December 2023

BESA Connectivity 2.0 Update History

Version 2.0 May 2023

Feature overview

BESA Connectivity 2.0 provides optimized, user-guided workflows for time-frequency and connectivity analysis of EEG/MEG data. Multiple well-established methods are provided. The program is optimized for user-friendly workflow-based interaction. All analyses are computed automatically; user interaction steps required are reduced to a minimum. The time-frequency and connectivity values computed in BESA Connectivity can be directly used for scientific reports. The outcomes can be exported in open ASCII formats for further statistical analysis. All results are visualized and can be directly used for publications.
BESA Connectivity 2.0 integrates optimally with data that were analyzed in BESA Research 7.0 or higher, but it can also process data from other software packages as long as they conform to the BESA Connectivity file format.
BESA Connectivity 2.0 automatically identifies connectivity patterns between montage channels, regional sources, dipole sources, or virtual sensors, which can be visualized using 2D matrices, 2D circular graphs, or 3D visualization.
Input data can be provided in sensor space (surface EEG/MEG channels, or polygraphic channels), or in source space (virtual channels located inside the brain, e.g. from a source montage).
Batch processing of multiple subjects is supported, as well as grand average calculations and displays.
Several colour maps are available. Two themes are supported: *BESA White* and *BESA Standard.*

Workflows

There are two workflows with four work steps each in BESA Connectivity:

- Time-Frequency Analysis

  The general approach to analyze event-related EEG/MEG oscillations is based on the decomposition of the EEG/MEG signals into magnitude and phase information for each frequency and to track their changes over time. This procedure is referred to as ‘time-frequency analysis‘ and comprises those methods that study a signal in both the time and frequency domains simultaneously.
  In BESA Connectivity 2.0, three approaches for computing time-frequency decomposition are provided:

  - Complex Demodulation is based on the convolution of the EEG/MEG signal with series of sine and cosine waves.
  - Wavelet Transform uses series of complex Morlet wavelets or Mexican Hat wavelets to extract the magnitude and phase information.
  - Multitaper analysis uses several tapers to decompose the signal into its frequencies. Here, Slepian Sequences are used to construct the tapers, which are then used in a time-frequency decomposition of the signal. Multitapering combines the properties of the different tapers to control the leakage and smooth the signal in the frequency domain. The multitaper transformation uses a sliding time window with a length that decreases with increasing frequency.

- Connectivity Analysis

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BESA Connectivity 2.0 offers nine connectivity measures in the frequency domain. Six measures belong to the class of phase-based methods: Coherence, Imaginary Part of Coherency, Phase Locking Value (PLV), Phase Lag Index (PLI), weighted Phase Lag Index (wPLI), and directed Phase Lag Index (dPLI). The other three measures belong to the class of Granger Causality-based connectivity approaches: Granger Causality in the frequency domain (or Granger–Geweke Causality), Partial Directed Coherence (PDC), and Directed Transfer Function (DTF). An overview of the distinctions between the connectivity measures is given in Table 1.

Table 1. Comparison of the methods for estimating brain connectivity

	Coherence	Imaginary Part of Coherency	PLV	PLI	wPLI	dPLI	Granger Causality	PDC	DTF
Non-directional	●		●	●	●				
Directional		●				●	●	●	●
Bivariate	●	●	●	●	●	●	●		
Multivariate								●	●
Linear	●	●	●	●	●	●	●	●	●
Frequency domain	●	●	●	●	●	●	●	●	●

Results display
Results are displayed

- either in a grid view to show all connectivities in one view,
- in a circular graph view with connection strength encoded in thickness of connecting arrows, where the channels are automatically arranged in four quadrants (left anterior / right anterior / left posterior / right posterior) to facilitate interpretation,
- or in a 3D view of the brain or skin surface, also with connection strength encoded in thickness of connecting arrows.

The displays are highly interactive and also support additional analysis options:

- Sum of inflow / outflow for each channel / source
- Average over a user-defined time range
- Average over a user-defined frequency range
- Average over both time and frequency - in this case the matrix view changes to a visualization of a single tile per connection, thus enabling a connectome view for the selected time-frequency range

Other visualization highlights:

- Freeze-Pane mode for TFC View: Channel labels will remain visible at the left-most column and top-most row of the matrix display even if the visualization is zoomed by the user.
- The 3D visualization takes into account the colors and sizes of the sources specified in the BESA Solution File Format (*.bsa).

In both workflows, comparison options are available:

- Up to 10 different conditions can be compared.
- Up to three different time-frequency decomposition methods can be compared.
- Grand average and individual subjects can also be compared.

Results of either workflow can be saved in a project file; projects can be organized in groups and can be re-loaded at any later point in time.

Export options
Data export:
Result data can be exported into open ASCII formats. The following export options are available:

- Time-frequency decomposition (average over all trials), using the current display calculation (absolute values or temporal-spectral evolution, for amplitude or power)
- Time-frequency decomposition (single trials)
- Averaged waveforms for all channels
- Time-frequency decomposition of the full project: Results of all selected methods and data sets are exported, using the current display calculation (absolute values or temporal-spectral evolution, for amplitude or power). They can directly be read in to BESA Statistics.
- Connectivity results (connectivities between all sensors / sources) for the currently selected method / subject / condition / time-frequency type
- Connectivity results of the full project: Results of all selected methods and data sets are exported. They can directly be read in to BESA Statistics.

Image export:
The result visualization can be exported as vector graphic (eps), portable network graphic with user-defined resolution (png), or scaleable vector graphic (svg).

Video export:
The connectivity change over time can be exported as video with user-defined time range, duration, and brain / head rotation.

A comprehensive Help function is available. Context-sensitive help is available for each workflow step.

Known issues

The following known issues could not be fixed for this release, and remain in the software:

Time-Frequency Analysis

- For visualization of TSE (amplitude and power), values are not displayed as percentages. To obtain the percentage value, multiply by 100 (#BC-624).
- When loading multiple subjects into the time-frequency workflow, the number of trials are only shown for the first few subjects in the *Load Data* workstep. However, data are processed correctly (#BC-674).

- Saving results after time-frequency analysis with multi-tapering may cause error messages for large data sets. To avoid the issue, reduce the size of the data set, e.g. by downsampling before exporting to BESA Connectivity, by reducing the time interval, or by using fewer time-frequency methods (#BC-679).
- If data have no padding interval (e.g. when imported from a third-party software), multi-taper analysis may show wrong scaling (#BC-697).

Connectivity Analysis

- 3D visualization of sensor data may cause issues on certain PCs, if a montage contains several channels with the same origin (e.g. bipolar channel montages). To avoid the issue, remove channels with identical locations from the montage before exporting data to BESA Connectivity (#BC-671).
- 3D visualization of sensor data may cause a program crash if sensors have coordinates that are exactly on the midline (e.g. a T7 channel with spherical coordinates -90, 0). This may happen if data are imported from a third-party software. Workaround: Edit the *.elp* file in a text editor and change these coordinates slightly to e.g. (-92,0) (#BC-688).
- Saving results after connectivity analysis may cause error messages for large data sets. To avoid the issue, reduce the size of the data set, e.g. by using fewer connectivity methods, fewer conditions, or fewer time-frequency methods (#BC-672).
- When loading a multi-subject time-frequency project into the Connectivity workflow, the Grand Average display of time-frequency data is wrong. Individual subject data are displayed correctly. Also, Grand Average of the finally computed Connectivity is correct. Workaround: To view Time-Frequency Grand Average data, open the project in the Time-Frequency workflow (#BC-673).
- In the circular graph view, it can happen that source channels are missing. This is for example the case for the DMN source montage. Workaround: Use the 3D plot instead (#BC-686).
- In the circular graph view, the scale bar information may be incorrect in the following scenario: Invoke circular plot with a non Granger-causality method. Then move to 3D plot and change the method. Then go back to the circular plot. Workaround: Update the method again (#BC-683).