Sleep Inertia Project: Progress Report ver. 1.1α

Tomasz M. Rutkowski
RIKEN Brain Science Institute, Japan

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Contents

1 Introduction

The aim of the report is to show novel methods in functional neuroimaging [1] of sleep inertia stages with emphasis on novel time-frequency preprocessing meth-

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14. ABSTRACT

The aim of the report is to show novel methods in functional neuroimaging of sleep inertia stages with emphasis on novel time-frequency preprocessing methods and models of effective connectivity evaluated by dynamic causal modeling and econometric models (such as Granger causality and related methods).

15. SUBJECT TERMS

Data Mining, Data Fusion, Sleep Research, Human Attention & Performance

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ods [2, 3, 4, 5, 6] and models of effective connectivity evaluated by dynamic causal modeling and econometric models (such as Granger causality and related methods) [7, 8, 1]

2 Methods

The EEG signals from two conditions #1 and #2 for all experimental factors $EEG08$ till $EEG17$ for the following channels: $C4 - A1$; $C3 - A2$; $Fz - A1$; $Pz - A1$; $Oz - A2$ where first preprocessed with EMD adaptive filtering procedures (removing mostly muscle artifacts in lower and high frequency ranges). The so obtained *clean EEG* signals were further with interdependence measures.

2.1 Empirical Mode Decomposition (EMD) EEG Preprocessing

...to be added soon...

2.2 Signals Interdependence Evaluation

Suppose that we are given n signals $X_1(k), X_2(k), \ldots, X_n(k)$, each stemming from a different channel. We consider the multivariate autoregressive (MVAR) model:

$$X(k) = \sum_{l=1}^{p} \mathbf{A}(j) X(k-l) + E(k), \tag{1}$$

where $X(k) \triangleq (X_1(k), X_2(k), \ldots, X_n(k))^T$, p is the model order, the model coefficients $\mathbf{A}(j)$ are $n \times n$ matrices, and $E(k)$ is a zero-mean Gaussian random vector of size n. In words: Each signal $X_i(k)$ is assumed to linearly depend on its own p past values and the p past values of the other signals $X_j(k)$. The deviation between $X(k)$ and this linear dependence is modeled by the noise component $E(k)$. Model (1) can also be cast in the form:

$$E(k) = \sum_{l=0}^{p} \tilde{\mathbf{A}}(j) X(k-l), \tag{2}$$

where $\tilde{\mathbf{A}}(0) = \mathbf{I}$ (identity matrix) and $\tilde{\mathbf{A}}(j) \triangleq -\mathbf{A}(j)$ for $j > 0$. One can transform (2) into the frequency domain (by applying the z-transform and by substituting $z \triangleq e^{-2\pi i \Delta t}$, where $1/\Delta t$ is the sampling rate):

$$X(f) = \tilde{\mathbf{A}}^{-1}(f) E(f) \triangleq \mathbf{H}(f) E(f). \tag{3}$$

The power spectrum matrix of the signal $X(k)$ is determined as

$$\mathbf{S}(f) \triangleq X(f)X(f)^* = \mathbf{H}(f)\mathbf{V}\mathbf{H}(f), \tag{4}$$

where $\mathbf{V}$ stands for the covariance matrix of $E(k)$.

2.2.1 Coherence (COH)

The coherence function quantifies linear correlations in frequency domain. One distinguishes the magnitude square coherence function and the phase coherence function. The former is dened as:

$$c(f) \triangleq \frac{|X(f)Y^*(f)|^2}{|X(f)|\,|Y(f)|}, \tag{5}$$

where $X(f)$ and $Y(f)$ are the Fourier transforms of x and y respectively; Y^* is the complex conjugate of $Y \in \mathbb{C}$, and $|Y|$ is the magnitude of Y . The phase coherence function is dened as

$$\phi(f) \triangleq \arg[X(f)Y^*(f)]. \tag{6}$$

In practice, one often subdivides the signals x and y in M segments (of equal length), and determines $c(f)$ by averaging over those segments:

$$c(f) \triangleq \frac{|\langle X(f)Y^*(f)\rangle|^2}{|\langle X(f)\rangle|\,|\langle Y(f)\rangle|}, \tag{7}$$

where $\langle\cdot\rangle$ denotes averaging over the M segments. Along the same lines, the phase coherence $\phi(f)$ is often computed as:

$$\phi(f) \triangleq \arg[\langle X(f)Y^*(f)\rangle]. \tag{8}$$

Note that both $c(f)$ and $\phi(f)$ depend on the frequency f.

As for properties of coherence, its estimated value ranges between 0 and 1. For a given frequency. A value of 0 indicates that the activities of the signals in this particular frequency bin are linearly independent, whereas a maximum value of 1 gives the top linear correlation for such particular frequency bin.

2.2.2 Directed Transfer Function (DTF)

$$\gamma_{ij}^2(f) \triangleq \frac{|H_{ij}(f)|^2}{\sum_{j=1}^{m}|H_{ij}(f)|^2} \in [0,1], \tag{9}$$

where the (frequency-dependent) normalization is chosen so that $\gamma_{ij}^2(f)$ quanties the fraction of inow to channel i stemming from channel j.

2.2.3 Partial Directed Coherence (PDC)

$$P_{ij}(f) \triangleq \frac{\tilde{A}_{ij}(f)}{\sqrt{\sum_{i=1}^{m} \left|\tilde{A}_{ij}(f)\right|^2}} \in \mathbb{C}, \tag{10}$$

2.2.4 Direct Directed Transfer Function (dDTF)

$$\chi_{ij}^2(f) \triangleq F_{ij}^2(f) C_{ij}^2(f) \in [0,1], \tag{11}$$

which is non-zero if the connection between channel i and j is causal (non-zero $F_{ij}^2(f)$) and direct (non-zero $C_{ij}^2(f)$).

3 Preliminary pairwise channel synchrony evaluation results

3.1 Magnitude coherence

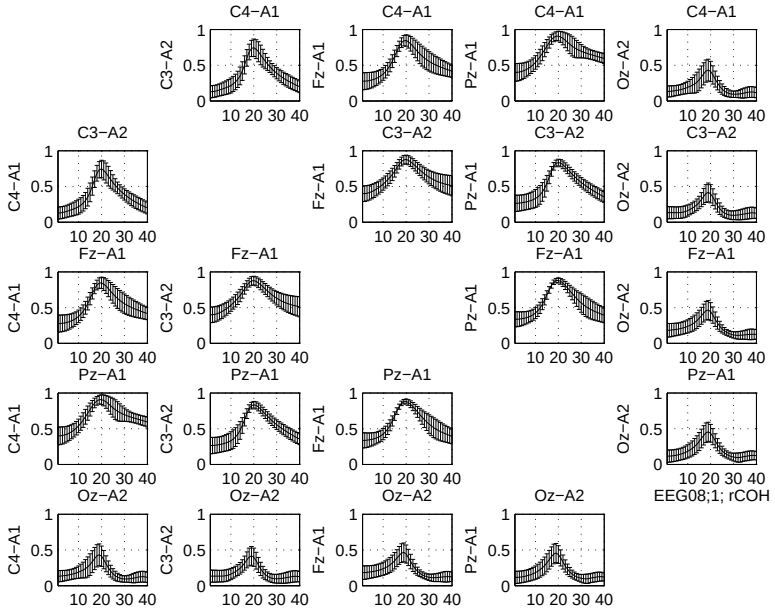

Figure 1: Magnitude coherence as in (5): Condition #1 & factor EEG08. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

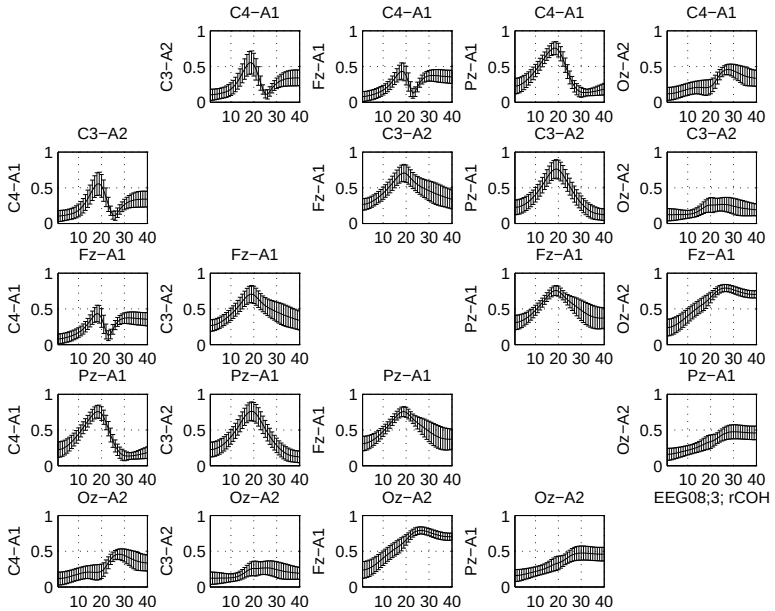

Figure 2: Magnitude coherence as in (5): Condition #3 & factor EEG08. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

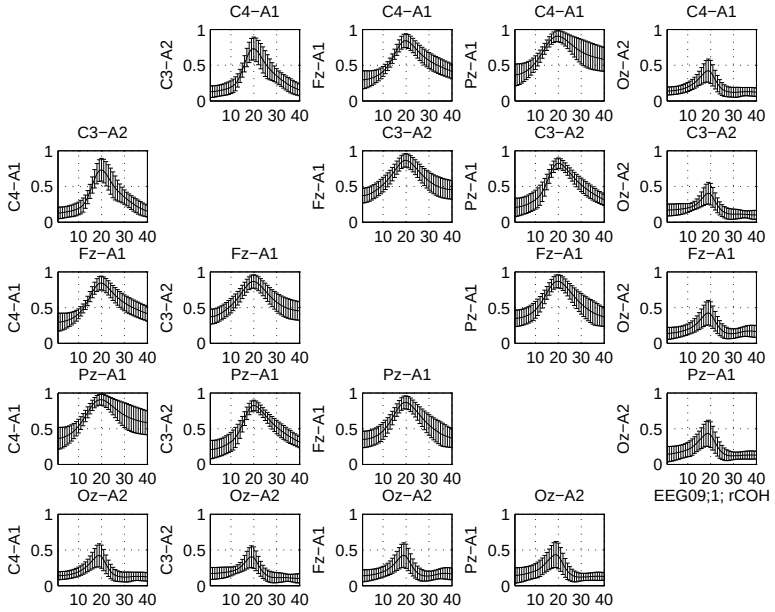

Figure 3: Magnitude coherence as in (5): Condition #1 & factor EEG09. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

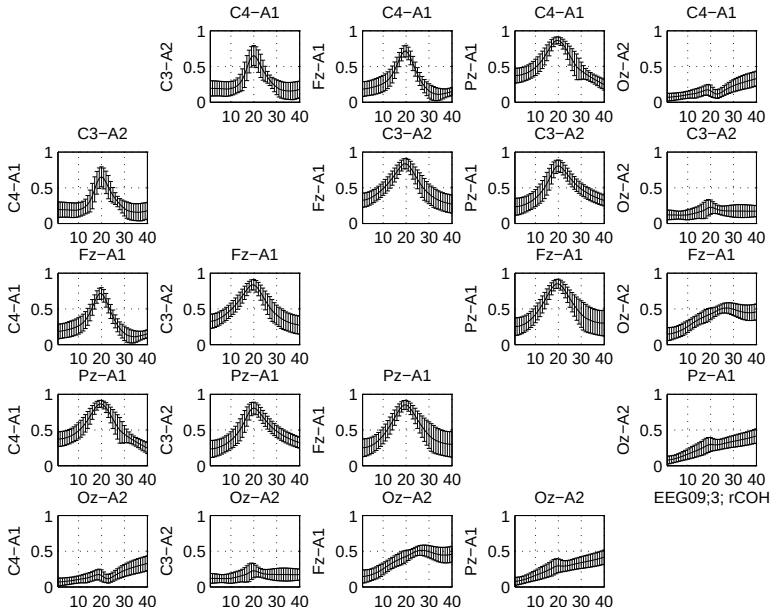

Figure 4: Magnitude coherence as in (5): Condition #3 & factor EEG09.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

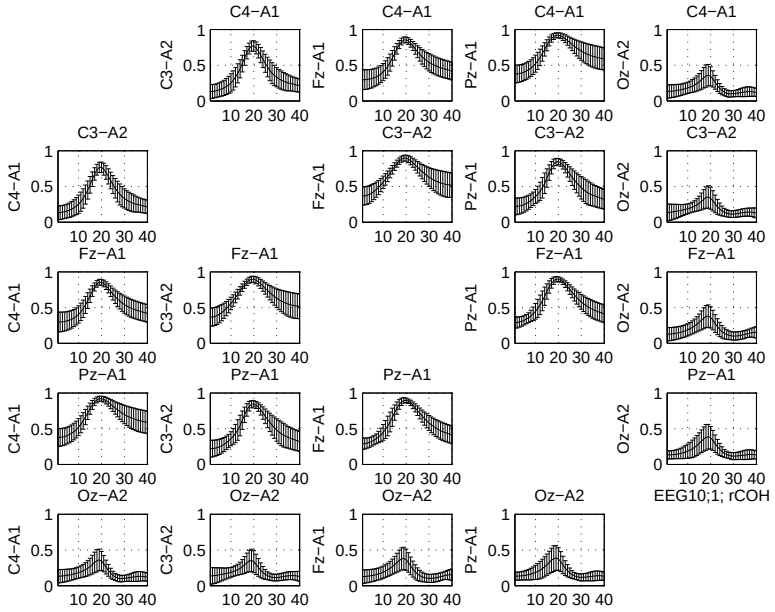

Figure 5: Magnitude coherence as in (5): Condition #1 & factor EEG10.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

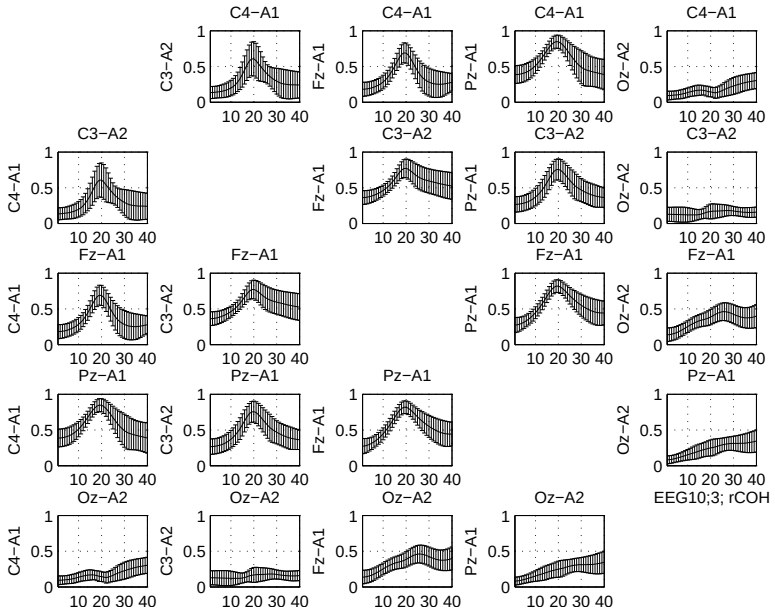

Figure 6: Magnitude coherence as in (5): Condition #3 & factor EEG10.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

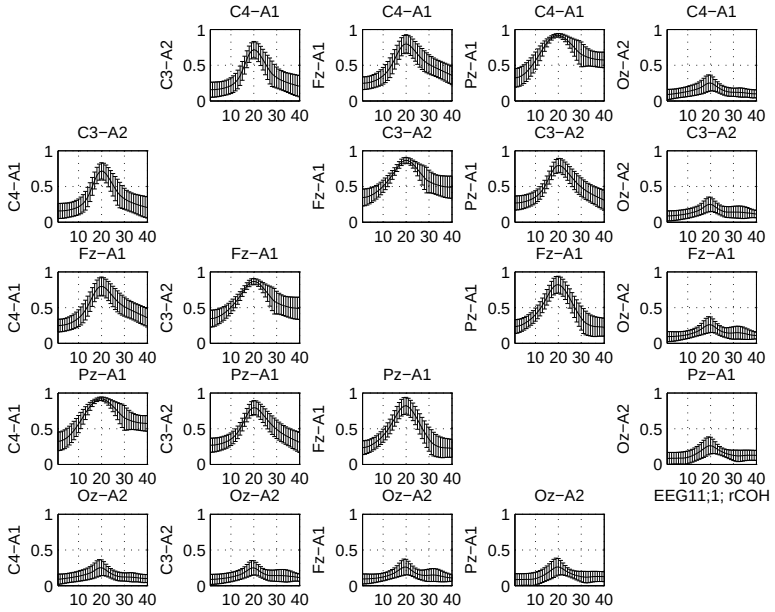

Figure 7: Magnitude coherence as in (5): Condition #1 & factor EEG11.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

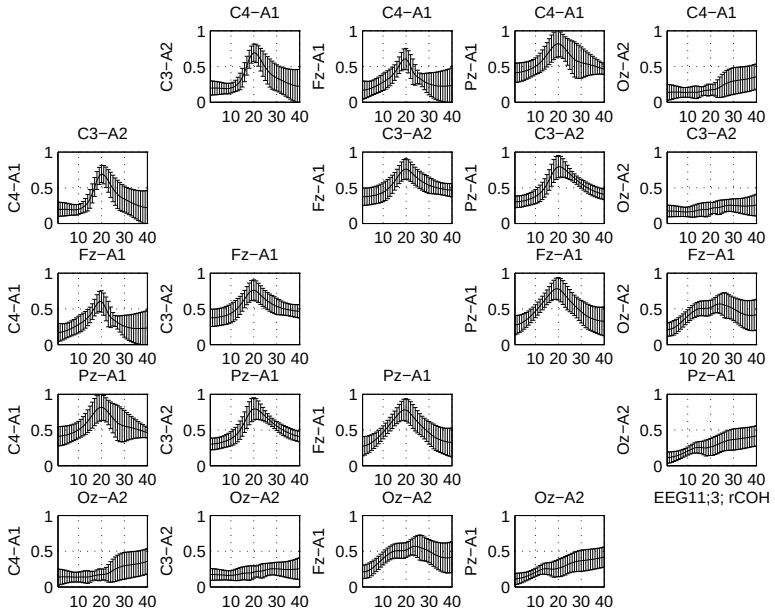

Figure 8: Magnitude coherence as in (5): Condition #3 & factor EEG11.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

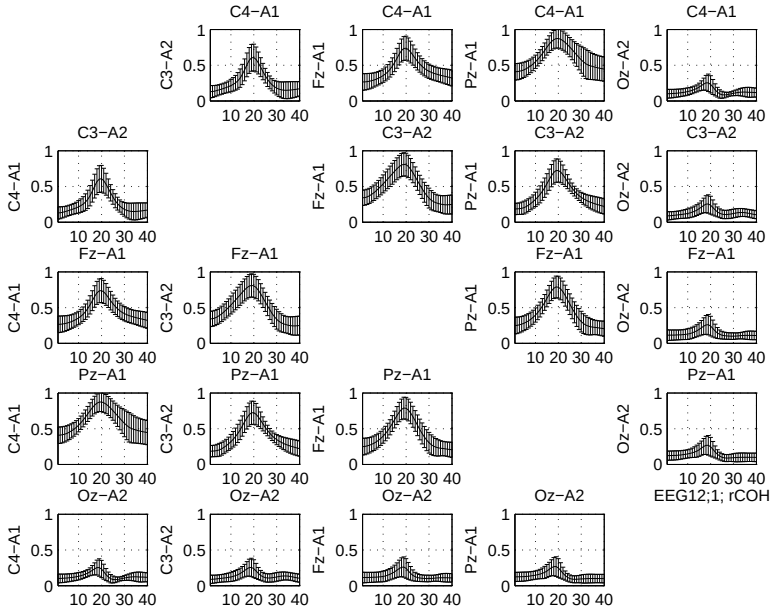

Figure 9: Magnitude coherence as in (5): as in (5): Condition #1 & factor EEG12.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

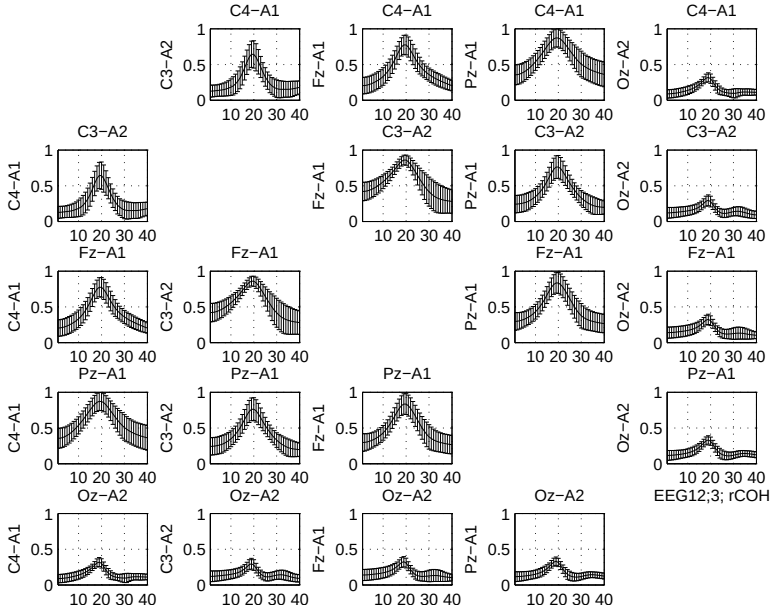

Figure 10: Magnitude coherence as in (5): Condition #3 & factor EEG12.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

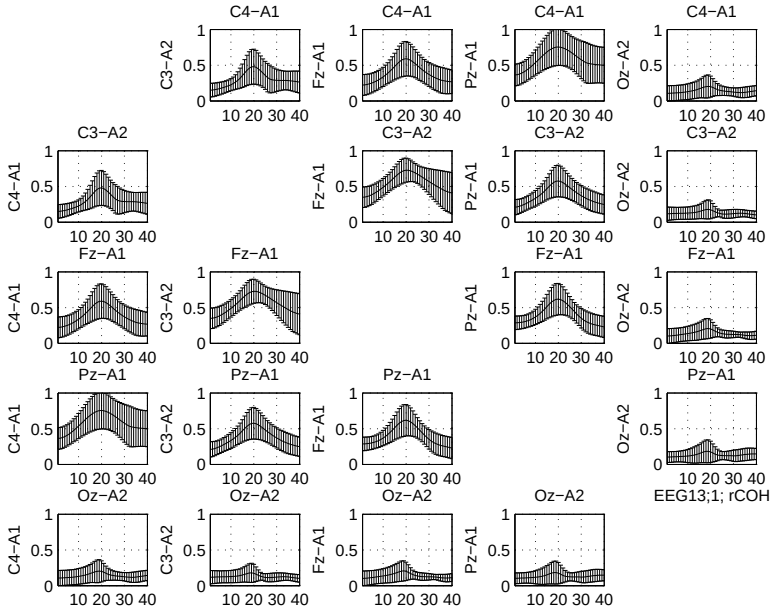

Figure 11: Magnitude coherence as in (5): Condition #1 & factor EEG13.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

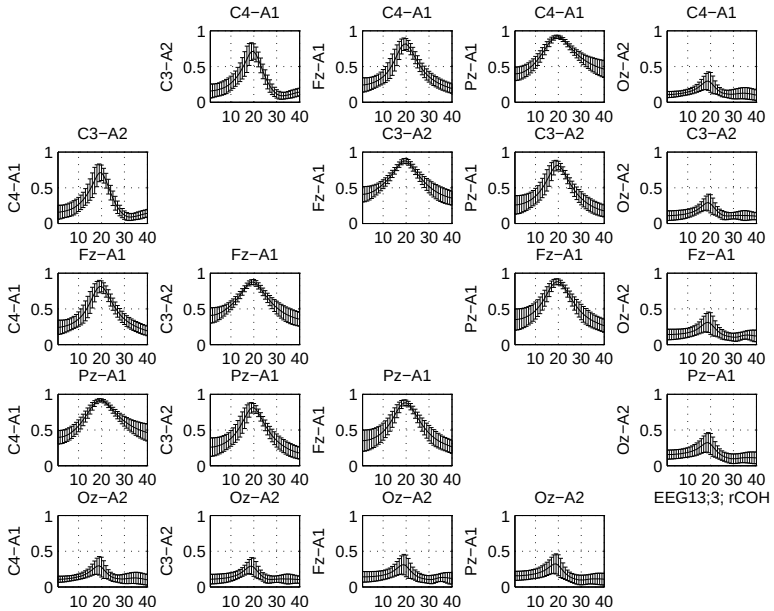

Figure 12: Magnitude coherence as in (5): Condition #3 & factor EEG13.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

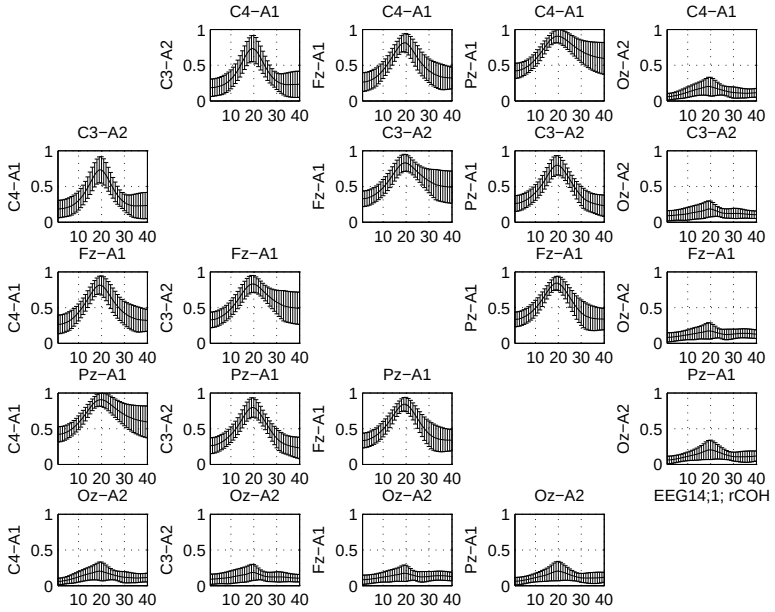

Figure 13: Magnitude coherence as in (5): Condition #1 & factor EEG14.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

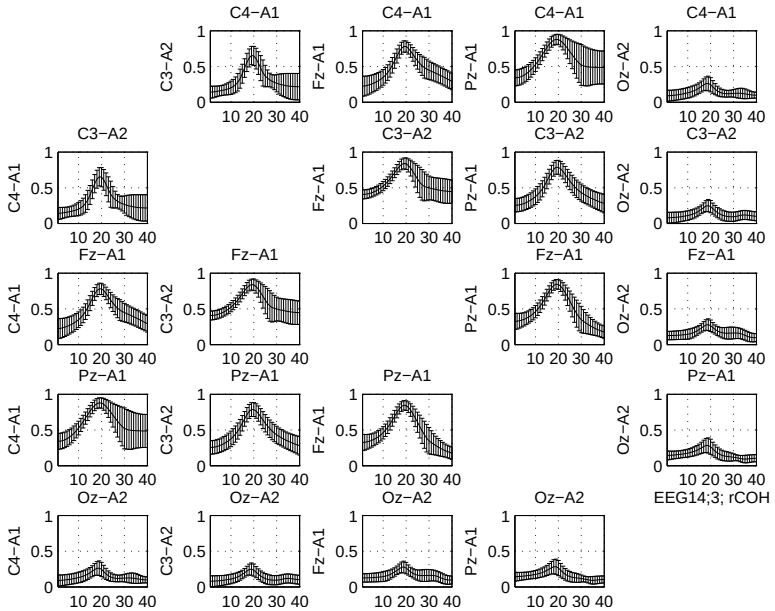

Figure 14: Magnitude coherence as in (5): Condition #3 & factor EEG14.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

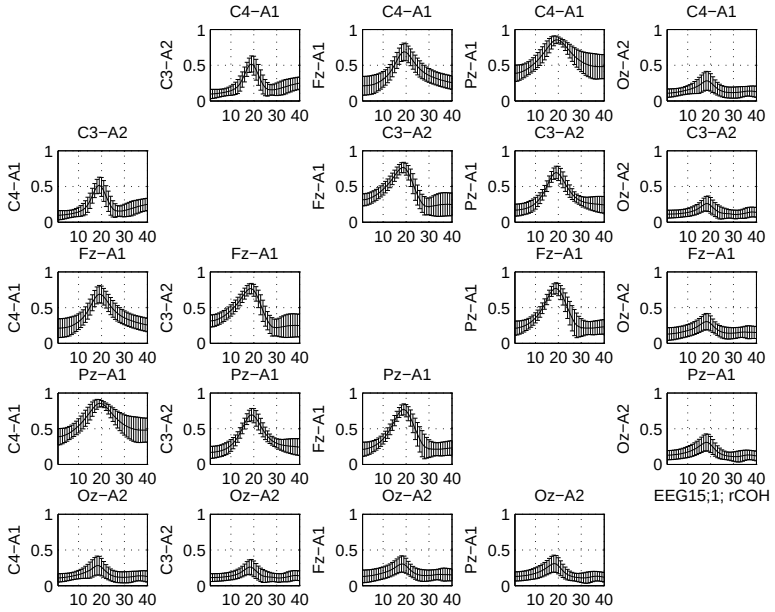

Figure 15: Magnitude coherence as in (5): Condition #1 & factor EEG15.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

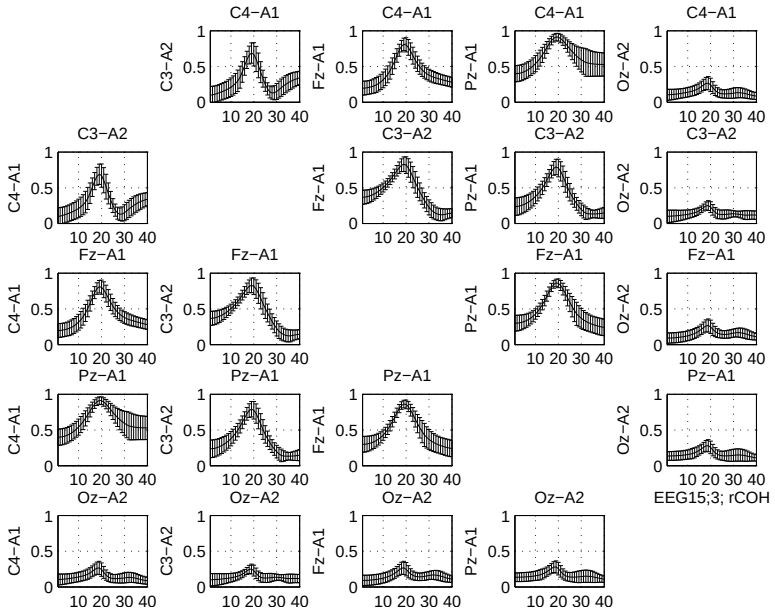

Figure 16: Magnitude coherence as in (5): Condition #3 & factor EEG15.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

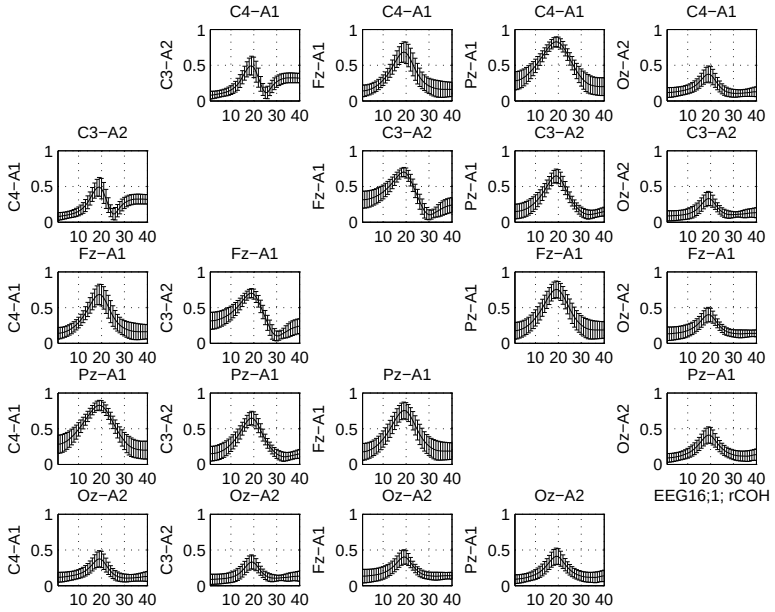

Figure 17: Magnitude coherence as in (5): Condition #1 & factor EEG16.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

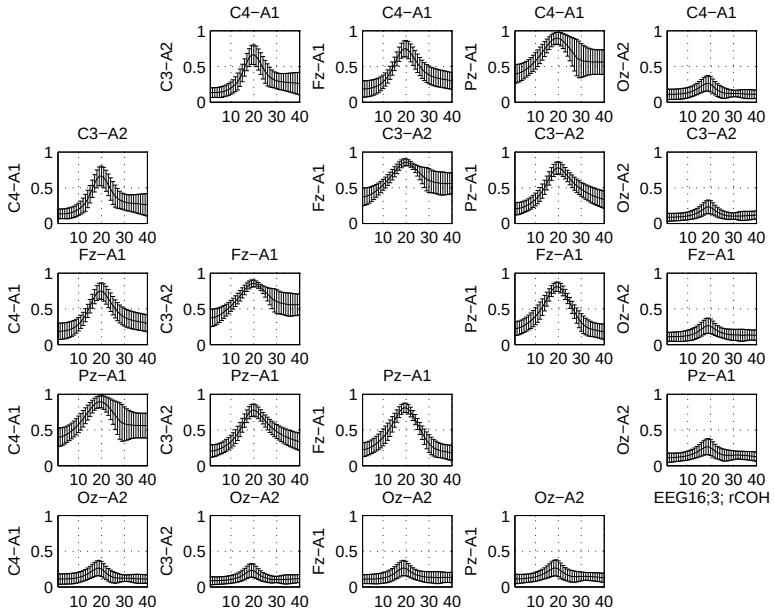

Figure 18: Magnitude coherence as in (5): Condition #3 & factor EEG16.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

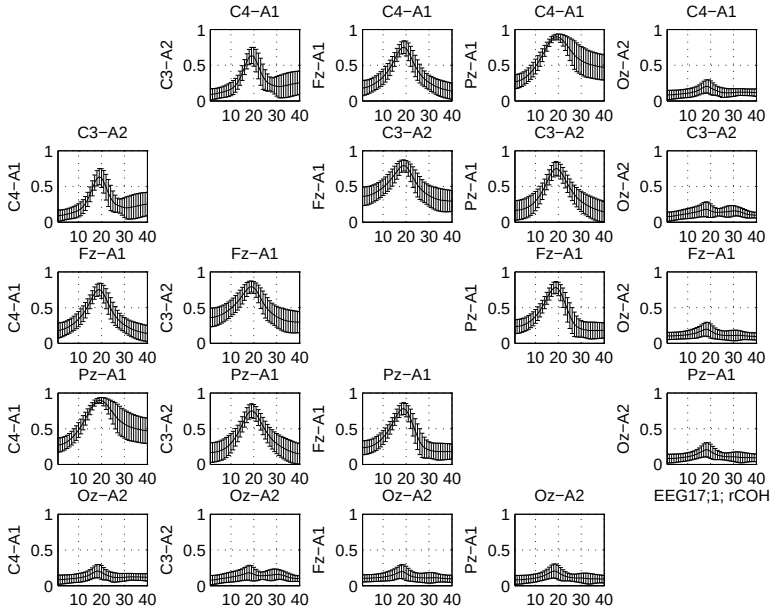

Figure 19: Magnitude coherence as in (5): Condition #1 & factor EEG17.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

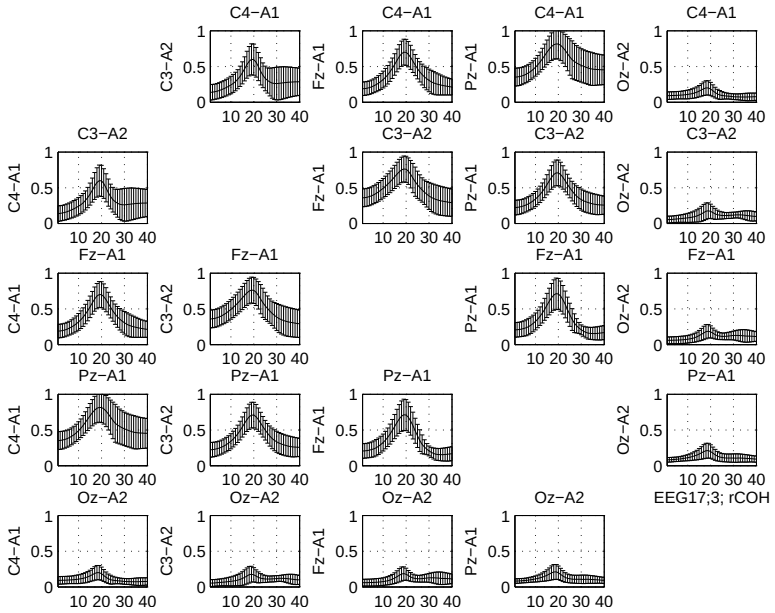

Figure 20: Magnitude coherence as in (5): Condition #3 & factor EEG17.*X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

3.2 Phase coherence

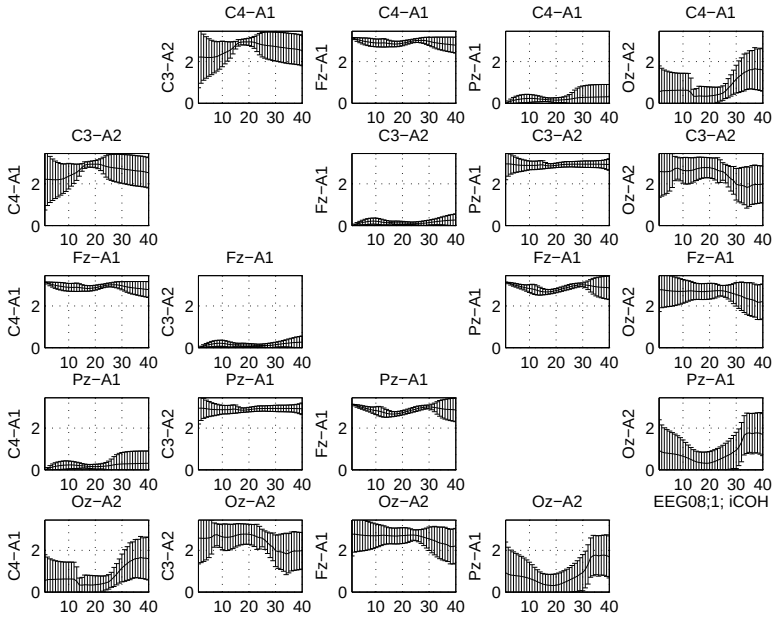

Figure 21: Phase coherence as in (6): Condition #1 & factor EEG08. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

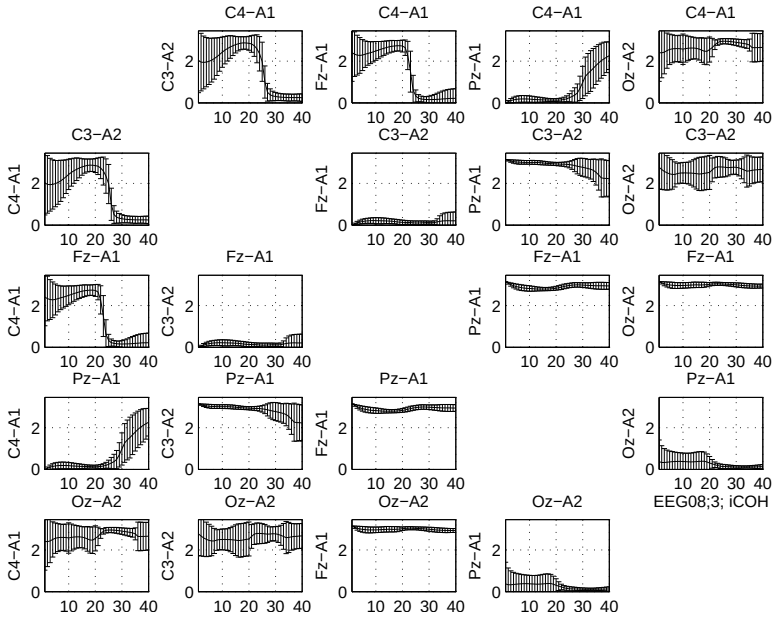

Figure 22: Phase coherence as in (6): Condition #3 & factor EEG08. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

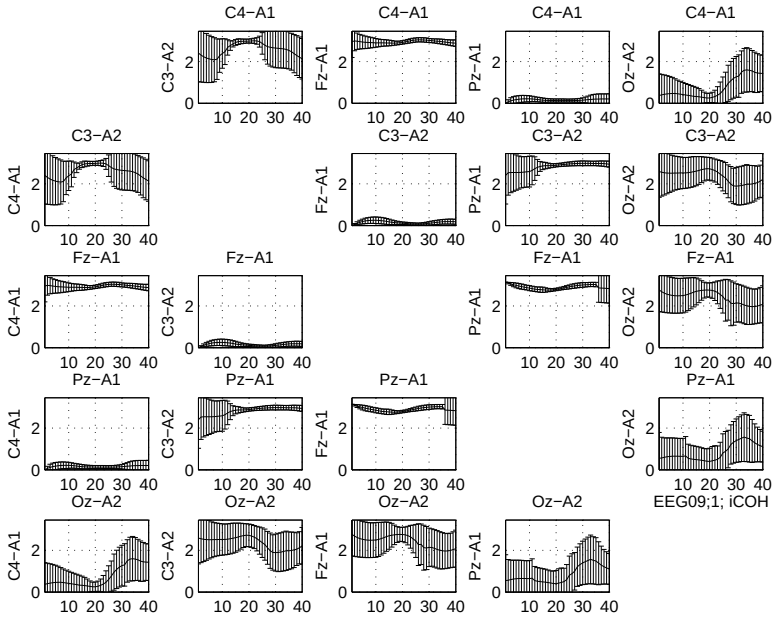

Figure 23: Phase coherence as in (6): Condition #1 & factor EEG09. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

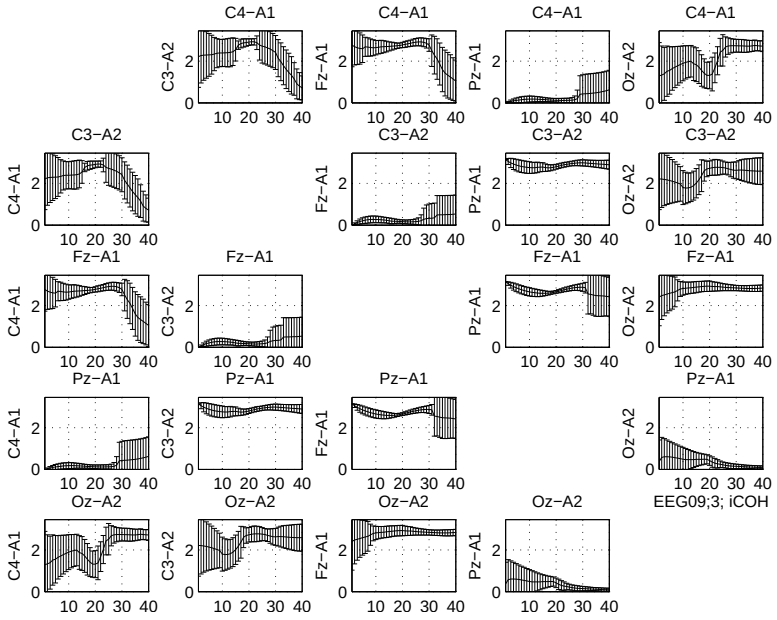

Figure 24: Phase coherence as in (6): Condition #3 & factor EEG09. *X-axes* in all plots are frequencies $0 - 20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

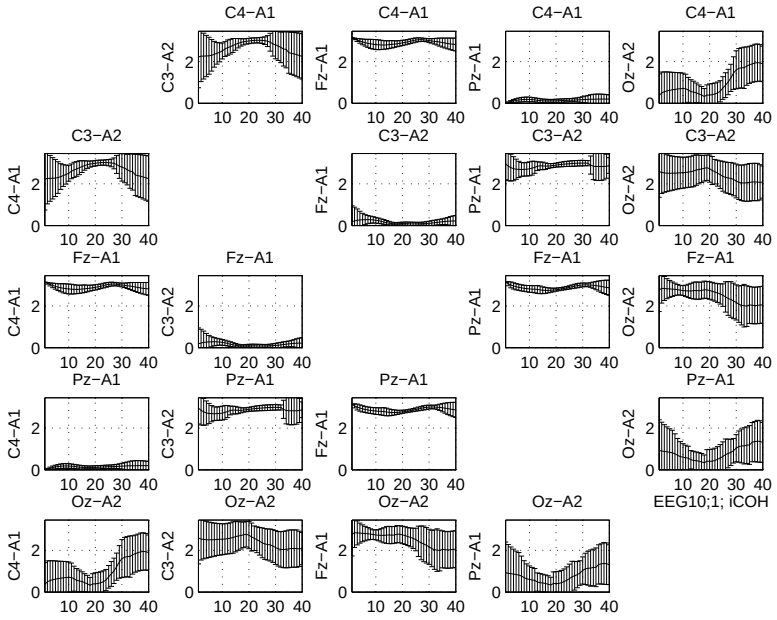

Figure 25: Phase coherence as in (6): Condition #1 & factor EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

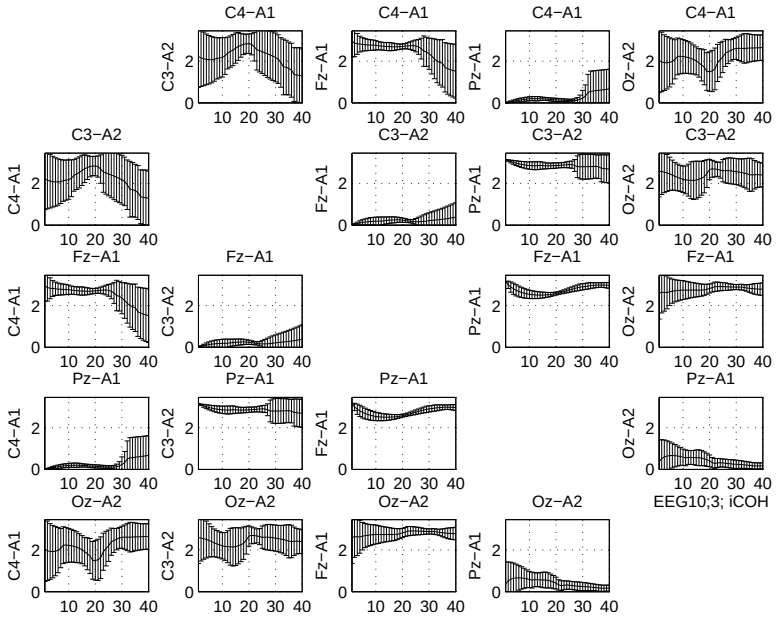

Figure 26: Phase coherence as in (6): Condition #3 & factor EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

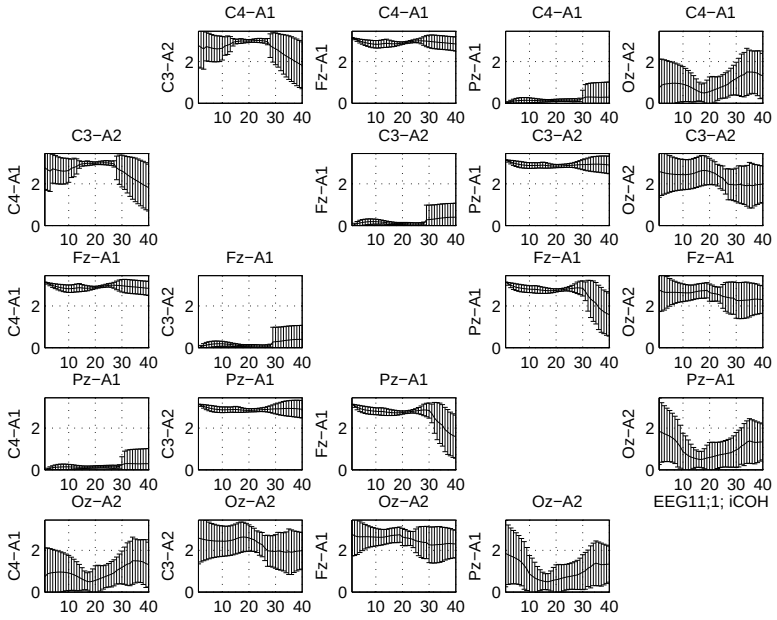

Figure 27: Phase coherence as in (6): Condition #1 & factor EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

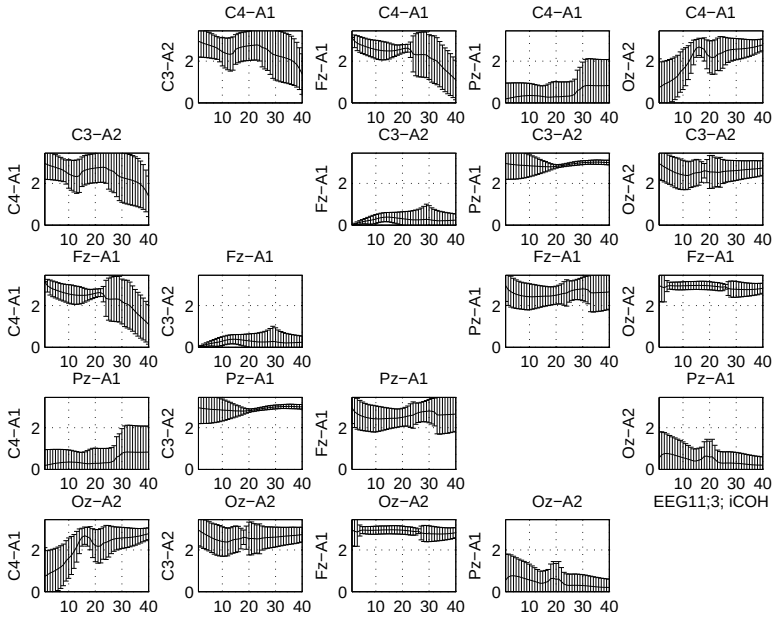

Figure 28: Phase coherence as in (6): Condition #3 & factor EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

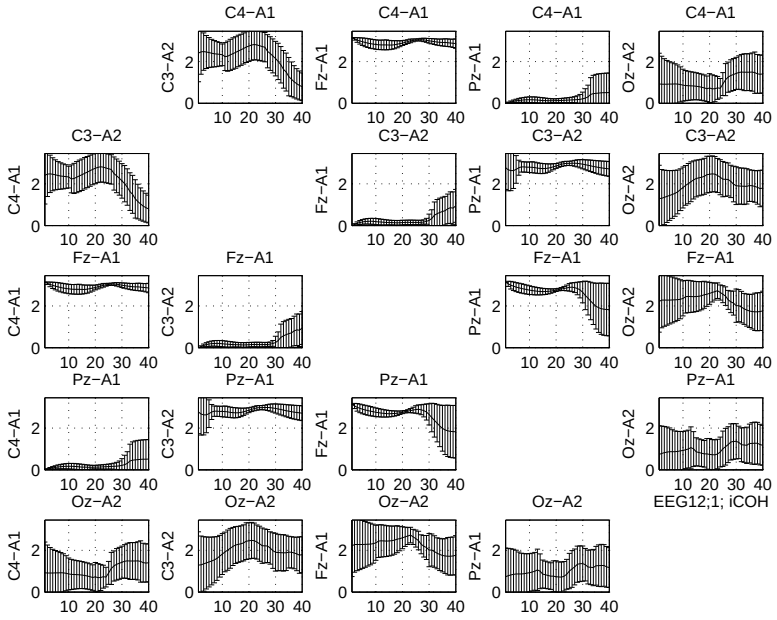

Figure 29: Phase coherence as in (6): Condition #1 & factor EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

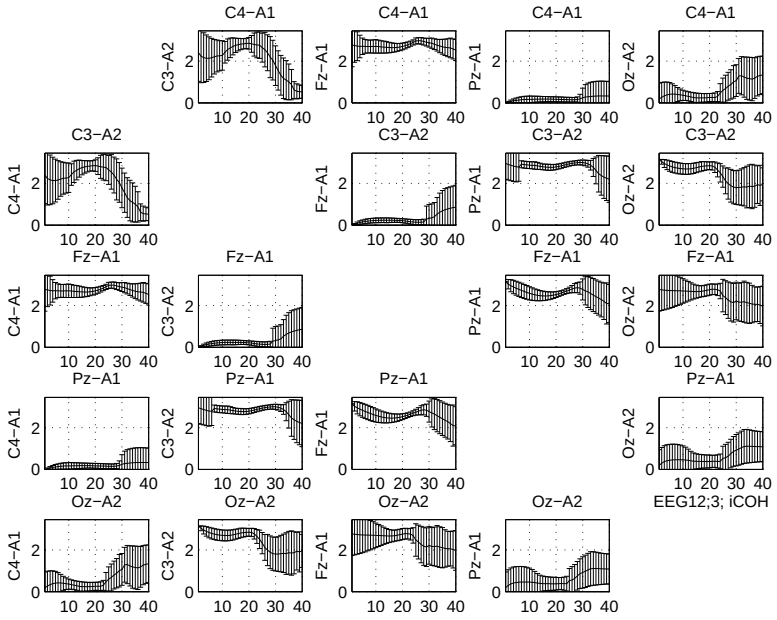

Figure 30: Phase coherence as in (6): Condition #3 & factor EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

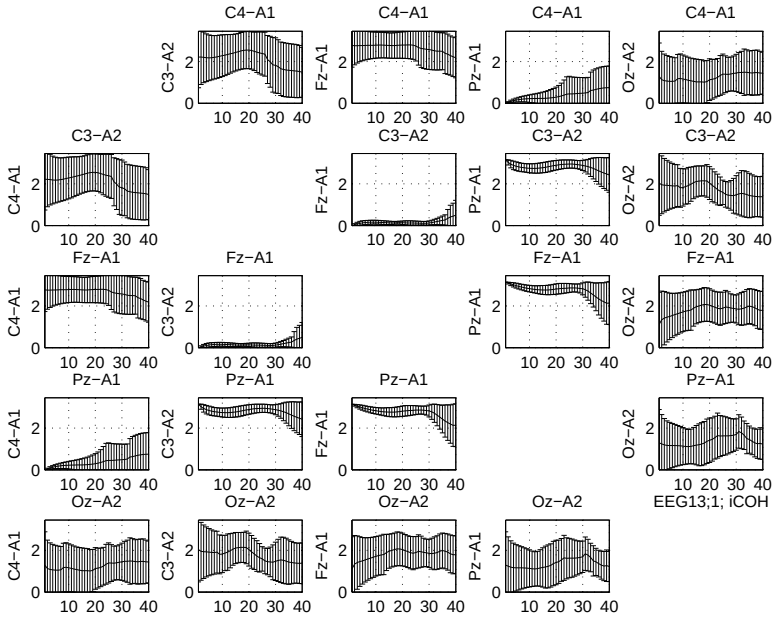

Figure 31: Phase coherence as in (6): Condition #1 & factor EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

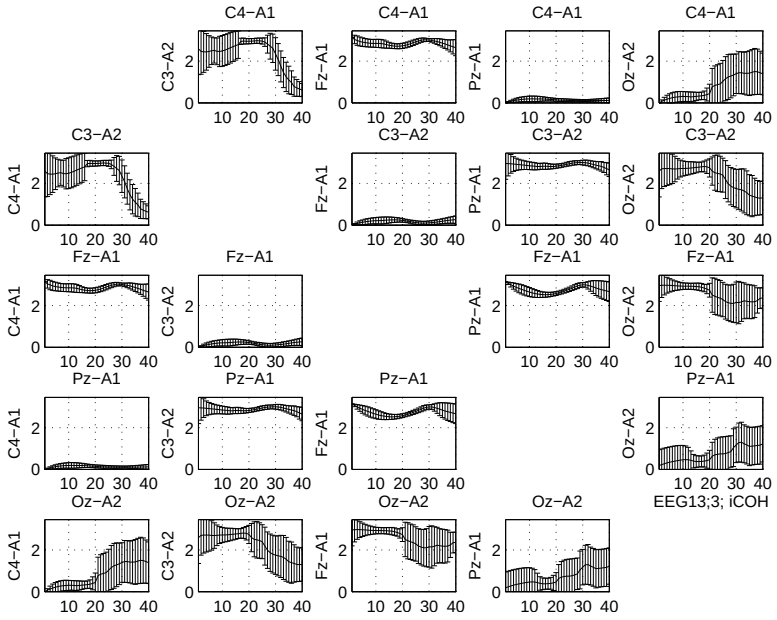

Figure 32: Phase coherence as in (6): Condition #3 & factor EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

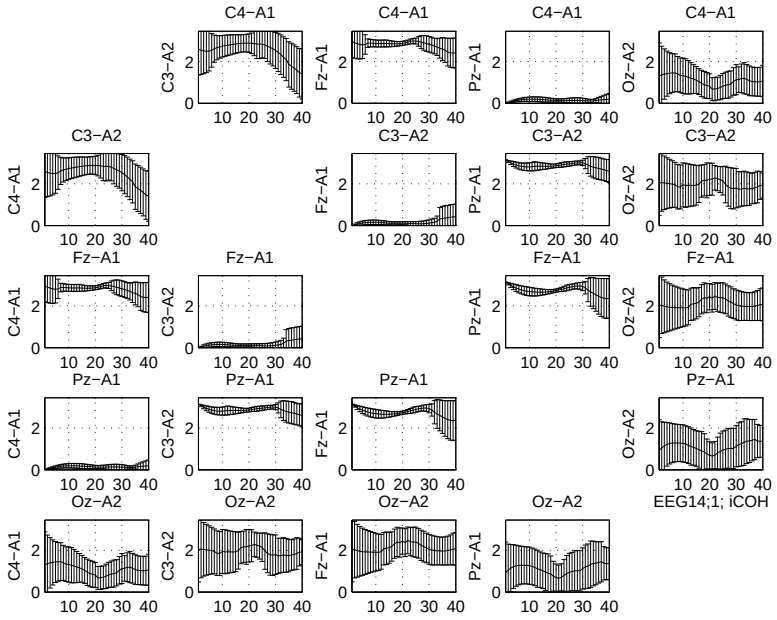

Figure 33: Phase coherence as in (6): Condition #1 & factor EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

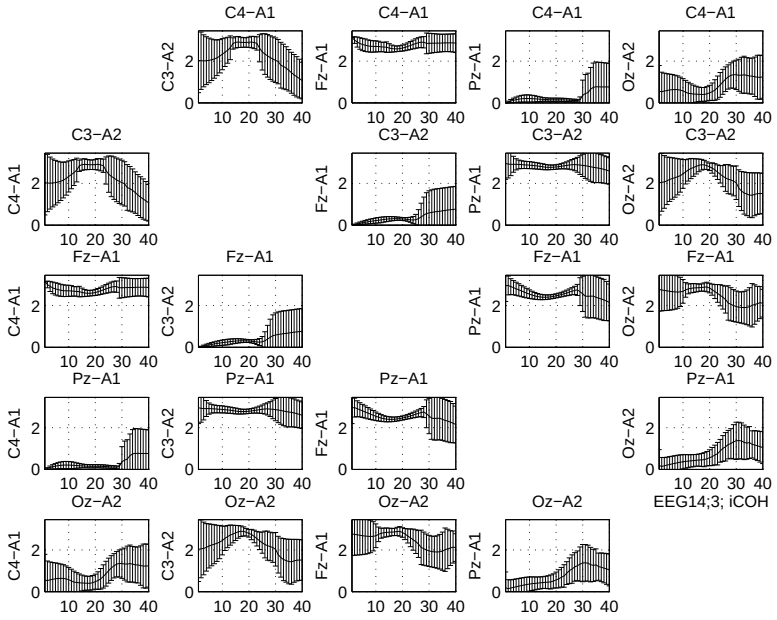

Figure 34: Phase coherence as in (6): Condition #3 & factor EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

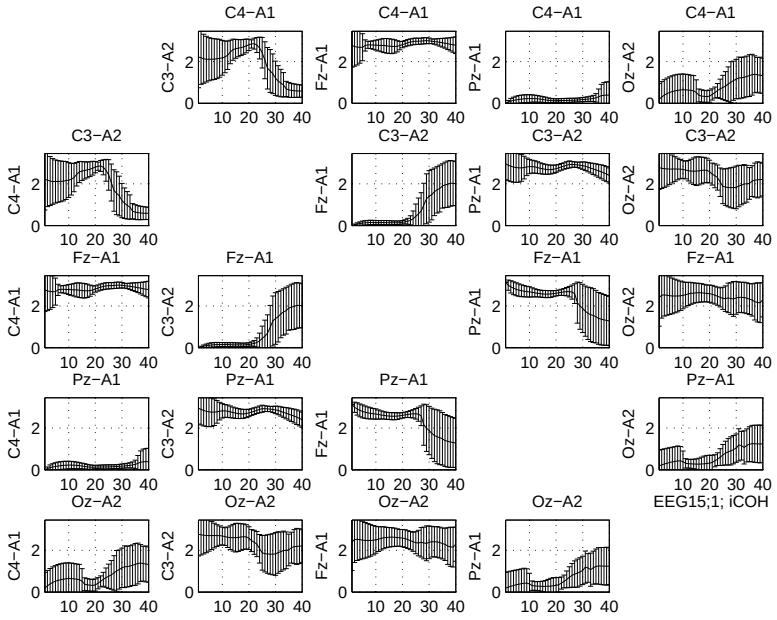

Figure 35: Phase coherence as in (6): Condition #1 & factor EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

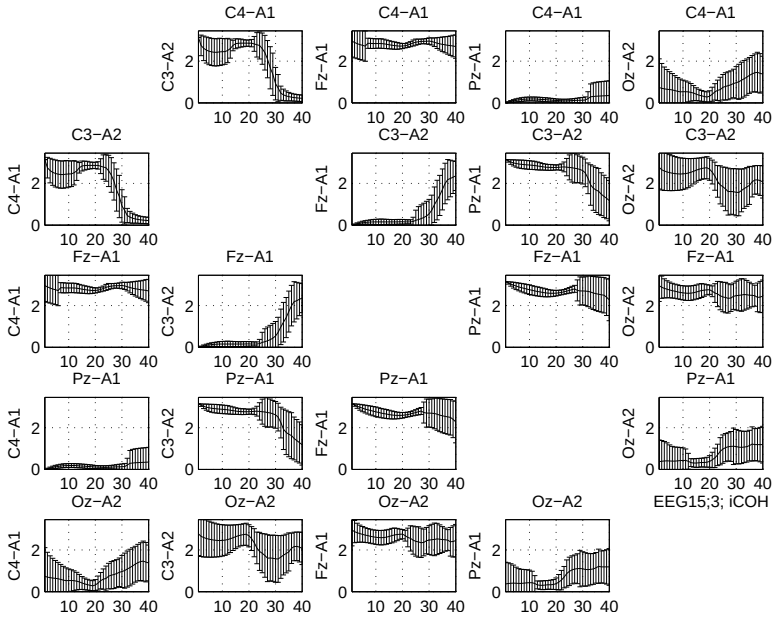

Figure 36: Phase coherence as in (6): Condition #3 & factor EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

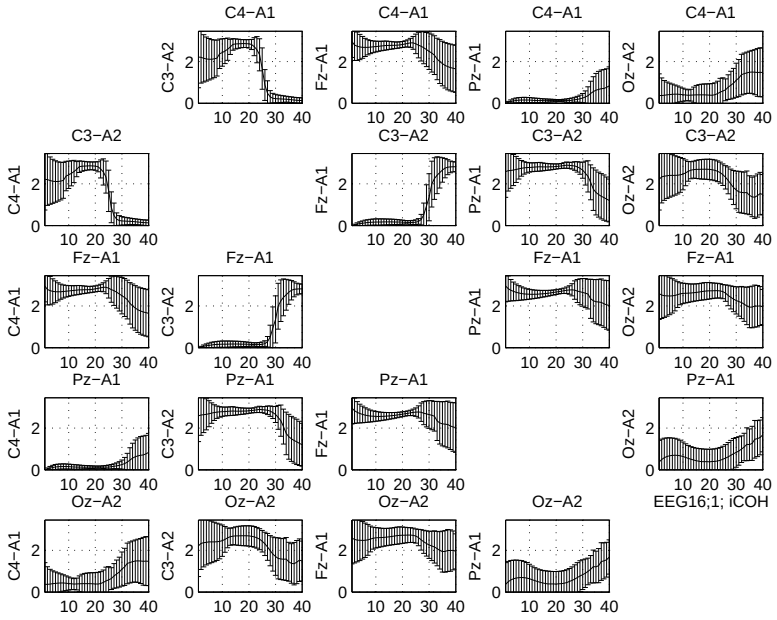

Figure 37: Phase coherence as in (6): Condition #1 & factor EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

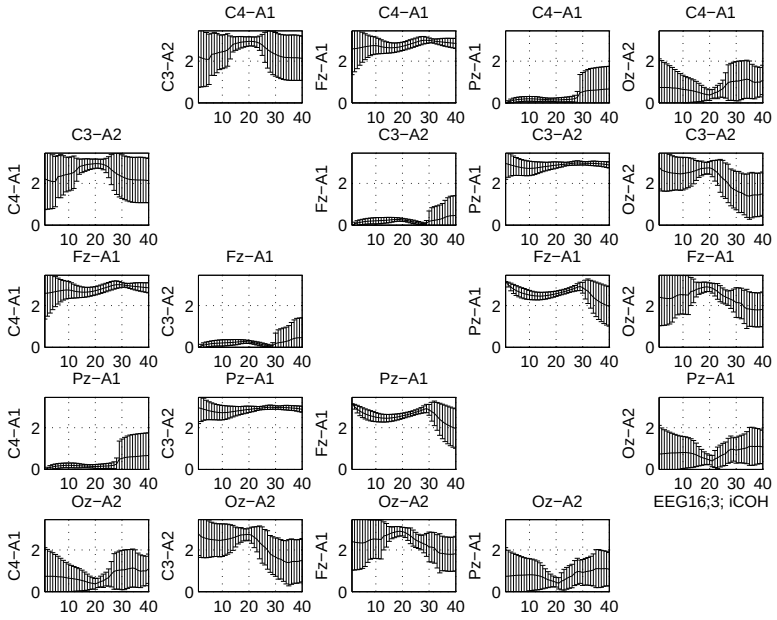

Figure 38: Phase coherence as in (6): Condition #3 & factor EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

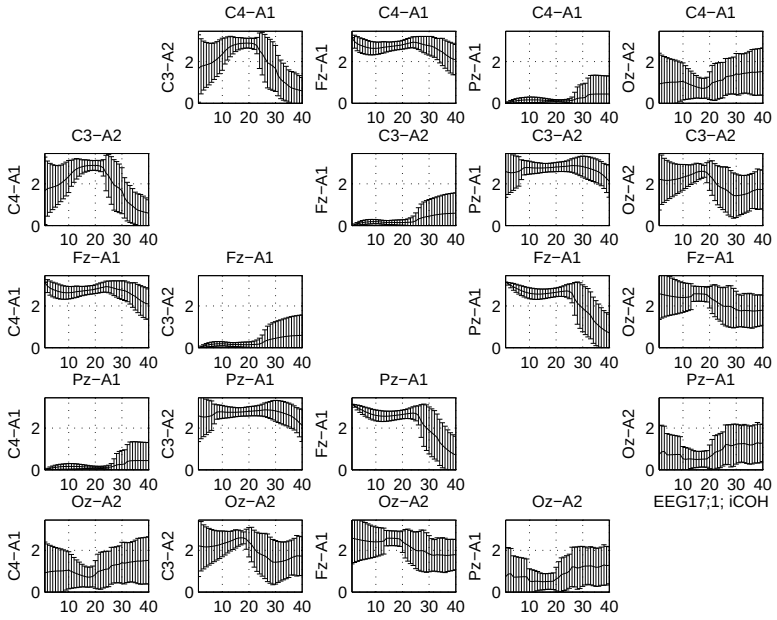

Figure 39: Phase coherence as in (6): Condition #1 & factor EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

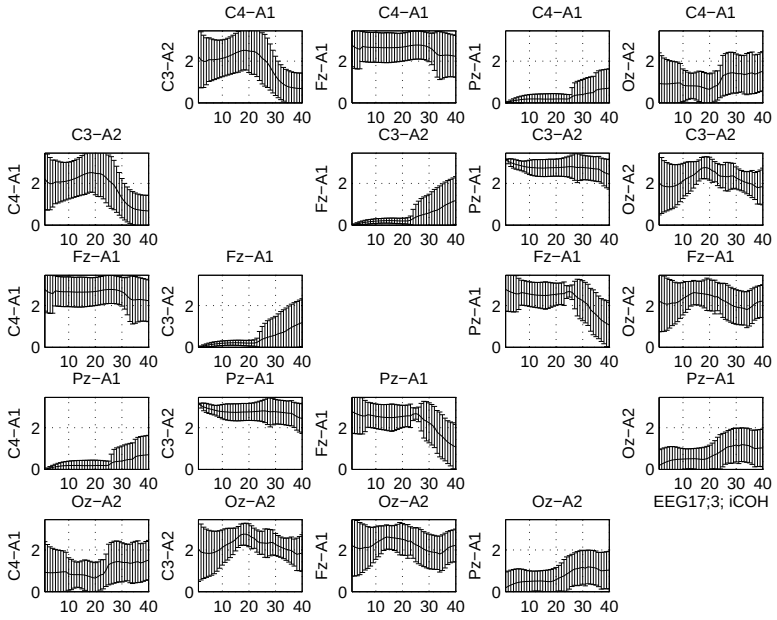

Figure 40: Phase coherence as in (6): Condition #3 & factor EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

3.3 Directed transfer function (DTF)

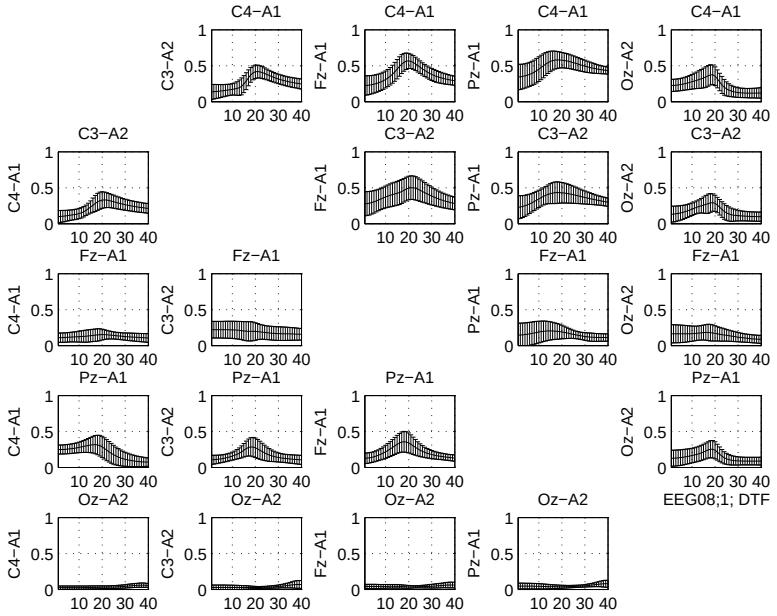

Figure 41: DTF as in (9): Condition #1 and factor EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

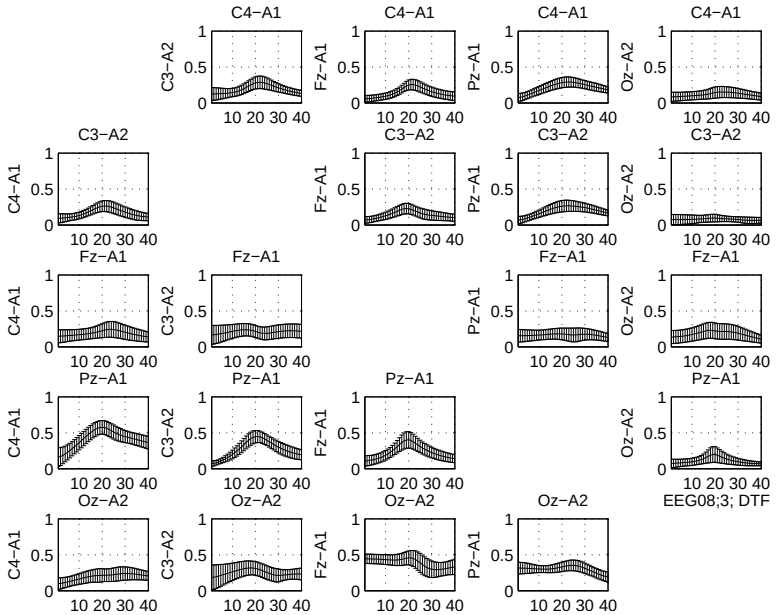

Figure 42: DTF as in (9): Condition #3 and EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

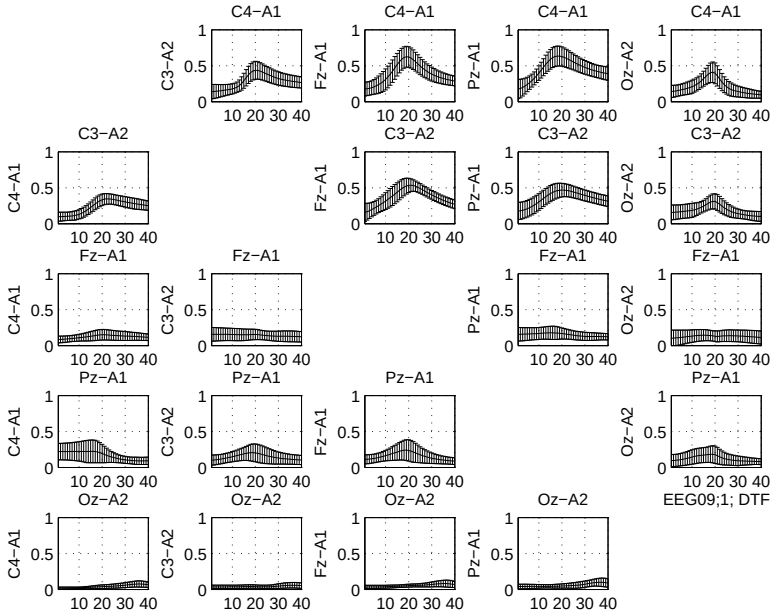

Figure 43: DTF as in (9): Condition #1 and factor EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

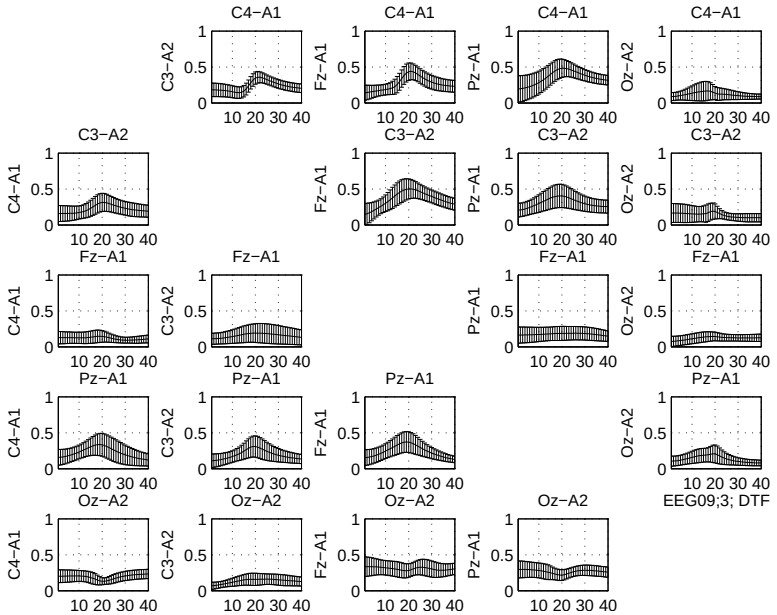

Figure 44: DTF as in (9): Condition #3 and EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

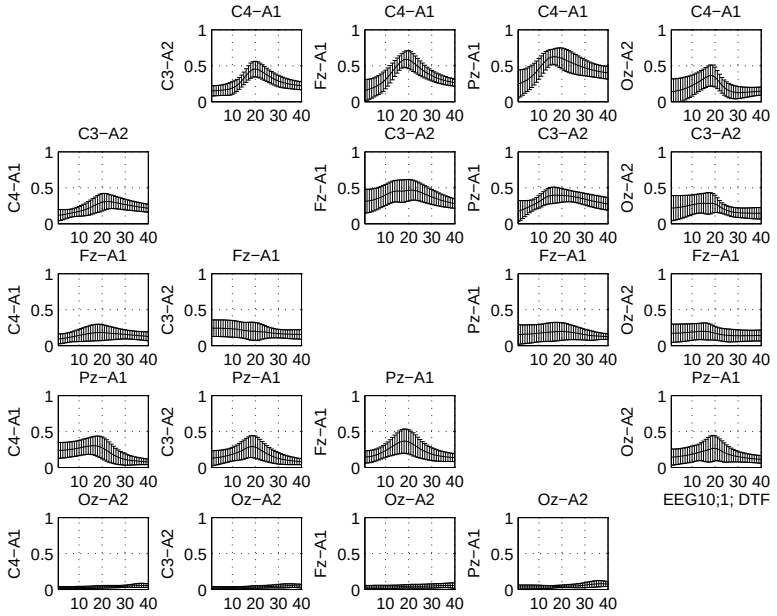

Figure 45: DTF as in (9): Condition #1 and factor EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

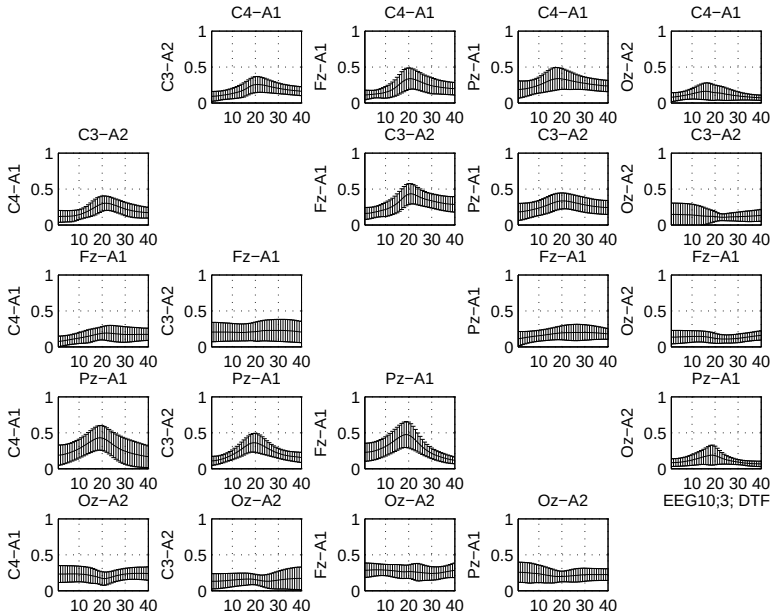

Figure 46: DTF as in (9): Condition #3 and EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

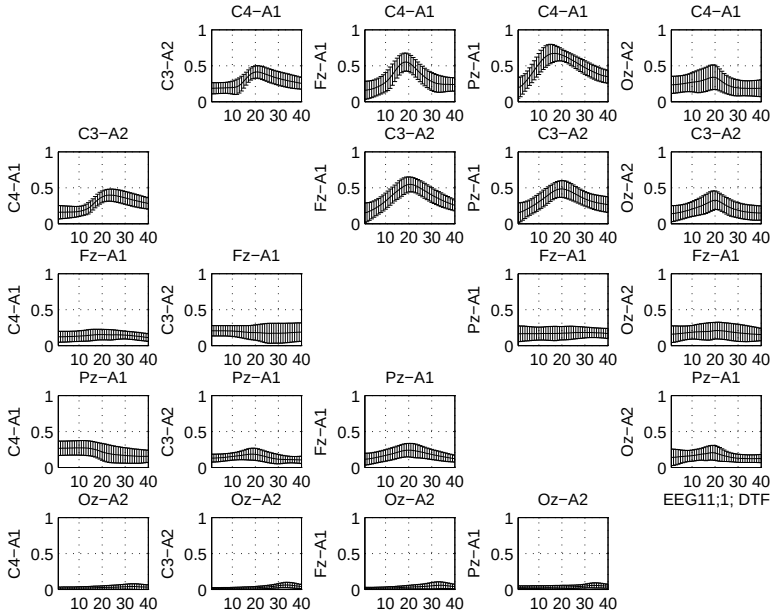

Figure 47: DTF as in (9): Condition #1 and factor EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

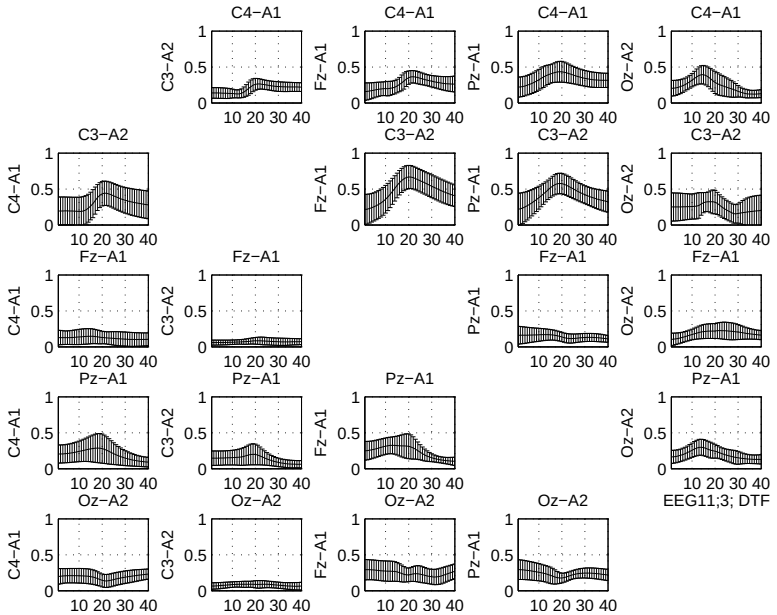

Figure 48: DTF as in (9): Condition #3 and EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

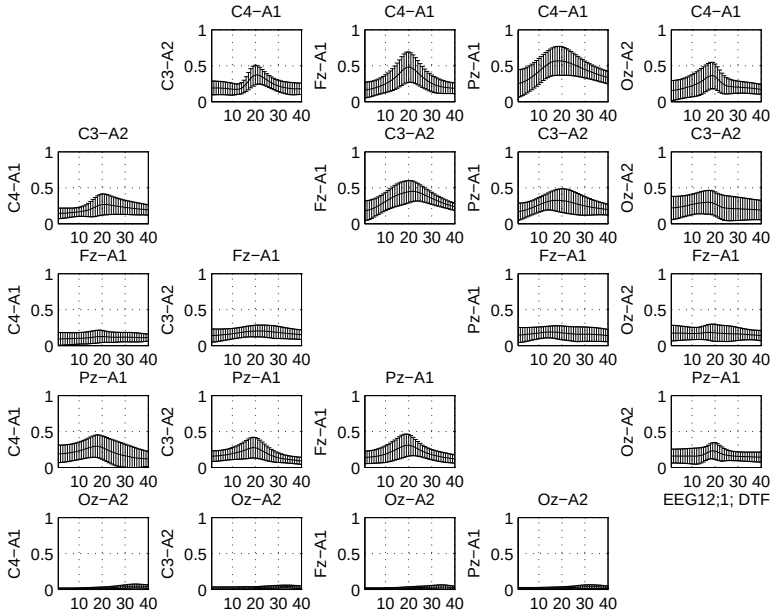

Figure 49: DTF as in (9): Condition #1 and factor EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

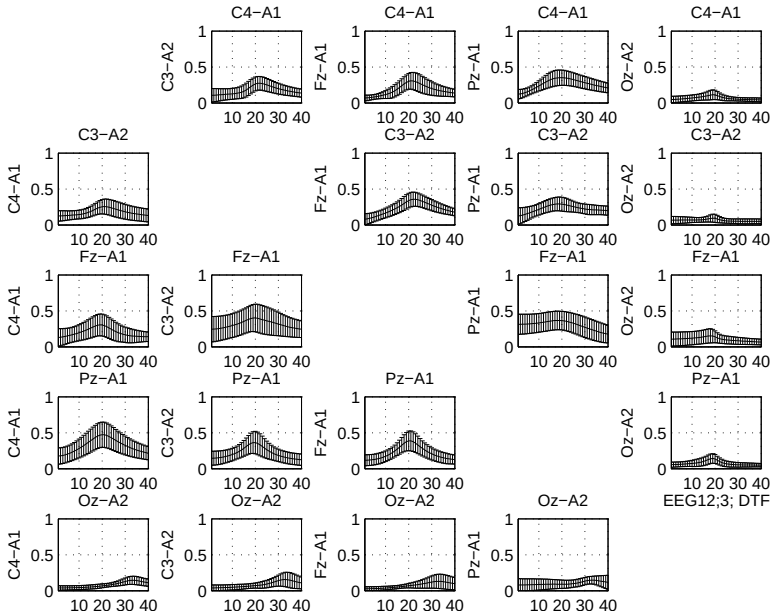

Figure 50: DTF as in (9): Condition #3 and EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

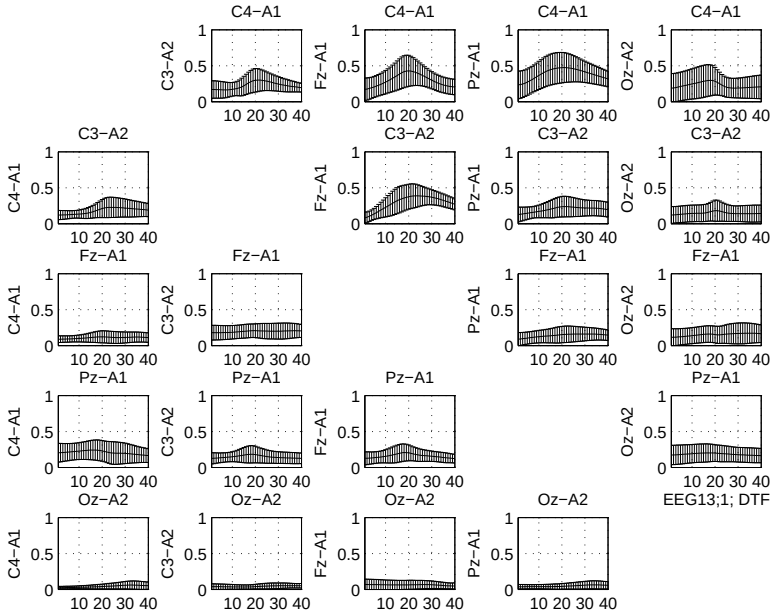

Figure 51: DTF as in (9): Condition #1 and factor EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

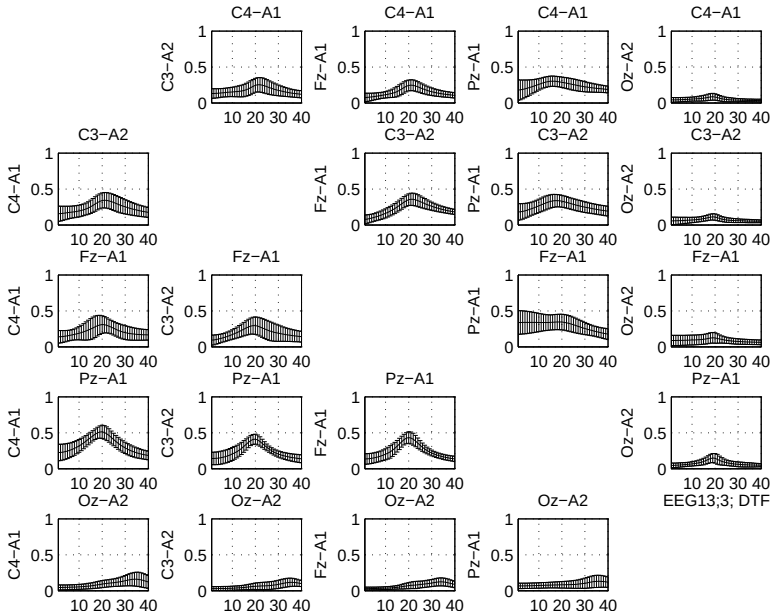

Figure 52: DTF as in (9): Condition #3 and EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

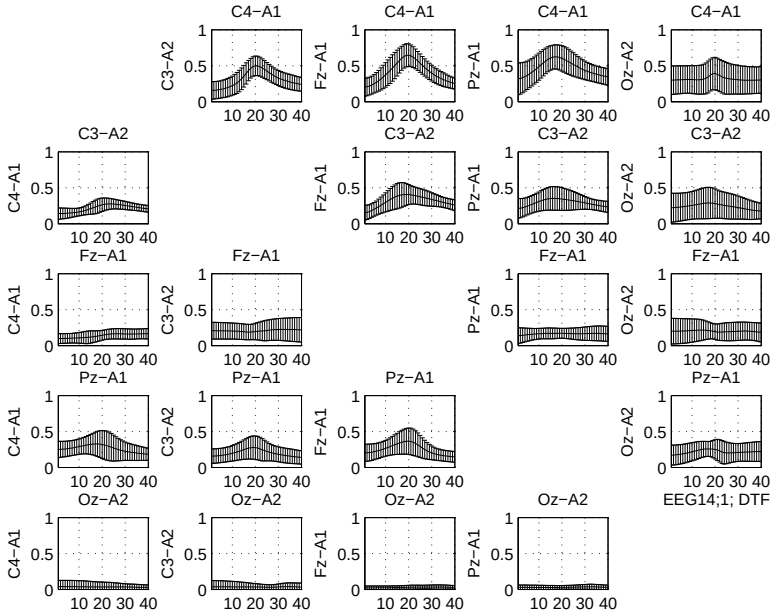

Figure 53: DTF as in (9): Condition #1 and factor EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

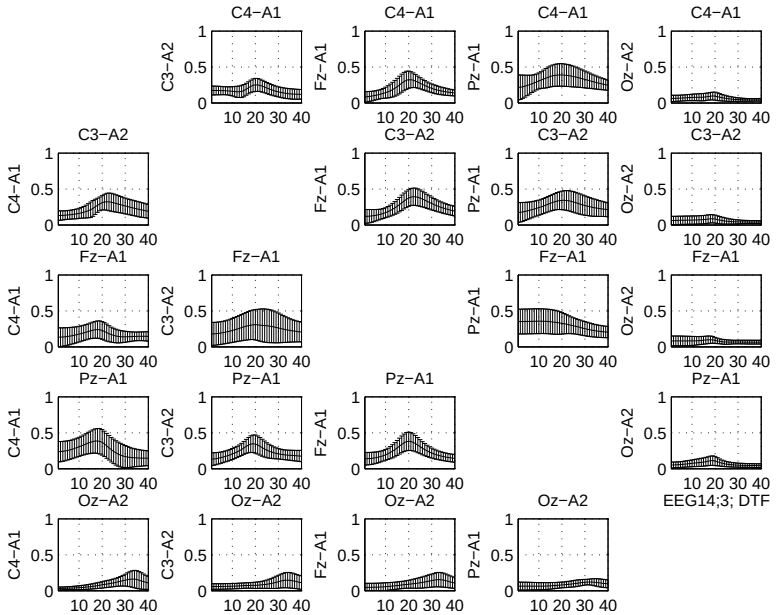

Figure 54: DTF as in (9): Condition #3 and EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

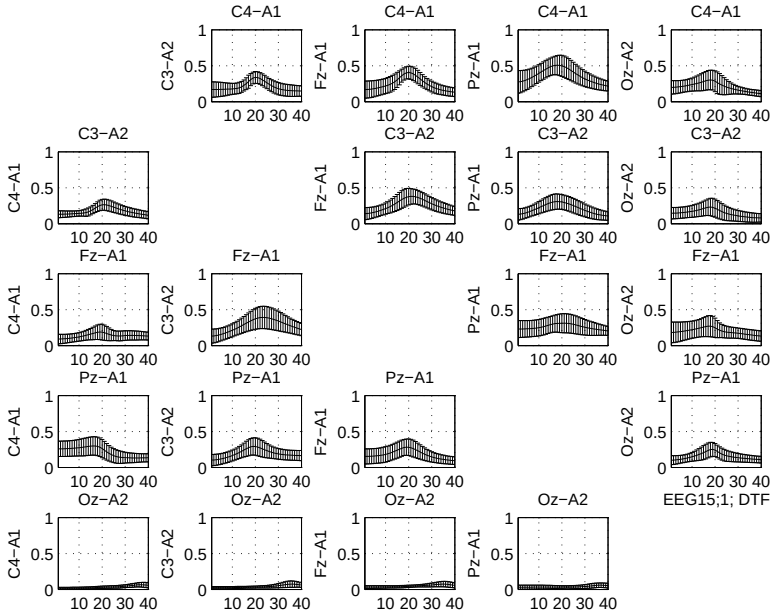

Figure 55: DTF as in (9): Condition #1 and factor EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

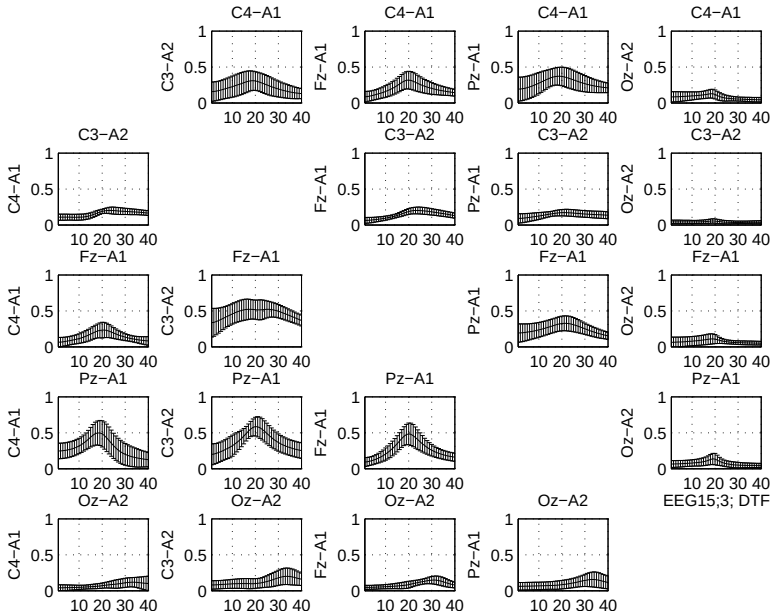

Figure 56: DTF as in (9): Condition #3 and EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

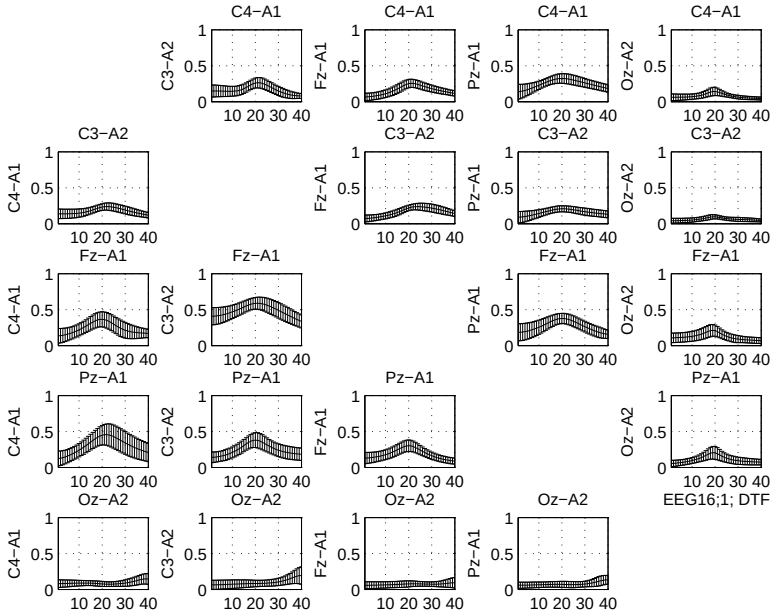

Figure 57: DTF as in (9): Condition #1 and factor EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

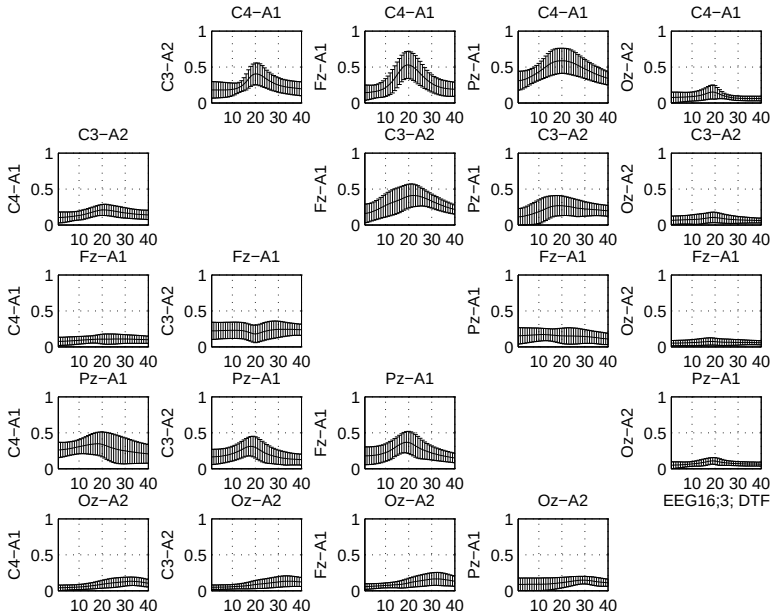

Figure 58: DTF as in (9): Condition #3 and EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

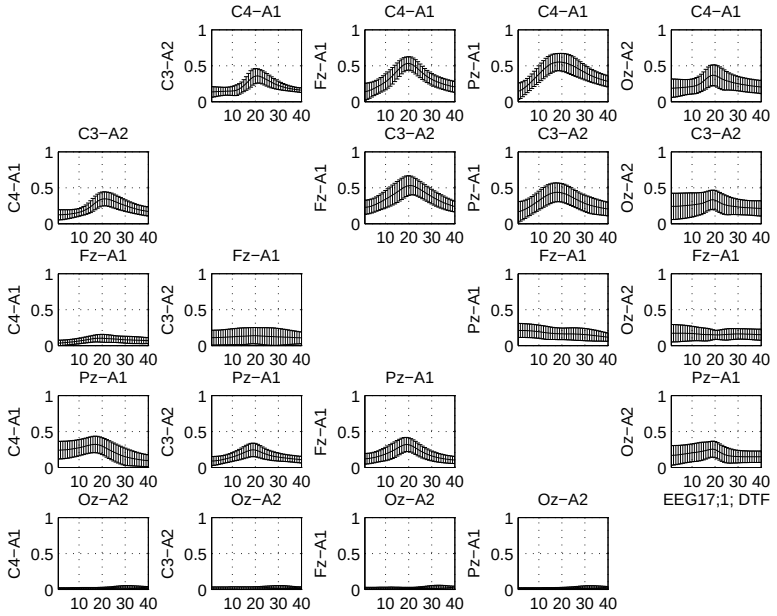

Figure 59: DTF as in (9): Condition #1 and factor EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

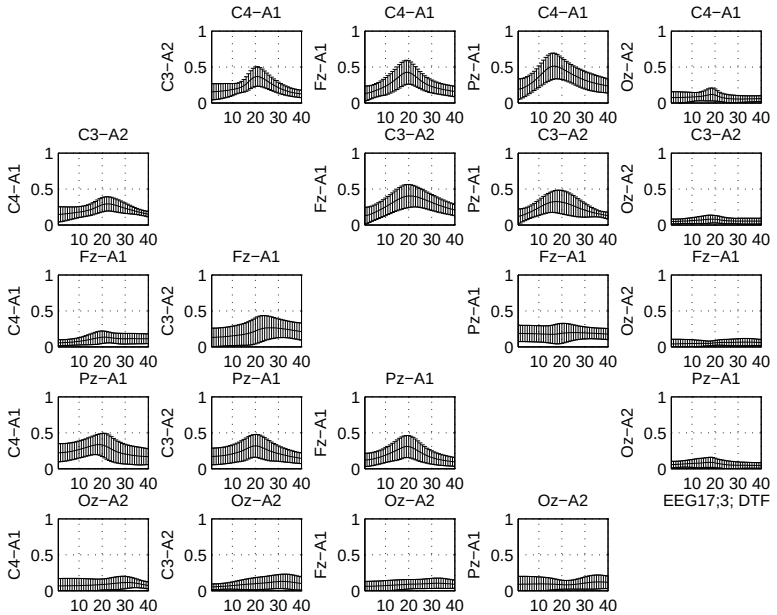

Figure 60: DTF as in (9): Condition #3 and EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

3.4 Direct directed transfer function (dDTF)

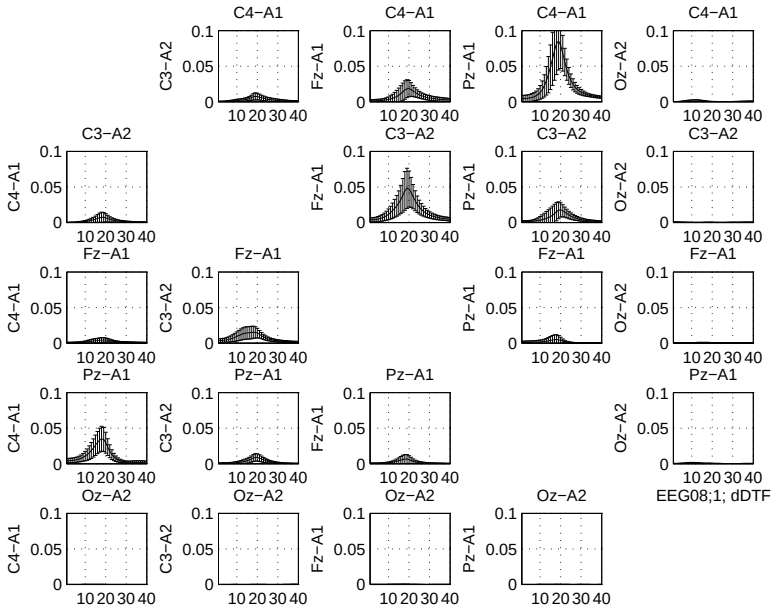

Figure 61: dDTF as in (11): as in (9): Condition #1 and EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

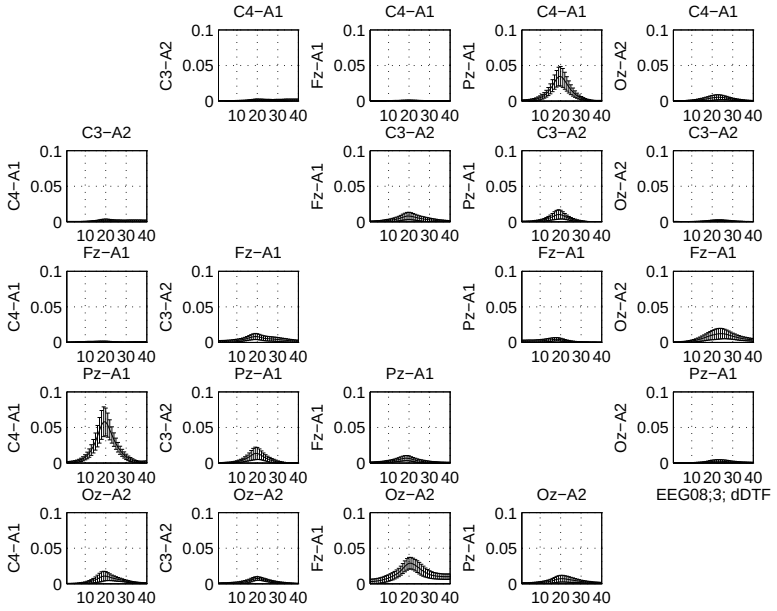

Figure 62: dDTF as in (11): Condition #3 and EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

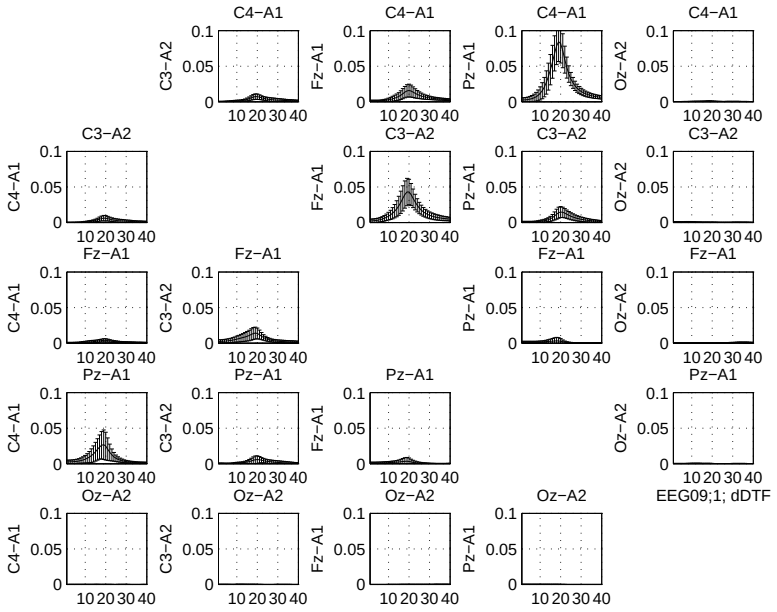

Figure 63: dDTF as in (11): Condition #1 and EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

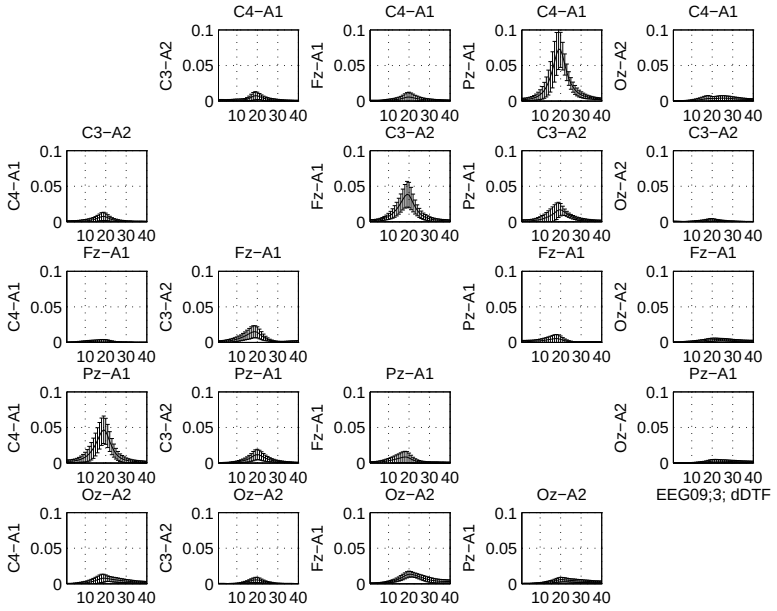

Figure 64: dDTF as in (11): Condition #3 and EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

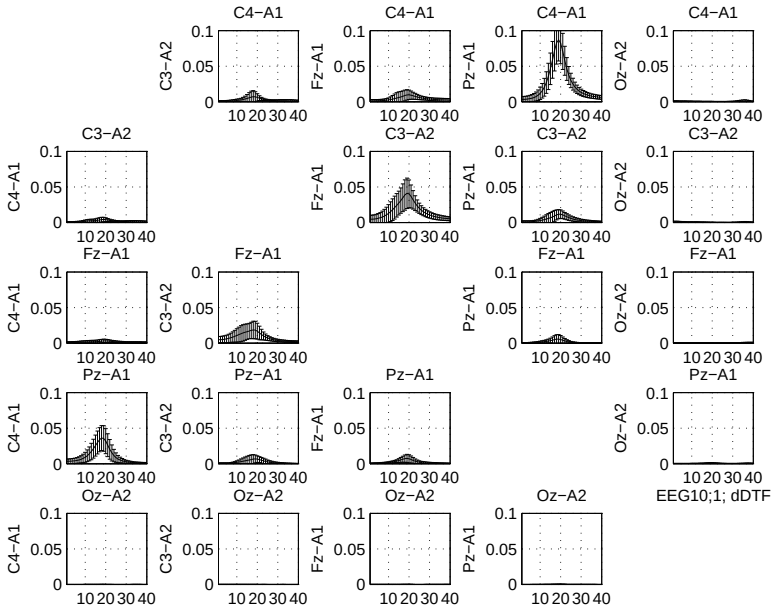

Figure 65: dDTF as in (11): Condition #1 and EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

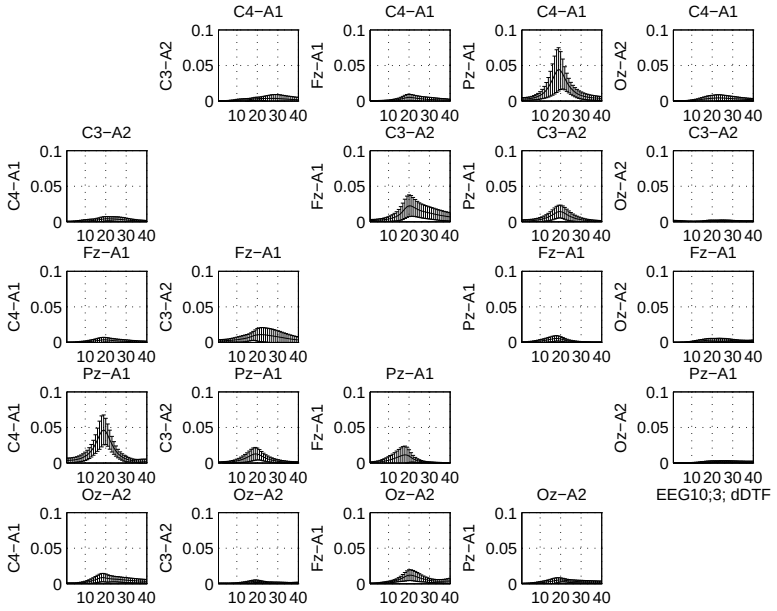

Figure 66: dDTF as in (11): Condition #3 and EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

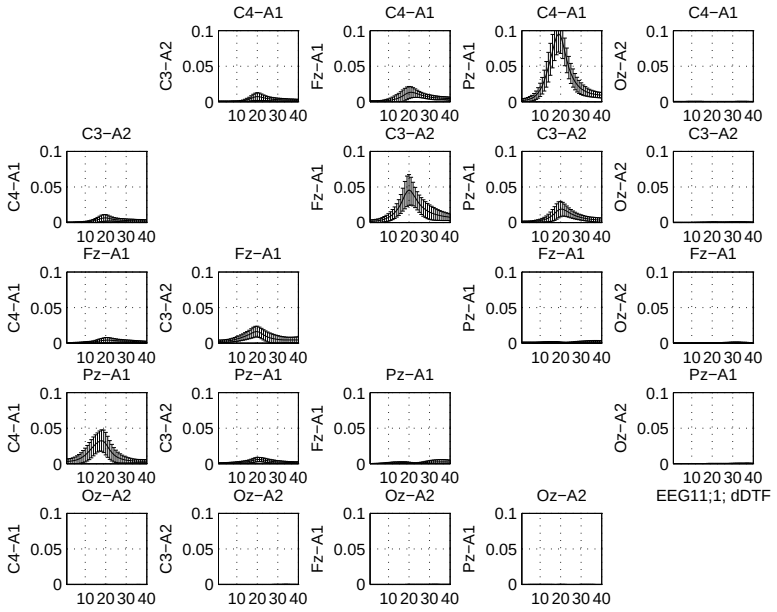

Figure 67: dDTF as in (11): Condition #1 and EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

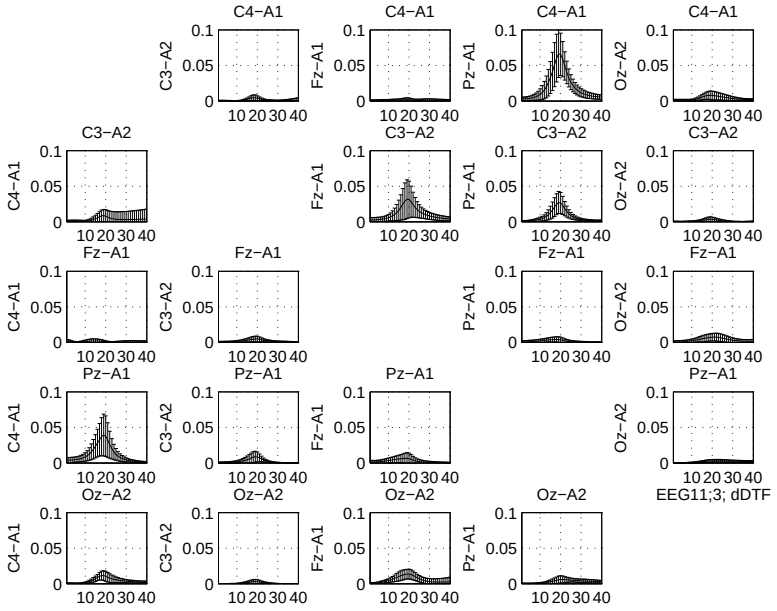

Figure 68: dDTF as in (11): Condition #3 and EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

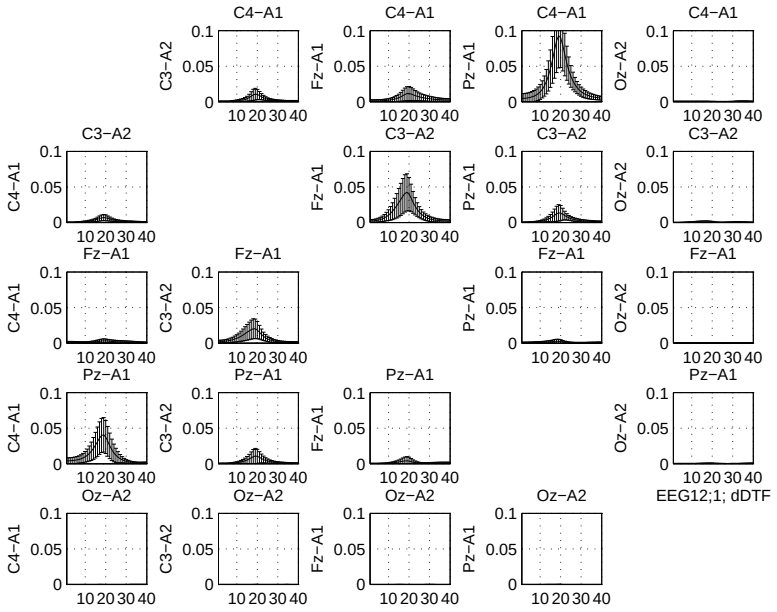

Figure 69: dDTF as in (11): Condition #1 and EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

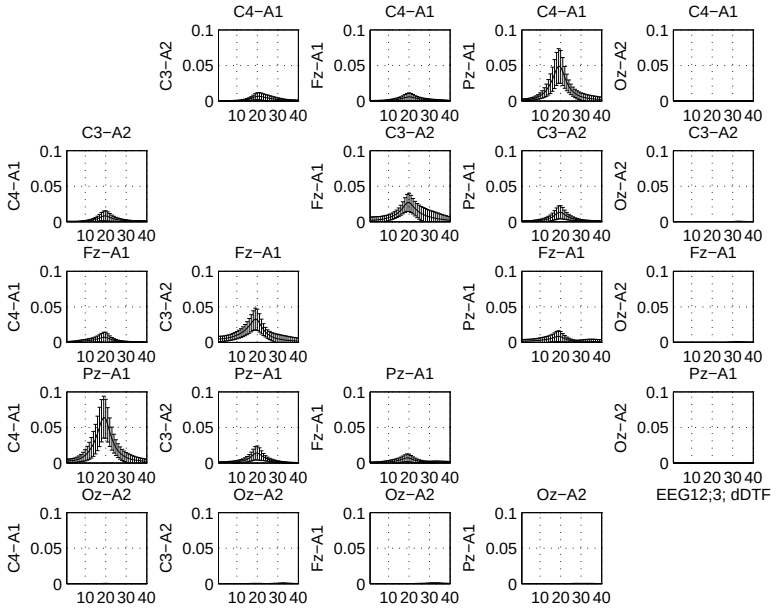

Figure 70: dDTF as in (11): Condition #3 and EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

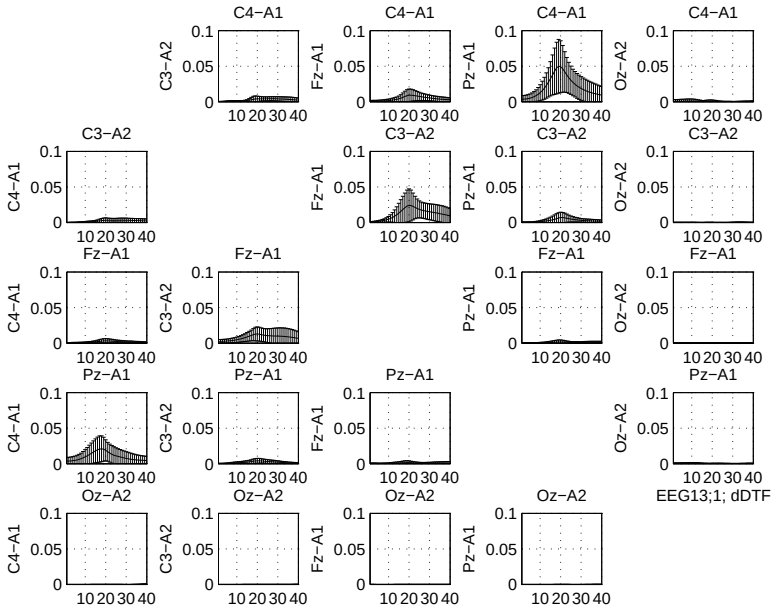

Figure 71: dDTF as in (11): Condition #1 and EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

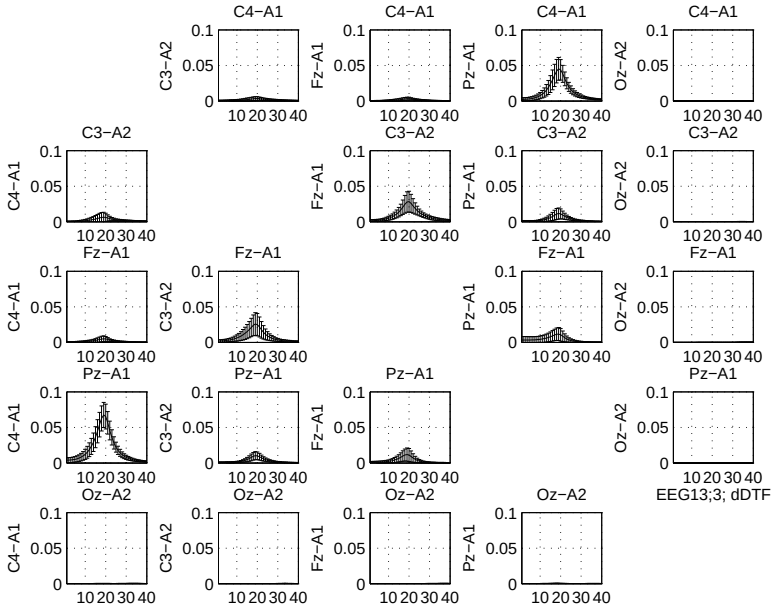

Figure 72: dDTF as in (11): Condition #3 and EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

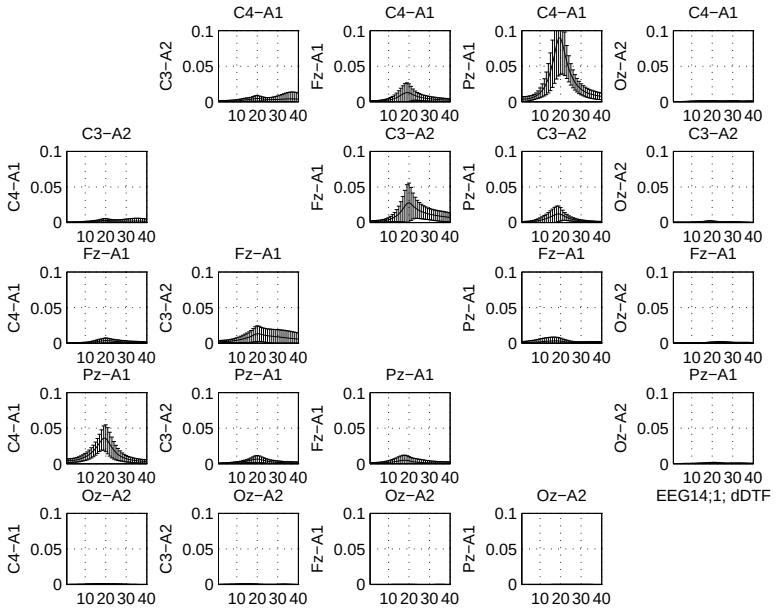

Figure 73: dDTF as in (11): Condition #1 and EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

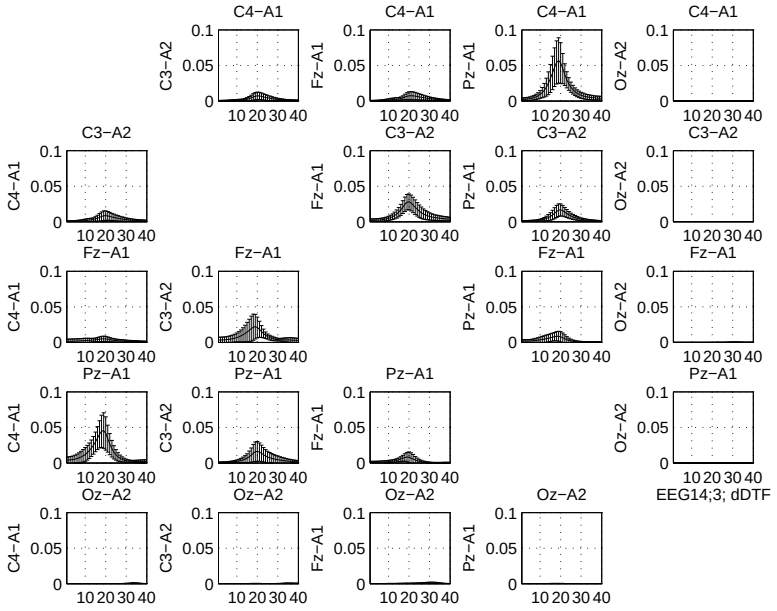

Figure 74: dDTF as in (11): Condition #3 and EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

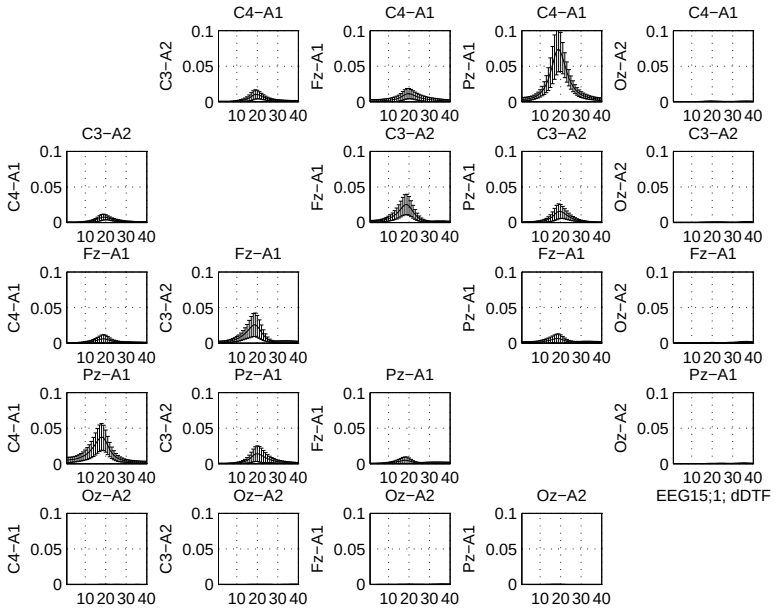

Figure 75: dDTF as in (11): Condition #1 and EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

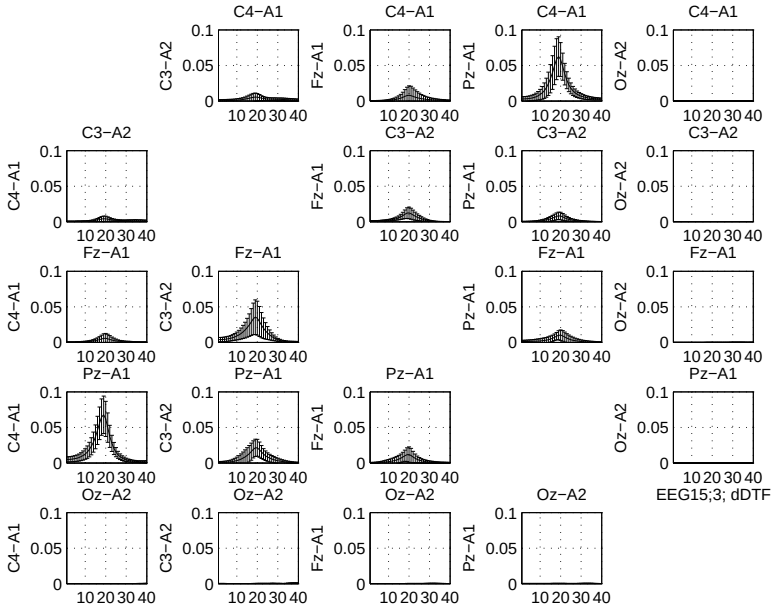

Figure 76: dDTF as in (11): Condition #3 and EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

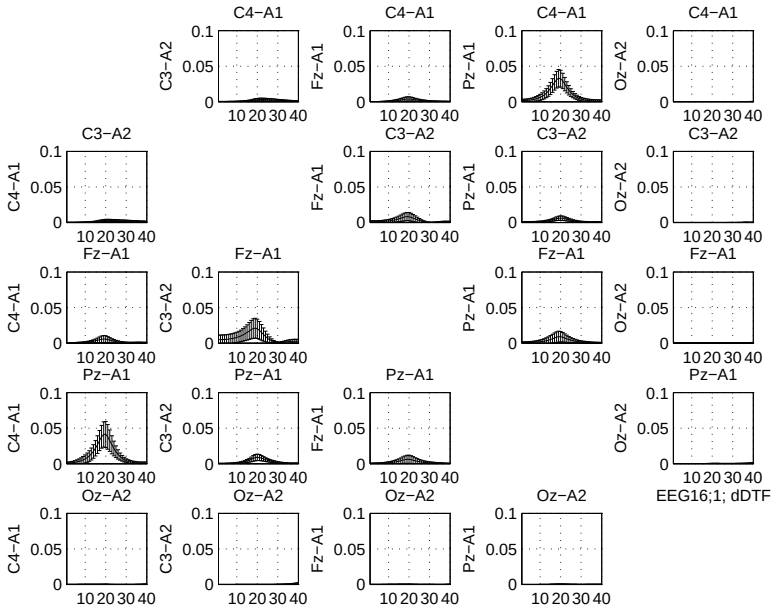

Figure 77: dDTF as in (11): Condition #1 and EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

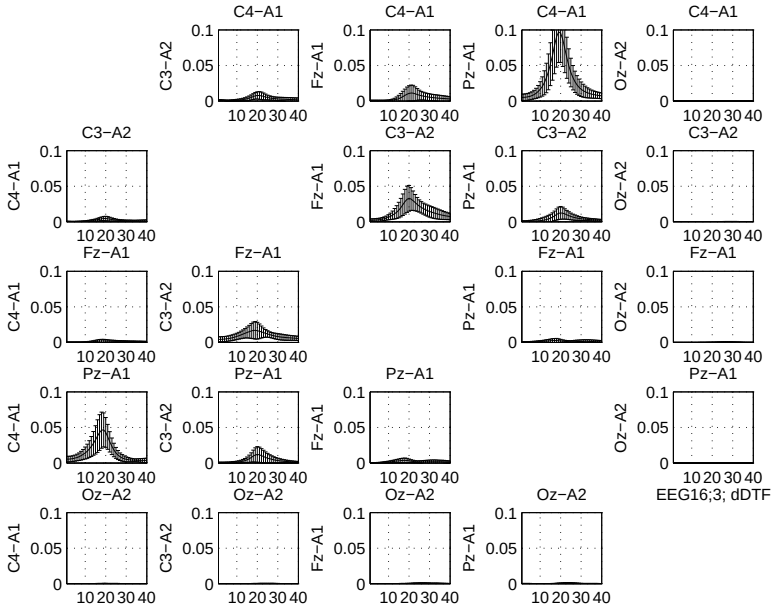

Figure 78: dDTF as in (11): Condition #3 and EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

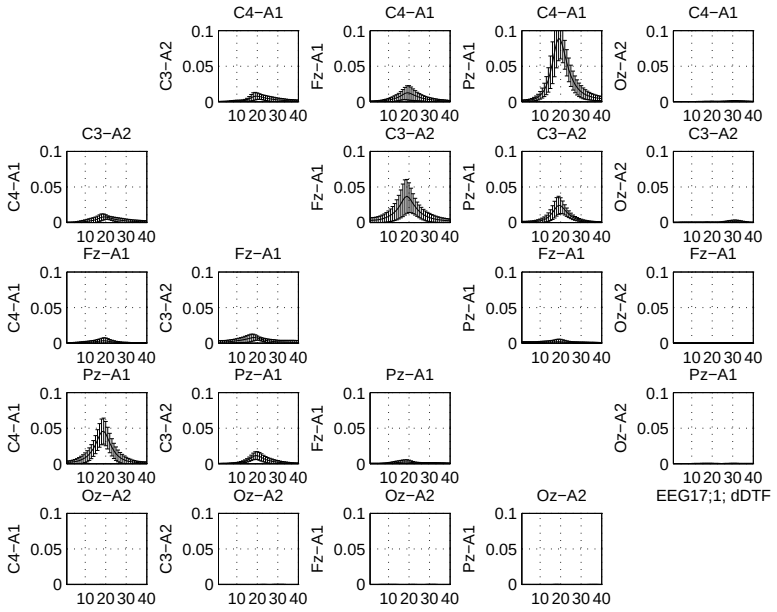

Figure 79: dDTF as in (11): Condition #1 and EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

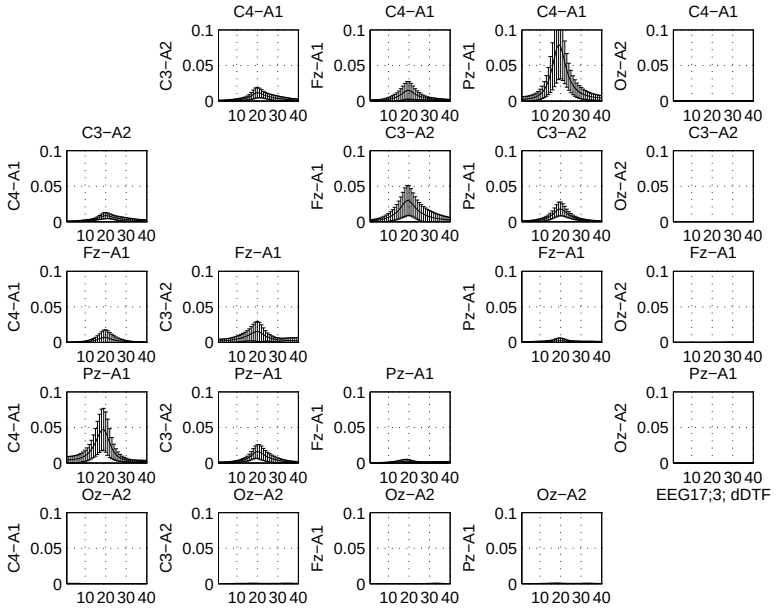

Figure 80: dDTF as in (11): Condition #3 and EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

3.5 Partial directed coherence (PDC)

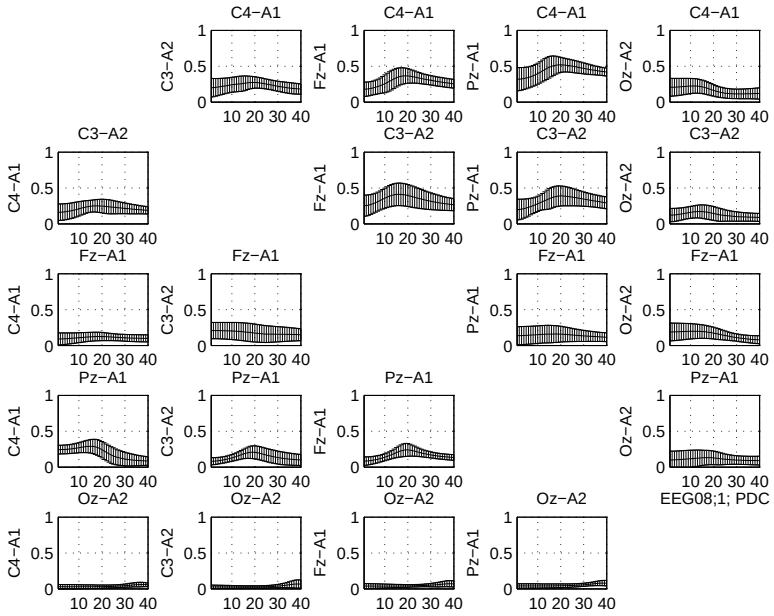

Figure 81: PDC as in (10): Condition #1 and EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

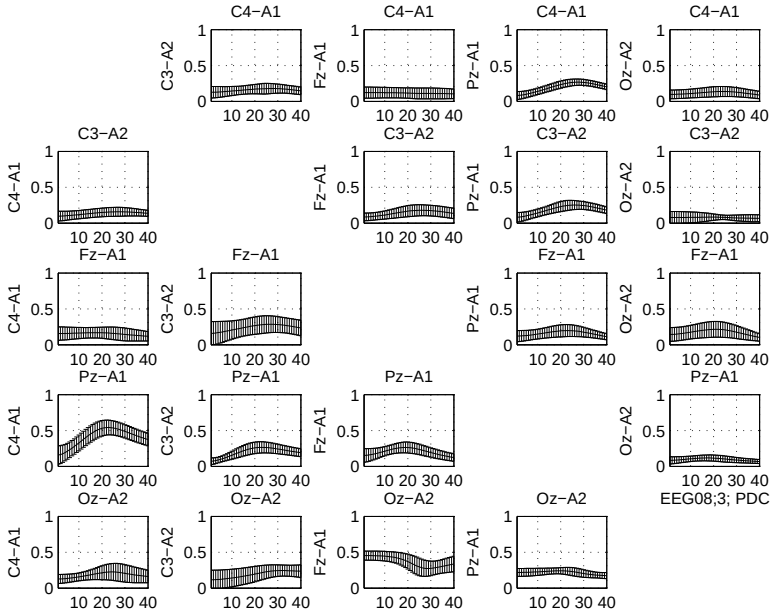

Figure 82: PDC as in (10): Condition #3 and EEG08. *X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

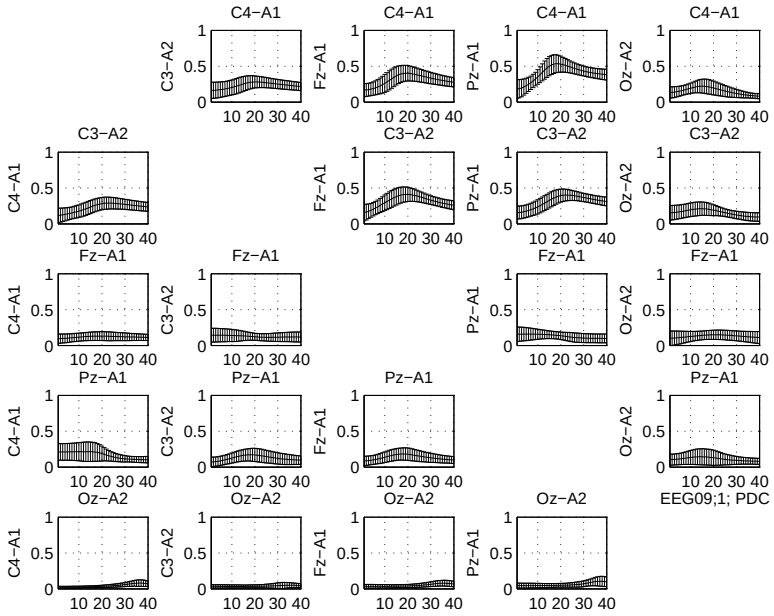

Figure 83: PDC as in (10): Condition #1 and EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

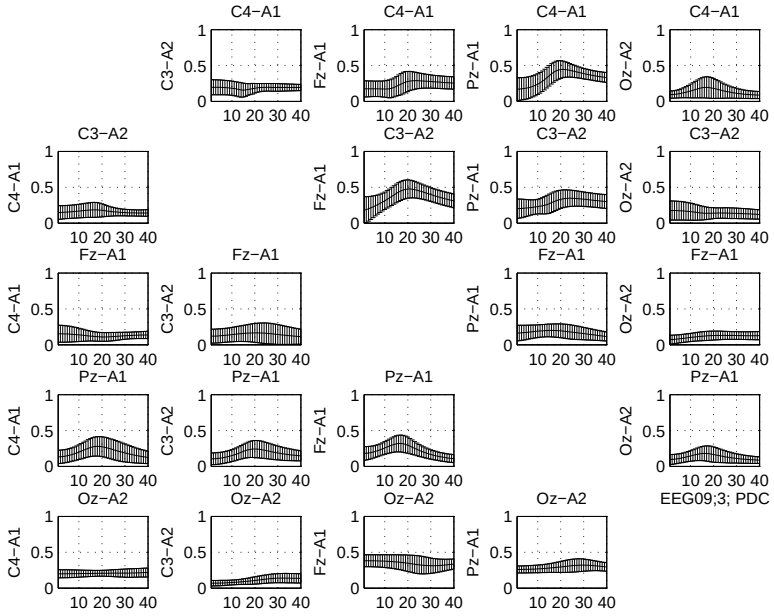

Figure 84: PDC as in (10): Condition #3 and EEG09.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

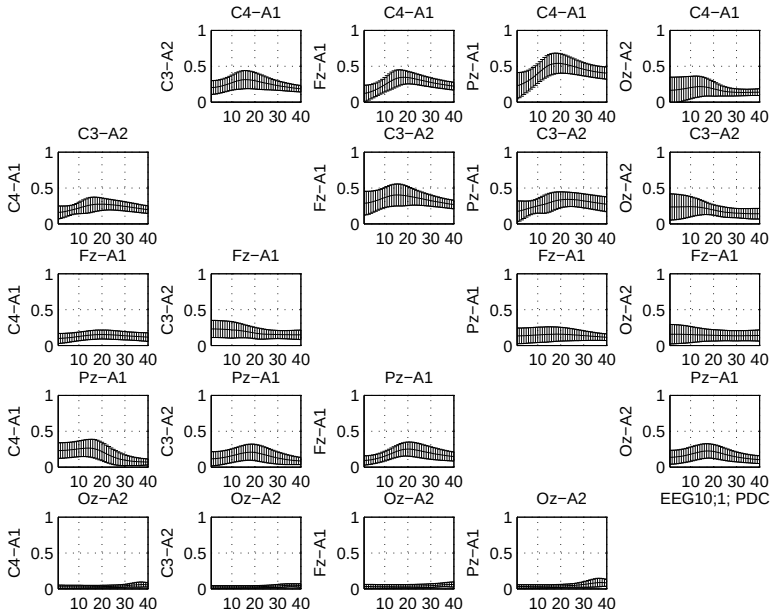

Figure 85: PDC as in (10): Condition #1 and EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

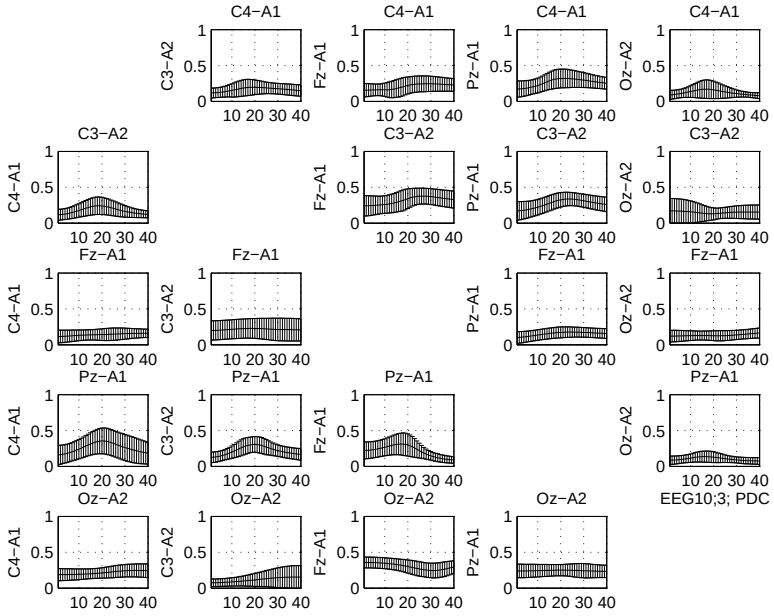

Figure 86: PDC as in (10): Condition #3 and EEG10.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

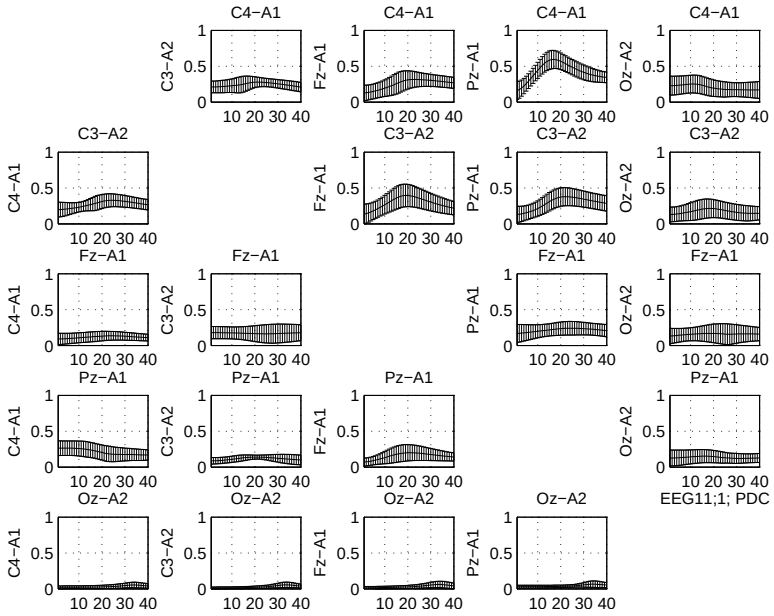

Figure 87: PDC as in (10): Condition #1 and EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

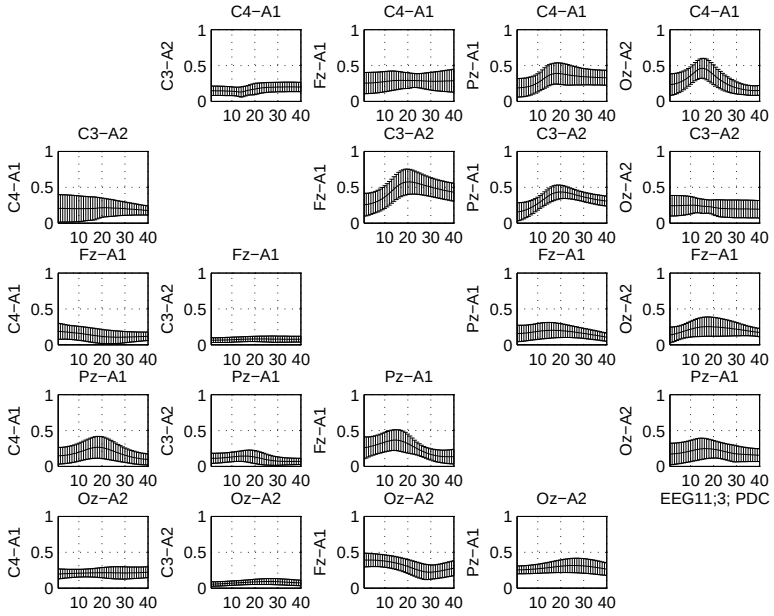

Figure 88: PDC as in (10): Condition #3 and EEG11.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

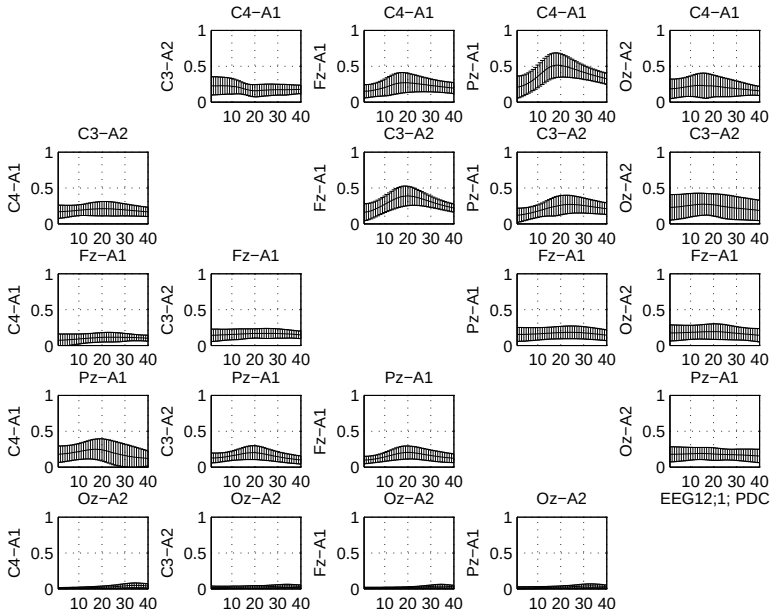

Figure 89: PDC as in (10): Condition #1 and EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

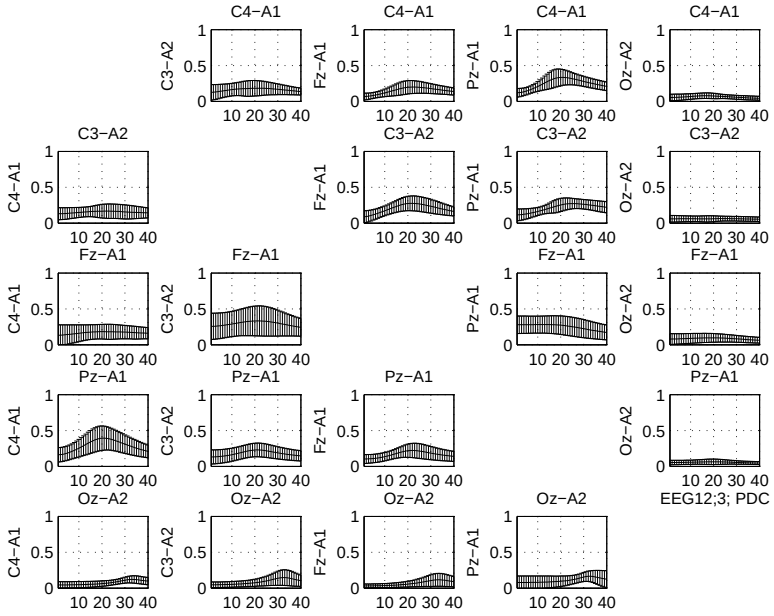

Figure 90: PDC as in (10): Condition #3 and EEG12.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

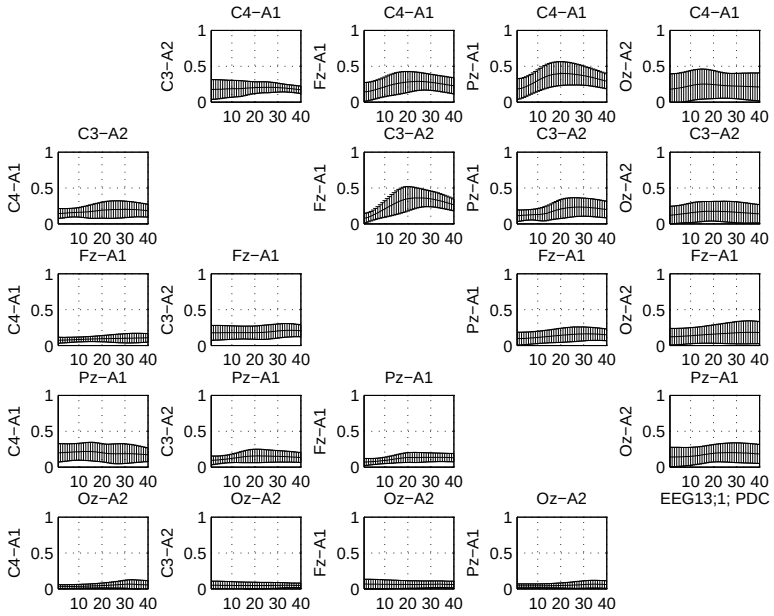

Figure 91: PDC as in (10): Condition #1 and EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

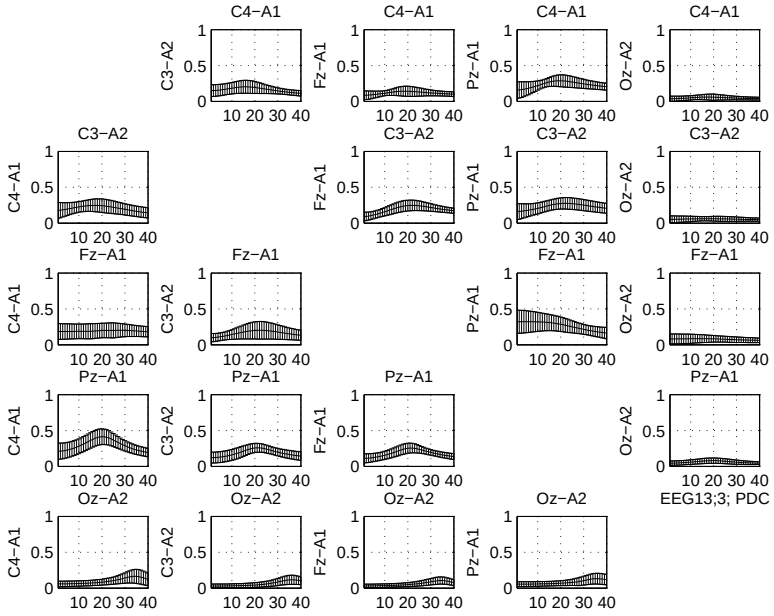

Figure 92: PDC as in (10): Condition #3 and EEG13.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

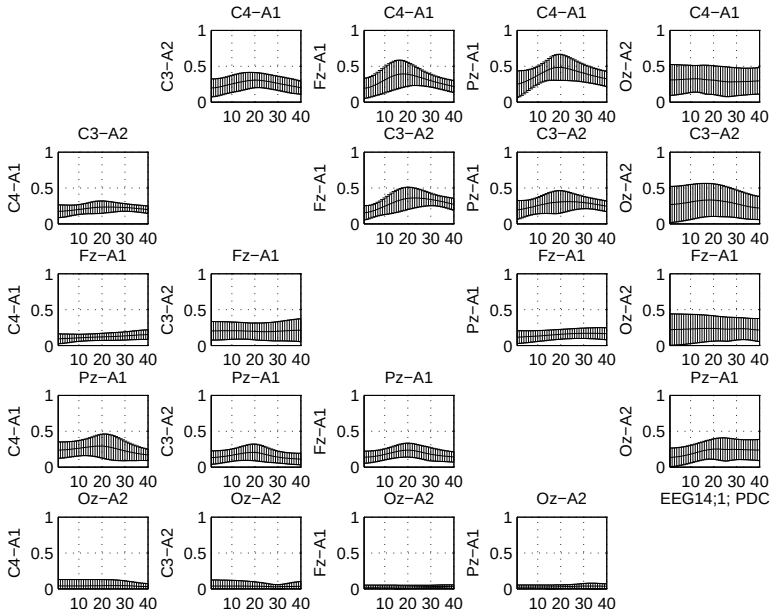

Figure 93: PDC as in (10): Condition #1 and EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

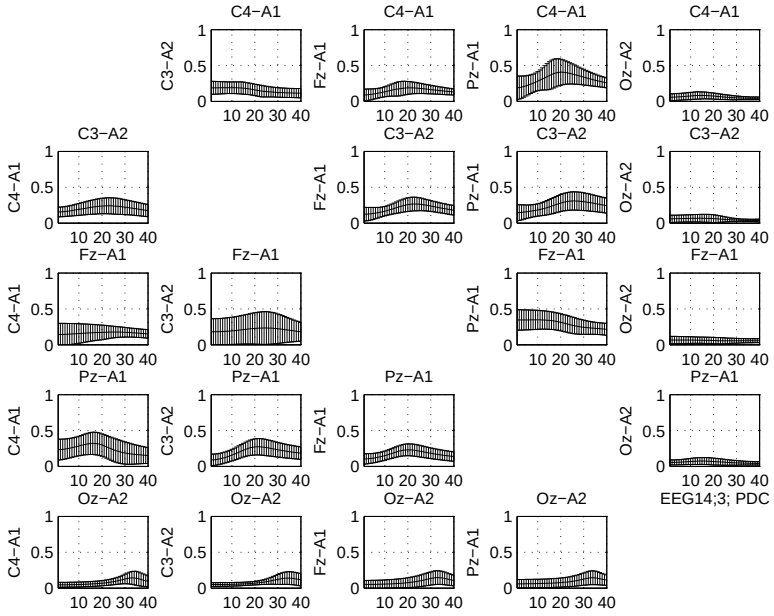

Figure 94: PDC as in (10): Condition #3 and EEG14.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

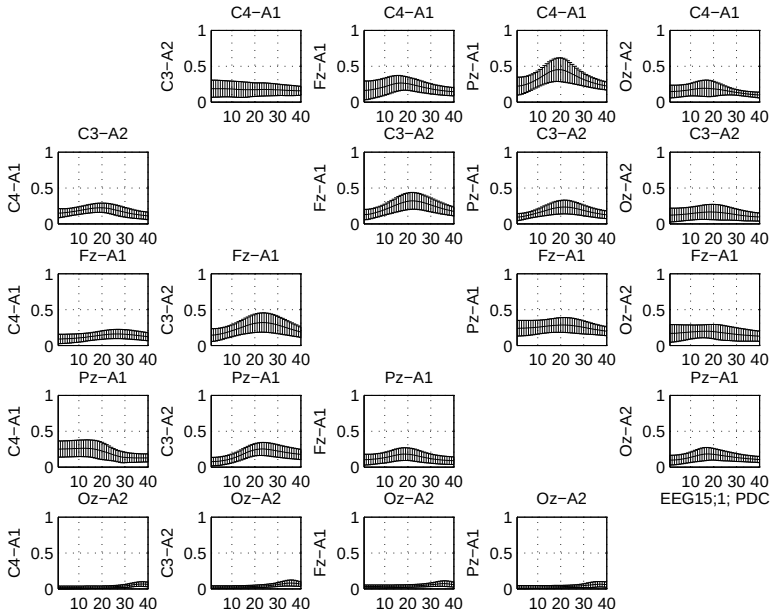

Figure 95: PDC as in (10): Condition #1 and EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

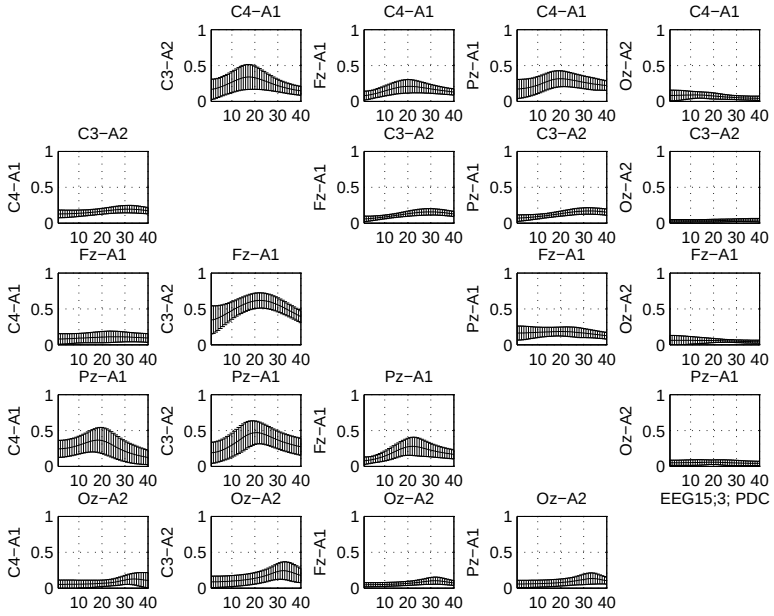

Figure 96: PDC as in (10): Condition #3 and EEG15.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

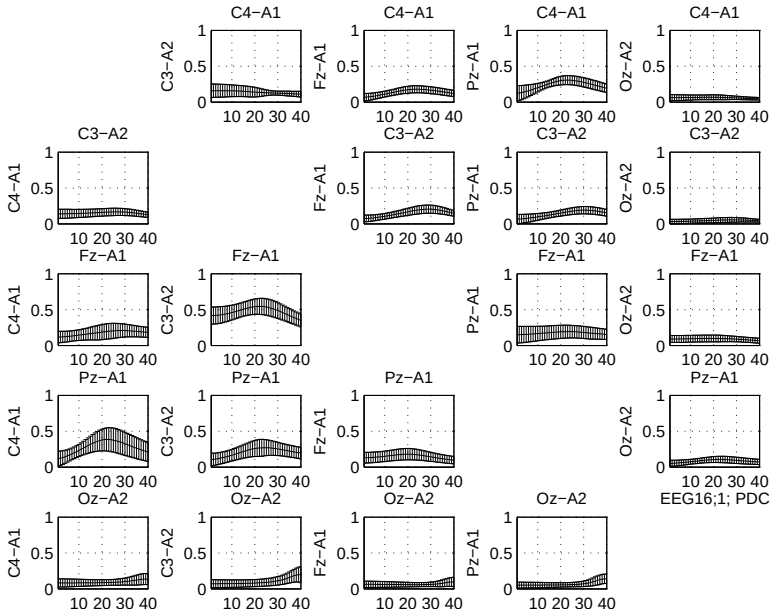

Figure 97: PDC as in (10): Condition #1 and EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

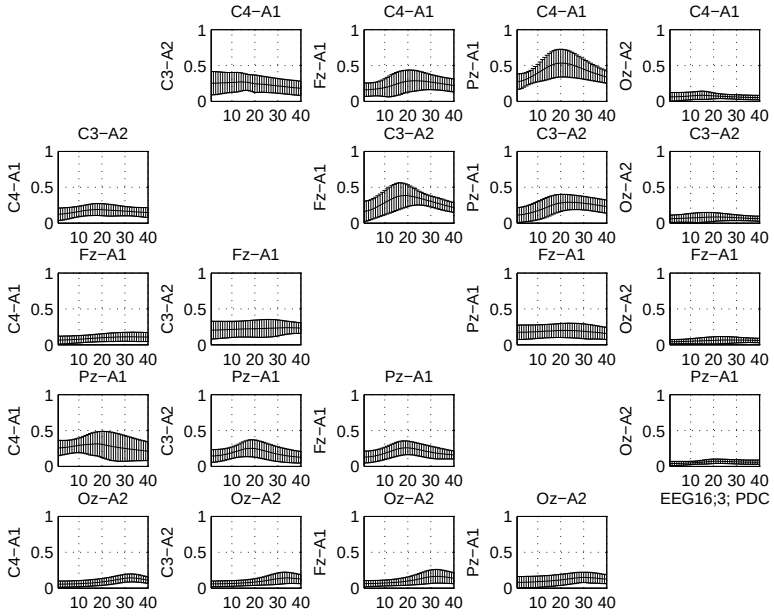

Figure 98: PDC as in (10): Condition #3 and EEG16.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

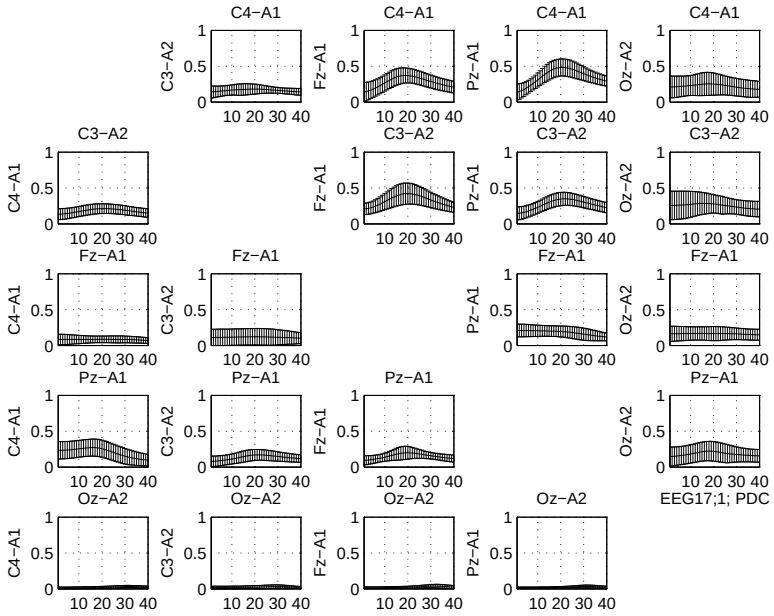

Figure 99: PDC as in (10): Condition #1 and EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

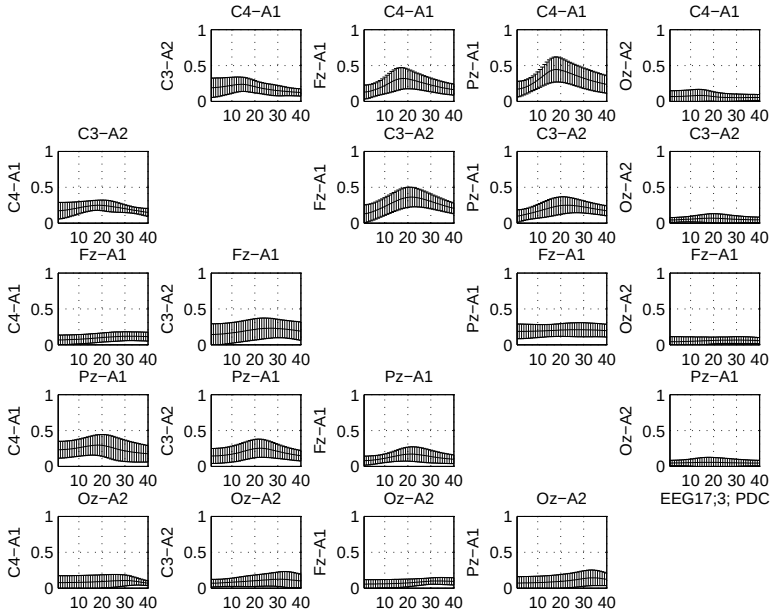

Figure 100: PDC as in (10): Condition #3 and EEG17.*X-axes* in all plots are frequencies $0-20$Hz (DC and frequencies around 1Hz are usually filtered by EMD thus no activity there analyzed).

4 Future work

4.1 Statistical analysis of synchrony patterns

Confidence levels of synchrony "patterns" in around 20Hz and around 70Hz to be analyzed.

4.2 Automatic classification/recognition based on synchrony patterns

4.2.1 Two classes of *no-nap* and *40 minute nap* conditions

4.2.2 Trial of clustering/classification of test batteries 8 to 17

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cation," in *Proceedings of the 2009 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP2009)*, pp. 373–376, IEEE, 2009.

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