Epileptic Rhythms

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Absence Seizure

10 seconds
The ElectroEnzephaloGram

- Time-Continuous recording of Voltage
- Neurophysiologic basis of the signals
- Prominent EEG rhythms
- Characteristic Changes in Epilepsy
Topographic Placement
Awake EEG in a non-epileptic child

Normal Awake EEG

Electrodes:
- Fp1
- Fp2
- F3
- F4
- C3
- C4
- P3
- P4
- O1
- O2
- F7
- F8
- T7
- T8
- P7
- P8
- Fz
- Cz
- Pz

Time (seconds):
- 0
- 80
- 160
- 240
- 320
- 400
- 480
- 560

about 10 minutes
Awake EEG in a non-epileptic child

Normal Awake EEG

Electrodes

Time (seconds)

10 seconds
Ten seconds of sleep EEG

Normal sleep rhythm
Awake EEG in an epileptic child

1 minute
Absence Seizure

Abnormal Rhythm
Rolandic Seizure

- Spatial and Temporal Differentiation
Partial Seizure

- Spatial and Temporal Differentiation
Photoparoxysmal Response

- Light-Frequency dependent response
Dealing with Epileptic Rhythms

- Multivariate Time Series Analysis
- 3D representation
- Spatio-temporal Modelling
Multivariate Time Series Analysis

Following Plerou et al. (1999):

- Eigenvalues and eigenvectors of C-matrix
- Details of correlation structure imprinted
- Measures from random matrix theory

Applied to epileptic recordings:

- Schindler et al., Brain (2007)
- Correlation changes during the seizure
Cluster Analysis

- Dominant contributions in “largest” eigenvectors
- Contribution of individual time series reflected in eigenvector components
Cluster Analysis

- This can be used to identify clusters in EEG.
- Problem: Linear combinations of components for inter-cluster relations
- CPV – optimise independency of “largest” eigenvectors

Auditory Display of Rhythms

- Data from Electrocardiogram or EEG
- Baseline is assigned “silence”
- Action potentials are assigned a noisy or pitched sound
- Amplitude controls volume

Sleep spindles:

Absence Epilepsy:

Dynamics in 3D

- Virtual Auditory Environment

Excellent perception of 3D spatio-temporal correlations

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3D Representation

✓ Audio-visual display
✓ Real-time monitoring
✓ Interactivity

Baier & Hermann: Sydney 2004; Freiburg 2007; Vienna 2008
The Dynamics of Disease

In 1977 Mackey and Glass proposed the term “Dynamical Diseases” to combine Dynamical Systems Theory and Medicine.

We believe there is a large class of dynamical diseases, two of which have been considered here, characterized by the operation of a basically normal control system in a region of physiological parameters that produces pathological behavior (22). Our analysis suggests the following approaches: (i) demonstrate the onset of abnormal dynamics in animal models by gradual tuning of control parameters; (ii) gather sufficiently detailed experimental and clinical data to determine whether sequences of bifurcations similar to those found here actually occur in physiological systems; and (iii) attempt to devise novel therapies for disease by manipulating control parameters back into the normal range.

Michael C. Mackey
Leon Glass
The Dynamics of Disease

Lopes da Silva et al. (2004): Epilepsy is a dynamical disease.

a) Healthy and the epileptic state may coexist in a bistable situation

b) Epileptic state may be created in a bifurcation

c) Epileptiform EEG may be induced by periodic stimuli

Hodgkin-Huxley model for action potentials

\[ C_m \frac{dV}{dt} = -g_L (V - V_L) - g_{Na} m^3 h (V - V_{Na}) - g_K n^4 (V - V_K) \]

\[ \frac{dm}{dt} = \alpha_m (V)(1 - m) - \beta_m (V)m \]

\[ \frac{dh}{dt} = \alpha_h (V)(1 - h) - \beta_h (V)h \]

\[ \frac{dn}{dt} = \alpha_n (V)(1 - n) - \beta_n (V)n \]

**Figure 12.** Theoretical action potential and conductance changes obtained by numerical solution of equation (8) and subsidiary equations for \( n, m \) and \( h \); the constants used were appropriate to a temperature of 18.5°C; from Hodgkin & Huxley (1952d). Total entry of Na\(^+\) = 4.33 pmole/cm\(^2\). Total exit of K\(^+\) = 4.26 pmole/cm\(^2\). Velocity = 19.8 m/sec. Temperature = 18.5°C.
Jansen model for neural populations

- A neural population responds to a pulse with a characteristic change of potential - the impulse-response function

- The resulting PSP then produces an average firing rate in the next population - via a sigmoid transform function

- This firing rate is the impulse for the receiving population and in turn transformed into a potential change (as above)
Jansen model for population potentials

\[
\begin{align*}
\dot{y}_0(t) &= y_3(t) \\
\dot{y}_3(t) &= Aa \text{Sigm}[y_1(t) - y_2(t)] - 2ay_3(t) - a^2 y_0(t) \\
\dot{y}_1(t) &= y_4(t) \\
\dot{y}_4(t) &= Aa \{p(t) + C_2 \text{Sigm}[C_1 y_0(t)]\} \\
&\quad - 2ay_4(t) - a^2 y_1(t) \\
\dot{y}_2(t) &= y_5(t) \\
\dot{y}_5(t) &= Bb \{C_4 \text{Sigm}[C_3 y_0(t)]\} - 2by_5(t) - b^2 y_2(t)
\end{align*}
\]
Modified Jansen model for partial seizures (TLE)

Breakspear et al. model for absence seizures

Figure 1. Schema of principle neural fields and loops within the corticothalamic model. Fields include $e =$ excitatory cortical; $i =$ inhibitory cortical; $s =$ specific thalamic nucleus; $r =$ thalamic reticular nucleus; $n =$ nonspecific subcortical noise. Connectivity and loops include intracortical (ee, ei), corticothalamic (er, se, es), intrathalamic (sr, rs), and ascending noise (sn).
All models work in the vicinity of SS bifurcations

None of the Models includes Space

But imaging suggests strong spatial component

Möller et al., Neuroimage (2007)
Spatio-temporal Mean-Field model

\[
\begin{align*}
\tau \frac{\partial u_1(x, t)}{\partial t} &= -u_1(x) + \int w_1(x-x')f[u_1(x', t)]dx' \\
&\quad - \int w_2(x-x')f[u_2(x', t)]dx' + h_1 + s_1 \\
\tau \frac{\partial u_2(x, t)}{\partial t} &= -u_2(x) + w_3 f[u_1(x, t)] + h_2 + s_2.
\end{align*}
\]

PDE known to display a large number of spatio-temporal patterns (e.g. Hopf-Turing mixed modes)

Amari 1977
Approach

➡️ Reduce PDE to a compartment model
➡️ Use physiologically reasonable coupling
➡️ Study pattern transitions
➡️ Interpret “mean-field” of ST model as representing one ECoG channel
➡️ What are the robust mechanisms?
Extension of mean-field model to include space
Coupling Scheme
Comparison

Transition in Mean Field may result from rhythmic rearrangement
Conclusions

➡ Epileptic EEG may result from a rearrangement of spatio-temporal relationships of neural populations

➡ Mean activity and amplitude of populations may be comparable in normal and epileptic activity

➡ Robust under parameter variation and inhomogeneities

➡ Next step: temporal evolution during seizure activity
Epileptic Rhythms During Absence

G. Baier, Rhythmus (2001)
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