RECURRENCE QUANTIFICATION ANALYSIS: A MODEL-FREE ANALYTICAL METHOD FOR CEREBRAL FMRI DATA

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Introduction

We introduce a novel model-free univariate strategy of functional Magnetic Resonance Image (fMRI) analysis ("patent pending"), based on Recurrence Quantification Analysis (RQA) [1]. RQA is an auto-regressive method able to study dynamic features in signals without any a-priori assumption and to describe both linear and non-linear processes, without requiring stationarity. The most widely used RQA parameters are recurrence and determinism [1]. The performance of RQA is compared to univariate statistics based on the General Linear Model (GLM) [2] for a set of simulated and real fMRI data.

Methods

In simulations, we produced nine whole brain data sets of an entire fMRI session (TR=1s; Nscans=257; block design: 16 scans ON/OFF cycle) with temporal contrast-to-noise ratio (tCNR) ranging from 0.1 to 0.4 as well as several haemodynamic and neuronal responses. In the experimental runs, we recorded signals from five different subjects each participating at two experimental sessions consisting in blocks of finger tapping (16scans ON/OFF cycle), see [3]. We analyzed both simulated and real data by means of SPM2 (http://www.fil.ion.ucl.ac.uk/spm/spm2.html) and of CROSS RECURRENCE PLOT TOOLBOX 5.8 (R22.4, http://www.agnld.uni-potsdam.de/~marwan/toolbox/).

Results

On simulated data, RQA is endowed with excellent accuracy for contrast-to-noise ratio greater than 0.2 (Fig. 1). Moreover, RQA appears more robust than GLM analysis with respect to variations in the shape and timing of both neuronal and haemodynamic responses (not shown). Group analysis of RQA descriptors revealed activation (Fig. 2B): in the primary motor area contra-lateral to the employed hand and in the supplementary motor area, in full agreement with the outcome of GLM analysis (Fig. 2D, red). By means of RQA, we also found significant activation in the right motor area and in parietal regions (precuneus), which corresponds to de-activation in the GLM approach (Fig. 2D, green). Finally, we found additional recurrent patterns in two (one) clusters in the middle (superior) frontal gyrus.

Conclusions

RQA provides an appealing alternative to conventional GLM techniques, due to its exclusive feature of being model-free. It also appears conceivable to use this method for systematic studies concerning spontaneous brain activity (resting brain, sleep, etc.).

Bibliography

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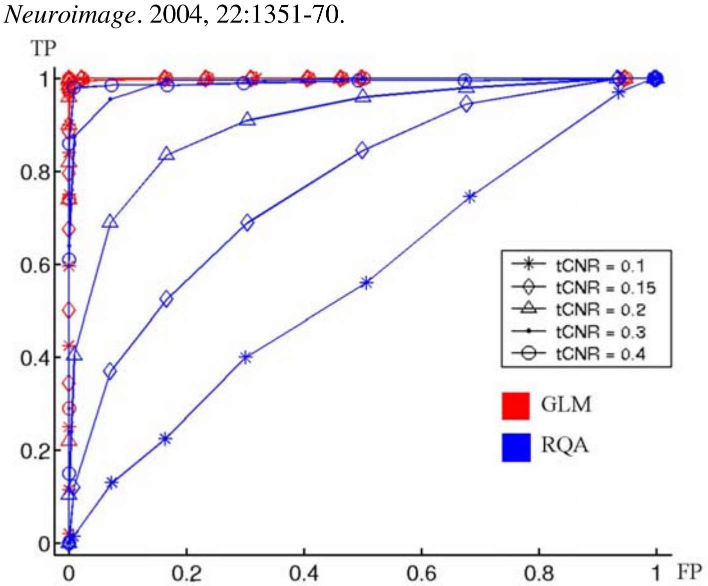

Fig.1 ROC curves of simulated data with changing tCNR for two statistical tests (t-test on GLM parameter estimates and RQA). X and Y axes refer respectively to false positives and true positives.

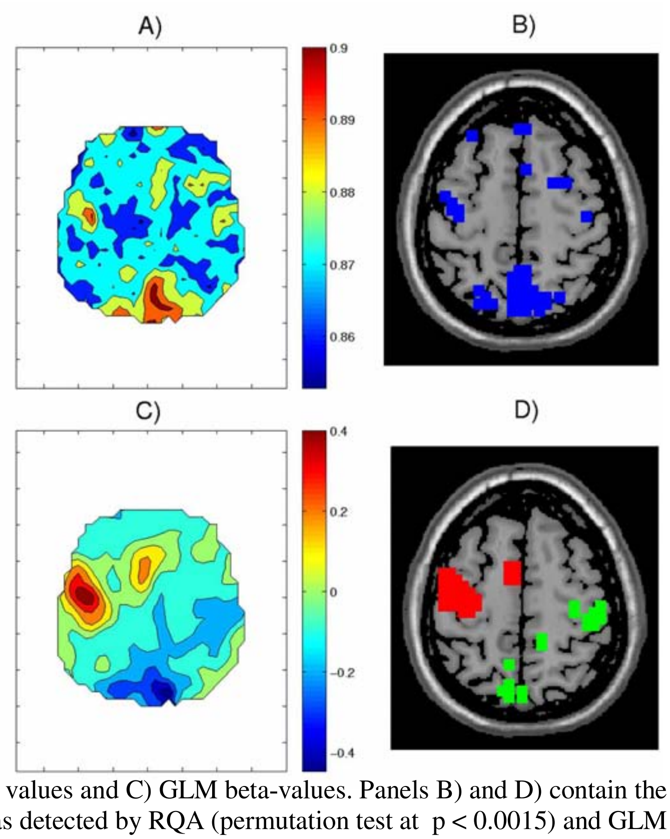

Fig.2 Group average map of A) determinism values and C) GLM beta-values. Panels B) and D) contain the significant activations at the population level as detected by RQA (permutation test at $p < 0.0015$) and GLM (activations - red, $p < 0.001$ and cluster extension = 10 voxels; deactivations – green $p < 0.005$), respectively.