Nonlinear Magnetosensory Evoked Potentials

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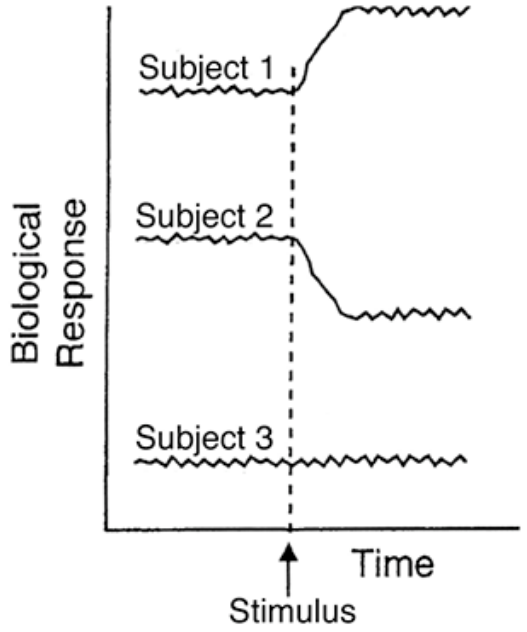
Abstract

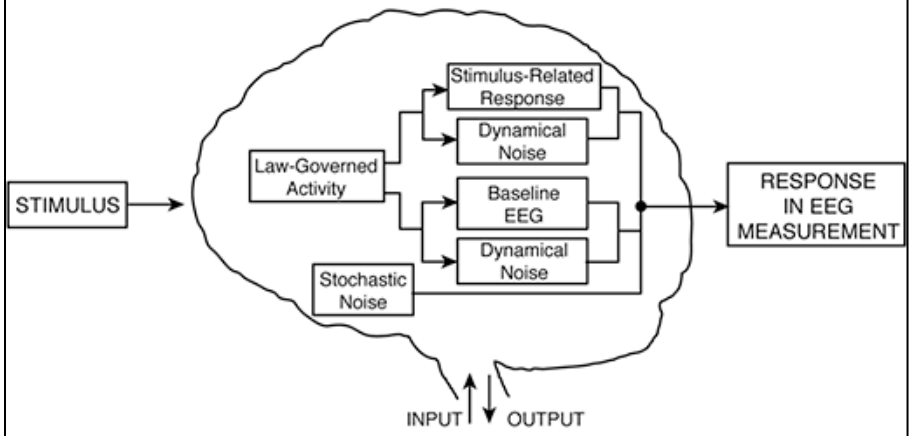
Published reports dealing with the effects of man-made environmental electromagnetic fields (EMFs) (powerlines and mobile phones, as examples) on human brain electrical activity have been inconsistent. We hypothesized that the problem arose from the widespread use of linear methods (time averaging, spectral analysis) to analyze what were essentially nonlinear stimulus-response relationships. We used a nonlinear analytical method to detect deterministic changes in brain electrical activity induced by weak magnetic fields (2 G, 60 Hz).

Nonlinearity in Biology



Different responses to the same stimulus from different subjects.

Stimulus Induced Changes in the Brain



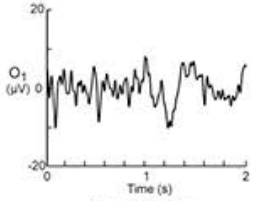
A typical EEG measurement contains contributions from multiple sources, only one of which is governed by the external stimulus.

Choice of Nonlinear Technique

The nonstationarity of the EEG, its finite length, and the multiple sources of the determinism it contains weaken the usefulness of standard nonlinear quantifiers (correlation dimension, Lyapunov exponent, as examples) for characterizing the EEG. We therefore used recurrence plot analysis.

Recurrence Plot Analysis of the EEG

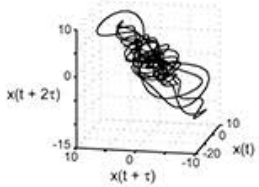
The EEG is measured from standard locations on the scalp (derivation O_1 is illustrated).



Time Series

The EEG is digitized at 300 Hz and analyzed offline.

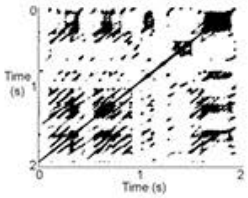
Each epoch of interest is embedded in a five-dimensional phase space with a delay of 5 points.



EEG Trajectory

$$\vec{x}(i) = (u(i), u(i+\tau), \ldots, u(i+\tau(m-1)))$$

A recurrence plot is computed for each epoch and the correlation sum ($C(\varepsilon)$) is computed.

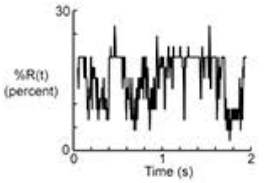


Recurrence Plot

$$R(i,j) = \Theta(\varepsilon - \|\vec{x}(i) - \vec{x}(j)\|, \quad \vec{x}(i) \in \mathbf{R}^m, \quad i,j = 1,\ldots,N$$

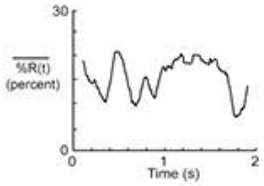
$$C(\varepsilon) = \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} \Theta\left(\varepsilon - \|x_i - x_j\|\right)$$

A %R time series is created by iterating the calculation of %R using a step of 1 point.

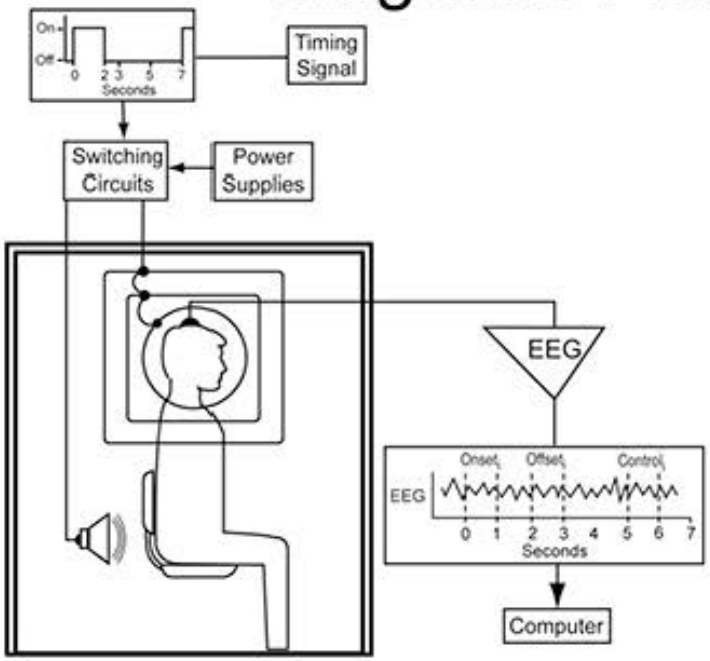


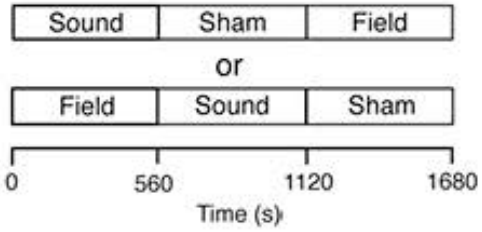
The correlation sum was renamed "percent recurrence" (%R) (Zbilut).

The %R time series is smoothed using a 30-point window to produce a time series %R(t), which is used in all statistical evaluations.



Measuring the EEG During Magnetic-Field Exposure





A computer-generated timing signal controlled application of the stimuli (on for 2 seconds, interstimulus period of 5 seconds). Location of onset, offset, and control epochs of the ith trial are shown.

Effect of Magnetic-Field Onset on Brain Electrical Activity of a 20-Year-Old Male

Linear Method

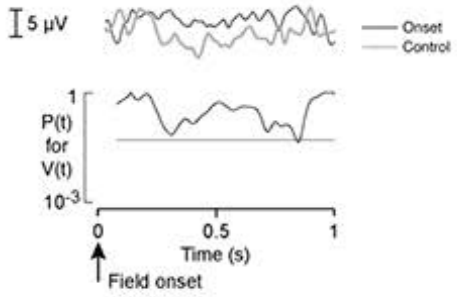
Point-by-point comparison-wise probability of a difference between average value of V(t) for the onset and control epochs, assessed using the paired T test.

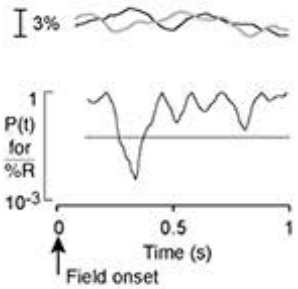
Nonlinear Method

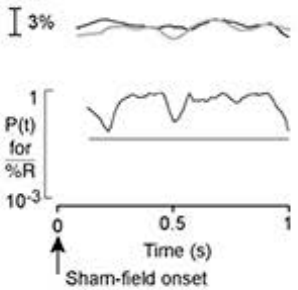
Corresponding probability for %R(t)

Results from the sham- field experiment.

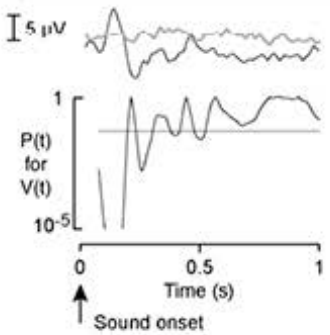
Magnetic Field

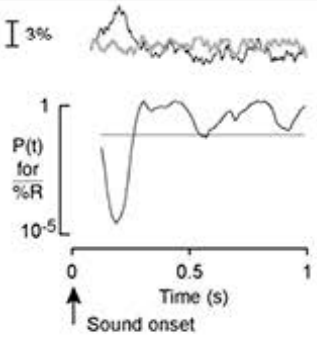


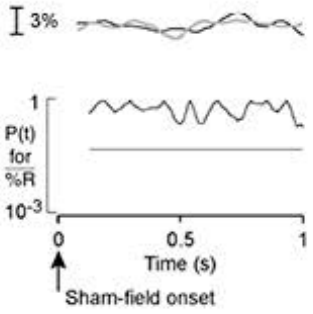




Sound

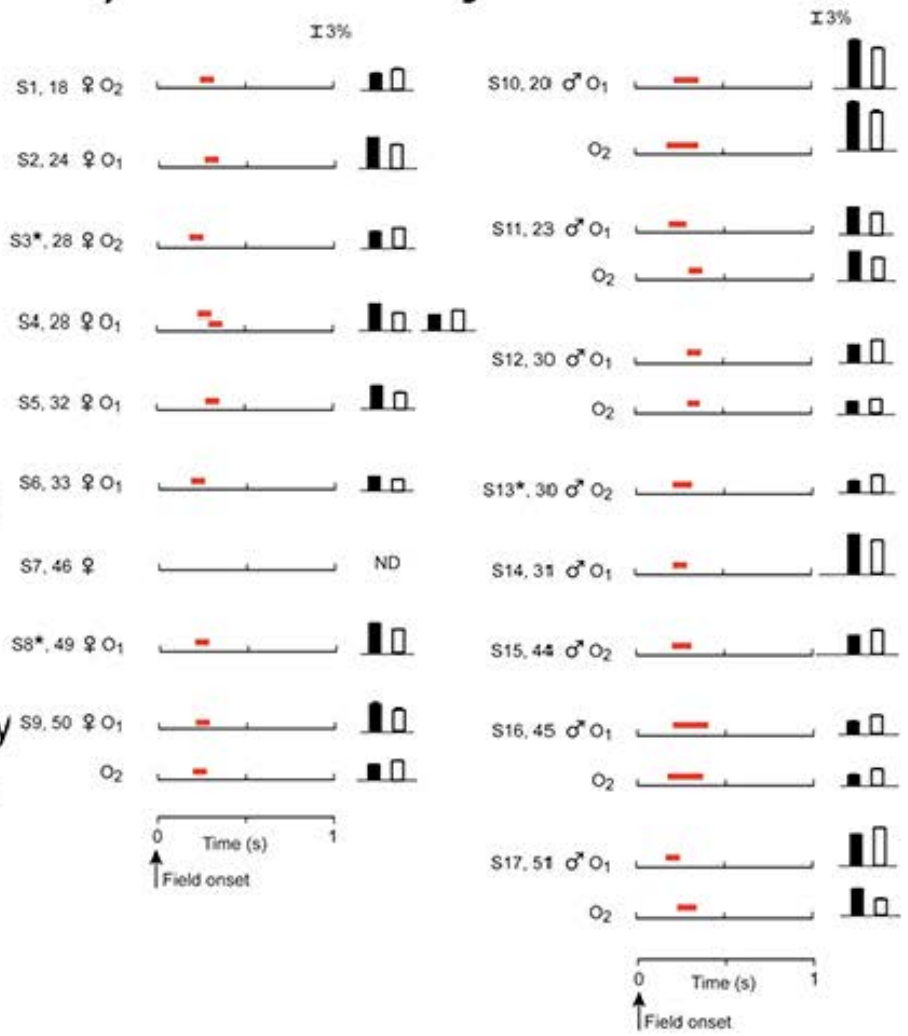






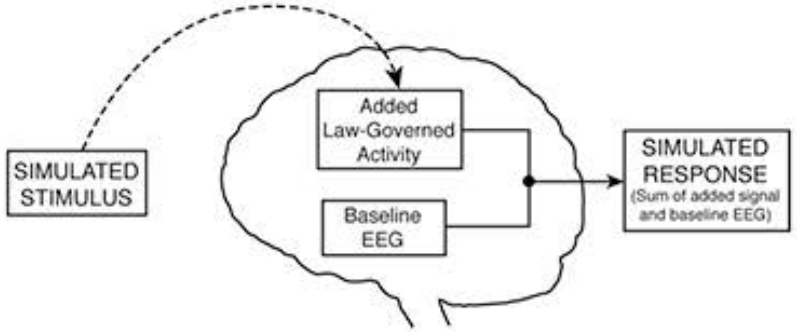
Detection of Onset Magnetosensory Evoked Potentials (MEPs) in 17 Subjects

Onset magnetosensory evoked potentials measured from occipital electrodes. Latency and duration in each subject are indicated by a red bar, which shows the location of the points in in the onset epochs that differed from the corresponding control. Bar graphs indicate the mean ± SD of the MEP observed in (average of the significant points). Black and white bars correspond to onset and control epochs, respectively (SD not resolved at scale presented). ND, not detected.

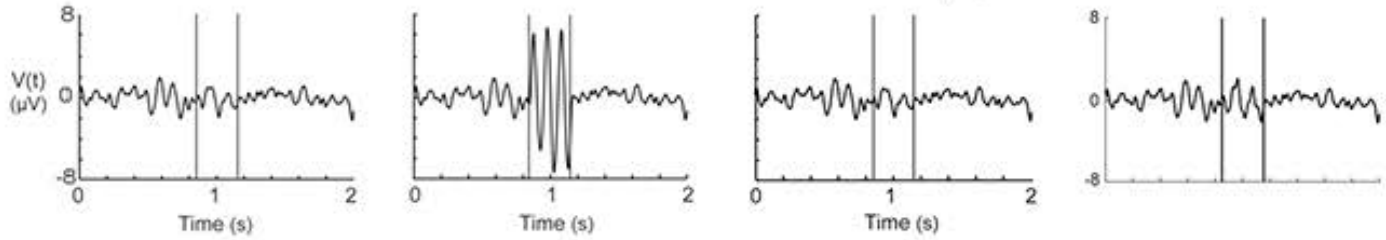


Models of Brain Electrical Activity

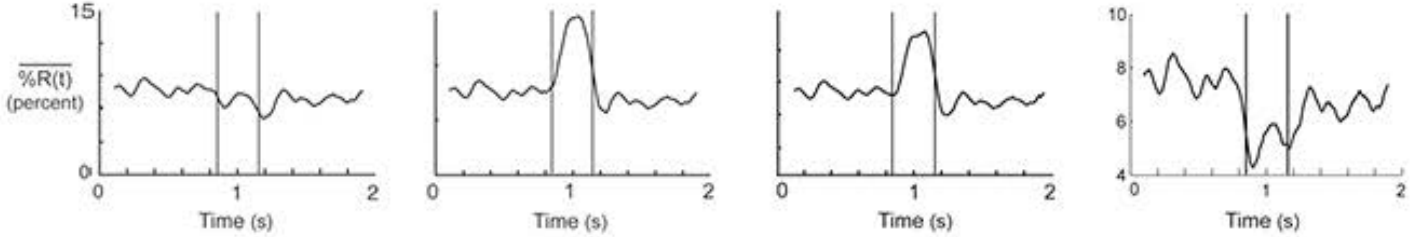
Basis of a mathematical model to mimic a stimulus-response relationship detected in an EEG measurement.



Time Averaging



Recurrence Analysis



Time average of baseline EEG from O_1.

Addition of fixed phase 10-Hz sine signal.

Addition of random phase 10-Hz sine signal.

Addition of Lorenz signals.

Conclusion

Nonlinear analysis of the EEG permits detection of MEPs, which cannot be detected by linear analysis.

References

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