19th May
Morning
Session III

Brain oscillations and perturbed states

Questions
- What conceptual framework should we use to understand real time mass electrical activity? Is the variability of single trial responses a reflection of meaningless noise added to a constant evoked event or is it a manifestation of a non-linear perturbation introduced by the external stimuli to the ongoing dynamics. How do the all pervasive oscillations fit into this picture? What neuronal properties and mechanisms orchestrate the synchronization and desynchronization of neural masses at local and global levels?
- How should we analyze the volume of time series generated by modern electrophysiology? How theoretical frameworks from information theory and graph theory help us build meaningful descriptions relating knowledge form anatomy and neuroimaging?

Chair:
Andreas A. Ioannides
Laboratory for Human Brain Dynamics
Brain Science Institute (BSI), Riken, 2-1, Hirosawa, Wako-Shi, Saitama 351–0198, Japan
Tel: 81 (0) 48 467 9730, Fax: 81 (0) 48 467 9731
email: ioannides@postman.riken.go.jp
Identifying Patterns of Distributed Dynamics in EEG Data

A leading-edge goal of systems neuroscience is to model cooperative brain processes that couple very high-order microscale brain dynamics to macroscopic dynamic patterns to select and guide appropriate behavior. Traditional dynamic imaging methods including single-cell spike counting and single-channel EEG averaging long have limited the possibility of identifying and modeling distributed brain dynamics. Our work in human EEG centers on identifying the activity of functionally distinct brain areas and discovering how they cooperate to guide 'top-down' behavioral choices in light of the anticipated consequences of events. Our approach begins with spatial filtering for information sources in high-density EEG data using independent component analysis (ICA). Next, we apply event-related time/frequency analysis to the recovered cortical source activity time courses. Trial-by-trial analysis and visualization methods easily isolate a variety of (additive) 'evoked' and (multiplicative) 'induced' event-related phenomena. Detailed examination of trial statistics beyond means and mean differences show that most endogenous EEG activities vary strongly from trial to trial in both power and frequency contents. ICA methods for isolating independent spectral modulations and co-modulations show promise for revealing event-related actions of cortical modulatory systems. They demonstrate that EEG rhythms are only rarely sinusoidal, despite their typical measurement using Fourier spectra. Spectral comodulation does not require phase-locking of the affected EEG source activities. Event-related coherence or phase coherence between maximally independent EEG components, while rare, reveals a class of distributed, brief (half-second), theta band events that appear at moments suggesting that they express corticolimbic dynamics associated with phasic release of dopamine. These and related methods may soon reveal much more about how distributed macroscopic brain dynamics support active cognition.
Dynamics of Oscillatory Networks in Human: from Intracranial EEG to Scalp EEG/MEG Recordings

Mental processes are known to activate distributed networks of specialized brain structures. Neuroimaging techniques provide more and more precise pictures of these networks in different sensory and cognitive situations. Electrophysiology (EEG and MEG), and more particularly evoked responses, give access to the chronology of activation of the elements of the networks. However, the dynamics of interactions between brain structures have been much less explored in human. It has been proposed that the co-operation, within or between brain areas involved in sensory and cognitive processes, could be based on the dynamic synchronization of the underlying neural populations in an oscillatory mode (particularly in the beta and gamma ranges). This hypothesis has been supported at different levels, with unit and local field potential recordings in animal studies, and at intermediate (intracranial EEG) and more macroscopic levels (scalp EEG/MEG) in humans. The emergence and modulations of stimulus-induced oscillations (not strictly phase-locked to the stimulus from trial to trial, as opposed to phase-locked evoked responses) have been assessed by means of time-frequency analysis (Bertrand et al., 1996). Furthermore, coupling and de-coupling between these oscillating regions could be estimated by a measure of phase synchrony in the time-frequency domain (Lachaux et al., 2001).

Stimulus induced oscillations can have different temporal dynamics, and can be modulated by bottom-up or top-down processes related to perception, attention or memory (Tallon-Baudry and Bertrand, 1999; Bertrand and Tallon-Baudry, 2000). They can be restricted to low-level sensory areas (local synchronization) or distributed over more extended networks for higher-level processing (long-distance interactions) (Tallon-Baudry, Bertrand, Fischer, 2001). Multiple foci of beta and gamma activities have been observed in the visual and auditory modalities, and were found to be modulated by stimulus and behavioral tasks.

In intracranial recordings, beta oscillations are getting desynchronized when evoked responses and gamma oscillations are emerging, and are sometimes followed by a rebound of activity after gamma returns to baseline. In some cases, the same brain region can
exhibit a shift of oscillations, from gamma to beta, each showing specific functional modulations and interactions with other structures. The existence of multiple, very localized, gamma and beta oscillatory generators can make the detection of those oscillations very difficult in scalp recordings (EEG or MEG). When several beta or gamma sources are active at the same time, only those time-periods when the generators are phase-synchronized lead to a measurable macroscopic oscillatory signal at the scalp level. In many instances, due to a complex spatial averaging, multiple independent gamma sources create, by volume conduction, a resultant scalp signal which could be of very small amplitude. To some extent, MEG, which provides a spatially better resolved signal than EEG, could help disentangling the multiple underlying oscillatory sources. Understanding the link between these different levels of recordings still needs further investigation, as well as their link with temporal spiking patterns in cell recordings.


On the Unification in Electroencephalography

Hans Berger’s search for correlates of mental energy has led to the discovery of EEG. Following decades of a more humble and practical approach produced an invaluable knowledge base of correlates between various properties of the EEG signal and behavioral states of the normal brain and its dysfunctions. Its value can be properly appreciated only if we consider the tremendous inter-subject variability in neurosciences, and resulting value of conclusions based upon limited numbers of cases. How is this worldwide knowledge base generated and accessed? The answer to both questions is: via visual analysis of the raw EEG traces (slide 1). It is a costly enterprise in clinical applications and severely impairs the repeatability of scientific EEG research. The latter cannot exist without visual analysis— c.f. the visual selection of relevant epochs, indispensable before any further mathematical processing. Up to now there are very few direct links between advanced signal processing methods (SP) and the traditional, visual analysis. Application of SP in clinical diagnosis is explicitly discouraged. It may be caused by the variety of SP methods applied in the field, often for the very sake of “scientific novelty”, which increases the chances of publication, but also the information noise: published results reflect either the underlying processes or the properties of particular SP methods.

A solution to some of these problems was proposed within a framework based upon adaptive time-frequency approximations of signals, currently implementable via the matching pursuit algorithm. Up to now, it encompasses e.g. a high degree of concordance with visual detection of some EEG transients (slide 2), description of epileptic EEG spikes and whole seizures (slide 3) and quantification of ERD/ERS microstructure (slide 3/4). Current presentation adds to this list an efficient preprocessing for the EEG inverse solutions (last slide). Apart from these experimental arguments, we discuss the major mathematical advantages of the proposed approach: explicit parametrization of signal structures in terms of physical parameters and universal robustness. The latter stems from the fact that, unlike other time-frequency methods, adaptive approximations are free from arbitrary choices regulating a priori the tradeoff between time and frequency resolutions of representation.
An increasing number of studies have demonstrated that brain networks (structural, functional and effective) are characterized by specific attributes, such as increased reciprocity of pathways, short path lengths, high clustering, an abundance of specific classes of structural and functional motifs, as well as conserved wiring volume or length. How do these structural attributes relate to functional characteristics of brain networks, to their processing power, robustness, or capacities to support flexible behavior? A computational approach to bridging structure and function is provided by “graph evolution”. Graph evolution utilizes evolutionary algorithms in an attempt to generate networks using an objective or fitness function that may encapsulate a functional hypothesis. Networks that have evolved under this cost function may then be examined for common attributes.

In my presentation I will review several examples of graph evolution and highlight how this computational approach may reveal relationships between seemingly unconnected network measures, including small-world features, informational measures such as complexity and information integration, and network motifs. I will also discuss some related work that puts network structure in the context of embodied cognition and coordinated behavior.