Comprehensive Neuroscience Techniques of Understanding the Brain: Brain Organization, Experimental Design, and Research Methods

Review of *Research Methods for Cognitive Neuroscience,* by Aaron Newman. London: Sage, 2019.

Jianrong Zhao

Jin Xue

School of Foreign Studies

University of Science and Technology Beijing

Correspondence:

Jin Xue

School of Foreign Studies

University of Science and Technology Beijing

NO. 30 Xueyuan Road, Haidian District, Beijing

P. R. China, 100083

Email: beijingxuejin@aliyun.com

The book *Research methods for cognitive neuroscience* is interdisciplinary since cognitive neuroscience has its commitment to multidisciplinary research. Since 1988, the application of the positron emission tomography (PET) allows the researcher to tap into brain activities and locate changes in neurocognitive responses in human brains (Petersen et al., 1988; Posner et al., 1988). Before PET, electroencephalogram (EEG) was the only way to examine brain activities, but it couldn't locate the origin of brain activities. Later, some other techniques for non-invasively studying brain activities were established, pushing forward the development of cognitive neuroscience. Nowadays, more and more researchers are increasingly curious about how our thoughts, behaviors, and feelings are generated, especially how they connect with the structure and activity patterns of the brain. Therefore, there is an appetite for a textbook that includes the complete range of modern neuroscience techniques. However, most published books on neuroscience techniques have focused on one specific method that requires a relatively high-level research background in fields such as physics and mathematics, thus making it not easily accessible for regular learners.

In this book, the author, Aaron Newman, as a professor of the Department of Psychology & Neuroscience, Paediatrics, and Surgery, and the director of the NeuroCognitive Imaging Lab at Dalhouse University, is experienced in applying neuroimaging techniques, especially electroencephalograph (EEG) and functional magnetic resonance imaging (fMRI) techniques in the research of psychology (p.17). He is, therefore, qualified to offer comprehensive neuroimaging techniques, relevant theories, and recent changes in the field for readers who are not very familiar with cognitive neuroscience and perhaps debating using a neuroscience technique.

A brief review of the chapter topics gives a sense of the scope of the book. The book contains 14 chapters on several subtopics in cognitive neuroscience, which could be divided into three main parts, including Part I (Chapter 1, introducing brain organization), Part II (Chapter 2, describing research methods and experimental design), and Part III (Chapters 3-14, elaborating specific neuroimaging techniques).

Part I (Chapter 1), *The Organization of the Brain and How We Study It*, first defines the scope and objectives of cognitive neuroscience, identifies the fundamental types of cells and their connections in the brain, and describes the primary organization of the brain across micro-, meso- and macro-anatomical scales. Then the following lists various brain imaging and stimulation methodologies, which are broadly categorized from four dimensions: whether they measure structural or functional parameters, the physiological parameters they measure, and their spatial and temporal resolutions.

In Part II (Chapter 2), entitled *Research Methods and Experimental Design*, the author begins by specifying several basic concepts running through all neuroimaging techniques and disciplines within this field, including variables, response time (RT), and accuracy. Then he explains some original experimental designs: subtractive and additive factor designs, factorial designs, parametric designs, between- and within-subjects designs. Finally, the author stresses the importance of statistical power since it determines whether a result could be reliable or replicated in other studies.

Part III, the pivotal element, from Chapters 3-14, introduces various brain-imaging tools including EEG/ERP, MEG, MRI (fMRI), DTI, PET, fNIRI, TMS, and tES (tDCS, tACS, tRNS). Due to the space limitation, I will mainly confine my comments to fMRI since it comprises the vast majority of cognitive neuroscience studies currently being published.

The author begins with EEG and ERP, presented in Chapter 3 and Chapter 4. Chapter 3 provides readers, especially beginners, with the working mechanism of EEG, and explanations of some fundamental and essential concepts such as dipole, open fields and closed fields, exogenous and endogenous components, time domain, frequency domain, and frequency. Then he turns to the discussion of recording clear EEG data, which requires careful attention to details: the preparation of the participant, the connection of the electrodes, and the instructions and feedback offered to the participant before and during the experiment. Chapter 4 revolves around ERP experimental design and data analysis. The author argues that designing ERPs or EEG experiments "requires a solid understanding of how the technique works, its limitation, and its strength" (p.199). Aaron Newman next addresses the necessary steps to analyze EEG data: preprocessing, filtering, artifact detection, removal and correction, re-referencing, and epoching.

In Chapter 5, *Magnetoencephalography (MEG)*, the author demonstrates what we measure, how we measure it, experimental design, and data analysis. In this part, the author mainly explains two points. First, the reason for which source localization approaches benefiting from larger amounts of data is the number of trials and the number of time points available in each trial epoch. Second, longer pre-stimulus baseline epochs may be more critical for MEG than EEG since for certain source localization methods, such as beamformer, the accurate detection and localization of the signal are related to the comparison between the pre- and post-stimulus epochs. In addition, the longer baseline periods of MEG could help decide the time between successive stimuli to make sure the minimal overlap between stimuli in different epochs.

Chapters 6-10 are about MRI. Chapter 6 touches upon the fundamentals of how MRI works in general, referring to essential concepts such as hydrogen, net magnetization vector, precession (a second type of circular movement around the axis for protons (p. 308)), resonance, and radiofrequency. At the end of this chapter, the author highlights the importance of safety since the strong magnetic field creates many safety risks. The author also indicates that MRI scans can be used in many different ways to examine brain function and structure. In Chapters 7-8, Aaron Newman focuses on fMRI about how it works, its experimental design, and how to analyze data. Three essentials need to be mentioned: first, the conventional approaches for experimental design are blocked designs and event-related designs, while conjunction/disjunction analysis, fMRI adaptation design, condition-rich and time-continuous designs are arisen due to the nature of fMRI data; second, as with all neuroimaging techniques, fMRI data requires many preprocessing steps prior to statistical analysis: temporal filtering, motion correction, spatial filtering, and spatial normalization; third, statistical analysis of fMRI data includes univariate analysis, multiple comparison correction, region of interest analysis, and multivariate analysis. What should be mentioned is that pattern classification and other statistical methods have recently been applied to fMRI data analysis.

In the past 30 years, fMRI has been widely used in many studies in cognitive neuroscience, psychology and clinical psychiatry, and it has also been increasingly used as a biomarker for disease, and to monitor therapy. fMRI has found its way to awareness (Owen, Coleman, & Boly, 2006), moral judgment (Greene et al., 2004) and free decision (Soon et al., 2008) as well. With the guidance of fMRI, more complex brain network modeling will facilitate people's understanding of the human brain. Chapter 9 explores structural MRI, mainly several different approaches to structural imaging. Structural MR images are obtained by computational neuroanatomy today employing automated algorithms and quantifying morphological changes in brain structure. Aaron Newman contends that computational neuroanatomy is a class of techniques including voxel-based morphometry, deformation-based morphometry, and tensor-based morphometry.

In addition to fMRI and structure MRI, some other uses of MRI have found widespread application in cognitive neuroscience in particular diffusion tensor imaging (DTI), which is covered in Chapter 10 about its mechanism, data collection, and data analysis. The author points out that "there's no single 'right' way to analyze DTI data" (p. 518). Like fMRI data, DTI data analysis also requires artifact correction, normalization, and derivation of diffusion tensor parameters. However, two additional pieces of information are also needed for analysis: the set of gradient directions corresponding to each brain volume in the file and the associated *b* value for that volume.

Chapter 11, *Positron Emission Tomography (PET)*, the author discusses its working mechanism, experimental design, data collection, and analysis. He indicates that PET introduces radioactive tracers into the body, therefore, making it usually more invasive than other imaging techniques. However, PET can be used with computerized tomography (CT) or MRI. The combination of these equipment offers many advantages over the application of PET alone.

Chapter 12, *Near-Infrared Optical Imaging (FNIRI),* mainly deals with the principle applied in fNIRI, measurements, data analysis, and multiple imaging. The author first explains that 'FNIRI' used here is to refer to all types of non-invasive optical imaging for the heterogeneity in the field in terms of approaches to using the technique by different researchers. As for the preprocessing and analysis steps, the author underlines two typically employed steps: data conversion and short-distance correction. The former is used to convert the raw time-series data, and the latter attempts to remove signals from photos that passed only through superficial tissues.

Chapters 13-14 center around non-invasive brain stimulation (NIBS) techniques, including transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (tES). In contrast to the previously mentioned techniques, TMS and tES involve an intervention, applying electrical or magnetic stimulation to the brain rather than recording brain activity (p. 639). Chapter 13 addresses the operation of TMS with its effects on the brain, considerations in experimental design, its combination with neuroimaging, and safety. From my perspective, I am more concerned about the integrating of TMS with neuroimaging such as PET, fMRI, and EEG since, as a stimulation method, TMS itself doesn't provide any means to measure this modulation directly. The combination of TMS and EEG can be used to measure the physiological effects of TMS-induced perception (Taylor, Walsh, & Emier, 2010), and to record the subsequent effects of TMS disruptive mode on both behavior and electrophysiological activity (Sadeh et al., 2011). The use of TMS-fMRI is "off-line" in which the TMS is typically delivered before the subject enters the scanner. What should be noticed in the combined use of TMS-PET is the placement of the TMS equipment relative to the PET scanner to prevent interference with the PET system's electronic since TMS does generate an electromagnetic filed while PET doesn't rely on electrical potentials or magnetic fields. From the above, combing neuroimaging with TMS can help us to understand the effects of TMS better.

In Chapter 14, *Transcranial Electrical Stimulation (tES: tDCS, tACS, tRNS)*, the author describes how tES is administered, compares and contrasts the three primary tES stimulation protocols (tDCS, tACS, tRNS), and presents different models of how tES affects brain activity. Although tES is generally quite safe at the range of stimulation levels, safety problems like skin burns are also emphasized.

The author also suggests the advantages and disadvantages of all these neuroimaging techniques. Compared with EEG, the oldest neurocognitive technique, MEG bears similar temporal resolution, but higher spatial resolution. Different from EEG and MEG, MRI bears a highly accurate localization of brain activity with fewer costs and is available to more users. fMRI is the most used technique in cognitive neuroscience with proper temporal resolution. As for structural MRI, researchers are interested in how different brain areas are connected, and it can be measured by using an MRI technique DTI, which is a special form of MRI. Different from fMRI, there is no magnetic field for PET, and it could scan people with implanted devices. However, PET is relatively uncommon because it introduces radiative materials into the body. fNIRI has a lower spatial resolution than fMRI. Unlike previous techniques recording brain activity, TMS and tES are non-invasive brain stimulation, which involves applying electrical or magnetic stimulation to the brain.

Overall, this book achieves its aim of presenting a full range of cognitive neuroimaging techniques in an appropriate level of detail for a wide range of readers, from undergraduates to faculty members. Another merit of this book is the general structure that every chapter includes “Learning objectives”, “Summary”, and “Things you should know”, which will be useful if some details of the technical research are beyond the reach of the reader. The reader will be getting high-level summaries of findings and interpretations from the principal practitioner in this field. It will also be found useful that there is a list of recommended further readings after each chapter and a glossary and key terms at the end of the book. Particularly welcome features of this book are its informativeness, thoroughness, and instructiveness in that it is abundant with many basic concepts and fundamental topics, experimental design, data collection, and analysis of different neuroimaging skills.

Finally, written in an easy-to-follow logic and a view to helping people from a range of research backgrounds and presented in full-color, including numerous illustrative materials, this book will be invaluable as a core text for students in cognitive neuroscience. Additionally, the author has intentionally tried to limit the number of mathematical formulae or detailed descriptions of biochemical pathways, preferring instead to focus on conceptual understanding. Therefore, it can be used as a critical reference in courses on cognition, cognitive neuropsychology, biopsychology, brain, and behavior. Those embarking on research will find it an invaluable starting point and reference.

Despite its benefits, some limitations of this book should also be considered. First, one of the most noticeable features is that the book is so long with more than 900 pages. Second, in section 3 of part I, the title, labeled *Studying the Organization of the Brain*, is confusing, since it’s unclear whether this section introduces the structure of the brain or the research methods of the brain structure. Third, there is an imbalance between EEG/ERP and MRI and the other sections, since EEG/ERP receives two chapters, and MRI is covered across a total of five chapters including two on fMRI and one on the basic physics of how MRI works, while most other techniques are covered only within one chapter. Finally, the book focuses more on methods rather than applications.

Nevertheless, this book is designed only to provide the first taste, and to form a groundwork for understanding these techniques about how they work and their strengths and limitations. It takes significant work to master any one technique. If subsequent editions are written, additional material, new sections, and more accessible explanations, including several online links, should be utilized to offer expanded or advanced treatment of selected topics.

References

Greene, J. D., Nystrom, L. E., Engell, A. D., et al. (2004). The neural bases of cognitive conflict and control in moral judgment. *Neuron, 44*(2), 389-400.

Owen, A. M., Coleman, M. R., Boly, M., et al. (2006). Detecting awareness in the vegetative state. *Science, 313*(5792), 1402.

Petersen, S. E., Fox, P. T., Posner, M. I., Mintun, M., & Raichle, M. E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature*, *331*(6157), 585.

Posner, M. I., Petersen, S. E., Fox, P. T., & Raichle, M. E. (1988). Localization of cognitive operations in the human brain. *Science, 240*(4859), 1627-1631.

Sadeh, B., Pitcher, D., Brandman, T., Eisen, A., Thaler, A., & Yovel, G. (2011). Stimulation of category-selective brain areas modulates ERP to their preferred categories. *Current Biology, 21*(2), 1894-1899.

Soon, C. S., Brass, M., Heinze, H. J., et al. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience, 11*(5), 543-545.

Taylor, P. C., Walsh, V., & Eimer, M. (2010). The neural signature of phosphene perception. *Human Brain Mapping, 31*(9), 1408-1417.

New technologies in neuroscience generate reams of data at an exponentially increasing rate, spurring the design of very-large-scale data-mining initiatives. Several supranational ventures are contemplating the possibility of achieving, within the next decade(s), full simulation of the human brain. I.Â large-scale approaches guarantee that we will reach a better understanding of the brain? UnitÃ© de Neuroscience, Information et ComplexitÃ© (UNIC-CNRS), Gif-sur-Yvette, France. Email: fregnac@unic.cnrs-gif.fr. This â€œopinionâ€ paper emphasizes the contrast between the accelerating technological devel-opment and the relative lack of progress in con-ceptual and theoretical understanding in brain sciences. To understand the brain, neuroscientists must measure and analyze the rapid changes in neuronal signaling activity that occur over the vast networks of cells and connections. The scope of this endeavor is immense.Â These databases contain precise information, obtained directly from experimental investigation, regarding the sequence of base pairs of specific genes, their locations on specific chromosomes, and the amino acid sequences of known and newly discovered proteins. Investigators consider these databases invaluable for a host of reasons.Â In contrast to molecular biology, understanding the diversity inherent in brain structure and functioning requires the three-dimensional display of many types of experimental information. Modern research through neuroimaging techniques, still uses the Brodmann cerebral cytoarchitectonic map (referring to study of cell structure) anatomical definitions from this era in continuing to show that distinct areas of the cortex are activated in the execution of specific tasks.[21].Â The understanding of neurons and of nervous system function became increasingly precise and molecular during the 20th century.Â For example, the International Brain Research Organization was founded in 1961,[25] theÂ Over time, brain research has gone through philosophical, experimental, and theoretical phases, with work on brain simulation predicted to be important in the future.[33]. Modern neuroscience[edit]. Main article: Outline of neuroscience. A neuroscience method to understanding the brain is to find and study the preferred stimuli that highly activate an individual cell or groups of cells. Recent advances in machine learning enable a family of methods to synthesize preferred stimuli that cause a neuron in an artificial or biological brain to fire strongly.Â Cognitive neuroscience methods are increasingly applied in educational research to examine the neural underpinnings of learning. As such, neuroscientific evidence can play an important role in advan Cite.Â Network science has facilitated these analyses and our understanding of how the brain is organized. While network science has catalyzed a paradigmatic shift in neuroscience, methods Cite. It shows what the latest brain imaging techniques and other advances in the neurosciences actually reveal about how the brain develops and operates at different stages in life from birth to old age and how the brain is involved in acquiring skills such as reading and counting.Â Can we slow the development of brain disorders like dementia and Alzheimerâ€™s? The co-author of Understanding the Brain: The Birth of a Learning Science, Koji Miyamoto from the OECDâ€™s Centre for Educational Research and Innovation, explains the answers neuroscience is beginning to provide to these questions and discusses how people can be helped to learn at every stage of life.