Brain Recurrence Analysis:
Not Your Father’s EEG

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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

Experimental Design
Distinct Brain Electrical Responses

- Onset Evoked Potential
- Presence Effect
- Offset Evoked Potential

Time

- Stimulus On
- Stimulus Off
Experimental Procedures

Evoked-Potential Study

Onset EP, Offset EP, and Presence Study

Stimulus On

Stimulus Off

Stimulus On

Onset

Presence

Offset

Control

Evoked Potential

Control

On

Off
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

### Basis for Functional Test for Multiple Sclerosis

<table>
<thead>
<tr>
<th>MS participant (age)</th>
<th>Onset Evoked Potential</th>
<th>Offset Evoked Potential</th>
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</thead>
<tbody>
<tr>
<td>1 (40)</td>
<td>No Response</td>
<td>No Response</td>
</tr>
<tr>
<td>2 (34)</td>
<td>No Response</td>
<td>O₁ O₂ P₄</td>
</tr>
<tr>
<td>3 (52)</td>
<td>No Response</td>
<td>O₁ C₃</td>
</tr>
<tr>
<td>4 (32)</td>
<td>O₁ O₂ C₄</td>
<td>C₃ C₄</td>
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<tr>
<td>5 (19)</td>
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<td>6 (30)</td>
<td>O₂ C₃</td>
<td>O₂ C₃ P₃</td>
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<tr>
<td>7 (18)</td>
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<td>C₃ C₄ P₃ P₄</td>
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<tr>
<td>8 (27)</td>
<td>C₃ C₄ P₄</td>
<td>O₂ C₄ P₄</td>
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<tr>
<td>9 (50)</td>
<td>No Response</td>
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<tr>
<td>10 (31)</td>
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<td>11 (38)</td>
<td>No Response</td>
<td>O₂ C₄</td>
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<table>
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<th>Normal participant (age)</th>
<th>Onset Evoked Potential</th>
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<tbody>
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<td>O₂</td>
<td>C₃ C₄ P₃</td>
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<td>2 (66)</td>
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<td>C₄ P₄</td>
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<td>3 (22)</td>
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<td>O₂ P₃</td>
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<td>4 (26)</td>
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<td>5 (23)</td>
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<td>C₄ P₄</td>
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<td>7 (23)</td>
<td>O₁ C₃</td>
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<td>8 (46)</td>
<td>O₁ C₃</td>
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<tr>
<td>10 (25)</td>
<td>P₃ P₄</td>
<td>C₃ P₃ P₄</td>
</tr>
</tbody>
</table>

Comparison of Baseline EEGs from MS and Control Patients

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

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

Nonlinear Dynamics of EEG in Alzheimer’s Disease

- Decreased complexity\(^1\)
- A particularly promising measure\(^2\)

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

Sleep States Derived from Manual and Nonlinear (Computational) Scoring

Nonlinear EEG Analyses in Sleep Medicine

- Sleep states stable in minutes $\implies$ 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 $\Delta t$?

Relative Success of Different Methods for Predicting Seizures

Basic-Science Studies: Anatomical Location of Field Detector

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

PET images of field-activated region in rat hindbrain

Basic-Science Studies: Field Detector is a Force Receptor

Summary

Limitation of MRI and CT

Almost limitless ability to display data

Nonlinear dynamic model can yield more neurophysiological information

Model Limitation: Not mechanistic