Time–Frequency Dynamics of Brain Connectivity by Stochastic Oscillator Models and Kalman Filtering

Arno Solin[1,2], Enrico Glerean[1,2], Simo Särkkä[1,2]

[1] Department of Biomedical Engineering and Computational Science, Aalto University, Espoo, Finland

[2] Advanced Magnetic Imaging Centre, Aalto University, Espoo, Finland

INTRODUCTION

A growing interest in brain connectivity has emerged with advances in non-invasive imaging techniques and development of methods to estimate connectivity (see [5] for a review). With functional magnetic resonance imaging (fMRI), functional connectivity is often estimated as the average pairwise similarity between the temporal dynamics of two regions of interests (ROIs) producing a static similarity index usually between −1 and 1. However there has been growing interest in estimating time-varying functional connectivity during rest [1] and during complex stimulation [2], where the stimulus is continuously changing, modulating the functional connectivity in time. Here, we study the functional connectivity between pairs of voxels by considering the time–frequency dynamics between them. Each pair of time series is decomposed into oscillatory components described by a stochastic oscillator model [4], and coherence between the different frequency components is converted into network edges time series, i.e. yielding a time-varying functional network.

METHODS

We use stochastic oscillator model, that is described by a second order stochastic differential equation, and fit it to the fMRI voxel data using Kalman filtering and smoothing. The model is based on [4], but evaluated over a set of fixed frequencies. The filtering result is converted into a cross-coherence power surface, and the sum over frequencies defines the functional activation between the regions (such as in [1]). We compare the pairwise activation time series to ground truth stimuli in order to estimate connectivity maps describing various types of connections.

Functional brain images together with anatomical data were acquired for fourteen healthy native speakers of Finnish. The subjects watched 22 min 58 s of a Finnish language film in an MRI scanner (3 T GE Signa Excite, 8-channel head coil). The film was a shortened version of the feature film “Match Factory Girl” (dir. Aki Kaurismäki, 1990, original length 68 min). The shorter version retained the storyline and smooth flow of scenes. Functional EPI brain imaging for 29 slices was carried out with sequence parameters: TR: 2 s, TE: 32 ms, matrix size: 64x64, FA: 90 degrees, voxel size: 3.4x3.4 mm, slice thickness: 4 mm, gap size: 1 mm. We then spatially downsampled the functional data into 6 mm isotropic voxels for a total of 6235 gray matter voxels and computed all pairwise time-varying functional connections for a total of ~19 million time series. Visual and auditory features from the film were extracted as ground truth references. These time series show activity of 16 different auditory and visual stimuli such as hand/head/body motion, visual contrast, speech, singing and music in the movie. See [3] for further details on this data and the preprocessing steps.

RESULTS

Fig. 1 shows two simulated oscillatory time series with changing frequencies and noisy observations. The cross-power and cross-coherence of the signals have been estimated using the proposed method, and the relative phase between the identified outcome is shown by arrows. The results indicate that the method works well on simulated data. Brief results for the experimental study is presented in Fig. 2, where we show the functional connectivity network related to sound volume (left) and picture contrast (right) stimuli. The results show that the two networks modulated by the auditory and visual stimuli are localized, identifying different connectivity patterns related to each modality.

Fig. 1

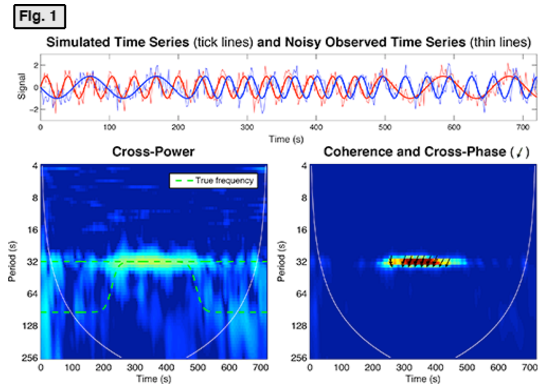
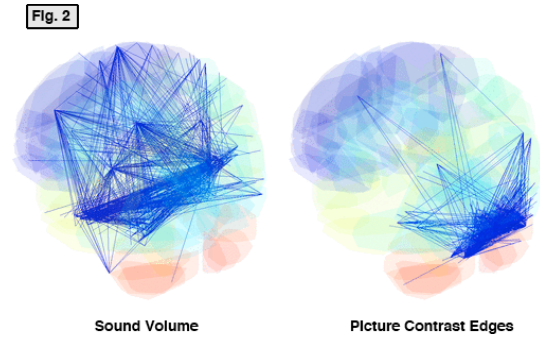


Fig. 2



CONCLUSIONS

We have proposed a method for estimating coupling of oscillatory phenomena in fMRI data. The method uses a Kalman filtering approach for inferring the states of a stochastic oscillator model from noisy data. The outcome can be used for estimating time-varying functional connectivity networks. This approach is related to that of [1], where a wavelet basis was used for modeling the cross-coherence.

REFERENCES

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