DETECTING BRAIN CONNECTIVITY CHANGES DURING SEIZURES USING GRANGER CAUSALITY MEASURES ON SCALP EEG

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Objective

In this work the objective is to detect brain connectivity changes during epileptic seizures using methods of multivariate time series analysis on scalp multi-channel EEG. Different brain regions represented by the electrode positions interact in terms of Granger causality and these directed connections formulate the brain network at a certain time window. The numerous proposed network features are believed to capture the information of many network characteristics. The ability of a single network feature of the brain network to detect the transition of brain activity from preictal to ictal is examined. The connectivity of the brain is estimated by 13 Granger causality indices on 7 epochs from multivariate time series (19 channels per epoch) at 15 time windows of 20 seconds (5 min in total) before seizure and during the seizure. The characteristics of the networks are estimated by 379 network features. Finally, the discrimination task (preictal vs. ictal) for each network feature is evaluated by the *area under receiver operating characteristic curve* (AUROC).

A. Electroencephalograms - EEG Data

(provided by the Division of Neuroscience, Rikshospitalet, Oslo, Norway)

7 preictal scalp EEG records:

- Single seizure episode of 7 patients.
- All (but one) are generalized tonic clonic (GTC) seizures.
- At least 3h and 10min duration prior to seizure onset.
- 19 channels (frontal channels excluded), 10-20 system.
- Sampling time 0.01s (after subsampling),
- Filtering (high-pass at 0.3Hz, low-pass at 40Hz),
- No other data pre-processing.

Consecutive non-overlapping segments of duration 20 s (time series length = 2000)

Classes

From each EEG record two brain states were used for the discrimination task:

- **Pre-ictal**: the last 5 min before the seizure onset, **totally 15 segments** of 20s.
- **Ictal**: from 1min 10s to 13min 44s depending on the duration of the seizure.

B. Causality measures and Network Features

B1. Five Granger causality measures [1,2]

Representative Granger causality (GC) measures, selected to be computationally efficient, from time (1) frequency (2) state (3) and phase (4) domain are used:

- (1). Restricted conditional Granger causality index RCGCI
- (2a). Restricted Generalized Partial Directed Coherence at the bands δ , θ , α , β , γ , denoted RGPDCd, RGPDCt, RGPDCa, RGPDCb and RGPDCg.
- (2b). Imaginary Coherence at the bands δ , θ , α , β , γ , denoted iCOHd, iCOHt, iCOHa, iCOHb and iCOHg.
- (3). Synchronization likelihood (SL)
- (4). Weighted phase lag index (wPLI).

Measures (1) and (2a) are the corresponding to CGCI and GPDC making use of dimension reduction (selecting a subset of terms in VAR model).

A weighted **causality network** is formed from each GC(i->j) measure computed for all (i,j) pairs **at each segment**.

B2. Network Features [3]

A large number (379) of network measures were computed **at each causality network**, including:

- global network measures (mean, std, skewness, kurtosis of the strength distribution, radius, diameter, centrality, transitivity ratio, eccentricity, clustering coefficient etc.) and
- the respective local (node-specific) measures.

Methodology

C. Evaluation of network measures with AUROC [4]

The ability of the network features to discriminate ictal from pre-ictal activity is assessed by the *area under receiver operating characteristic curve* (AUROC). If AUROC=1 there is perfect discrimination of the two classes (the feature values in the two groups do not overlap), if AUROC=0.5 the classification is considered as random.

Results

Figure 1: Boxplots of network measure values before and during the seizure of one epoch. (a) **Global clustering coefficient**, (b) **mean strength**. Both network measures are computed on networks generated by the Granger causality index **RCGCI**

Figure 2: Network measure **mod(5)** on the pre-ictal and ictal period of all recordings. Network formulation with **RGPDCa**.

Figure 3: Evaluation of Granger causality measures. Each causality measure is assigned the average AUROC value (over 7 epochs) of the network measure with the highest rank for this causality measure.

Causality index	Network measure	Avg AUROC
RGPDCa	mod(5)	0.887
iCOHb	str in channel P3	0.870
RGPDCd	mod(3)	0.861
iCOHg	str channel F10	0.855
iCOHg	clustering coef WD F10	0.853
iCOHb	clustering coef WD Cz	0.852
RGPDCd	mean in strength	0.851
RGPDCd	mean out strength	0.851
RGPDCd	mean strength	0.851
RGPDCd	global clustering coef WD	0.848

Table 1: the top 10 features (causality index combined with network measure) in terms of average AUROC value over 7 epochs

Conclusions

- Connectivity analysis indicates structural changes of the brain network during seizures
- Increase of total connectivity, strength of the links and clustering of the nodes (i.e. brain regions) is observed during the seizures of all epochs
- The Granger causality index RGPDC (alpha band) enables network characteristics such as modularity to discriminate the pre-ictal period from the ictal with high discriminative ability evaluated with average AUROC greater than 0.88

References

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