Introduction to Human Neuroimaging

Developed specifically for students in the behavioral and brain sciences, this is the only textbook that provides an accessible and practical overview of the range of human neuroimaging techniques.

Methods covered include functional and structural magnetic resonance imaging, positron emission tomography, electroencephalography, magnetoencephalography, multimodal imaging, and various brain stimulation methods. Experimental design, image processing, and statistical inference are also addressed, with chapters for both basic and more advanced data analyses.

Key concepts are illustrated through research studies on the relationship between brain and behavior, and practice questions are included throughout to test knowledge and aid self-study.

Offering just the right amount of detail for understanding how major imaging techniques can be applied to answer neuroscientific questions, and the practical skills needed for future research, this is an essential text for advanced undergraduate and graduate students in psychology, neuroscience, and cognitive science programs taking introductory courses on human neuroimaging.

Hans Op de Beeck is a Professor in the Brain and Cognition Research Unit at the University of Leuven (KU Leuven), Belgium. His research in cognitive and systems neuroscience has appeared in top scientific journals (such as *Science, Nature Neuroscience, Journal of Neuroscience,* and *Psychological Science*) and has been awarded and funded by national and international organizations, including the European Research Council and the Human Frontier Science Program. He teaches on topics such as behavioral neuroscience, neuropsychology, and human brain imaging in bachelor's and master's programs of psychology and the biomedical sciences.

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Developed in response to a growing need to make neuroscience accessible to students and other non-specialist readers, the *Cambridge Fundamentals of Neuroscience in Psychology* series provides brief introductions to key areas of neuroscience research across major domains of psychology. Written by experts in cognitive, social, affective, developmental, clinical, and applied neuroscience, these books will serve as ideal primers for students and other readers seeking an entry point to the challenging world of neuroscience.

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Preface

We want to understand the world around us. Society and some of its most brilliant minds invest considerable energy and resources in finding out the laws and the origin of the universe, exposing us to exotic concepts such as big bangs and string theories. For this enterprise, researchers measure all sorts of *signals from outer space* through huge telescopes and satellites. In science fiction movies these devices pick up signals from extraterrestrial beings, but in reality the signals inform us about what physical events happen very far away around other stars and in other galaxies.

Humankind, or at least the physicists among us, is interested not only in the big and the large, such as the borders of the universe, but also in the small and the submicroscopic. We need to know what happens at the smallest as much as at the largest scale before we can truly understand the physical world. For this small scale, scientists make inferences based on *signals from events happening at the subatomic level*. Ironically, the smaller the scale, the larger the apparatus that physicists need to use to detect these events. The current state of the art is the Large Hadron Collider, which detected the signal allowing scientists to infer the existence of the Higgs boson.

This book is about other signals, signals that are perhaps even more interesting. Of course outer space is great, as is picking up signals from an unimaginably small particle using a machine large and complicated enough to make every human nerd drool. However, there is one thing we as humans want to get a grip on even more than our environment, and that is ourselves. We want to understand and control ourselves. For this, we have to look where our "self" is situated, and that is in our head. It turns out that the head, and more specifically the brain, also emits all sorts of signals. This text is about these *signals from our brain* and how to measure them.

We must immediately warn the reader that these brain signals are not simple to understand and not easy to measure. Much must be learned. Measuring signals from outer space is complicated and involves armies of physicists and engineers, but we also need to learn some facts about physics and engineering to understand how we can measure brain signals. We need bits and pieces of knowledge from biology, neurophysiology, electricity, engineering, advanced statistics, radiology, neurology, cognitive science, and even philosophy. Getting the complete picture from brain signals requires you to take a truly interdisciplinary viewpoint. You are, it is hoped, ready for this.

Aims of This Text

The goal of this text is to bring students from a wide background to the point where they can read human neuroscience papers and understand all sections, including methodology – that is, how a technique works and why it was chosen, data analysis, and interpretation of the results. It will take hard work, but it is worth it. We avoid complexity as much as possible, and you should not worry about complicated formulas. For example, you do not need a physics degree to understand the concepts of physics as they are introduced in this book. Rather, our intent is that a motivated student who has successfully obtained an academic bachelor's degree in a scientific discipline should be able to grasp most of this book.

With this knowledge in your backpack, you as a reader will have what it takes to add human brain imaging to your own thinking, in whatever remote subject area you are interested in (e.g., psychology, economics, social sciences, law) and whatever type of neuroscience that might be most relevant to you (e.g., cognitive neuroscience, clinical neuroscience, educational neuroscience, neuroeconomics). And who knows, if you are particularly adventurous, the provision of just enough details about how the techniques are implemented and how the data are analyzed might bring you to the point where you want to do such research yourself. In that case, this book should be a perfect primer.

Key Features

We have included the following features to aid students and instructors in getting the most out of this text:

- **Learning objectives** are listed at the beginning of each chapter.
- **Further reading** suggestions are included, along with explanations of their relevance.
- **Chapter summaries** are provided at the end of each chapter to recap the key points that students should be aware of.
- **Review questions** are included to test knowledge as part of homework or self-study.
- **A detailed glossary** is supplied, with all key words also highlighted in bold throughout the text.
- **Online resources** include lecture slides, answers to the review questions, and links to further tutorials and useful websites.

Choice of Topics

This book covers the most popular neuroimaging techniques at a level of detail that takes into account the following trade-off: On the one hand, we want to avoid unnecessary details to make sure that the book as a whole can be read as part of

a normal course or as an introduction to a multi-methods lab environment rather than used as an encyclopedia-style reference. On the other hand, we aim to include sufficient details to provide the student with a relatively in-depth understanding of all the different domains related to human neuroimaging – indeed, also including physics, neuroscience, statistics, and cognition. For example, we do not abstain from a chapter on the physics of MRI, but we focus on the basics needed to understand a typical methods section in a paper and to know the parameters that a *non-physicist* researcher might alter during scanning. As another example, we include many examples of applications of imaging in various research fields in order to illustrate basic concepts, but we do not aim to provide a review of any specific field (no chapter such as "the cognitive neuroscience of attention"). Nevertheless, the knowledge acquired in this book will be tremendously helpful for a better understanding of the many books that focus on specific fields, including many of the contributions in the series to which this book belongs: *Cambridge Fundamentals of Neuroscience in Psychology*.

Our overview of brain imaging does not shy away from criticism. Criticism can be voiced at many levels, from the general level of philosophy of science ("Can brain imaging really help us understand the human mind?") all the way down to very specific criticisms about a particular statistical method. Yet readers will notice that there is no chapter called "Criticisms of Human Brain Imaging." This choice reflects our belief that a thorough, in-depth discussion of the various pros and cons of particular approaches or methods requires sufficient knowledge about conceptual as well as technical issues. Thus, at the appropriate time and place, we present many important discussions, including neuro-hypes, neo-phrenology, brain activity in a dead salmon, reverse inference, open science or lack thereof, the limitations of group studies, the trade-off between spatial and temporal resolution, the relative value of different methods, and why a neuroscientist interested in neurons would measure blood flow, among others. This approach should help the reader not only to become an expert in terms of conceptual and technical knowledge, but also to apply this knowledge to develop a critical mindset when reading about and applying human brain imaging.

Acknowledgments

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