

# Preface

Magnetoencephalography (MEG), an invaluable functional brain imaging technique, provides direct, real-time monitoring of neuronal activity which is necessary for gaining insight into dynamic cortical networks. One distinct advantage of measuring weak extracranial neuromagnetic fields is that there is little attenuation in amplitude and/or smearing of the signals since they are primarily generated by primary current sources and are minimally perturbed by the intervening tissues of brain, skull, and scalp. MEG permits spatiotemporal tracking of cortical pathways with sub-millisecond temporal resolution. Over the last four decades families of analysis approaches have been developed and, to various degrees, evaluated for their accuracy and effectiveness while corroboration of results from independent methods such as intracranial recordings or combined fMRI/EEG confirms that MEG is able to provide novel insights and details of mechanisms mediating the functional organization of the human brain.

The field of MEG resulted from a merger of two lines of curiosity-driven research in physics and biophysics. One aimed to explore quantum phenomena related to low-temperature superconductivity which led to the development of the most sensitive magnetic field sensors, *Superconducting Quantum Interference Devices* (SQUIDs). The other aimed to understand physiological processes by measuring the weak magnetic fields they generate. This merger was driven by physicist David Cohen and electrical engineer/physicist James E. Zimmerman, respectively. The fortuitous timing of their research programs was capitalized on by Edgar Edelsack from the Office of Naval Research. By funding both of their projects he brought them together which resulted in the first measurements of biomagnetic signals generated by the human heart in the MIT shielded room. Their joint paper published on April 1, 1970 suggested “medical uses of SQUIDs” and marked the beginning of the field of biomagnetism. Only two years later (1972), David Cohen published the first MEG paper and since then the field of neuromagnetism has been growing steadily. The excitement of being able to reliably measure weak magnetic signals generated by the human brain led to intensive instrumentation development for two decades, with a goal of capturing the entire extracranial distribution of neuromagnetic fields via whole-head systems with hundreds of sensors. Hardware development was accompanied by algorithm development with the goal to identify the neuronal substrates of human perceptual

and cognitive processes as well as the functional connectivity between brain regions.

Although MEG developed in the laboratories of physicists and biomedical engineers it quickly spread to include researchers with varied backgrounds including those interested in imaging brains in health and disease. The range of both basic and clinical applications of MEG is impressive and growing exponentially; this book provides many examples of these research achievements. The pace of acceptance of MEG methods was stymied some by the realization of the need to apply inverse procedures to the field measurements. However, in actuality all noninvasive methods apply reconstruction algorithms to the signals measured. In contrast with other noninvasive functional imaging methods, the signals measured in MEG are direct measures of neural activity, not a correlate of it. Hemodynamic measures, for example, will always be limited in temporal resolution due to the sluggishness of the hemodynamic response itself (e.g., seconds for fMRI and tens of seconds for PET). Additional advantages of MEG are: (1) single subject analyses are conducted which are necessary for clinical applications while averaging of data across subjects can also be accomplished if desired; (2) subtraction techniques between experimental conditions is not necessary; (3) excellent spatiotemporal resolution can be achieved without the burden of using complex head models as in EEG; and (4) it is an absolute measure and thus does not require a reference as in EEG.

Our intentions for this book are to cover the richness and transdisciplinary nature of the MEG field, make it more accessible to newcomers and experienced researchers, and to stimulate growth in the MEG area. The book presents a comprehensive overview of MEG basics and the latest developments in methodological, empirical, and clinical research, and is directed toward master and doctoral students, as well as senior researchers. There are three levels of contributions: (1) tutorials on instrumentation, measurements, modeling, and experimental design; (2) topical reviews providing extensive coverage of relevant research topics; and (3) short contributions on open, challenging issues, future developments, and novel applications. The topics range from neuromagnetic measurements, signal processing, and source localization techniques to dynamic functional networks underlying perception and cognition in both health and disease. Topical reviews cover, among others: development on SQUID-based and novel sensors, multi-modal integration (low field MRI and MEG; EEG and fMRI), Bayesian approaches to multi-modal integration, direct neuronal imaging, novel noise reduction methods, source-space functional analysis, decoding of brain states, dynamic brain connectivity, sensory-motor integration, MEG studies on perception and cognition, thalamocortical oscillations, fetal and neonatal MEG, pediatric MEG studies, cognitive development, clinical applications of MEG in epilepsy, pre-surgical mapping, stroke, schizophrenia, stuttering, traumatic brain injury, post-traumatic stress disorder, depression, autism, cognitive neuropharmacology, aging and neurodegeneration, and an overview of the major open-source analysis tools.

The book is divided into six parts. Part I includes tutorials on MEG measurements, physical and physiological foundations of MEG, and experimental design.

The remaining parts include topical review chapters and short contributions written by leading MEG researchers. They are grouped around important MEG thrust areas on source analysis and multi-modal integration, functional connectivity and oscillatory activity, neurodevelopment across lifespan, and basic and clinical studies. The book concludes with a range of emerging technologies which offer a bright future for the field of neuromagnetism including combining MEG with ultra-low field MRI, a prospect for direct neuronal current imaging, exciting developments in magnetic relaxometry, and advances in a new generation of sensors.

While we aimed to combine didactic and academic elements in this book, a systematic synthesis was beyond our scope. The authors were asked to introduce particular topics, including an extensive review of the relevant research area, and to inject their own insights into their selected topic. All chapters were reviewed by the two editors. However, no effort was made to achieve strict standardization of symbols across contributions. There is some degree of overlap between certain chapters, left intentionally for the benefit of the reader, which present aspects of a given topic from differing viewpoints or by authors of differing backgrounds.

We hope that this book will be useful as a textbook for advanced master and doctoral students as well as a valuable resource for new and experienced researchers and practitioners. Since in quite a few chapters MEG is discussed in the context of other major functional brain imaging methods and multi-modal integration, the book may be of interest to researchers currently outside of MEG research as well. The general aim of the book was to foster the development of the MEG field by introducing most of the relevant concepts and topics, bringing the latest cutting-edge MEG research results to the forefront as well as passing on our enthusiasm and excitement for this field which is steadily advancing and growing in relevance and applicability.

We had a great time interacting with so many friends and colleagues that we have known for years, including pioneers in this field. This experience was most pleasant, gratifying, and inspiring. We appreciate their support of this book project and we are thankful for their contributions. Collaboration with Springer editor Dr. Christoph Baumann was both pleasant and constructive. We appreciate his guidance and assistance as well as the support of all the staff at Springer-Verlag that made this project a pleasurable experience. We also acknowledge several grants that supported our efforts on working on the book: a bilateral agreement between the University Zagreb and University of New Mexico, the Croatian Ministry of Science, Education, and Sport (grant 199-1081870-1252), NIH grants from the National Institute on Aging (R01 AG029495), and the National Institute of General Medical Sciences (8P20 GM103472-06). Regarding NIH support, the content is solely the responsibility of the editors and chapter authors and does not necessarily represent the official view of the National Institutes of Health.

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