Spectral differences in language processing areas in good and dyslexic readers

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Introduction Recent functional connectivity results for a continuous Phoneme Mapping task [1] have shown differences in BOLD signal changes in normal and dyslexic readers in areas associated with phonological processing, such as inferior frontal gyrus (IFG), angular gyrus (AG) etc. Of interest now is to investigate how the signals in the specified regions and the coherence between the brain regions evolve during task performance. A meticulous spectral analysis can help develop a task-specific connectivity model to compare subject populations.

Theory Duality between the temporal and spectral signal characteristics allow to identify periodic oscillations present in individual signals [2]. A frequency spectrum remains the same for different phase shifts and provides means to locate signals with similar temporal profile at different time lags. Spectral similarity and a subsequent phase changes could be determined from the cross spectrum of the series, $s_{xy}(f)$. Coherence can be viewed as the analogue to the correlation coefficient in the frequency domain. The squared coherency between the time courses x_t and y_t at frequency f is a standardized cross-spectrum defined as

$$coh(x_t, y_t) = |R_{xy}(f)|^2 = \frac{|s_{xy}(f)|^2}{s_{xx}(f)s_{yy}(f)}$$, where $s_{xx}(f)$ ($s_{yy}(f)$) is the power spectrum of x_t (y_t).

By transferring the observed signal into the frequency domain one looses temporal information making it impossible to determine at which particular time point the frequency of interest was contributing to the signal. A continuous wavelet analysis provides an optimal resolution for every frequency [3]. Since the wavelet filters are localized in time and are scale-specific, wavelet analysis is a versatile tool to investigate signal changes across both time and frequency scales. Analogously to the Fourier analysis, we can define power spectrum, cross-spectrum and coherence characteristics in the wavelet domain as follows. Let $W_{X,j}$ define the wavelet coefficients for the stochastic process X_t at scale τ_j at time t. Wavelet *coherence* for two stochastic processes $\{X_t\}$ and $\{Y_t\}$ at scale τ_j is defined as $\rho_{XY}(\tau_j) = \frac{\nu_{XY}(\tau_j)}{\sqrt{\nu_X(\tau_j)\nu_Y(\tau_j)}}$,

where $\nu_{XY}(\tau_j) = \mathrm{cov}(W_{X,j}, W_{Y,j})$ is the wavelet *covariance* between X_t and Y_t, and $\nu_X(\tau_j) = E(W_{X,j}W^*_{X,j})$ is a wavelet *spectrum* for X_t (similarly for Y_t).

Wavelet spectrum and wavelet covariance represent the contribution due to changes at the particular scale to the variance of X_t and covariance of X_t and Y_t, respectively. Values of the wavelet coherence close to 1 indicate a linear relation between the two processes at the particular scale and time [3]. Wavelet times and scales are locally correlated, thus, the derivation of the asymptotic distribution is non-trivial. The statistical significance of the wavelet spectrum can be assessed using Monte-Carlo simulations [4]. In this work a continuous wavelet transform based on the Morlet wavelet was used (www.pol.ac.uk/home/research/waveletcoherence).

Methods fMRI was performed using a commercial 1.5T GE MRI scanner with parameters: TR/TE 2s/40 ms, FA 82deg, FOV 24x24, 64x64, thick 6mm/1mm, 20 axial slices. 13 dyslexics and 12 unaffected controls, all healthy adult male, were selected for the study. Each subject underwent a thorough training before the scanning. The Phoneme Mapping paradigm consists of a continuous 5-minute stimulation period (*without any interleaving rest periods*) during which the word-pairs are visually presented every 6 secs. In each of the words in a pair, certain letters are colored in pink, e.g. DOAK, SOTE. The subject has to indicate by pressing a button whether these highlighted letters stand for the same phoneme. Each participant was presented with 50 word-pairs. Functional images were co-registered to the standardized brain using FSL (FMRIB, Oxford). Four brain regions were chosen a priori based on fMRI studies of phonological processes [5,6]: right and left IFG , right and left AG.

Results and Conclusion A notable difference between the spectra of the left IFG (Fig.1) in the low frequency range (0.04-0.12Hz) indicates that the contributions to the signal from the frequencies in the functional connectivity range are much larger for controls (blue curve) than for dyslexics (green curve). The average coherence curves (Fig.2) for controls (blue) and dyslexics (green) show more coherent signal fluctuations in the left and right IFG in controls than in dyslexics. Dyslexics show higher coherency than controls between the left IFG and right AG in a wide range of frequencies. The wavelet coherence estimate (Fig.3) between the left IFG and right IFG is quite high in the control readers across the entire time range and the entire low frequency band. The thick black contour defines 5% significance level for testing the hypothesis of the null coherence between each pair of signals; shaded areas indicate the regions prone to the edge effect [4]. The right IFG and right AG are consistently coherent during the task in controls, and the estimate is rather small in dyslexics. The coherence between right IFG and left AG is significant across entire time span at the frequency band around 0.3Hz. These results suggest possible functional discontinuity of the left IFG and right IFG in dyslexic readers and a possibly compensatory role of the left IFG in the reading strategies employed by dyslexics.

References [1]Stanberry et al. Group fMRI connectivity maps showing cortical and cerebellar-cortical connections in dyslexic readers (ISMRM 2005) [2] Bloomfield (2000) Wiley&Sons Inc. [3] Percival and Walden (2000) Cambridge U Press. [4]Maraun and Kurths (2004) Nonlinear Processes in Geophysics 11: 505-514. [5] Pugh et al (2000) Psychological Science 11:51-56. [6] Aylward et al (2003) Neurology 61:212-219.

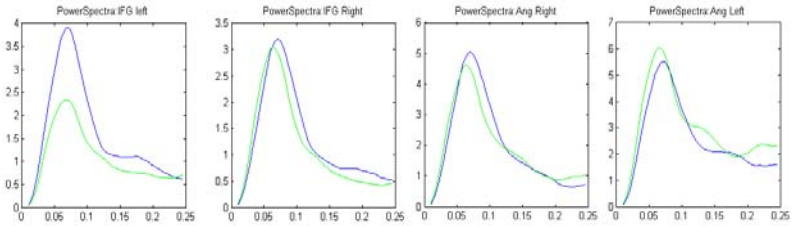

Figure 1

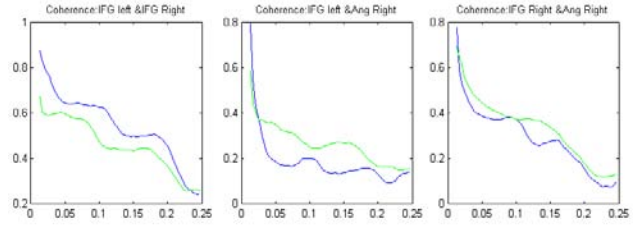

Figure 2

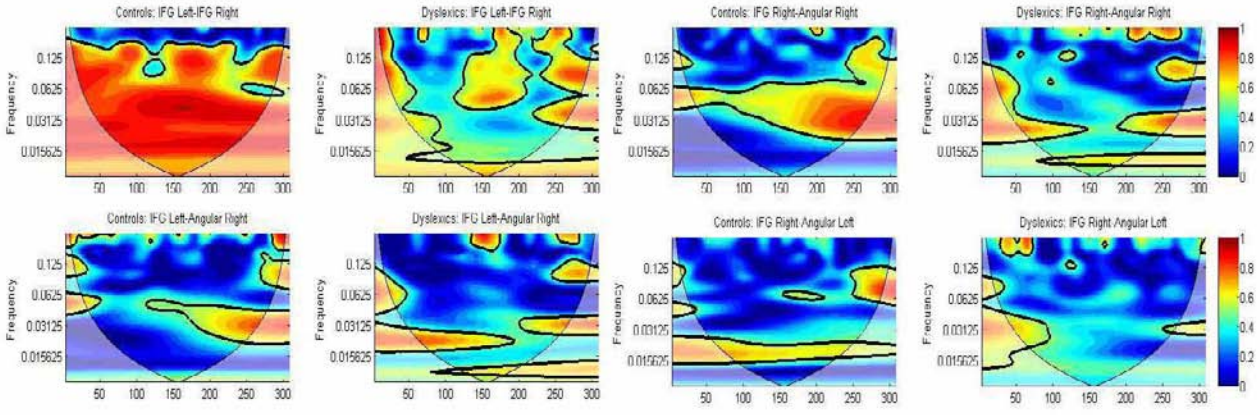

Figure 3