Tutorial on Adulteration of Phase Relations when using Independent Components Analysis/Blind Identification and other Regression Methods to "Correct for Artifact"

Let us consider the rejection of eye movement artifact (EOG) using the ICA method which is the mathematical basis for Blind Source analysis. The ICA method decomposes a time series into a set of globally independent time series. Mathematically ICA can invert the equation and exactly reproduce the original time series based on the mathematical components. In this case the originally measured time or phase differences between each electrode are preserved and the cross-spectrum is unaltered.

However, everything changes when the ICA or PCA or Blind Source, etc. methods are used to remove artifact by reconstructing 19 channels based on a smaller set of components, e.g., 17 or 18 channels and then deleting or omitting the EOG "components" to reconstruct 19 channels. This is because a regression process (interpolation) is used to minimize the deviation of the original 19 channel time series from the 17 or 18 "components" by which the remainder is used as weights to produce a second time series that has altered all of the phase relations in the original time series.

The regression uses the average of the entire time series and therefore "smooths" time or phase at each time point. Averaging a time series and computing deviations (whether information min-max, equimax, or simple linear regression) and then using the result to weight each time point by averages thereby smooths each data point's phase relations at each moment of time, distorting coherence, and destroys the time and phase relations present in the original time series.

Scientific Studies Demonstrating ICA/Regression Distortions of EEG:

Castellanos NP, Makarov VA. 2006. Recovering EEG brain signals: artifact suppression with wavelet enhanced independent component analysis. *J Neurosci Methods*. 15;158(2):300-312.

Hyvarinen, A., Karhunen,J. and Oja, E. (2001). Independent Components Analysis. John Wiley & Sons, NY.

Jervis, B.W., Coelho, M. and Morgan, G. (1989). Effect on EEG responses of removing ocular artifacts by proportional EOG subtraction. Medical and Biological Engineering and Computing, 27:484–490.

Kierkels J, Boxtel G,Vogten L. 2006. A model-based objective evaluation of eye movement correction in EEG recordings. *IEEE Trans Biomed Eng.*; 53:246–253.

Mannan MMN, Jeong MY and Kamran MA (2016). Hybrid ICA-Regression: Automatic Identification and Removal of Ocular Artifacts from Electroencephalographic Signals. *Front. Hum. Neurosci.* 10:193. doi: 10.3389/fnhum.2016.00193

Montefusco-Siegmund, R., Maldonado, P.E. and Devia, C. (2013). Effects of ocular artifact removal through ICA decomposition on EEG phase. 6th Annual International IEEE EMBS Conference on Neural Engineering San Diego, California, 6 - 8 November, 2013.

Wallstrom G, Kass R, Miller A, Cohn J, Fox N. 2004. Automatic correction of ocular artifacts in the EEG: a comparison of regression-based and component-based methods. *Int J Psychophysiol* 2004; 53:105–119.

Consensus by Experts Confirming Alteration of Phase Differences by ICA Replacement (ICA-R)

Professionals at the University of California at San Diego EEGLablist that have numerous public discussions and evaluations of ICA have independently confirmed that ICA replacement alters phase differences. For example:

1- "If you remove IC and reconstruct channel EEG by back projecting the remaining ICs, of course it changes channel EEG phase!" (Makoto Miyakoshi, Eeglablist ICA and signal phase content, Sept. 16, 2014)

2- "The EEG reconstruction after removing bad components/sources MAY change the phase value of the signal at any electrode." (M. Rezazadeh Eeglablist ICA and signal phase content, Sept. 18, 2014).

3- "The reconstructed data after removing spurious ICA components differs from the original time series, and because of that there are phase differences." (Arnaud Delorme, Eeglablist ICA misinformation, June 10, 2017).

4- "I first noticed the problem with phase distortion more than a decade ago" (Robert Lawson, Eeglablist ICA misinformation, June 14, 2017).

5- "I think he is right that the relative phase will be changed by deleting 1 or 2 artifact components." (Ramesh Srinivasan, Eeglablist ICA misinformation, June 14, 2017).

6- "We found phase distortions in the 8-10 Hz alfa band (greatest near the source of artefact) but also on more remote electrodes such as occipital and also in artefact free strokes of EEG." (Georges Otte, Eeglablist ICA misinformation, June 15, 2017).

Tutorial Demonstration of ICA Distortion

Step 1- Download the Original non-ICA Demo TBI patient EEG.edf in EDF format at:
https://www.appliedneuroscience.com/Downloads/Original_non-ICA_Demo_TBI_patient_EEG.zip

Step 2 - Download and install WinEEG from:
https://wineeg.software.informer.com/2.8/

Step 3- In WinEEG, import the original EEG file "Original non-ICA Demo TBI patient EEG.edf" file by clicking in the menu - File > Open File browse and select the file labeled "Original non-ICA Demo TBI patient EEG.edf" file.

Step 4 - For the ICA method, select at least **1-2 minutes** of EEG including the eye movement artifact (see pages 12-13 of the WinEEG manual) by manually select from a beginning point by depressing the left mouse button and dragging over the eye movement artifact to the ending point. Note: mouse clicks in second area of the window will show yellow marker.

Step 5 - From the menu options select - Analysis > Artifacts correction…a window opens up and select ICA method (wait for processing) and press OK button.

Step 6 - Save the ICA corrected file by clicking from the menu - File > Export Data then select Full EEG file and format EDF. Name the file "ICA artifact corrected Demo TBI patient.edf". Press OK button. This file can also be downloaded at:

https://www.appliedneuroscience.com/Downloads/ICA_artifact_corrected_Demo-TBI_patient.zip

You will now have two files: 1- The "Original non-ICA Demo TBI patient EEG.edf" file and, 2- The "ICA artifact corrected Demo TBI patient.edf" file

Step 7 – Launch NeuroGuide and click File > Open > EDF and navigate to where the "Original non-ICA Demo TBI patient EEG.edf" file was saved (see Step #1) and import into NeuroGuide. In the EDF Parameters window select the Collection Hardware for Lexicor (High Pass Off). Click OK and click Cancel in the subject information panel. Double click Linked Ears. Re-size NeuroGuide to the upper ½ of the computer screen.

Step 8 – Launch a 2nd NeuroGuide and click File > Open > EDF and navigate to where the "ICA artifact corrected Demo TBI patient.edf" file was saved (see Step #6) and import into the 2nd NeuroGuide. Click OK and click Cancel in the subject information panel. Double click Linked Ears. Re-size NeuroGuide to the lower ½ of the computer screen.

Step 9 - Click View > Dynamic JTFA > Phase (Absolute), Repeat Click View > Dynamic JTFA > View Time Series. Position the original time series at the top and the ICA corrected time series on the bottom. No distortion is defined as no difference between the top and bottom displays. This demonstration shows major and persistent differences between the original time series and the ICA reconstructed time series. Time and phase differences arise because of underlying neurophysiological factors such as conduction velocities, synaptic rise times, synaptic delays, etc. Any distortion of the original time series is an adulteration and precludes linking the time series to neurophysiological processes. In other words, ICA invalidates the EEG and all subsequent analyses of the EEG, especially those involving phase.

Figure One: Pre vs Post Artifact Correct Digital EEG

Pre vs Post ICA Artifact Correction

Original EEG Data with Eye Movement Artifact

ICA Corrected EEG & Removal of Eye Movement Artifact
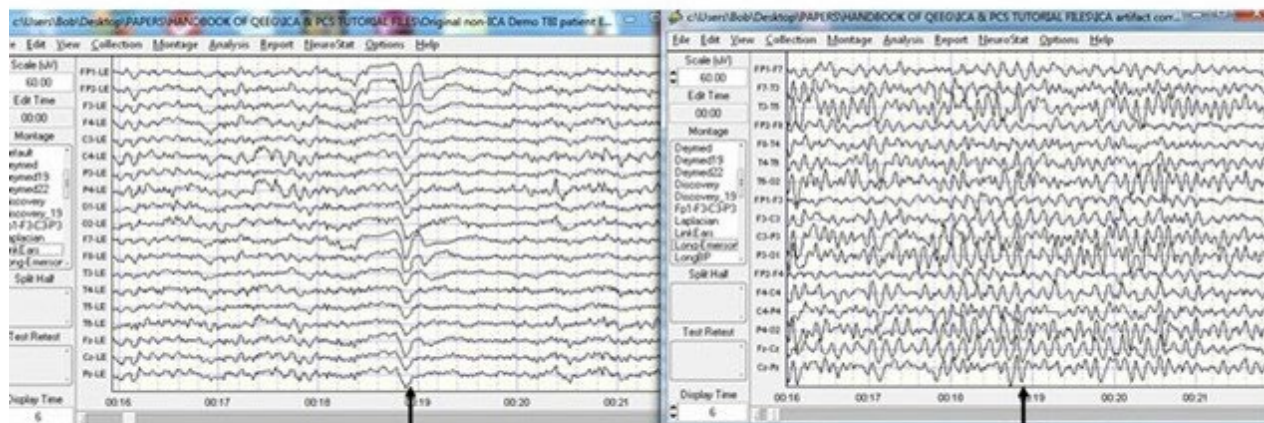
Eye Movement Artifact at 19 seconds

No Eye Movement Artifact at 19 seconds

Figure Two – NeuroGuide JTFA Control Panel

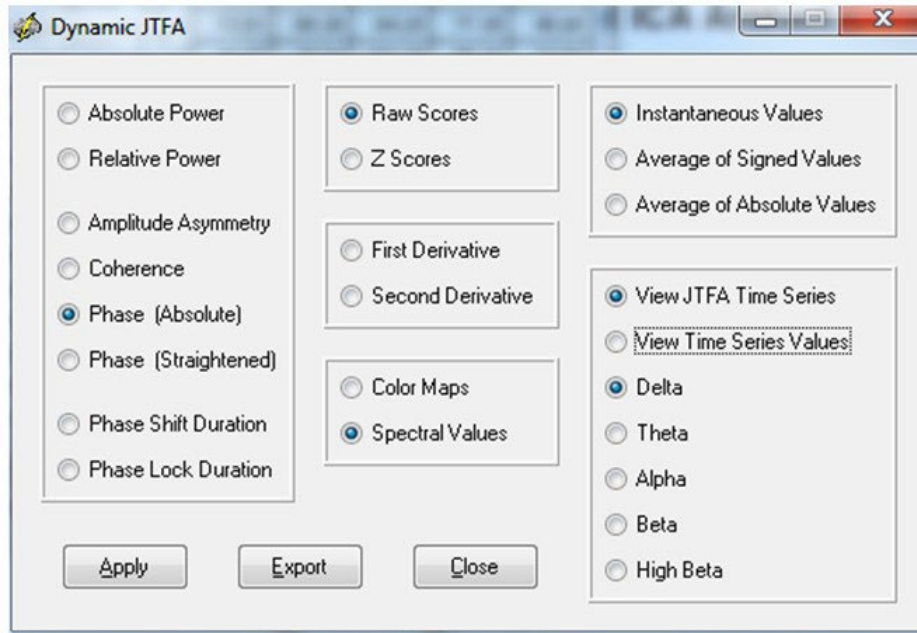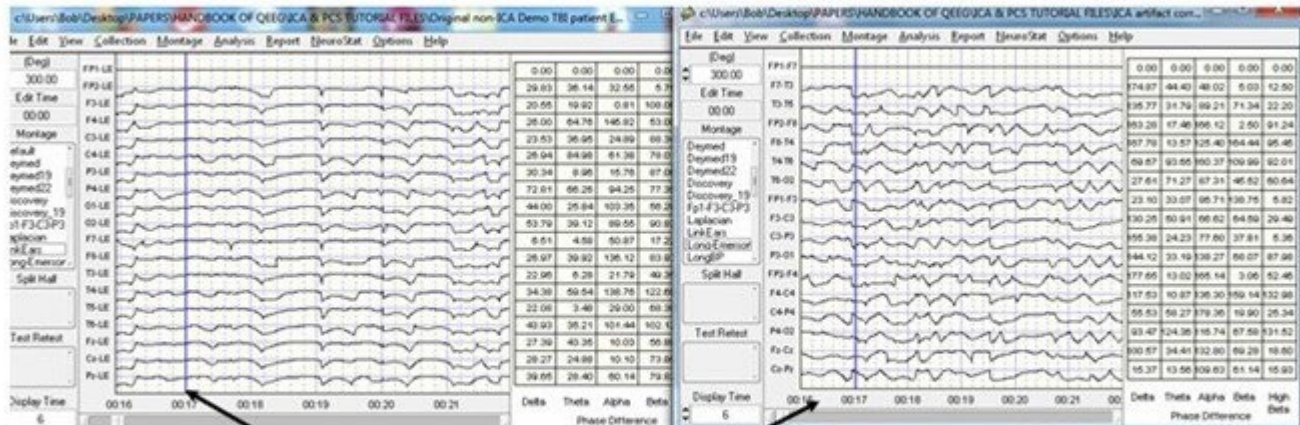**Example of NeuroGuide JTFA Control Panel Selections**

Figure Three- Absolute Phase Differences Between
All Pairs of Electrodes are Not the Same After ICA Correction

Phase Differences Between Pre vs Post ICA Artifact Correction

Original EEG Data
ICA Corrected EEG

Depress Left Mouse Button at any Time Point and Verify that
All Phase Differences Between All Channel Pairs are Not the Same

Statistical Tests of Absolute Phase Differences –
Original EEG vs ICA "Corrected" Time Series

FFT Phase Lag Paired t-Test (P-Value)

Intrahemispheric: LEFT

	DELTA	THETA	ALPHA	BETA
FP1 F3	0.000	0.244	0.009	0.000
FP1 C3	0.510	0.000	0.000	0.008
FP1 P3	0.000	0.000	0.000	0.002
FP1 O1	0.000	0.000	0.000	0.000
FP1 F7	0.989	0.244	0.286	0.001
FP1 T3	0.024	0.000	0.000	0.000
FP1 T5	0.000	0.000	0.000	0.000
F3 C3	0.000	0.000	0.000	0.008
F3 P3	0.000	0.000	0.000	0.000
F3 O1	0.000	0.000	0.000	0.000
F3 F7	0.372	0.000	0.002	0.000
F3 T3	0.000	0.000	0.000	0.000
F3 T5	0.000	0.000	0.000	0.000
C3 P3	0.000	0.000	0.000	0.000
C3 O1	0.000	0.000	0.000	0.000
C3 F7	0.006	0.000	0.000	0.011
C3 T3	0.000	0.000	0.003	0.000
C3 T5	0.000	0.000	0.000	0.000
P3 O1	0.000	0.000	0.854	0.719
P3 F7	0.000	0.000	0.000	0.001
P3 T3	0.000	0.000	0.000	0.000
P3 T5	0.000	0.001	0.077	0.005
O1 F7	0.000	0.000	0.000	0.000
O1 T3	0.000	0.000	0.000	0.002
O1 T5	0.012	0.000	0.928	0.003
F7 T3	0.079	0.000	0.000	0.000
F7 T5	0.000	0.000	0.000	0.000
T3 T5	0.000	0.000	0.000	0.027

Intrahemispheric: RIGHT

	DELTA	THETA	ALPHA	BETA
FP2 F4	0.003	0.000	0.714	0.049
FP2 C4	0.094	0.286	0.074	0.035
FP2 P4	0.000	0.431	0.000	0.044
FP2 O2	0.000	0.000	0.000	0.000
FP2 F8	0.554	0.127	0.327	0.031
FP2 T4	0.001	0.178	0.061	0.007
FP2 T6	0.000	0.000	0.000	0.001
F4 C4	0.027	0.134	0.025	0.108
F4 P4	0.007	0.096	0.000	0.018
F4 O2	0.000	0.000	0.000	0.000
F4 F8	0.258	0.551	0.383	0.067
F4 T4	0.092	0.073	0.475	0.065
F4 T6	0.000	0.000	0.000	0.000
C4 P4	0.489	0.315	0.002	0.055
C4 O2	0.000	0.000	0.000	0.004
C4 F8	0.000	0.717	0.240	0.352
C4 T4	0.771	0.936	0.379	0.928
C4 T6	0.000	0.000	0.001	0.050
P4 O2	0.398	0.923	0.009	0.201
P4 F8	0.000	0.011	0.000	0.133
P4 T4	0.017	0.195	0.514	0.803
P4 T6	0.055	0.001	0.021	0.010
O2 F8	0.000	0.000	0.000	0.000
O2 T4	0.000	0.000	0.000	0.001
O2 T6	0.605	0.051	0.008	0.011
F8 T4	0.000	0.031	0.031	0.032
F8 T6	0.000	0.000	0.000	0.000
T4 T6	0.000	0.000	0.014	0.631

Interhemispheric: HOMOLOGOUS PAIRS

	DELTA	THETA	ALPHA	BETA		DELTA	THETA	ALPHA	BETA
FP1 FP2	0.000	0.000	0.002	0.816	F3 F4	0.813	0.058	0.931	0.000
C3 C4	0.004	0.180	0.001	0.000	P3 P4	0.076	0.128	0.000	0.000
O1 O2	0.577	0.001	0.000	0.018	F7 F8	0.000	0.001	0.272	0.000
T3 T4	0.000	0.000	0.000	0.000	T5 T6	0.000	0.000	0.000	0.000

Delta (1.0 - 4.0 Hz) Theta (4.0 - 8.0 Hz) Alpha (8.0 - 12.0 Hz) Beta (12.0 - 25.0 Hz)
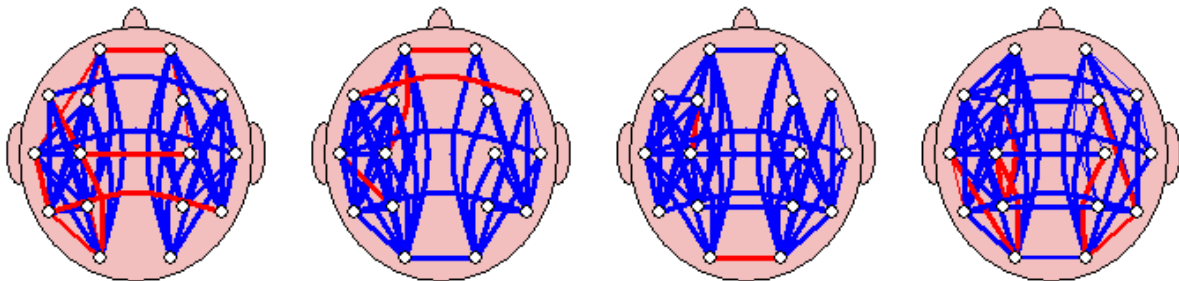
-   +   P-Value <= 0.050   -   +   P-Value <= 0.025   -   +   P-Value <= 0.010

18