
S. Carrubba, A. Minagar, E. Gonzalez-Toledo, A.L. Chesson Jr., C. Frilot II, A.A. Marino: Neurol. Res. 32:297, 2010.

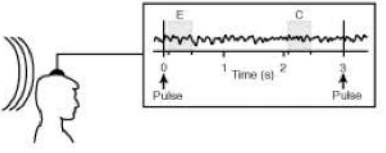
Comparison of Baseline EEGs from MS and Control Patients



S. Carrubba, A. Minagar, A.L. Chesson Jr, A.A. Marino: Submitted.

Effect of Cell-Phone Magnetic Fields (EMFs) on Brain Electrical Activity





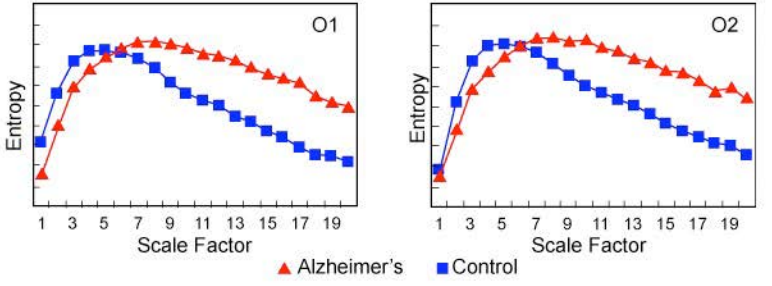
Subject	Evoked Potentials	Family-wise Error
1 (24/M)	O1 O2 P4	0.010
2 (53/F)	C3 C4 P3	0.002
3 (22/F)	C3 P3 P3	0.001
4 (22/M)	C3 C4 P3	0.001
5 (22/F)	O1 O1	0.081
6 (43/F)	O1 C4	0.006
7 (22/F)	O2 P4	0.031
8 (50/F)	02 P3 P4	0.062
9 (62/M)	—	—
10 (18/F)	O2 C3	0.078
11 (36/F)	O2 C3	0.043
12 (47/F)	C3 P3 P4	0.085
13 (32/F)	O1 P3	0.006
14 (24/F)	O1 O2	0.038
15 (52/M)	C3 P3	0.015
16 (22/F)	C3 C4	0.021
17 (23/F)	—	—
18 (29/M)	C4 P3	0.043
19 (23/M)	C3 P3	0.023
20 (26/M)	P3 P4	0.015

Summary: Typical cell phone triggers 216 evoked potentials per sec of use

S. Carrubba, C. Frilot 2nd, A.L. Chesson Jr., A.A. Marino: Neurosci. Lett. 469:164–168, 2009.

Nonlinear Dynamics of EEG in Alzheimer's Disease

- Decreased complexity[1]
- A particularly promising measure[2]

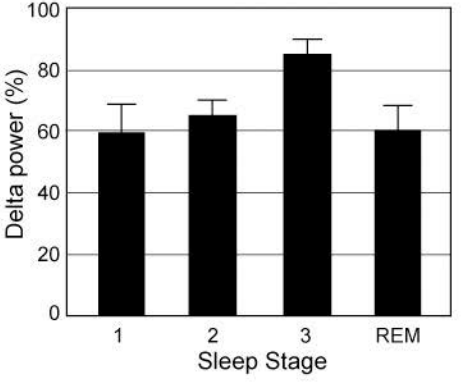


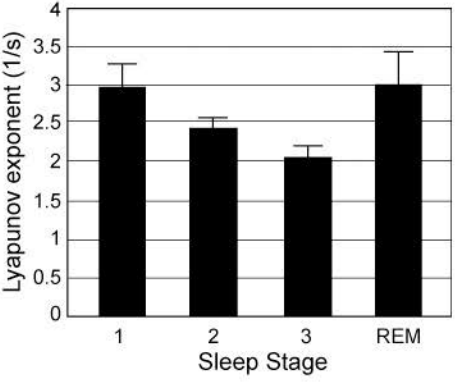
1. J. Jeong: Clin. Neurophysiol. 115:1490-1505.
2. T. Mizuno, T. Takahashi, R.Y. Cho, M. Kikuchi, T. Murata, K. Takahashi, Y. Wada: Clin. Neurophysiol. 121:1438–1446, 2010.

Sleep Medicine: Frontier for Nonlinear EEG Analysis

- Sleep phenomenology/pathology defined using EEG
- Goal No. 1: Automated scoring
- Goal No. 2: Fine structure of macro states

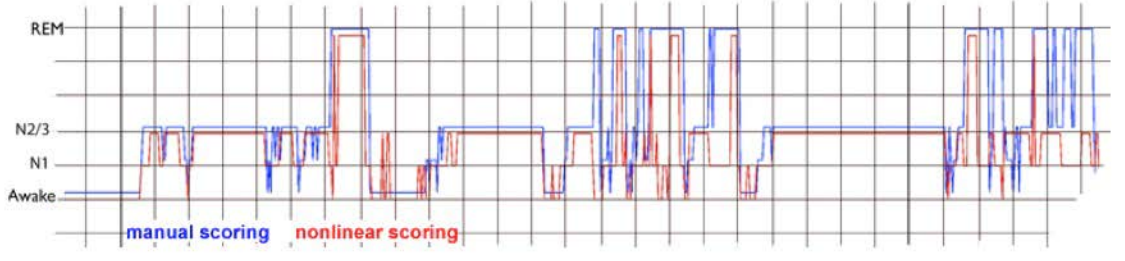
Discrimination of Sleep Stages: Comparison Between Linear and Nonlinear Measures





J. Fell, J. Röschke, K. Mann, C. Schäffner. Electroencephalog. Clin. Neurophysiol. 98:401–410, 1996.

Sleep States Derived from Manual and Nonlinear (Computational) Scoring



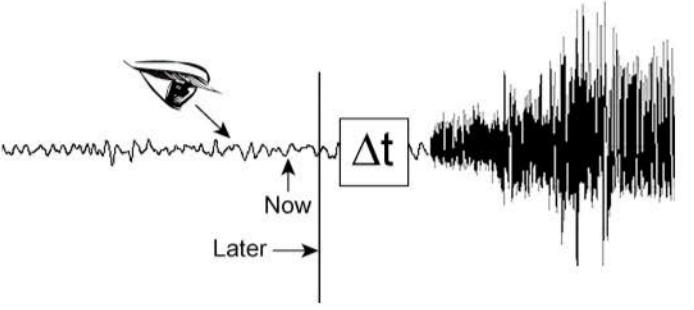
M.R. Titchener: Entropy sensitive to sleep state. NOLTA, 2006.

Nonlinear EEG Analyses in Sleep Medicine

- Sleep states stable in minutes $\Longrightarrow$ Sleep ideal for testing computational schemes to distinguish brain states
- Expect additional (not redundant) information
- Applications:
  - Diagnosis
  - Effects of drugs
  - Aging

Epilepsy: Is a Seizure Coming?

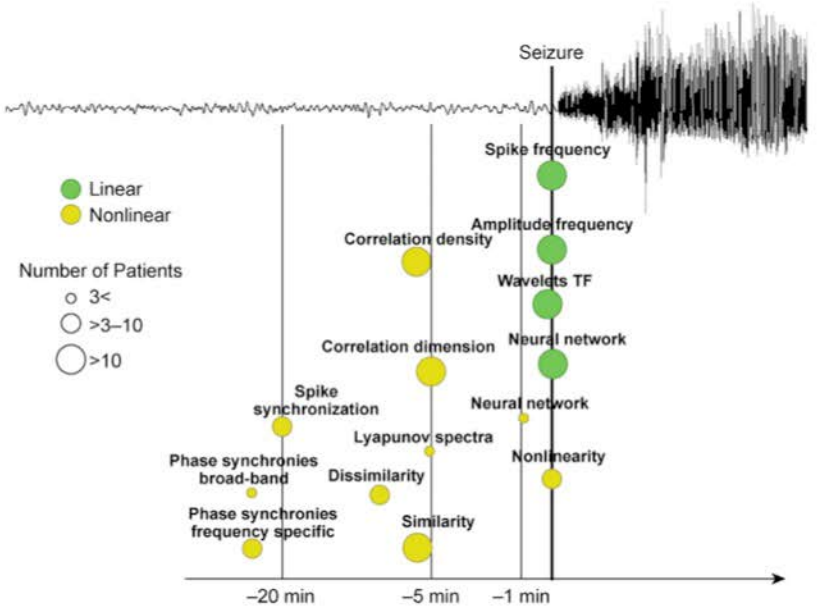
Basic Idea:



- Is such a thing possible?
- How long is Δt?

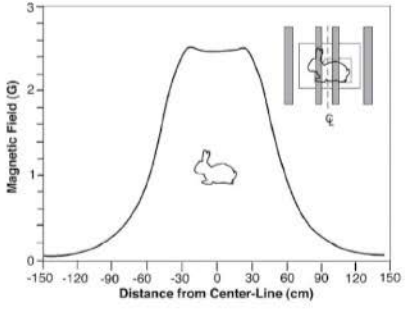
M. Le Van Quyen, J. Martinerie, V. Navarro, P. Boon, M. D'Havé, C. Adam, B. Renault, F Varela, M. Baulac: The Lancet 357:183–188, 2001.

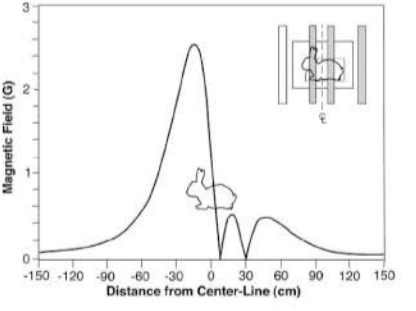
Relative Success of Different Methods for Predicting Seizures



M. Le Van Quyen, J. Martinerie, V. Navarro, M. Baulac, F.J. Varela: J. Clin. Neurophysiol. 18:191–208, 2001.

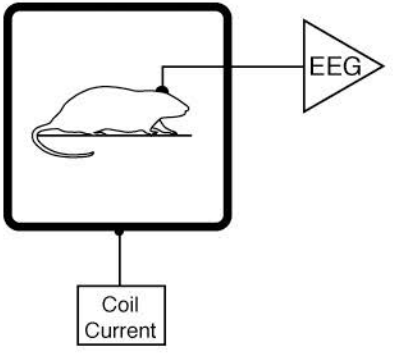
Basic-Science Studies: Anatomical Location of Field Detector

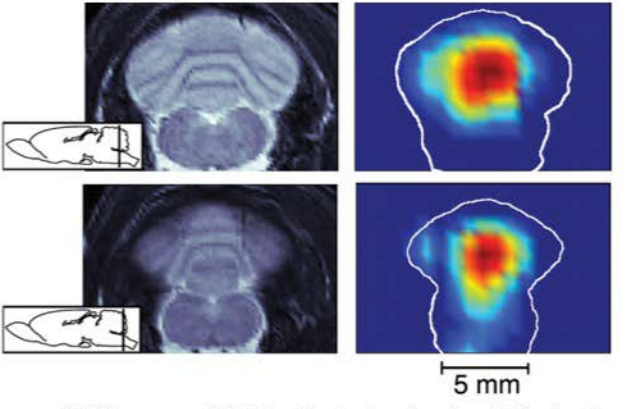




A.A. Marino, E. Nilsen, C. Frilot: Physiol. Behav. 79:803–810, 2003.

Basic-Science Studies: Field-Activated Brain Region Assessed Using PET

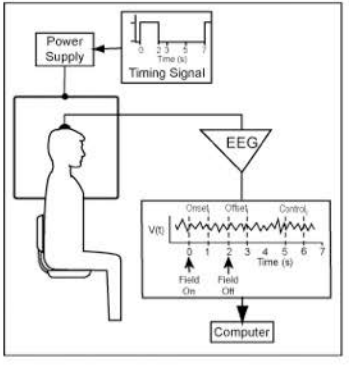


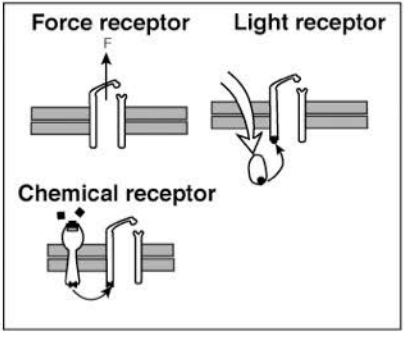


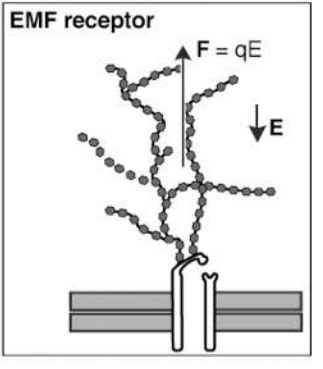
PET images of field-activated region in rat hindbrain

C. Frilot II, S. Carrubba, A.A. Marino: Synapse 63:421–428, 2009.

Basic-Science Studies: Field Detector is a Force Receptor





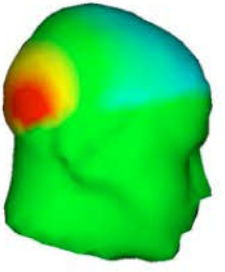


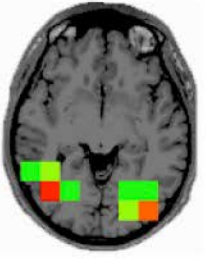
A.A. Marino, S. Carrubba, C. Frilot, A.L. Chesson Jr.: Neurosci. Lett. 452:119–123, 2009.
S. Carrubba, C. Frilot 2nd, F.X. Hart, A.L. Chesson Jr., A.A. Marino: Int. J. Radiat. Biol. 85:622–632, 2009.

Summary

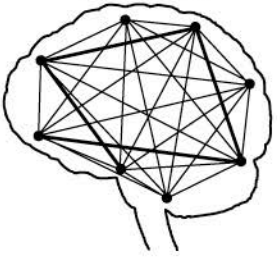
Limitation of MRI and CT

Almost limitless ability to display data





Nonlinear dynamic model can yield more neurophysiological information



Model Limitation: Not mechanistic