LOW FREQUENCY PHASE SYNCHRONISATION ANALYSIS OF MEG RECORDINGS FROM CHILDREN WITH ADHD AND CONTROLS USING SINGLE CHANNEL ICA

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This work presents a study on networks of brain activity based on the analysis of low frequency MEG recordings of children with Attention Deficit Hyperactivity Disorder (ADHD) and controls whilst performing attentional and perceptual tasks. Single channel independent component analysis (SCICA), a blind source separation technique that only uses temporal information inherent in single channel recordings, is applied here to isolate slow waves within the data and perform denoising. Phase synchronisation analysis is then carried out to quantify any interaction between distant brain regions during various rest and task conditions.

Introduction

The human brain is intrinsically organised into dynamic, anti-correlated functional networks. (Fox *et al.* 2005)

- One network that is active when the brain is apparently at rest is **the default mode network**, which is:
  - Associated with stimulus independent processes
  - Particularly observable during resting states.
- Within this default network of brain activity there are spontaneous coherent low frequency oscillations <0.1 Hz, which sometimes re-emerge during task periods to compete with active goal-directed attention.
- Thus there exists spontaneous low f toggling of:
  Task negative components ⟹ task-independent,
  Task positive components ⟹ related to activity.
  This competition results in interference in task related performance.

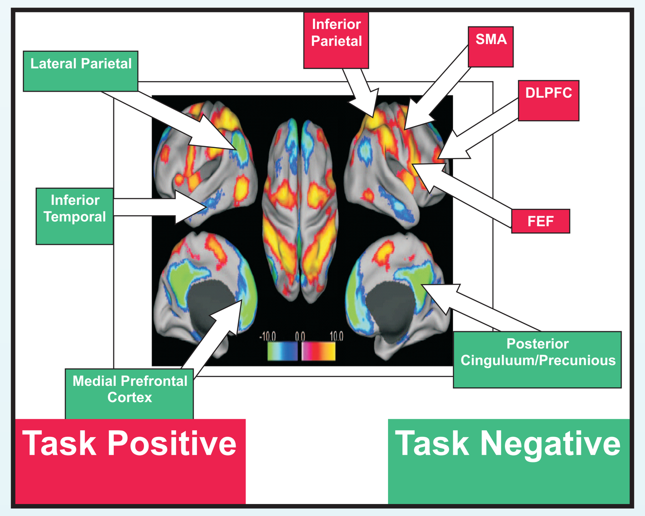

Fig. 1 Neuroanatomical components of the task positive and negative components

- This is illustrated by spontaneous fluctuations in fMRI BOLD (Blood Oxygen Level Dependent) images at rest, and forms the basis of the Default Mode Interference (DMI) Hypothesis.

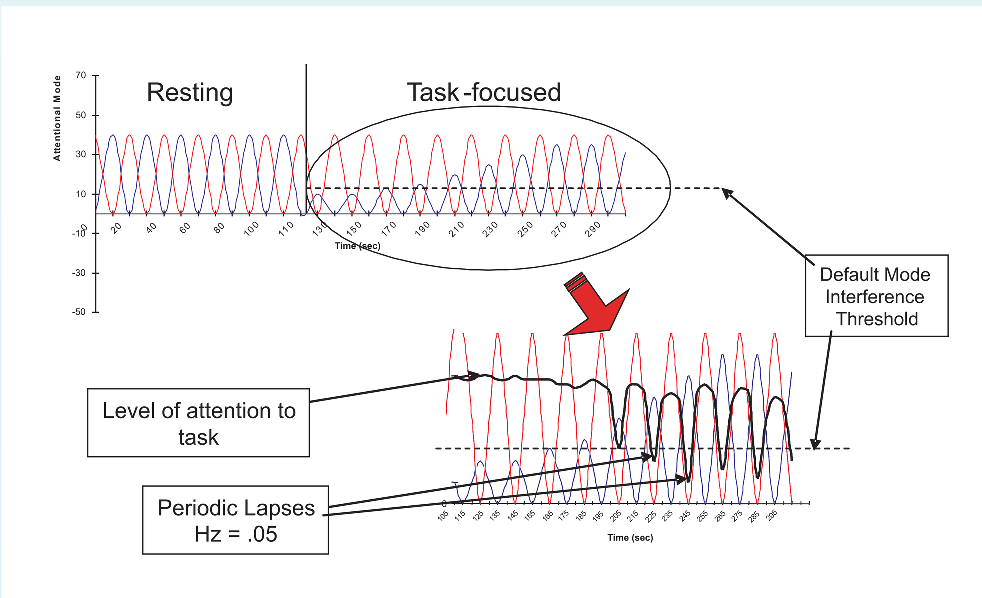

Fig. 2 Illustration of the DMI Hypothesis. Attenuation of the task negative component at the onset of the task results in a high level of attention. Its re-emergence leads to periodic attention lapses.

DMI and Attention-Deficit Hyperactivity Disorder

- ADHD is one of the most well recognised childhood developmental problems, characterised by patterns of inattention, impulsivity and hyperactivity. The DMI hypothesis suggests that sustained attention lapses in ADHD are due to periodic lapses in attention which:
  - Result from the intrusion of the task negative components and
  - Cause increased performance variability.
- Here we present a preliminary investigation of these findings and address the following issues:
  i. Can the LFOs associated with the default network be identified within MEG recordings?
  ii. Are distinct brain areas interacting during different rest and task conditions, forming a network of brain activity?
  iii. Is there a change in this interaction with a switch from rest to task?
  iv. What are the differences (if any) between ADHD and controls?

Single Channel Independent Component Analysis (SCICA)

- Requirements for the analysis:
  - Dimensionality reduction of the 148 channel MEG system
  - Denoising to extract artifactual & neurophysiologically meaningful sources
  - Identifying frequency bands of interest
- SCICA extracts independent components (ICs) from a scalar time series $x(t)$ by forming a matrix of delay vectors $X(t)$ such that:

$$X(t) = [x(t), x(t-1), \ldots, x(t-m+1)] \in \Re^m$$

m = no. of delay vectors, must be large enough to capture the signal dynamics.

- $X(t)$ is represented as a purely temporal ICA source model
- Independence criterion = sources must have disjoint spectral support
- SCICA algorithm learns a set of filters to discriminate between ICs with distinct frequency responses

Phase Synchrony (PS)

- PS is a measure that shows whether the phase shift between any two signals is close to a constant over the specified time interval. It is derived following a three step process:
  i. Estimating the instantaneous phase of each signal by the Hilbert Transform
  ii. Establishing a phase locking coefficient, Phase Locking Value (PLV):

$$PLV = \left| \frac{1}{N_{trial}} \sum_{n=1}^{N_{trial}} e^{j(\Delta\varphi(t,n))} \right|$$

where N_{trial} is the length of window in samples and $\Delta\varphi(t,n)$ is the phase difference between the two channels.

  iii. Establishing a statistical criterion to quantify the degree of phase locking - Phase Locking Statistics:
  Compare original PLV between 2 channels to surrogate PLVs that preserve all the individual structure of the data while destroying any interdependencies between the signals. Construct a distribution for the surrogate PLVs, its 95 % quantile provides a significance threshold.

MEG Data

- A 148-channel whole-head magnetometer array (Magnes® 2500 WH, 4-D Neuroimaging, San Diego, California, USA)
- Brain recordings of 2 DSM-IV diagnosed ADHD children and 2 age and intelligence-matched controls
- Sampling rate of 100 Hz
- 20 minute (for attention task) and 12 minute (for perception task) recordings for every participant
- Each recording contains 3 minutes task blocks separated by variable resting period
- Within each block 100 ms long stimuli appeared on screen, each followed by a variable interstimulus interval of 400-650 ms

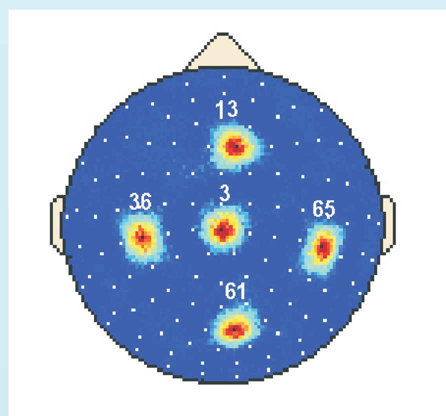

Fig. 3 Location of the MEG Channels chosen for the SCICA analysis

Analysis Strategy

- For each recording: FastICA applied to the multichannel raw data; ICs related to eye blinks, eye movement and ECG subtracted from the data
- Data downsampled to 10 Hz, then low pass filtered to 2 Hz
- 5 channels selected (Fig.3), temporally whitened and dimension reduced by the discrete cosine transform
- For each channel, underlying ICs extracted and their magnitude frequency response found
- Established phase locking between ICs belonging to each pair of channels, (PS: 20 seconds time windows, randomly cycle-shifted surrogates)

PS & SCICA Results

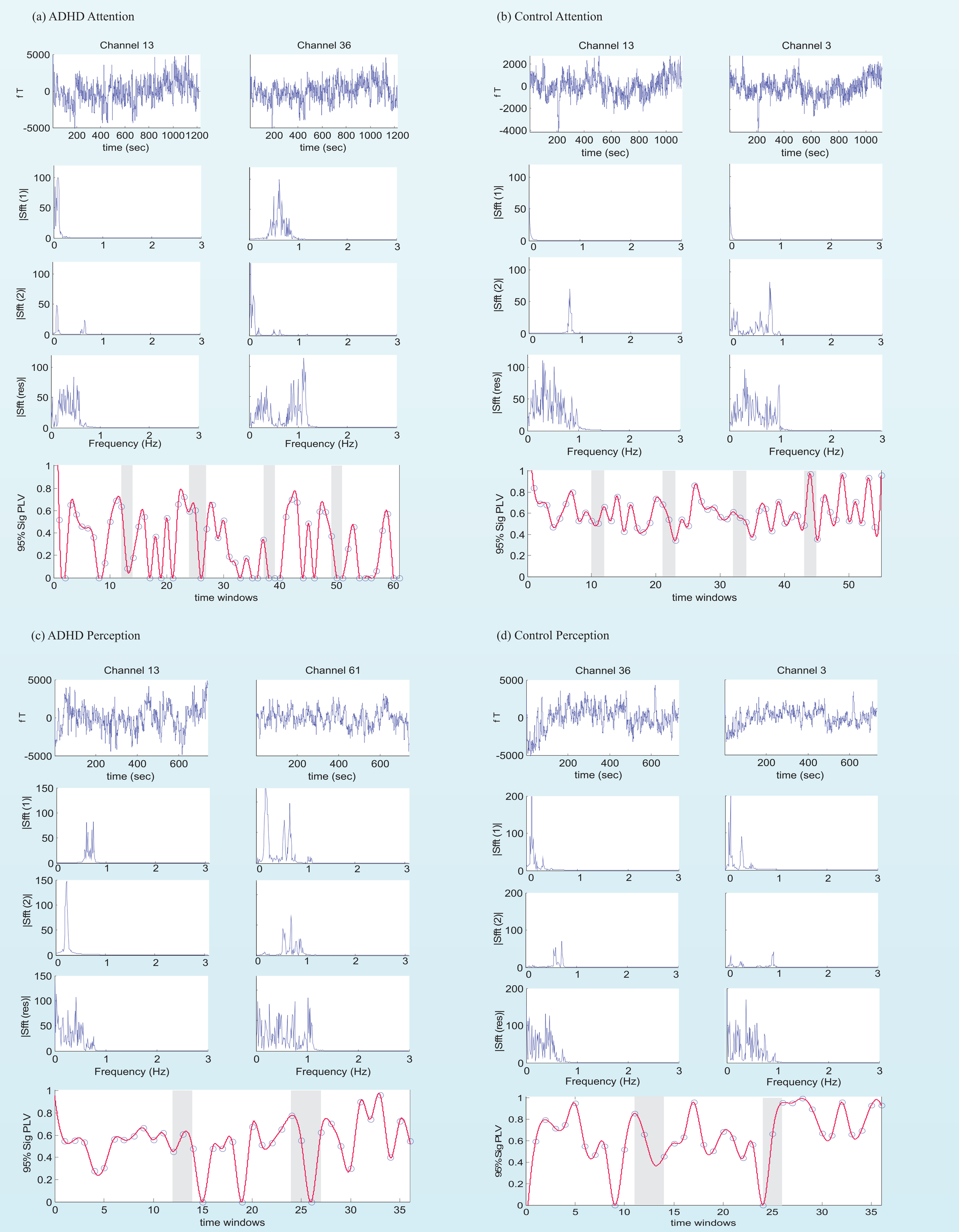

Fig. 4 Each quadrant shows 2 channels (cleaned from ECG and occular artifacts), and the frequency response of their ICs extracted by SCICA; |Sfft| denotes the magnitude of the single-sided amplitude spectrum of the ICs.

The 95 % significant PLV plot shows the overall phase synchrony obtained by considering the maximum significant PLV between all pairs of ICs of the two channels having overlapping frequency bands.

The resting periods are shaded in grey, following the task periods. Quadrant (a) shows ADHD attention, (b) Control attention, (c) ADHD perception and (d) Control perception task.

Conclusion

- Results indicate synchronisation between fronto-central & parietal areas
- Drop in phase locking following a switch from task to rest, (possibly due to suppression of task +ve component)
- More fluctuations in PS during attention task blocks for ADHD than for control patients (possible effect of task -ve component)
- Future analysis:
  - Identifying further active seed regions within and outside the DM network
  - Phase locking variations with stimuli within task blocks w.r.t. response times
  - Modulation of response time to stimuli by slow waves

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