Preface

The Numerous Aspects of Coordinated Activity in the Nervous System

It is reasonable to say that the ultimate goal of neuroscience is to understand how nervous systems, and brains in particular, process information. Whether it be a nematode or a primate nervous system, the foundation of information processing lies in the interactions between units, which in the case of nervous systems means neurons and glial cells. Each cell's activity is meaningful only with respect to what other cells are doing. Hence, these multiple cellular interactions imply that some sort of coordinated activity must exist at some level. Synchronization of the cellular and network activities is one such aspect, and because of this, measures of synchronized activity are fundamental to the understanding of neuronal information processing. The search for methods and conceptual frameworks to capture coordinated activities in nervous systems has had a long history, as expressed by Varela and colleagues: "...since the time of Sherrington and Pavlov the understanding of global distributed properties has been an El Dorado of neuroscience, one that is difficult to reach. The reasons for these difficulties have been both technical and conceptual" (F.J. Varela, E. Thompson, E. Rosch, *The Embodied Mind*, MIT Press, 1991). This book contains contributions that address some of those technical and conceptual matters that continue to hinder, to various extents, the comprehension of coordinated activity in the brain.

It is generally accepted that synchronization of neuronal activity supports the temporal correlations in cell action potential firing that seem to be necessary for neuronal networks to activate one another (information processing relies on the stable propagation of action potentials from network to network). However, the functional role of the synchronization of cellular activity upon cognition and brain pathologies is still debated. From the "binding problem" to the extent of pathological synchrony in epilepsy, different perspectives have been advanced regarding the possible roles of the synchronization that may be seen and measured using a variety of methods. It is important to note that some of these methods will also record activity from glial cells, and that therefore the measured synchrony will reflect neuronal and glial contributions, despite the fact that most studies of nervous system synchrony focus exclusively on neurons. There may be a coming danger that, with the advent of more powerful recording methods and sophisticated analytical techniques, fast data processing may lead to misinterpretations in the physiological account of synchrony measures. Since the analysis of brain coordinated activity will be of fundamental importance in the years to come, careful consideration of the limitations in the recording and analytical methodologies is fundamental for enthusiasts and apprentices in the field. This book is designed to serve that purpose, to illustrate novel developments and basic methodologies, along with some of their constraints, in the assessment of neuronal correlated activity.

A general introduction to the field along with some historical facts is presented in chapters "Correlations of Cellular Activities in the Nervous System: Physiological and Methodological Considerations" and "Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain". Classical analysis methods such as phase synchronization are described in chapters "Correlations of Cellular Activities in the Nervous System: Physiological and Methodological Considerations", "Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain", and "From Synchronization to Networks: Assessment of Functional Connectivity in the Brain", and other methods based on spectral analysis are detailed in various chapters. Chapter "The Size of Neuronal Assemblies, Their Frequency of Synchronization and Their Cognitive Function" in particular focuses on coherence and power spectral analyses. Chapter "Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain" devotes sections to the need for source localization when analysing synchrony, using methods such as independent component and beamformer analysis. This is of importance because the data obtained are coming from sensors (usually electroencephalographic or magnetoencephalographic), whereas the synchrony that is actually sought is that between brain sources. Along these lines, chapter "Correlations of Cellular Activities in the Nervous System: Physiological and Methodological Considerations" demonstrates that it is possible to measure (spurious) synchrony between sensor data signals in the setting of completely desynchronized neural sources. Wavelet analysis, another popular analytical method used to assess synchronization, is described in chapters "Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain", "Denoising and Averaging Techniques for Electrophysiological Data", and "Time–Frequency Methods and Brain Rhythm Signal Processing" along with more details on Fourier analysis. A clear and intuitive comparison between wavelet and Fourier decomposition is presented in chapter "Denoising and Averaging Techniques for Electrophysiological Data". Cluster analysis of phase differences is detailed in chapters "Detection of Phase Synchronization in Multivariate Single Brain Signals by a Clustering Approach" and "Denoising and Averaging Techniques for Electrophysiological Data". Methods to determine not only the synchronization between brain areas but also the directionality of coupling are detailed in chapters "Approaches to the Detection of Direct Directed Interactions in Neuronal Networks" and "Synchrony in Neural Networks Underlying Seizure Generation in Human Partial Epilepsies", particularly as applied to studies of epilepsy. The important new developments in graph theory as applied to the study of coordinated brain activity are described in chapters "From Synchronization to Networks: Assessment of Functional Connectivity in the Brain" and “Complex Network Modeling: A New Approach to Neurosciences”. Chapter “Complex Network Modeling: A New Approach to Neurosciences” presents a more technical description of graph theory, with many mathematical details. Graph theory applied to the study of brain functional connectivity is an emerging area of research that combines synchronization analysis with complex systems theory, and can serve to identify universal principles and statistical properties common to disparate systems. An historical introduction to the field is presented in a section of chapter “From Synchronization to Networks: Assessment of Functional Connectivity in the Brain”, and examples of graph theory applied to the study of neural functional connectivity are discussed in chapters “From Synchronization to Networks: Assessment of Functional Connectivity in the Brain” and “Complex Network Modeling: A New Approach to Neurosciences”.

Variability in electrophysiological recordings is a common source of distress for the experimentalist, and the authors of chapter “Denoising and Averaging Techniques for Electrophysiological Data” discuss that what is normally considered a sensory-evoked or event-related potential may be a modulation of the ongoing, spontaneous brain activity, and techniques are described to improve noisy data, specifically addressing the important question of the variability present in single trials. These queries about variability in the signals are closely related to the debate on whether a resting baseline in brain activity really exists. Chapters “Detection of Phase Synchronization in Multivariate Single Brain Signals by a Clustering Approach” and “Denoising and Averaging Techniques for Electrophysiological Data” address these questions of what can be considered baseline for event-related potentials and single trials. Fluctuations in whole-head recordings are related to fluctuations in the activity of individual cells, a topic that is addressed in chapter “Dissection of Synchronous Population Discharges in Vitro”, with elegant descriptions of in vitro experiments combining local field potentials, multiunit cellular activity and intracellular recordings, designed to address the cellular and network mechanisms underlying the generation of synchronous population activity. A theoretical framework for understanding the emergence of coherent activity in nervous systems is presented in chapter “The Phase Oscillator Approximation in Neuroscience: an Analytical Framework to Study Coherent Activity in Neural Networks”, focusing on coupled oscillator formalisms and the reduction to a phase model. In the end, the correlated activity estimated from electrophysiological recordings represents a summation of synaptic potentials and ion movements, and therefore a close consideration of the nature of these events, in terms of the number of active synapses/cells and cell assemblies resulting from the functional contacts, is fundamental. In this regard, chapter “The Size of Neuronal Assemblies, Their Frequency of Synchronization and Their Cognitive Function” presents some estimations on the number of active cells needed to produce field potentials or electroencephalographic signals, as well as a discussion of the relation between the frequencies at which synchronization takes place and the size of the cell assemblies.

Several chapters make reference to particular software and code sources used to perform specific analyses, including the following: BESA (“Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional

Networks in the Human Brain"), EEGLAB ("Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain"), MATLAB ("Correlations of Cellular Activities in the Nervous System: Physiological and Methodological Considerations", "Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain", and "The Size of Neuronal Assemblies, Their Frequency of Synchronization and Their Cognitive Function"), BioSig ("Synchronization Between Sources: Emerging Methods for Understanding Large-Scale Functional Networks in the Human Brain"), Spikoscope and Labview ("Dissection of Synchronous Population Discharges in Vitro"). Available as a free download on the book's website at http://www.springer.com/978-0-387-93796-0 are specific codes for the following purposes: MATLAB code to estimate power and coherence spectra ("The Size of Neuronal Assemblies, Their Frequency of Synchronization and Their Cognitive Function") as well as MATLAB code (software package FDMa) containing scripts and data files to compute the simulations and application to tremor signals as described in chapter "Approaches to the Detection of Direct Directed Interactions in Neuronal Networks".

Finally, we would like to express our profound gratitude to all of the contributing authors who heeded our requests to provide chapters for this book. Their shared enthusiasm and dedication to progress in this multidisciplinary area, combined with the inspiring breadth and depth of their expertise, is something we hope will serve to stimulate much further thought and experimentation into the coordinated activity of the brain.

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