Introduction to Functional Magnetic Resonance Imaging

Principles and Techniques

Functional magnetic resonance imaging (fMRI) has become a standard tool for mapping the working brain's activation patterns, both in health and in disease. It is an interdisciplinary field and crosses the borders of neuroscience, psychology, psychiatry, radiology, mathematics, physics, and engineering. Developments in techniques, procedures and our understanding of this field are expanding rapidly. In this second edition of *Introduction to Functional Magnetic Resonance Imaging*, Richard Buxton – a leading authority on fMRI – provides an invaluable guide to how fMRI works, from introducing the basic ideas and principles to the underlying physics and physiology. He covers the relationship between fMRI and other imaging techniques and includes a guide to the statistical analysis of fMRI data. This book will be useful both to the experienced neuroscientist, and the clinician or researcher with no previous knowledge of the technology.

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SECOND EDITION

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For Lynn

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Preface to the second edition

The field of functional magnetic resonance imaging (fMRI) has expanded enormously since the mid-1990s. The field is still dominated by basic neuroscience research, but increasingly fMRI is being used to study disease, and clinical applications are growing rapidly. This book is intended as an introduction to the basic ideas and techniques of fMRI. My goal was to provide a guide to the principles of fMRI with sufficient depth to be useful to the active neuroscience investigator using fMRI in research, but also to make the material accessible to the new investigator or clinician with no prior knowledge of the field. To this end, the key ideas are all presented in Part I as a general overview and then developed in more detail in Parts II and III.

The second edition has been extensively revised to reflect new developments in the field since publication of the first edition in 2002. As in the first edition, the emphasis is on examples that illustrate the basic principles rather than a comprehensive review of the field. The viewpoint of the book reflects my own background as a physicist, focusing on how the techniques work and the physiological mechanisms underlying fMRI. The early sections on the basic connections between neural activity, blood flow, and energy metabolism have been completely revised to reflect the large body of the new work since the first edition was published. The final chapter addresses what I think is the primary challenge for fMRI today: how can we take fMRI from a mapping tool to a quantitative probe of brain physiology?

I have been fortunate to be able to work with an exceptional group of colleagues at UCSD, and over the years the material in the book has been shaped by many helpful discussions with Eric Wong, Larry Frank, Tom Liu, David Dubowitz, Miriam Scandeng, Giedrius Buracas, Kun Lu, Adina Roskies, Karla Miller, Kamil Uludag, Marty Sereno, Joan Stiles, Frank Haist, Greg Brown, Anna Devor, and Anders Dale. I have also benefited from numerous stimulating discussions with other colleagues in the field, particularly on ideas related to the physiological foundations of fMRI, including Peter Bandettini, David Boas, Noam Harel, Joe Mandeville, Marcus Raichle, Robert Turner, Essa Yacoub and many others.

Finally, this book could not have been completed without the loving support of Lynn Hall, and the book is dedicated to her.

Richard B. Buxton

Preface to the first edition

The field of functional magnetic resonance imaging (fMRI) is intrinsically interdisciplinary, involving neuroscience, psychology, psychiatry, radiology, physics, and mathematics. For me, this is part of the pleasure in working in this area, providing an opportunity to collaborate with scientists and clinicians with a wide range of backgrounds. This book is intended as an introduction to the basic ideas and techniques of fMRI. My goal was to provide a guide to the principles of fMRI with sufficient depth to be useful to the active neuroscience investigator using fMRI in their research, but also to make the material accessible to the new investigator or clinician with no prior knowledge of the field. The viewpoint of the book reflects my own background as a physicist, focusing on how the techniques work. The emphasis is on examples that illustrate the basic principles rather than a more comprehensive review of the field or a more rigorous mathematical treatment of the fundamentals.

This book grew out of courses I taught with my colleagues L. R. Frank and E. C. Wong, and their insights have significantly shaped the way in which the material is presented. Our courses were geared toward graduate students in neuroscience and psychology, but the book should also be useful for clinicians who want to understand the basis of the new fMRI techniques and potential clinical applications, and for physicists and engineers who are looking for an overview of the ideas of fMRI. Some of the techniques described are not yet part of the mainstream of basic neuroscience applications, such as arterial spin labeling, bolus tracking, and diffusion tensor imaging. However, the clinical application of these techniques is rapidly growing, and I think that over the next few years they will become an integral part of many neuroscience fMRI studies. This book should also serve as an introduction to recent excellent multiauthor works that present some of this material in greater depth, such as *Functional MRI* edited by C. T. W. Moonen and P. A. Bandettini (published in 1999 by Springer).

In writing this book, I have benefited from helpful discussions and critical readings from several of my close colleagues, including Eric Wong, Larry Frank, Tom Liu, Karla Miller, Antigona Martinez, and David Dubowitz. I am also fortunate to be able to work with faculty and students in the San Diego neuroscience community, including Geoff Boynton, Greg Brown, Adina Roskies, Marty Sereno, Joan Stiles, Dave Swinney, and many others. Their insights, comments, and questions have stimulated me to think about many of the topics discussed in the book. In addition, I have also benefited from numerous discussions with colleagues in the field over the years, including Peter Bandettini, Anders Dale, Arno Villringer, Robert Weisskoff, Joe Mandeville, Van Wedeen, Bruce Rosen, Ken Kwong, Robert Turner, Gary Glover, Robert Edelman, Mark Henkelman, and many others. Although these individuals have strongly influenced my own thinking, they are not responsible for what appears here, particularly any errors that may remain.

Finally, this could not have been completed without the loving support of Lynn Hall, and the book is dedicated to her.

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