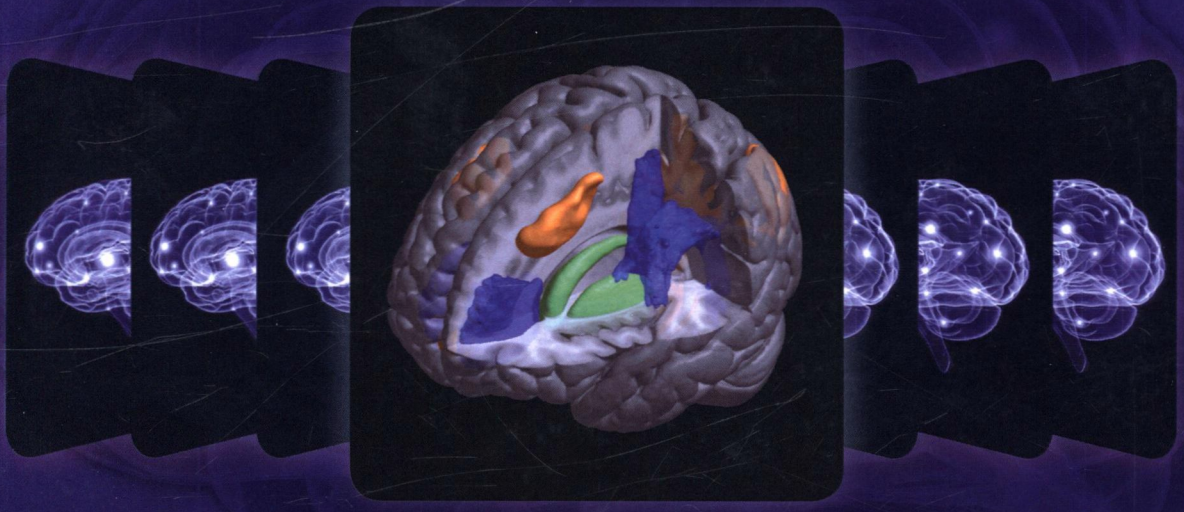
OXFORD NEUROIMAGING PRIMERS

Introduction to Neuroimaging Analysis



Mark Jenkinson
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Mark Jenkinson and Michael Chappell

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MRI has emerged as a powerful way of studying in vivo brain structure and function in both healthy and diseased states. While, for acquisitions, advice and support are often available from operators, radiologists, and technicians, this is less common for analysis; and yet it is important for researchers to obtain an understanding of the principles of analysing neuroimaging data. This is crucial not only for the analysis itself, but also when choosing acquisition parameters, designing and performing appropriate experiments, and correctly interpreting the results.

This primer gives a general and accessible introduction to the wide array of MRI-based neuroimaging methods that are used in research. Supplemented with online datasets and examples designed to enable the reader to obtain hands-on experience in working with real data, it provides a practical and approachable introduction for those who are new to the neuroimaging field. The text also covers the fundamentals of what the different MRI modalities measure, what artifacts commonly occur, the essentials of the analysis, and common pipeline elements such as brain extraction, registration, and segmentation.

As it does not require any background knowledge beyond high-school mathematics and physics, this primer is essential reading for anyone who wants to work in neuroimaging or to grasp the results coming from this rapidly expanding field.

The *Oxford Neuroimaging Primers* are short texts aimed at new researchers or advanced undergraduates from the biological, medical, or physical sciences. They are intended to provide a broad understanding of the ways in which neuroimaging data can be analyzed and how that process relates to acquisition and interpretation. This primer provides an overview of neuroimaging, with other primers written so that they are stand-alone introductions to more specific areas, as well as working together to provide a comprehensive foundation for this increasingly influential field.

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Jenkinson • Chappell

Introduction to **Neuroimaging Analysis**

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Introduction to Neuroimaging Analysis

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Impression: 1

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Introduction to Neuroimaging Analysis

Oxford Neuroimaging Primers

Series Editors: Mark Jenkinson and Michael Chappell

Introduction to Neuroimaging Analysis
Mark Jenkinson
Michael Chappell

Introduction to Resting State fMRI Functional Connectivity
Janine Bijsterbosch
Stephen Smith
Christian Beckmann

Introduction to Perfusion Quantification using Arterial Spin Labeling
Michael Chappell
Bradley MacIntosh
Thomas Okell

This book is dedicated to our parents.

Preface to the Series

The Oxford Neuroimaging Primers are aimed to be readily accessible texts for new researchers or advanced undergraduates in neuroimaging who want to get a broad understanding of the ways in which neuroimaging data can be analyzed and interpreted. All primers in this series have been written so that they can be read as stand-alone books, although they have also been edited so that they "work together" and readers can read multiple primers in the series to build up a bigger picture of neuroimaging and be equipped to use multiple neuroimaging methods.

Understanding the principles of the analysis of neuroimaging data is crucial for all researchers in this field, not only because data analysis is a necessary part of any neuroimaging study, but also because it is required in order to understand how to plan, execute, and interpret experiments. Although MR operators, radiologists, and technicians are often available to help with data collection, running the scanner, and choosing good sequences and settings, when it comes to analysis, researchers are often on their own. Therefore, the Oxford Neuroimaging Primers seek to provide the necessary understanding of how to do analysis while at the same time trying to show how this knowledge relates to being able to perform good acquisitions, design good experiments, and correctly interpret the results.

The series has been produced by individuals (both authors and editors) who have developed neuroimaging analysis techniques, used these methods on real data, packaged them as software tools for others to use, taught courses on these methods, and supported people around the world who use the software they have produced. We hope that this means everyone involved has not only the experience to instruct, but also the empathy to support the reader. It has been our aim for these primers to not only lay out the core principles that apply in any given area of neuroimaging, but also to help the reader avoid common pitfalls and mistakes (many of which the authors themselves probably made first). We also hope that the series is also a good introduction to those with a more technical background, even if they have to forgo some of the mathematical details found in other more technical works. We make no pretense that these primers are the final word in any given area, and we are aware that the field of neuroimaging continues to develop and improve, but the fundamentals are likely to remain the same for many years to come. Certainly some of the advice you will find in these primers will never fail you—such as *always look at your data*.

Our intention with the series has always been to support it with practical examples, so that the reader can learn from working with data directly and will be equipped to use the knowledge they have gained in their own studies and on their own data. These examples, including datasets and instructions, can be found on the associated website (www.neuroimagingprimers.org), and directions to specific examples are placed throughout each primer. As the authors are also the developers of various software tools within the FMRIB Software Library (FSL), the examples in the primers mainly use tools from FSL. However, we intend these primers to be as general as

possible and present material that is relevant for all readers, regardless of the software they use in practice. Such readers can still use the example data available through the primer website with any of the major neuroimaging analysis toolboxes. We encourage all readers to interact with these examples, since we strongly believe that a lot of the key learning is done when you actually use these tools in practice.

Mark Jenkinson
Michael Chappell
Oxford, January 2017

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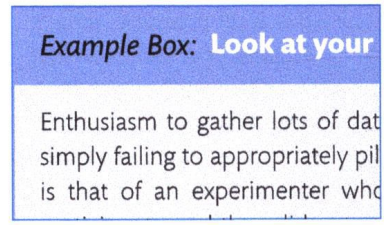
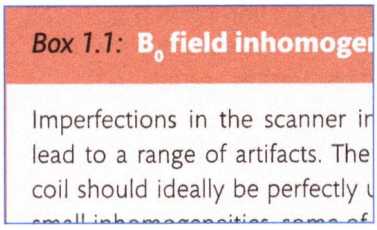
Preface

Welcome to this, the introductory primer in the Oxford Neuroimaging Primers series. This primer is aimed at people who are new to the field of MRI neuroimaging research. Over the past few decades magnetic resonance imaging (MRI) has emerged as an increasingly popular and powerful way of studying in vivo brain structure and function, in both healthy and pathological individuals. MRI is a highly flexible imaging method and there are a lot of different types of images that can be acquired (e.g., structural, diffusion, functional, perfusion, etc.). Although this is a great strength, it can also make for a steep learning curve for those entering the field. Our intention for this primer is to provide a general and accessible introduction to the wide array of MRI-based neuroimaging methods that are used in research—an introduction suitable for people from a broad range of different backgrounds and with no previous experience with MRI or neuroimaging. The main emphasis is on ways of analyzing images, but as this interacts greatly with both image acquisition and interpretation, each of these aspects is also covered in this primer. To make this primer as helpful as possible, we also illustrate the text throughout with examples from real datasets; you will find these datasets, along with instructions on how to visualize and analyze them, on the primer website (www.neuroimagingprimers.org).

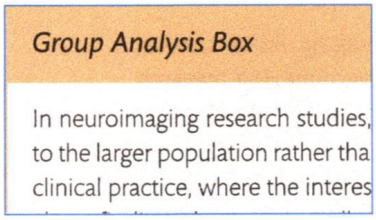
The text contains several different types of boxes that aim to help you navigate the material or find out more information for yourself. To get the most out of this primer, you might find the description of each type of box below helpful.

Example box These boxes either contain additional written illustrations of key points or direct you to the Oxford NeuroImaging primers website (www.neuroimagingprimers.org), where you will find examples that allow you to directly interact with real data and perform practical exercises to apply the theory described in this primer. These examples are intended to be a useful way to prepare you for applying these methods to your own data; but you do not need to carry out such exercises immediately as you are reading through the primer. The examples are placed at the relevant places in the text, so that you know when you can get a more hands-on approach to the information being presented.

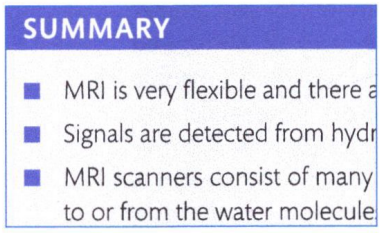




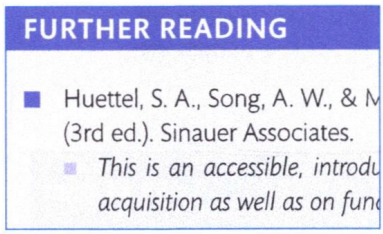
Box These boxes contain more technical or advanced descriptions of some topics covered in the primer or information on related topics or methods. None of the material in the rest of the primer assumes that you have read these boxes, and they are not essential for understanding and applying any of the methods. If you are new to the field and are reading this primer for the first time, you may therefore prefer to skip the material in these boxes and come back to them later.



Group analysis box This primer includes one longer box on the topic of Group Analysis. This box describes some general statistics material needed to prepare you for running your own analyses; hence this box should not be skipped. It contains material that is relevant to many topics covered in different chapters of the primer and it is therefore written in relatively general terms.



Summary Each chapter or major section contains, toward the end, a box of summary points that provide a very brief overview, emphasizing the most important topics discussed. You may like to use these boxes to check that you have understood the key points in each chapter or section.



Further Reading Each chapter or major section ends with a list of suggestions for further reading, which contain both articles and books. A brief summary of the contents of each suggestion is included, so that you may chose which references are most relevant to you. The primer does not assume that you have read any of the further reading material. Rather these lists represent a starting point for diving deeper into the existing literature. These boxes are not intended to provide a full review of the relevant literature; should you go further in the field, you will find a wealth of other sources that are helpful or important for the specific research you are doing.

Neuroimaging is a dynamic field and will continue to see developments in the coming years, as new acquisition and analysis options become available. Thus this primer will not cover all aspects of neuroimaging or neuroimaging analysis; it is intended as a preparatory text that builds up a framework for understanding the important analysis and acquisition principles for the common neuroimaging modalities, in order to enable new researchers to enter the world of neuroimaging more easily. We hope that it will provide a good preparation for anyone who delves deeper into specific modalities and their analyses, through other primers in this series, or more generally into the vast literature on neuroimaging.

Mark Jenkinson
Michael Chappell

Acknowledgments

There are a great many people who have helped make this primer what it is today, and we are grateful for all their support and assistance. To start with, we would like to thank our editor at OUP, Martin Baum, for enthusiastically getting behind this project and making the whole series a reality. For this primer, special thanks are due to Matteo Bastiani, Janine Bijsterbosch, Jon Campbell, Liv Faull, and Sam Harrison for their huge amount of help, proofreading, and advice with the overall content, the datasets, and innumerable details. We would also like to express our thanks to Iman Aganj, Jesper Andersson, Zobair Arya, Holly Bridge, Mark Chiew, Stuart Clare, Alexandra Constantinescu, Gwenaëlle Douaud, Uzay Emir, Matthew Glasser, Sezgi Goksan, Doug Greve, George Harston, Caroline Hartley, Saad Jbabdi, Sarah Jenkinson, Renée Koolschijn, Saloni Krishnan, Jacob Levenstein, Bradley MacIntosh, Paul McCarthy, Clare O'Donoghue, Thomas Okell, Martin Reuter, Ged Ridgway, Emma Robinson, Adriana Roca-Fernandez, Michael Sanders, Zeena-Britt Sanders, Stamatios Sotiropoulos, Charlotte Stagg, Sana Suri, Eelke Visser, Joseph Woods, Mark Woolrich, and Eniko Zsoldos for invaluable proofreading, advice, and support that helped shape and improve this primer. Much of the material for it developed through the FSL Course and the FMRIB Graduate Programme. We are also thankful to all the participants, lecturers, and tutors on these courses, especially for their feedback over the years, as this has been crucial in developing and honing this material.

Mark Jenkinson
Michael Chappell

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