8-9: Phase and Topography of Coherently Oscillating Sources

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Objective: In order to demonstrate cortical motor control a pinch grip task is used, requiring subjects to execute an isometric muscular contraction. In this task electromyographic activity (EMG) recorded from finger muscles oscillates coherently with brain activity recorded over primary motor cortex using electro- (EEG) or magnetoencephalography (MEG)[1]. Looking at the derivative of the phase with respect to frequency the time delay between brain signals and EMG is inferred. Phase differences between EMG and the brain signal as well as the topography of the coherent activity are usually estimated for individual frequencies. In order to improve the estimates of topography, phase shifts and time lags a new approach is presented. Methods: In this method the estimate of topography and phase is based on an extended frequency range. The complex coherence spectrum for different channels c and frequencies f, B=(bcf), is regarded as linear combination of the topographies of different sources s, L=(lcs) that are weighted by a complex matrix W=(wsf) describing phase shifts and contributions of different sources. Decomposing the coherence spectrum B=LW using a least-square fit approach, phase angles, topographies and weights are obtained. Results: Simulations and the analysis of experimental data are presented, demonstrating the applicability of the method. Conclusion: The method allows for robust estimates of source topographies of cortico-motor coherence as well as phase information. Moreover, the method is also useful for the study of cortico-cortical coherence. A slightly modified approach can be even used for the removal of powerline artifacts taking into account the specific topography of the artifact. References & Acknowledgments: [1] Braun et al. 2007. Supported by BMBF Bernstein-Project 01GQ0761 and DFG (SFB 550/C6).

8-10: Magnetomyographic Recording And Identification Of Uterine Contractions Using Hilbert-Wavelet Transform

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Objective: To detect uterine contractions, measured with non-invasive magnetomyogram (MMG), using Hilbert-Wavelet transform (HWT).

Materials and Methods: Using a 151-SQUID sensor array we recorded uterine MMG (sampled at 312.5 Hz) from five pregnant women in the gestation age between 36 and 38 weeks. Each recording lasted for 20 minutes. In order to effectively detect the low frequency contractions, the data was down sampled to 25 Hz. These signals were digitally band-pass filtered between 0.1-1 Hz using 8th order zero-phase Butterworth filter. We then partitioned the signals in 30 sec disjoint windows and decomposed them into nine levels using second order Daubechies wavelet. Each level of decomposition would result in a set of approximate coefficients and detail coefficients (dc). In each decomposition level the signals were reconstructed using the dc at that particular level. We further applied the Hilbert transform (HT) to the reconstructed signals and computed the Hilbert amplitude (HA). The power of the signals in each window was quantified by integrating HA which were then partitioned using a novel clustering technique - affinity propagation. These results were compared to the contractions perceived by the mother that were recorded along with the MMG measurement.

Results: Significant power changes were observed in two frequency bands: 0.1-0.2Hz and 0.2-0.4Hz. Qualitatively, there is a good agreement between the contractions detected by this approach and the contractions perceived by the mothers.

Conclusions: Uterine MMG technique provides a non-invasive approach to study the spatio-temporal distribution of uterine contractions. Future studies including the frequency of the contractions would help to predict the nature of the labor.

8-11: Multivariate statistical analysis applied to MEG time series

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We propose a new method to detect task-related brain activity from MEG measurements based on Multivariate Analysis of Variance (MANOVA) modeling. Minimum-norm inverse imaging, combined with Morlet wavelet time-frequency decomposition, provides power observations over several time and frequency bands for each cortical source. We form vector observations by concatenating the power in each frequency band, and fit them in separate MANOVA models for each time band and cortical location. Experimental conditions are used as predictor variables in the design matrix of the
MANOVA models. By defining contrasts of interest and calculating the residual matrices, we estimate Roy's maximum root statistic in each location and time region. To control the familywise error rate, we threshold the resulting spatiotemporal maps using permutation tests and the maximum statistic approach. The proposed MANOVA approach is suitable to neuroscience studies where experimental effects are expected in several frequency regions, and it is more sensitive than direct pairwise comparisons among isolated frequency bands.

8-12: Localization of MEG sources using vector autoregressive modelling and subcortical recordings

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Insight into how brain structures interact is critical for understanding the principles of brain function and may lead to better diagnosis and therapy. To study interactions between the cortex and deep brain structures (basal ganglia and the thalamus) we recorded, simultaneously, local field potentials (LFPs) from deep brain stimulation (DBS) electrodes and magnetoencephalographic (MEG) signals from the cerebral cortex (CTF 275 channel system) from Parkinson's disease patients with bilateral DBS electrodes in the subthalamic nucleus (STN). High-amplitude artefacts in the MEG, originating from slight movements of ferromagnetic parts of the electrode, pose a challenge to conventional analysis methods. However, using constant phase-relations between the artefact-free LFP signal and the MEG it is possible to extract physiologically meaningful patterns from the data. Here, we demonstrate one way of doing this using vector autoregressive (VAR) modelling. The coefficients of VAR models fitted to the LFP signal with each MEG signal separately can be used for localizing cortical sources, whose activity predicts the LFP or is predicted by it. For this approach to work, the VAR coefficients should scale linearly with the MEG signal. This is achieved by fitting the model the usual way for the LFP to MEG direction and inverting the time axis for MEG to LFP direction. Averaging the VAR coefficients over a sufficient number of trials reveals dipolar topographical patterns consistent with cortical sources, despite the presence of artefact. Critically, these patterns are a linear mixture of the data and can be localized using conventional source reconstruction methods that employ a linear forward model. We have validated our approach using simulated MEG data with artefacts and applied it to simultaneously recorded MEG and LFP data from patients.

8-13: Applicability of signal space separation method in clinical and experimental MEG studies

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Background: Contamination of biomagnetic signals by external artifact signals is a major problem for MEG analysis in hospital settings; there are various electromagnetic signals arising from electronic devices, nearby traffic, magnetized materials attached to patients etc.

Objective: To evaluate the signal space separation (SSS) method applied in clinical and experimental MEG analysis.

Method: Between June 2007 and February 2008, MEG was recorded from 164 subjects (110 patients and 54 healthy volunteers). Comparisons between MEG data with and without application of SSS were performed in 70 consecutive subjects to evaluate the feasibility of SSS in removing artifact signals.

Results: After application of SSS, significant reduction of environmental artifact signals was achieved in all subjects; marked improvement of dipole source localization was noted in analysis of epileptic discharges and evoked magnetic fields. With regard to artifact sources related to the subjects, SSS was also successful in minimizing the artifact signals originating from dental materials. Furthermore, SSS suppressed the artifact signals derived from liquid crystal display that was used for visual evoked magnetic fields. In experimental MEG measurements, SSS was capable of extracting components of sensory high frequency oscillations, though their amplitudes are often as low as those arising from power line harmonics at corresponding frequencies.

Conclusion: SSS is a highly useful method to improve both clinical and experimental MEG data by eliminating various artifact signals.
8-14: ICA-based pattern recognition system for the classification of Coronary Artery Disease patients studied with Magnetocardiography

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MCG recordings were registered for 100 s at rest, during and after pharmacological stress (dobutamin) using a 61-channel MCG (4D Neuroimaging, San Diego) in 10 patients with suspected Coronary Artery Disease (CAD), which was negative in 6 (no-CAD group) whereas 4 had an angiographic narrowing of the coronary arteries > 50% (CAD group).

We estimated the ICA basis functions of CAD and no-CAD groups for the rest, stress and recovery conditions and for different regions of interest: PQRST waves, QRS complexes and ST-T segments.

The information on the features of the cardiac signals provided by ICA was used to train a multilayer perceptron neural network (MLPNN) employing Linear Discriminant Analysis for automatic patient classification. A different set of CAD and no-CAD patient records was used to test system performance.

Analysis including all conditions showed: for PQRST waves 96% accuracy, 100% specificity and 92% sensitivity, for QRS complexes 99% accuracy, 99% specificity and 100% sensitivity, and for ST-T segments 95% accuracy, 94% specificity and 97% sensitivity. Moreover, by comparing system performances when only rest, or stress or recovery data were used, we found that the use of rest data, regardless of the region of interest, always results in 100% accuracy in the classification of CAD patients. This implies that, after having assessed the system on a larger population, it might support the diagnosis in patients with suspected CAD with no need for stress testing.

8-15: Local and Global Weight Matrices of Linearly-Constrained Minimum-Variance Beamformer

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For neural current reconstruction from neuromagnetic data by a beamformer, such as a linearly-constrained minimum-variance beamformer, the weight vectors or matrices for different current locations should be, at least substantially, linearly independent each other to obtain uncorrelated current sources; this is one of the prerequisites to obtain the beamformer weight matrices. This requirement is also important to further analyze the obtained currents because if the obtained currents, say in the frontal and the occipital regions, are correlated or linearly dependent, the analysis of those currents results in the activation in the frontal region whenever the occipital region is activated; this might be misleading because this is not the physiological result. To satisfy this requirement, the number of current locations should be at most a half of the number of magnetic sensors in a spherical head model (low-rank signal model); this is not a sufficient but a necessary condition. This applies not only to the beamformer but also to most of linear current reconstruction methods. In this low-rank signal model, a combined weight matrix created simply by concatenating conventional local weight matrices, each calculated separately at each scan location, is proved to be equivalent to a single global weight matrix, which is obtained simply by replacing a local lead field matrix with a global lead field matrix in one of the conventional local weight matrices. This means that the brain currents, reconstructed from neuromagnetic data with a low-rank signal model by conventional local weight matrices separately at each scan location, are equivalent to those calculated by a single global weight matrix. [Supported by an NSF Science of Learning Center grant to the University of Washington's LIFE Center (SBE-0354453) and by Tokyo Denki University's Research Center for Advanced Technologies.]

8-16: Realtime analysis of 275 channel MEG data in MATLAB using the FieldTrip toolbox

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Realtime analysis of multichannel electrophysiological signals is an important area of biomedical signal processing, fundamental to the development of automated monitoring in clinical neurophysiology, e.g., for seizure detection, as well as brain-computer interface (BCI) systems. Realtime analysis of MEG and EEG could also become an increasingly important research tool in the cognitive neurosciences, facilitating the development of novel, "brain-state" dependent experimental paradigms.

While most realtime applications have been limited to relatively few EEG channels, the advent of MEG and high-density EEG systems, and the development of increasingly sophisticated analysis methods offer exciting
opportunities, particularly for signal extraction from specific brain areas. We describe the architecture and implementation of a system for realtime processing of MEG data. The software is based on a modular design that makes it very flexible. It is implemented in MATLAB, a programming language well known to many neuroscientists. Using MATLAB, and more specifically the FieldTrip toolbox, allows the implementation of new realtime applications by other neuroscientists. It also facilitates migration of offline analysis methods to a realtime/online setting. Signals are processed in small segments in MATLAB, while buffering new samples as they come in is performed in a separate application thread. The data buffer is a network transparent server that allows multiple MATLAB analysis clients to connect to it, each analyzing a specific aspect of the data concurrently.

We have successfully applied this approach in a BCI context using spatial time-frequency decomposition of 275 channel MEG data during motor imagery. The realtime acquisition supports several EEG systems and will be linked to the BC12000 framework. These developments and the use of MATLAB will be beneficial for the rapid development of realtime analysis tools for BCI and cognitive neuroscience.

8-17: Matching pursuit adaptive approximation: A powerful tool in the analysis of evoked and induced magnetic fields in MEG

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We discuss the advantages of adaptive time-frequency approximations, implemented by the matching pursuit (MP) algorithm, in the analysis of evoked and induced magnetic fields generated by auditory stimulation using simple sinusoidal (pure) tones and frequency-modulated sweeps in three different applications. First, in a study of event-related synchronization and desynchronization, we show that MP is able to resolve much more detailed structures in the time-frequency plane than it is possible with short-time Fourier transform and wavelet transform. This representation is also free of bias, present in the traditional spectrogram or wavelet estimates, which stems from the prior setting of the trade-off between time resolution and frequency resolution. In matching pursuit, owing to an adaptive approximation of the signal, the trade-off between time and frequency resolution is adapted to the local properties of the signal. Second, we present single-trial analysis of MEG data using different multivariate (multi-trial) versions of the MP algorithm (MMP) which allows studying inter-trial variation of evoked magnetic fields. Finally, multichannel MP (MMP) also constitutes a promising approach concerning the preprocessing of time series with the aim of localizing the generators underlying such fields. Here, MMP acts as a de-noising algorithm and thus serves as a preprocessing stage for the input to the inverse solution in MEG source modelling.

8-18: An efficient lossless compression of MEG data by MPEG-4 ALS

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We have enhanced a performance and reduced a complexity of the encoder of the MPEG-4 Audio Lossless Coding (ALS) international standard for compressing multichannel time-series MEG signals. In addition, we have introduced an archive format for packing various associated data which will be standardized in the MPEG. The ALS supports a Multi-Channel Coding (MCC) scheme that exploits interchannel correlation to improve the compression performance. In the MCC mode, adaptively weighted subtraction is carried out between the linear prediction residual signals of the coding channels and those of the reference channel. The combination of the reference channel and the coding channel affects the compression performance. This paper describes a new search algorithm that quickly finds interchannel relationships between the coding channel and the reference channel. The algorithm has tree structure and can reduce data size with remaining the international standard. The devised method is based on a restricted greedy algorithm. It chooses the most efficient branch that does not make any loops in the existing path. The results of comprehensive evaluation show that this method can compress magnetoencephalography signals to around 1/3 of the original size. This algorithm enables practical lossless compression of MEG data by the ALS, and at the same time, opens the way to a new multichannel analysis tool that may be used for purposes other than compression. Furthermore, the compressed data are archived into one package file, which includes the folder structure, metadata, and context information etc. The continual maintenance of these standards will make it possible to perfectly reconstruct encoded files even 100 years from now.