Improved recurrence quantification analysis for the investigation of ERP data

Norbert Marwan[1], Andreas Groth[2]

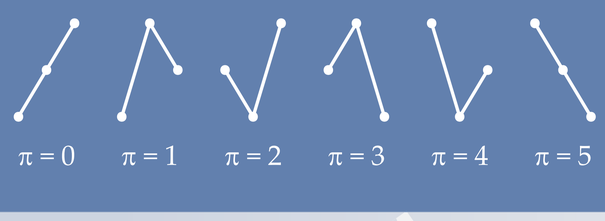
[1]Nonlinear Dynamics Group, University of Potsdam, [2]Department of Mathematics and Informatics, Ernst-Moritz-Arndt Univeristy of Greifswald

Order Patterns Recurrence Plots

For the investigation of dynamical systems, recurrence based methods have proven its potential even for short and non-stationary data series. A recurrence plot is usually defined as a binary matrix representing the pairwise closeness of the values of a data series:

$$\mathbf{R}(i, j) = \Theta(\varepsilon - \| \mathbf{x}(i) - \mathbf{x}(j) \|).$$

Instead of using the pairwise closeness, the pairwise comparison of order patterns $\pi(i)$ can be used. An order pattern π of dimension m is defined by the discrete order sequence of the data series $x(i)$ of length m. For $m = 3$ we have, e.g., six order patterns:



Using such order patterns, a data series $x(i)$ can be symbolized by order patterns:

$$x(i), x(i - \tau_1), \ldots, x(i - \tau_{m-1}) \rightarrow \pi(i).$$

The order patterns recurrence plot is then defined by the pairwise test of order patterns (Groth, 2005):

$$\mathbf{R}(i, j) = \delta(\pi(i), \pi(j)).$$

Such a recurrence plots represents those times, when specific rank order sequences in the system recur. Its main advantage is its much better robustness against non-stationary data.

Recurrence quantification analysis can also be applied to order patterns recurrence plots. Common measures are recurrence rate (density of recurrence points), determinism (ratio of recurrence points forming diagonal lines), laminarity (ratio of recurrence points forming vertical lines), mean diagonal line length and mean vertical line length (for an overview cf. Marwan. 2003).

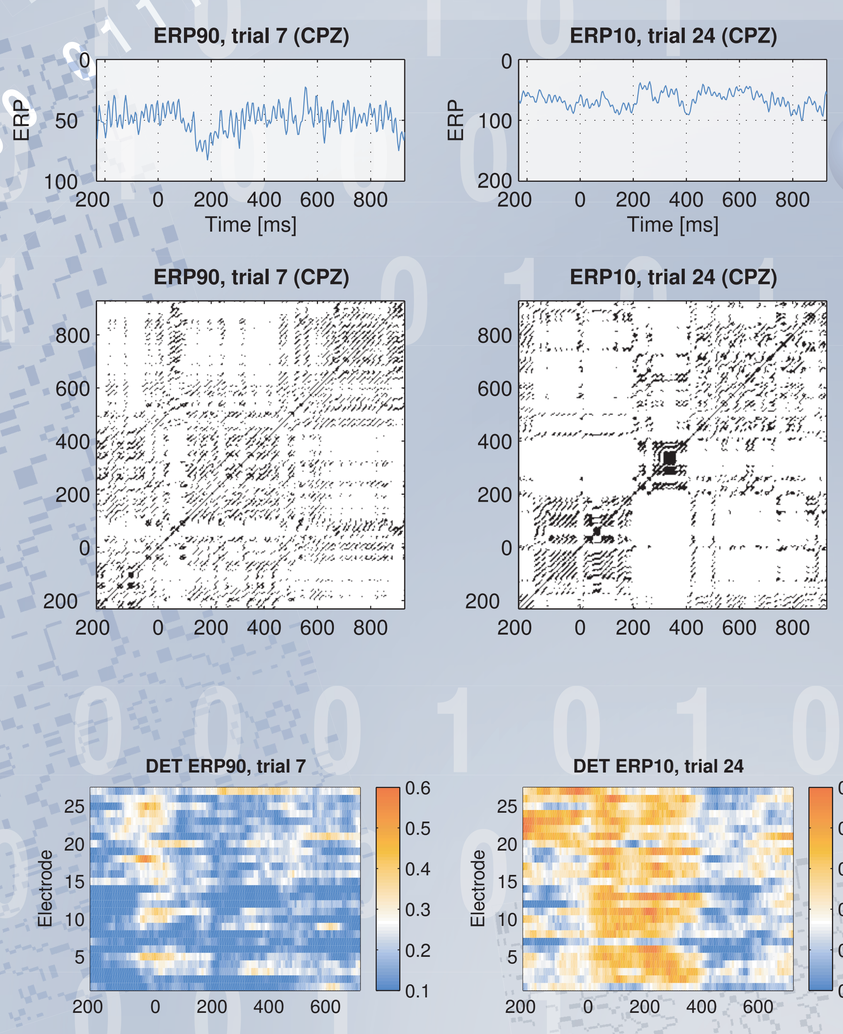
Application to Data of Event Related Potentials (ERP)

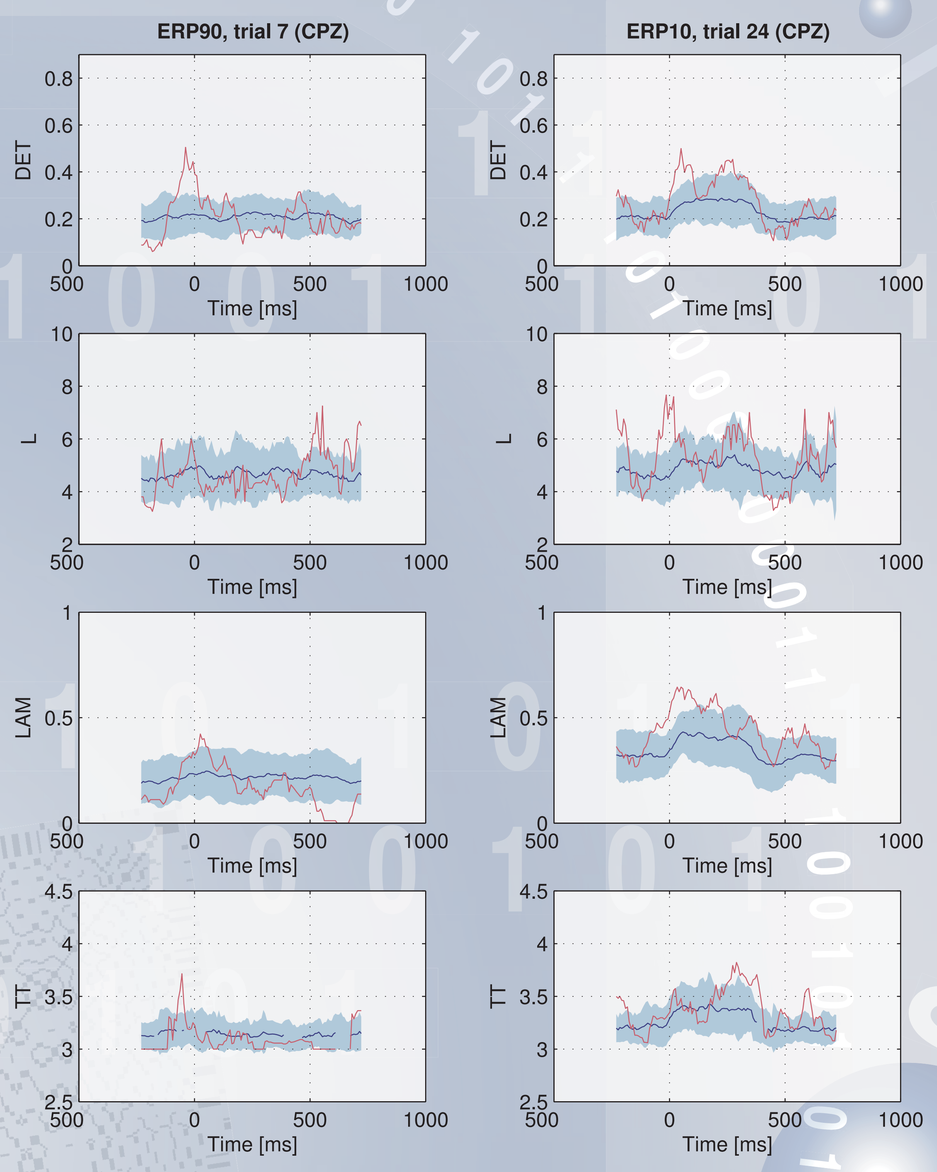
In the Oddball experiment, a number of visual or acoustic stimulii of different surprising effect (10% and 90% event probability) is shown to a proband. The averaging of the measured EEG data reveals a P300 component, which is anti-correlated with the event probability. This component reflects the switching between two modi of cognitive behaviour: During episodes where the frequent stimuli are presented to the subjects, they went into a mode of automatic processing of the events. When suddenly the rare stimulus arises, the brain function is switched to controlled processing.

The investigation of such ERPs on a single trial basis is rather difficult. However, recurrence based methods have the potential to recognize the specific ERP components even on a single trial basis (Marwan and Meincke, 2004). Using the new introduced order patterns recurrence plots, this method can be further improved.

Common Recurrence Plot (fixed amount of nearest neighbours)

Recurrence plots (fixed amount of nearest neighbours) for ERP data of event probability 90% (left) and 10% (right) reveal significant differences between ERP90 and ERP10 data at 300 ms after event (P300 component).

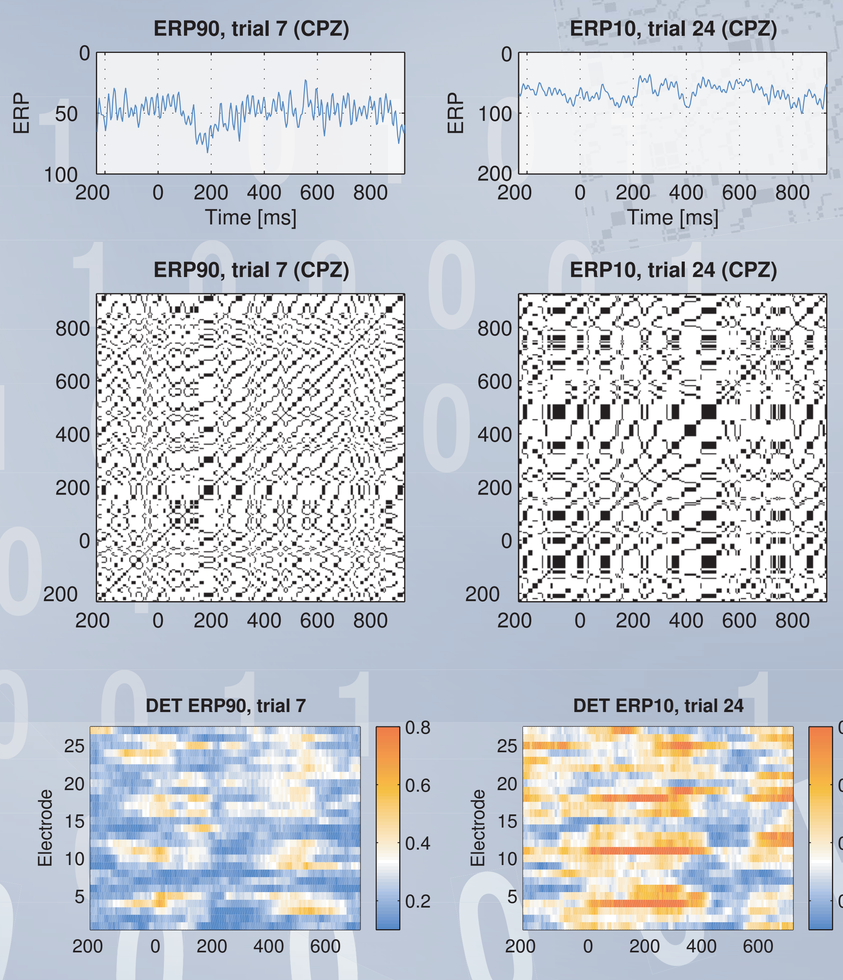


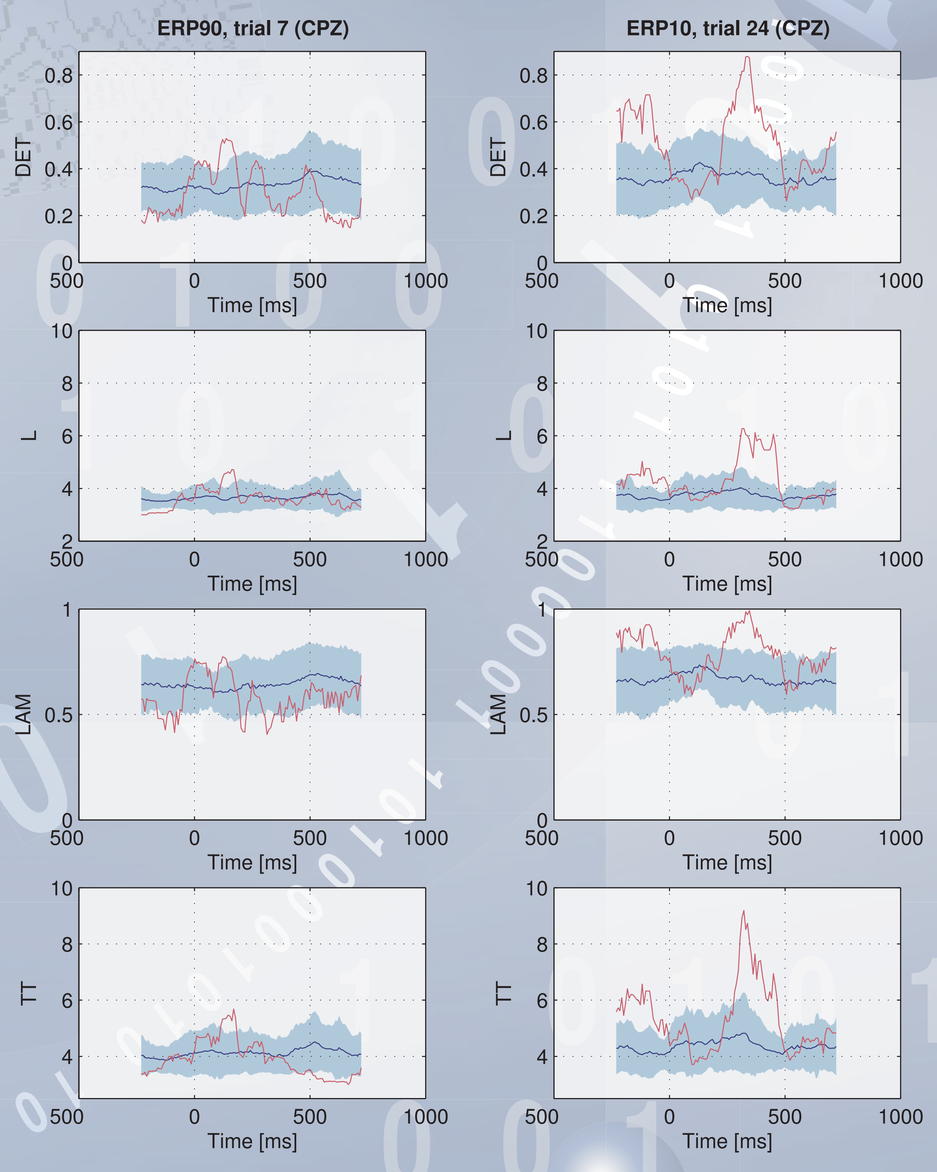


Recurrence quantification measures for ERP data of event probability 90% (left) and 10% (right) reveals clearly the N100 and P300 component.

Order Patterns Recurrence Plot

Order patterns recurrence plots for ERP data of event probability 90% (left) and 10% (right) have a different appearance in comparison to common recurrence plots.





Recurrence quantification measures yielded from order patterns recurrence plots for ERP data of event probability 90% (left) and 10% (right) have higher values than the same measures of common recurrence plots (especially around 300 ms after the event). The P300 component can be better recognized by using order patterns recurrence plots.

References

Groth, A.: Vizualization and detection of coupling in time series by order recurrence plots, Preprint series of the DFG priority program 1114, 67, ISBN: 3-88722-642-9, 2004

Marwan, N., Meincke, A.: Extended recurrence plot analysis and its application to ERP data, International Journal of Bifurcation and Chaos, 14(2), 2004, 761-771

Marwan, N: Encounters with Neighbours – Current Developments of Concepts Based on Recurrence Plots and their Applications, PhD thesis, University of Potsdam, 2003, ISBN 3-00-012347-4

Norbert Marwan
Nonlinear Dynamics Group
University of Potsdam
Tel.: 0049 (0) 331 977-1302
eMail: marwan@agnld.uni-potsdam.de

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