
BESA®

BESA incorporates expert know-how in comprehensive software tools for Neuroscientists and Neurologists

BESA GmbH was founded as MEGIS Software GmbH in 1995 by Dr. Michael Scherg. It is a leading company in the field of EEG / MEG analysis and a home base for highly skilled people.

Our products have been developed on the basis of 30 years' experience in human brain research. BESA provides state-of-the-art scientific analysis tools covering the complete range of neurophysiological applications.

We strive to bring you the latest methods for advanced EEG and MEG analysis in a user-friendly and optimized implementation.

Dr. Tobias Scherg
CEO / General Manager

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Find the Product That Fits Your Needs

BESA offers four different products which cover many usage scenarios in neurophysiological data analysis in EEG and MEG.

Data Formats

Manage EEG/MEG data recorded by different systems in one application: **BESA Research** can read files of more than 40 different EEG/MEG data formats. Exporting whole files or segments to EDF is possible.

ERP/ERF

Use **BESA Research** for complete pre-processing and analysis. It includes artifact correction and rejection, peak finding, paradigm definition and grand averaging.

Use **BESA Statistics** to perform group and/or condition comparisons; it intrinsically solves the multiple testing problem and runs parameter free statistics. F-Test and t-Test are available.

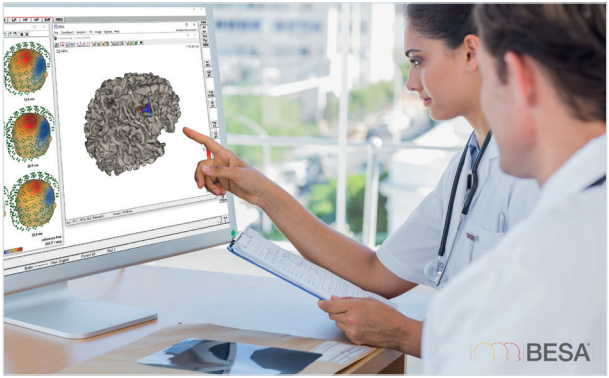
EP

Use **BESA Research** to perform artifact rejection, averaging, and analysis. Save time with the intuitive, graphical user interface.

Source Analysis/Source Imaging

BESA Research is the most comprehensive toolbox for EEG/MEG source localization. Pattern search and averaging support your discrete and distributed source analysis. Generate source montages for reviewing the data. Fit single dipoles and regional sources, or use volume or cortical imaging methods for distributed source imaging. If you have no MRI data available, simply choose realistic children's and adults' FEM head models.

BESA MRI is required for source analysis with individual MRI. The integrated workflow concept makes it very easy to use. Create a 3-layer individual BEM head model or a 4-layer individual FEM head model and co-register with EEG/MEG sensors.



Brain Connectivity and Spectral Analysis

Use **BESA Research** to calculate DSA or FFT of your data. Time frequency transforms, parametric and non-parametric connectivity estimators are available in the included Source Coherence module and **BESA Connectivity** program.

Resting-State Analysis

Use **BESA Research** and **BESA Connectivity** to analyze and visualize resting-state connectivity in brain space.

Cross-subject Statistics

Perform cluster permutation statistics on ERPs, source waveforms, images, time-frequency and coherence results with **BESA Statistics**.

Spikes in Epilepsy Research

Use **BESA Research** to mark spikes manually. 3D Mapping and source montages support evaluation of the interictal activity. Run a pattern search to find similar patterns quickly and reliably. Average spikes for discrete or distributed source analysis. Analyze spike onset and check for propagation guided by semi-automated tools. If you have MRI data available, use **BESA MRI** to create an individual head model for source analysis.

Use both products in the **BESA Pipeline** to analyze interictal spikes and seizure onset.

Seizures in Epilepsy Research

Use **BESA Research** to visualize seizure epochs in DSA. FFT supports your seizure analysis. Localize seizure onset using phase maps and averaged cycles. If you have MRI data available, use **BESA MRI** to create an individual head model for source analysis.

Use both products in the **BESA Pipeline** to analyze interictal spikes and seizure onset.

MEG Data Analysis

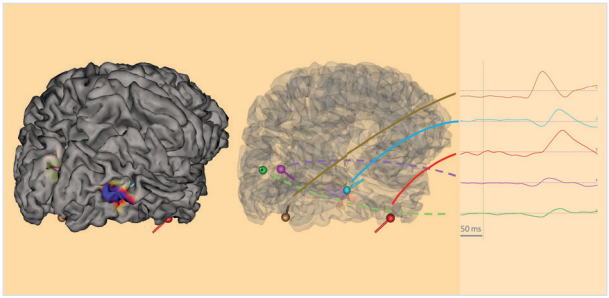
Use MEG source montages in **BESA Research** to save time and facilitate MEG data review. Search for spikes and perform source analysis in MEG. Combine MEG and EEG data to localize brain activity in joint EEG-MEG recordings.

BESA Research 7.1

The most comprehensive signal processing toolbox for EEG / MEG source localization

BESA Research has set the standard for state-of-the-art EEG and MEG data analysis for more than two decades. Then as well as now, the imperative was to provide innovative and tailored analysis methods which go hand in hand with intuitive and easy-to-use data processing and data review tools. The Matlab interface provides a convenient and extremely smooth pathway for following up with your own additional analysis, or with add-on Matlab tools provided by the research community.

Furthermore, detailed tutorials, the BESA Wiki, a YouTube channel with instructive videos, and the customer support supplied by experts in the field contribute to the overall user experience.



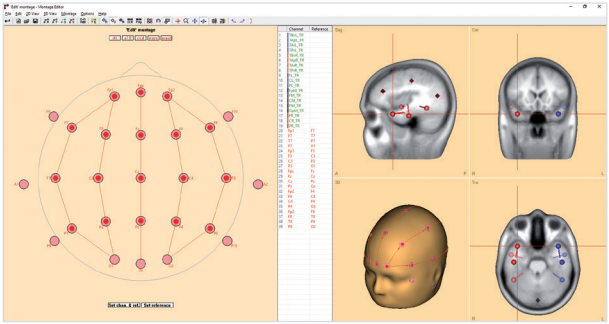
Cortical map – Cortical CLARA
Combined cortical imaging and time course analysis illustrated for a visual motion processing example

Data Review and Data Processing

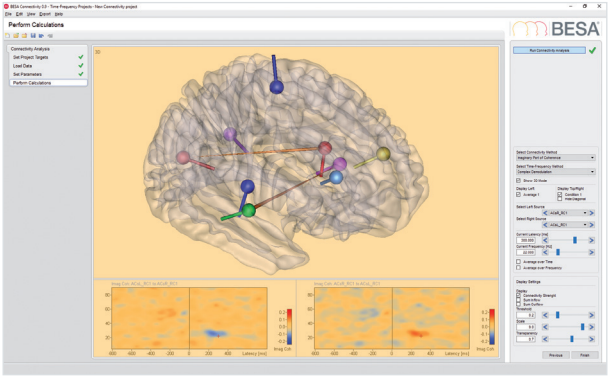
- Reading and writing of multiple formats
- Graphical montage editor
- Source montages for
  - standard review, epilepsy review, ERP/ERF
  - resting state networks
  - brain atlas regions
- ICA/PCA
- Superior artifact removal tools including EEG-fMRI
- ERP/ERF paradigms and averaging
- Graphical artifact rejection tool
- Co-registration with individual MRI/fMRI
- Grand averaging of subjects and conditions

Time-Frequency Analysis

- Time-frequency transformation of any montage data
- Connectivity analysis
  - Wavelets and/or complex demodulation
  - In source space or sensor space
  - Using state-of-the-art methods including Granger Causality, Partial Directed Coherence
  - Visualize data in clear 2D and 3D result plots
  - Create publication images or video
- Workflow-guided user interaction



Data review
User montages can be defined easily in the graphical Montage Editor



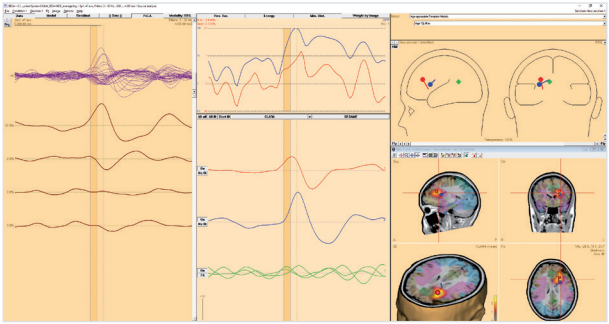
Connectivity analysis
Three-dimensional visualization of imaginary part of coherency between source channels

Source Analysis and Source Imaging

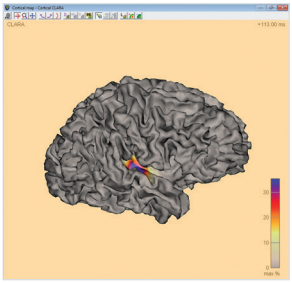
- Dipole fitting/regional, single dipoles
- Volume imaging: (s)LORETA, CLARA, LAURA, sSLOFO, user-defined
- SESAME: Bayesian source imaging
- Cortical imaging on individual or standard cortical surface
  - Minimum Norm
  - Cortical LORETA, Cortical CLARA
- Multiple or single source beamforming in time-domain or time-frequency domain
- Individual source montages or virtual sensor montages, including pre-defined brain atlas regions
- Joint fitting of EEG and MEG data
- Realistic head models (BEM and/or FEM) in combination with **BESA MRI** for both EEG and MEG
- Co-registration with individual MRI/fMRI
- Confidence limit display for dipole fits
- Brain atlases
- Realistic children's and adults' FEM head models for various age groups based on real averaged MRIs
  Kindly provided by John Richards, University of South Carolina, USA

Tools Available in all Modules

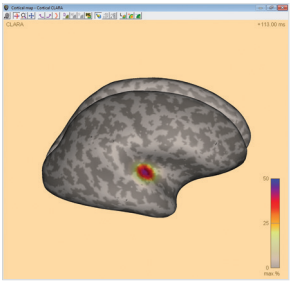
- Comprehensive online help
- Batch processing for multi-subject analysis
- MATLAB® interface
- Result export for further analysis



Source analysis
Combined volume imaging and dipole source analysis using a template head model



Source imaging 1
Cortical CLARA using an individual cortex for an auditory task



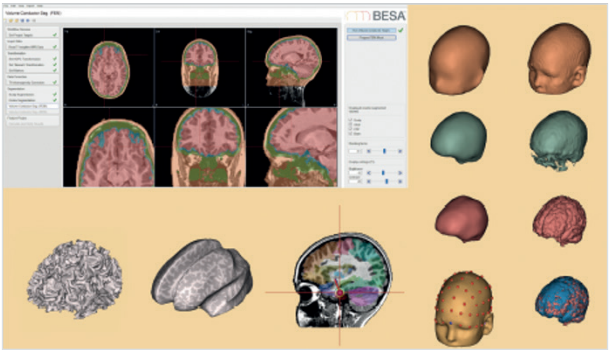
Source imaging 2
Cortex inflation enables viewing all activity while retaining anatomical details

BESA MRI 3.0

Creating individual BEM and FEM models made easy: use of individual anatomy enables superior source analysis results

BESA MRI is a software program to generate individual head models (BEM/FEM) that can be used for EEG and/or MEG source analysis.

BESA MRI also allows co-registration of EEG/MEG data with individual MRI data, and visualization of dipole solutions generated in **BESA Research** in the individual anatomy. **BESA MRI** is the first software that offers an easy, intuitive interface with an integrated workflow guiding the user step-by-step.



Overview of BESA MRI results
Volume and surface reconstructions including 3-shell BEM or 4-shell FEM models, brain surface with inflation, source and atlas display and M/EEG co-registration

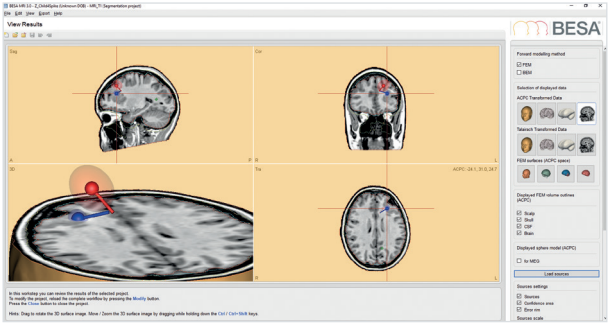
MRI data import is easily performed with DICOM, ANALYZE/NIFTI, VMR readers. The preparation of the MRI data to be automatically processed by **BESA MRI** requires just a few simple work steps which typically demand only a few minutes of user attention. **BESA MRI's** automatic processing can be applied to all subjects prepared by the user in one go, therefore conveniently minimizing the time the user has to work on the computer.

BESA MRI's automatic segmentation includes an automated inhomogeneity correction to correct for scan artifacts, generates a high quality cortex and scalp reconstruction with optional cortex inflation for enhanced visualization, and, in an optional step, can also generate an individual head model (BEM, FEM) with 3 layers (scalp, skull, brain – BEM) and/or 4 layers (scalp, skull, CSF and brain – FEM).

BESA MRI 3.0 runs in combination with **BESA Research 7.x**. Individual head models (BEM, FEM) generated with **BESA MRI 3.0** can be imported by **BESA Research 7.x** for EEG and/or MEG source analysis. EEG/MEG data can be co-registered with individual MRI data using individually digitized electrode positions or head shape points.

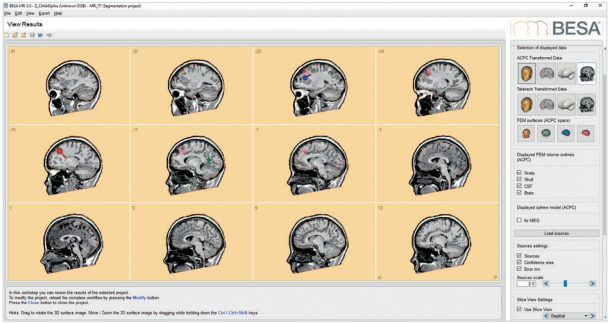
As a unique feature of **BESA MRI 3.0**, 10-10 standard electrodes (including inferior electrodes) can also be morphed with individual MRI data. Co-registered electrode coordinates are immediately available in **BESA Research**. Thus, source images / localizations can be displayed on the individual MRI even if no individual digitization of electrodes has taken place.

The MRI data can be visualized in a user-defined multi-slice view. Discrete solution files generated by **BESA Research** can be overlayed over the individual anatomy, as well as one of several available brain atlases.



Visualization of dipole fitting results

Shown in individual anatomy including confidence volumes and head model boundaries

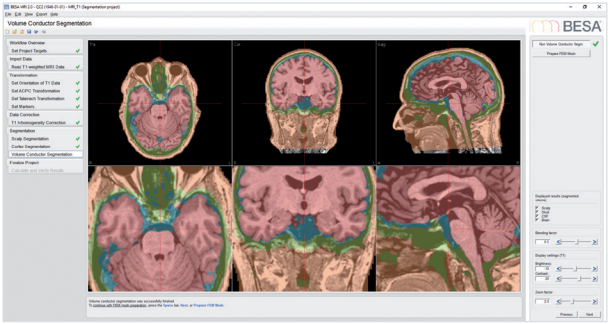


Fully configurable slice view

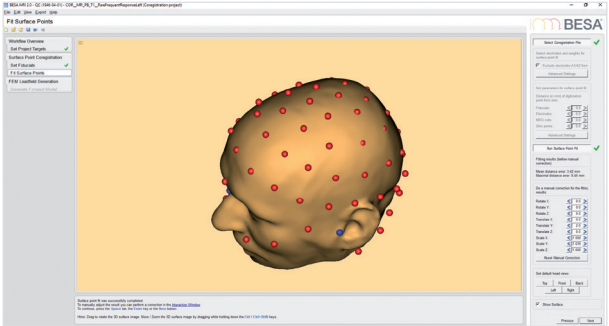
Slice view includes source localization results with confidence ellipsoids

Workflow-Driven Segmentation and Co-Registration

- Integrated workflow
  - Maximally intuitive and user-friendly
  - Context-related help
- Automatic inhomogeneity correction and segmentation
  - For superior brain surface reconstruction and optimized segmentation results of all tissue classes
- Automated registration of T1- and T2-images
  - Scalp, skull, CSF, brain
- Reconstruction of scalp, cortex, and inflated cortex (used in visualization in BESA Source Analysis)
- Vizualization of dipole solutions in individual brain anatomy
- Brain atlas overlay
- Multi-slice view
- BEM/FEM model generation for both EEG and MEG
  - Automated setup of FEM model including CSF layer
  - Geometry-adapted hexahedral meshes
  - All FEM meshes, surfaces, and lead fields are exportable
- Co-registration
  - With individually digitized electrodes and MEG sensors
  - 10-10 or 10-20 system
- Using individual anatomy
  - Individual realistic BEM/FEM models sent to **BESA Research** for source analysis
  - Individual source space for volume-based and cortex-based source imaging



FEM model
Automatic setup of 4-layer FEM model



Electrode co-registration
Easy co-registration of standard or digitized electrodes with MRI data

BESA Connectivity 2.0

The comprehensive toolbox for state-of-the-art brain connectivity analysis in sensor space and source space

BESA Connectivity provides optimized, user-guided workflows for time-frequency and connectivity analysis of EEG/MEG data. Multiple well-established methods are provided. They were optimized for stream-lined performance that yields results for multiple combinations of input data types, time-frequency methods, and connectivity measures. Batch analysis of multiple subjects and conditions further facilitates data processing.

The time-frequency and connectivity values computed in **BESA Connectivity** can be directly used for scientific reports.

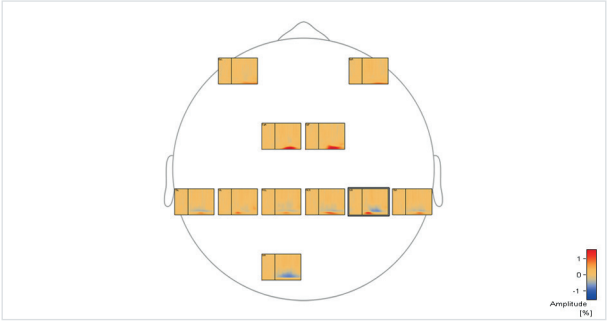
Brain connectivity in source space
Source space analysis in an error-related negativity experiment reveals strong connectivity of cingulate gyrus to associated brain areas

Time-Frequency Analysis

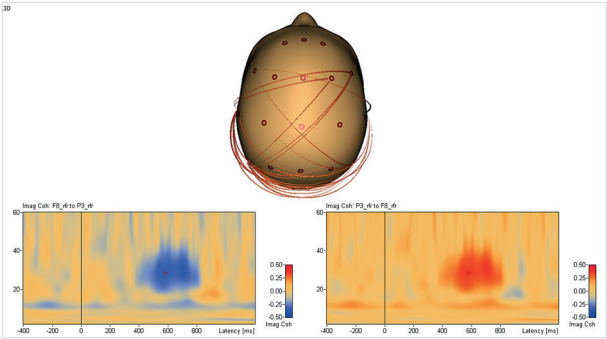
- Complex Demodulation
- Wavelet Analysis (Morlet or Mexican Hat)
- Multitaper
- Support for source montages including brain atlas montages, as well as sensor-level data and polygraphic channels
- Batch processing of all subject data
- Grand Average and individual average review
- Directly compare conditions, and time-frequency methods
- Temporal-spectral evolution (TSE), power and amplitude displays
- Export of all data including full multi-subject project

Connectivity Analysis

- Several state-of-the art methods
  - Coherence (Rosenberg et al., 1989)
  - Imaginary Part of Coherency (Nolte et al., 2004)
  - Phase Locking Value (Lachaux et al., 1999)
  - Phase Lag Index, Weighted PLI, Directed PLI (Stam, Vinck, et al.)
  - Granger Causality (Granger, 1969; Geweke, 1982)
  - Partial Directed Coherence (Baccala and Sameshima, 2001)
  - Directed Transfer Function (Kaminski and Blinowska, 1991)
- Averaging over time and / or frequency ranges Matrix Connectome view using combined time-frequency averages
- Circular Connectome view for one-glance overview of connectivity
- Directly compare conditions, and connectivity methods
- Grand Average visualization



Time-frequency decomposition
Temporal-spectral evolution of brain source regions computed for an ERN experiment using wavelet transform reveals strong ERS and ERD activity in cingulate and occipital areas



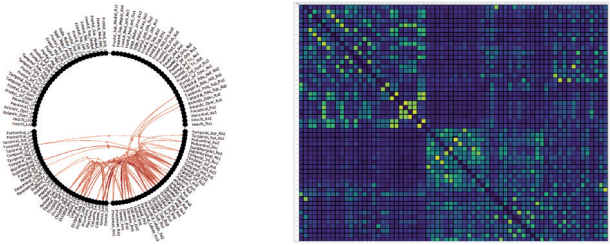
Connectivity in sensor space
Imaginary part of coherency calculated for a reference-free montage in sensor space. The connectivity diagrams show channels C3 and T8 between 4 Hz and 50 Hz.

- Highly interactive 3D visualization in brain or on skin surface
- Highly versatile image and video export of results
- Direct export of complete multi-subject project

General

- Workflow-based user guidance through the analysis steps
- Modern 64-bit architecture optimized for multi-core processing
- Several color maps and themes available
- ASCII data result export and input support for MATLAB

The outcomes can be exported and directly opened in BESA Statistics for further statistical analyses. All results are visualized and can be directly used for publications. BESA Connectivity integrates optimally with data that were analyzed in BESA Research, but it can also process data from other software packages.

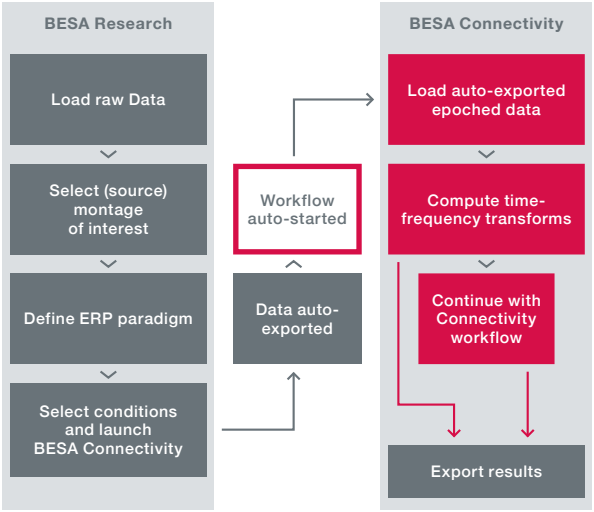


Left: Circular connectome view of directed Phase Lag between atlas brain regions during a Visual Motion stimulation **Right:** Connectome of coherence between brain regions during a Visual Motion stimulation

Interaction With BESA Research

Definition of epoched data for connectivity analysis is performed in the ERP module of **BESA Research**.

When launching **BESA Connectivity**, epoched data are auto-saved in the current montage, and the workflow for time-frequency analysis in **BESA Connectivity** is started.

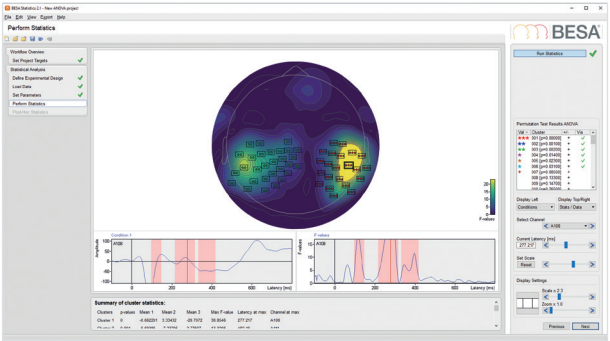


BESA Statistics 2.1

Cluster permutation statistics for robust and reliable results

BESA Statistics provides optimized, user-guided workflows for cross-subject analysis of EEG/MEG data. The statistical method used is parameter-free permutation testing on the basis of Student's t-tests (Maris, E. and Oostenveld, R., 2007), F-tests (for ANOVA/ANCOVA), and correlations.

The program is maximally user-friendly. All analyses are computed automatically with user-interaction minimized to defining time and/or frequency ranges of interest. Statistical values computed in **BESA Statistics** can be directly used for



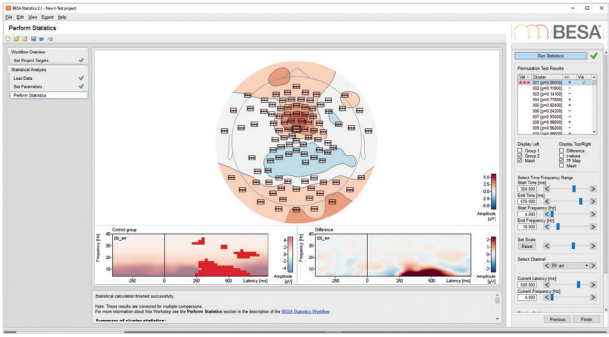
Cluster permutation statistics results
ANOVA of an MEG experiment reveals several clusters where the null hypothesis is rejected. The map shows the first cluster

scientific reports. No further analysis in other programs is needed. All results are visualized and can be directly used for publications.

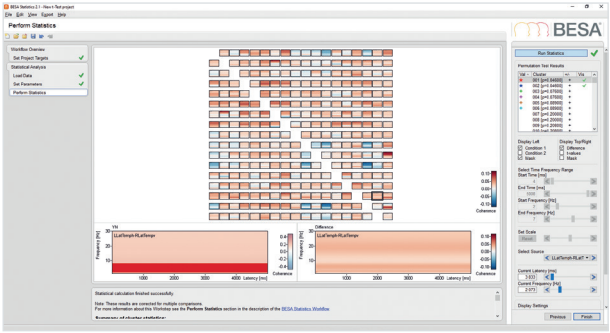
BESA Statistics 2.1 integrates optimally with data that were analyzed in **BESA Research** or **BESA Connectivity**, but it can also process data from other software packages as long as they conform to the **BESA Statistics** file format. The Brain-Vision Analyzer 2 native data format is supported for time and time-frequency data.

BESA Statistics will automatically identify clusters in time, and if applicable frequency and space where data of the input groups/conditions are not interchangeable, i.e. where the null-hypothesis that all groups/conditions are interchangeable must be rejected. Results are considered corrected for multiple comparisons, as only those clusters will be identified that have higher cluster values than 95 % of all clusters derived by random permutation of data. Thus, results obtained by **BESA Statistics** are objective and robust.

For ANOVA/ANCOVA analysis, an additional non-parametric post-hoc Scheffe's test is computed to determine, which pair-wise comparison(s) were responsible for the groups/conditions main effect. A Bonferroni-Holm correction for multiple comparisons of the different pairwise combinations is applied subsequently.



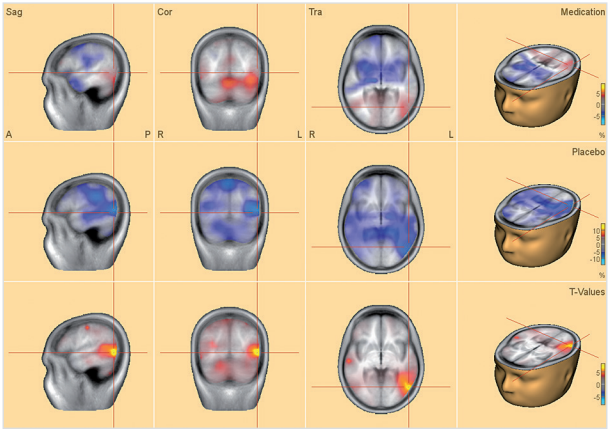
Perform statistics
Time-frequency map of the first cluster of a t-test computed on an ERP experiment comparing erroneous with correct responses to a task



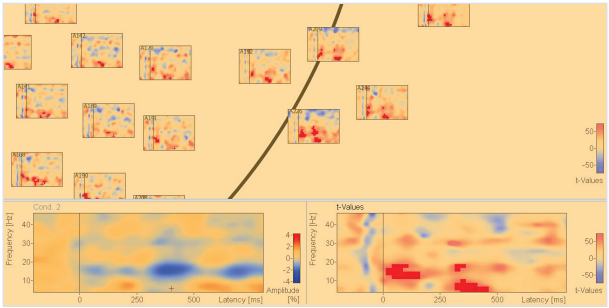
Statistical evaluation of Connectivity results
In a resting-state experiment, average connectivity in different stages was computed using a Default Mode Network source montage

Tailored Workflows for t-Test, AN(C)OVA, and Correlation

- Cross-subject statistics of
  - Event-related potentials/fields
  - Volume image data, e.g. LORETA, beamforming; 4D data also supported (3D+time)
  - Time-frequency data, e.g. temporal-spectral evolution, coherence, intertrial phase-locking
  - Connectivity data
  - Source waveforms
- t-test for comparing two groups (e.g. patients, controls) or conditions within the same group of subjects (e.g. target, control)
- Single-trial time data or time-frequency data can be processed to work on single subjects
- One-way Analysis of Variance (ANOVA) and Analysis of Covariance (ANCOVA)
  - within-group or between-group testing
  - post-hoc tests possible
- Correlation analysis for testing the relationship between covariates of interest and EEG/MEG data
- Significant clusters in time and if applicable space and frequency are determined and visualized in categories (highly significant, significant, trend)
- Results are corrected for multiple comparisons
- Works as a standalone package with BrainVision Analyzer 2 for time and time-frequency data
- All statistical parameters can be exported, and pictures saved as vector graphics suitable for publications
- Several color maps and two color themes available



Cross-subject statistics
Cluster permutation testing applied to image data exported from BESA Research



Visualization of data
Significant clusters are visualized in time-frequency plots; high resolution export of images possible

BESA Pipeline

Analyze interictal spikes and seizure onset in EEG and MEG Research

The **BESA pipeline** is the seamless combination of **BESA Research 7.1** and **BESA MRI 3.0**. Introducing the perfect aide in evaluating epileptiform interictal and ictal activity in EEG and MEG!

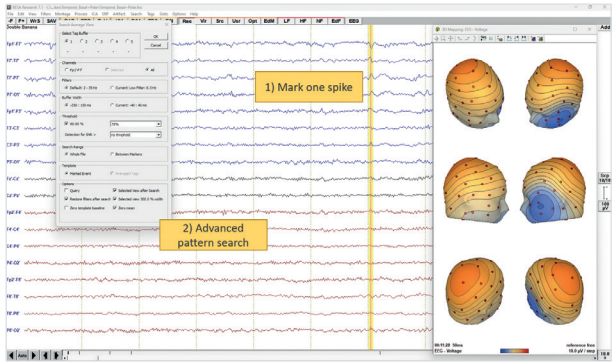
Interictal activity (spikes)

Use **BESA Research** for reviewing patient data. To make decisions easier, **BESA Research** supports the evaluation of interictal activity with 3D Mapping, source montages and filters optimized for evaluation of epilepsy data.

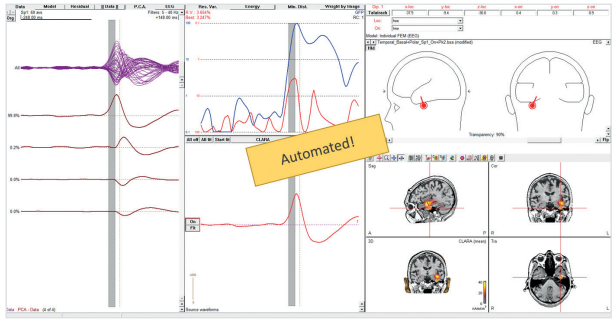
Just mark the first spike manually and then run the fully adjustable pattern search to find similar events quickly and reliably. Optionally, refine the search pattern using the auto-averaged spikes.

Average spikes for discrete or distributed source analysis. Analyze spike onset and check for propagation. Finally perform a source analysis using the averaged data to analyze e.g. the onset phase.

Use **BESA MRI** for the segmentation of MR data and for a co-registration with the EEG. You can calculate an individual head model, and use it in the source analysis of **BESA Research** to obtain superior localization results.



Spike Hunting
Find the first spike, let the automated search engine do the rest!

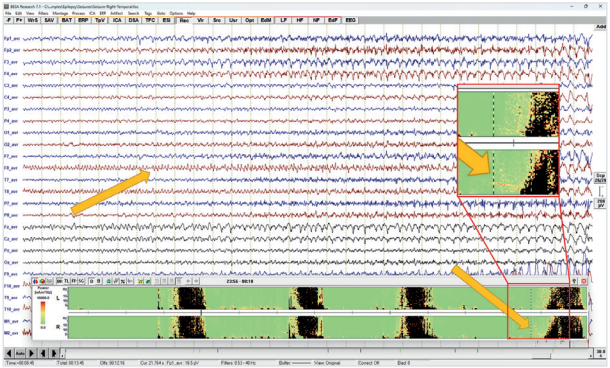


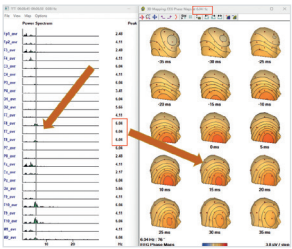
Source analysis
Get from a spike to its source in 5 mouse clicks!

Ictal activity (spikes)

Use the customizable **BESA Research** DSA module to search for seizures and to analyze e.g. the onset phase. Use FFT and **BESA Research's** FFT 3D phase maps to visualize and understand frequency (band)-specific activity and propagation.

Use **BESA MRI 3.0** in the same way as for the interictal activity.

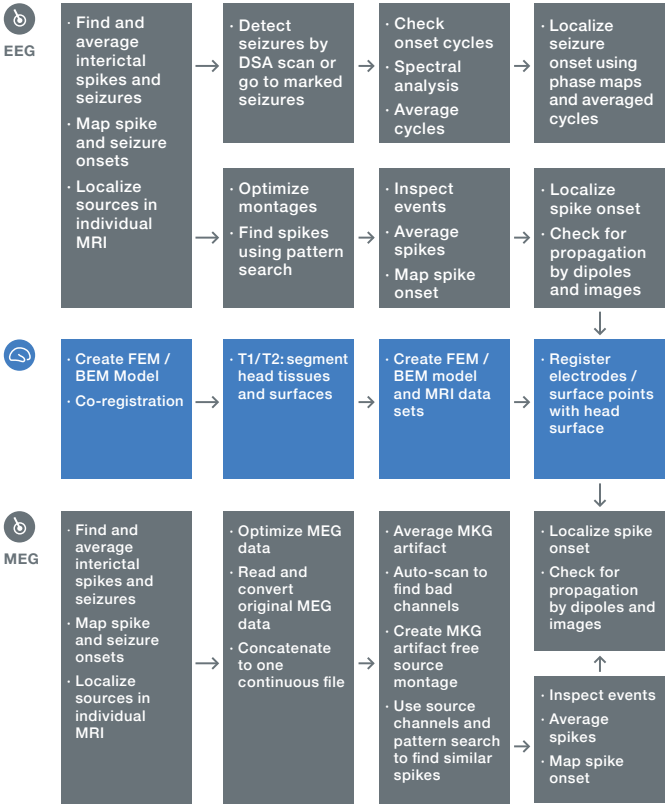




Top: Chirp preceding seizure depicted by DSA in right hemisphere points to propagating right-temporal seizure

Bottom: FFT phase maps show propagation to anterior temporal lobe

BESA Pipeline



BESA Team

BESA GmbH is the leading company in the field of EEG / MEG analysis and a home base for highly skilled people. Our team is a thriving mixture of researchers from different disciplines, skilled software engineers and highly motivated young professionals. We believe that the interaction between experienced researchers and young, creative and dedicated people is the key to success. This helps us in developing the most innovative software for data analysis in the field of EEG / MEG.

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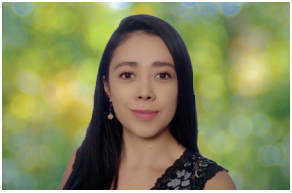

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