

The Statistical Analysis of fMRI Data

Martin A. Lindquist

Abstract. In recent years there has been explosive growth in the number of neuroimaging studies performed using functional Magnetic Resonance Imaging (fMRI). The field that has grown around the acquisition and analysis of fMRI data is intrinsically interdisciplinary in nature and involves contributions from researchers in neuroscience, psychology, physics and statistics, among others. A standard fMRI study gives rise to massive amounts of noisy data with a complicated spatio-temporal correlation structure. Statistics plays a crucial role in understanding the nature of the data and obtaining relevant results that can be used and interpreted by neuroscientists. In this paper we discuss the analysis of fMRI data, from the initial acquisition of the raw data to its use in locating brain activity, making inference about brain connectivity and predictions about psychological or disease states. Along the way, we illustrate interesting and important issues where statistics already plays a crucial role. We also seek to illustrate areas where statistics has perhaps been underutilized and will have an increased role in the future.

Key words and phrases: fMRI, brain imaging, statistical analysis, challenges.

1. INTRODUCTION

Functional neuroimaging has experienced an explosive growth in recent years. Currently there exist a number of different imaging modalities that allow researchers to study the physiological changes that accompany brain activation. Each of these techniques has advantages and disadvantages and each provides a unique perspective on brain function. In general, these techniques are not concerned with the behavior of single neurons, but rather with activity arising from a large group of neurons. However, they differ in what they attempt to measure, as well as in the temporal and spatial resolution that they provide. Techniques such as electroencephalography (EEG) and magnetoencephalography (MEG) are based on studying electrical and magnetic activity in the brain. They provide temporal resolution on the order of milliseconds but uncertain spatial localization. In contrast, functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) provide information on blood flow

changes that accompany neuronal activity with relatively high spatial resolution, but with a temporal resolution limited by the much slower rate of brain hemodynamics. While each modality is interesting in its own right, this article focuses on statistical issues related to fMRI which in the past few years has taken a dominant position in the field of neuroimaging.

Functional MRI is a noninvasive technique for studying brain activity. During the course of an fMRI experiment, a series of brain images are acquired while the subject performs a set of tasks. Changes in the measured signal between individual images are used to make inferences regarding task-related activations in the brain. fMRI has provided researchers with unprecedented access to the brain in action and, in the past decade, has provided countless new insights into the inner workings of the human brain.

There are several common objectives in the analysis of fMRI data. These include localizing regions of the brain activated by a task, determining distributed networks that correspond to brain function and making predictions about psychological or disease states. Each of these objectives can be approached through the application of suitable statistical methods, and statisticians play an important role in the interdisciplinary

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The Statistical Analysis of Functional MRI Data Nicole Lazar, 2008-06-10 The study of brain function is one of the most fascinating pursuits of modern science Functional neuroimaging is an important component of much of the current research in cognitive clinical and social psychology The excitement of studying the brain is recognized in both the popular press and the scientific community In the pages of mainstream publications including The New York Times and Wired readers can learn about cutting edge research into topics such as understanding how customers react to products and advertisements If your brain has a buy button what pushes it The New York Times October 19 2004 how viewers respond to campaign ads Using MRI to see politics on the brain The New York Times April 20 2004 This is your brain on Hillary Political neuroscience hits new low Wired November 12 2007 how men and women react to sexual stimulation Brain scans arouse researchers Wired April 19 2004 distinguishing lies from the truth Duped The New Yorker July 2 2007 Woman convicted of child abuse hopes fMRI can prove her innocence Wired November 5 2007 and even what separates cool people from nerds If you secretly like Michael Bolton we'll know Wired October 2004 Reports on pathologies such as autism in which neuroimaging plays a large role are also common for instance a Time magazine cover story from May 6 2002 entitled Inside the world of autism

Statistical Analysis of fMRI Data, second edition F. Gregory Ashby, 2019-09-17 A guide to all aspects of experimental design and data analysis for fMRI experiments completely revised and updated for the second edition Functional magnetic resonance imaging fMRI which allows researchers to observe neural activity in the human brain noninvasively has revolutionized the scientific study of the mind An fMRI experiment produces massive amounts of highly complex data for researchers to analyze This book describes all aspects of experimental design and data analysis for fMRI experiments covering every step from preprocessing to advanced methods for assessing functional connectivity as well as the most popular multivariate approaches The goal is not to describe which buttons to push in the popular software packages but to help researchers understand the basic underlying logic the assumptions the strengths and weaknesses and the appropriateness of each method The field of fMRI research has advanced dramatically in recent years in both methodology and technology and this second edition has been completely revised and updated Six new chapters cover experimental design functional connectivity analysis through the methods of psychophysiological interactions and beta series regression decoding using multi voxel pattern analysis dynamic causal modeling and representational similarity analysis Other chapters offer new material on recently discovered problems related to head movements the multivariate GLM meta analysis and other topics All complex derivations now appear at the end of the relevant chapter to improve readability A new appendix describes how to build a design matrix with effect coding for group analysis As in the first edition MATLAB code is provided with which readers can implement many of the methods described Statistical Analysis of fMRI Data, second edition F. Gregory Ashby, 2019-09-17 A guide to all aspects of experimental design and data analysis for fMRI experiments completely revised

and updated for the second edition Functional magnetic resonance imaging fMRI which allows researchers to observe neural activity in the human brain noninvasively has revolutionized the scientific study of the mind An fMRI experiment produces massive amounts of highly complex data for researchers to analyze This book describes all aspects of experimental design and data analysis for fMRI experiments covering every step from preprocessing to advanced methods for assessing functional connectivity as well as the most popular multivariate approaches The goal is not to describe which buttons to push in the popular software packages but to help researchers understand the basic underlying logic the assumptions the strengths and weaknesses and the appropriateness of each method The field of fMRI research has advanced dramatically in recent years in both methodology and technology and this second edition has been completely revised and updated Six new chapters cover experimental design functional connectivity analysis through the methods of psychophysiological interactions and beta series regression decoding using multi voxel pattern analysis dynamic causal modeling and representational similarity analysis Other chapters offer new material on recently discovered problems related to head movements the multivariate GLM meta analysis and other topics All complex derivations now appear at the end of the relevant chapter to improve readability A new appendix describes how to build a design matrix with effect coding for group analysis As in the first edition MATLAB code is provided with which readers can implement many of the methods described

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Yongmei Chen,2002 [Web-based Tutorial for Statistical Analysis of Functional Magnetic Resonance Imaging Data](#) Ian Lai,2003 *Template Free Methods for the Statistical Analysis of FMRI Data* William Frederick Auffermann,2002 *A Client-server Software Application for Statistical Analysis of FMRI Data* Vijay Singh Choudhary,2004 Statistical analysis methods used for interrogating functional magnetic resonance imaging fMRI data are complex and continually evolving There exist a scarcity of educational material for fMRI Thus an instructional based software application was developed for teaching the fundamentals of statistical analysis in fMRI For wider accessibility the application was designed with a client server architecture The Java client has a layered design for flexibility and a nice Graphical User Interface GUI for user interaction The application client can be deployed to multiple platforms in heterogeneous and distributed network The future possibility of adding real time data processing capabilities in the server led us to choose CGI Perl C as server side technologies The client and server communicates via a simple protocol through the Apache Web Server The application provides students with opportunities for hands on exploration of the key concepts using phantom data as well as sample human fMRI data The simulation allows students to control relevant parameters and observe intermediate results for each step in the analysis stream spatial smoothing motion correction statistical model parameter selection etc Eventually this software tool and the accompanying tutorial will be disseminated to researchers across the globe via Biomedical Informatics Research Network BIRN portal *Handbook of Neuroimaging Data Analysis* Hernando Ombao,Martin Lindquist,Wesley Thompson,John Aston,2016-11-18 This book explores various state of the art aspects behind the statistical analysis of

neuroimaging data It examines the development of novel statistical approaches to model brain data Designed for researchers in statistics biostatistics computer science cognitive science computer engineering biomedical engineering applied mathematics physics and radiology the book can also be used as a textbook for graduate level courses in statistics and biostatistics or as a self study reference for Ph D students in statistics biostatistics psychology neuroscience and computer science Handbook of Functional MRI Data Analysis Russell A. Poldrack, Jeanette A. Mumford, Thomas E.

Nichols, 2024-02-08 Functional magnetic resonance imaging fMRI has become the most popular method for imaging brain function Handbook of Functional MRI Data Analysis provides a comprehensive and practical introduction to the methods used for fMRI data analysis Using minimal jargon this book explains the concepts behind processing fMRI data focusing on the techniques that are most commonly used in the field This book provides background about the methods employed by common data analysis packages including FSL SPM and AFNI Some of the newest cutting edge techniques including pattern classification analysis connectivity modeling and resting state network analysis are also discussed Readers of this book whether newcomers to the field or experienced researchers will obtain a deep and effective knowledge of how to employ fMRI analysis to ask scientific questions and become more sophisticated users of fMRI analysis software *Risk Patterns and Correlated Brain Activities. Multidimensional Statistical Analysis of FMRI Data with Application to Risk Patterns* Alena Mysickova, 2017 Decision making usually involves uncertainty and risk Understanding which parts of the human brain are activated during decisions under risk and which neural processes underly risky investment decisions are important goals in neuroeconomics Here we reanalyze functional magnetic resonance imaging fMRI data on 17 subjects which were exposed to an investment decision task from Mohr et al 2010b We obtain a time series of three dimensional images of the blood oxygen level dependent BOLD fMRI signals Our goal is to capture the dynamic behavior of specific brain regions of all subjects in this high dimensional time series data by a flexible factor approach resulting in a low dimensional representation We apply a panel version of the dynamic semiparametric factor model DSFM presented in Park et al 2009 and identify task related activations in space and dynamics in time Further we classify the risk attitudes of all subjects based on the estimated low dimensional time series Our classification analysis successfully confirms the estimated risk attitudes derived directly from subjects decision behavior *Risk Patterns and Correlated Brain Activities: Multidimensional Statistical Analysis of FMRI Data with Application to Risk Patterns*, 2011 Decision making usually involves uncertainty and risk Understanding which parts of the human brain are activated during decisions under risk and which neural processes underly risky investment decisions are important goals in neuroeconomics Here we reanalyze functional magnetic resonance imaging fMRI data on 17 subjects which were exposed to an investment decision task from Mohr et al 2010b We obtain a time series of three dimensional images of the blood oxygen level dependent BOLD fMRI signals Our goal is to capture the dynamic behavior of specific brain regions of all subjects in this high dimensional time series data by a flexible factor approach resulting in a low

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Handbook of Functional MRI Data Analysis Russell A. Poldrack, Jeanette A. Mumford, Thomas E. Nichols, 2011-08-22 Functional magnetic resonance imaging fMRI has become the most popular method for imaging brain function Handbook for Functional MRI Data Analysis provides a comprehensive and practical introduction to the methods used for fMRI data analysis Using minimal jargon this book explains the concepts behind processing fMRI data focusing on the techniques that are most commonly used in the field This book provides background about the methods employed by common data analysis packages including FSL SPM and AFNI Some of the newest cutting edge techniques including pattern classification analysis connectivity modeling and resting state network analysis are also discussed Readers of this book whether newcomers to the field or experienced researchers will obtain a deep and effective knowledge of how to employ fMRI analysis to ask scientific questions and become more sophisticated users of fMRI analysis software

Stochastic Modeling and Statistical Analysis of EEG-fMRI Data, 2016 The Relationship Between Neural Circuitry and Biomechanical Action Redha Taiar, Mario Bernardo-Filho, Borja Sañudo, Yuri Ivanenko, 2022-03-07

Statistical Learning Methods for Group Analysis in FMRI Data Arunava Samaddar, 2019 In this dissertation we aim to answer three questions concerning group analysis of functional magnetic resonance imaging fMRI data First we propose a model free cluster method that groups brain signals in to clusters based on wavelet transformation and principal component analysis From the clustered maps we identify activated regions related to the given tasks We then use a resampling approach to compare clustered maps between practice groups and scan sessions Second we compare

differences of groups of subjects in brain activation changes across two scan sessions Using the property that brain signals in regions of interest ROIs may contain a similar pattern across subjects in a task related experiment we develop a semiparametric approach under shape invariance to quantify and test differences between sessions and groups We conduct statistical inference on the scale parameter in the model to determine whether attenuation is present between two sessions for each group and whether a group difference exists between two sessions in multiple ROIs Last we take a functional data analysis approach to classify fMRI data We propose a spatially weighted functional support vector machine FSVM that utilizes a parameter to estimate correlation between different brain regions Using both numerical study and a real fMRI dataset we show our proposed method achieves higher classification accuracy compared to a regular FSVM method

Use of Statistical Classifiers in the Analysis of FMRI Data Thomas William John Ash,2011

The Development of Biomarkers in Psychiatry Takashi Nakano,Takahiro A. Kato,Masahiro Takamura,Shin-ichi Kano,2023-01-03

Between Theory and Clinic: The Contribution of Neuroimaging in the Field of Consciousness Disorders Olivia Gosseries,Steven Laureys,Caroline Schnakers,2019-05-16

The amount of patients surviving severe brain injury has gradually increased over these last decades thanks to the development of intensive care These patients either recover quickly from coma or go through prolonged disorders of consciousness such as vegetative state unresponsive wakefulness syndrome VS UWS or minimally conscious state MCS While patients in a minimally conscious state are to some extent aware of themselves and the environment and show fluctuating but reproducible signs of consciousness patients in a vegetative state unresponsive wakefulness syndrome are awake but only show reflexive behaviors These patients are unable to communicate and present vigilance fluctuation sensory deficits as well as severe motor and language impairments Even though behavioral assessment currently remains the gold standard for diagnosis a number of studies highlights the difficulty in making the distinction between conscious and unconscious patients based on clinical examinations and show a misdiagnosis rate as high as 40% Misdiagnosis can nevertheless have serious consequences on patient s management medically but also ethically i e regarding end of life decision The emergence of functional neuroimaging techniques such as positron emission tomography PET and functional magnetic resonance imaging fMRI opened new opportunities to study brain activity in patients with disorders of consciousness DOC Recent neuroimaging tools have brought new understandings on how the brain functions after coma and how these tools can complement bedside assessment by improving diagnosis and prognosis of DOC patients Indeed we know now that most patients in VS UWS present partial activation of sensory networks and impaired functional connectivity contrary to patients in MCS The reemergence of thalamo cortical connections has also been associated with recovery of consciousness whereas thalamic atrophy has been associated to chronic DOC Recent findings have also stressed the interest of neuroimaging in the management and the treatment of these patients fMRI has been used as brain computer interfaces to detect consciousness in unresponsive patients and to allow basic communication in minimally conscious patients

Neuroimaging techniques are also currently being used to examine the effects of potential therapy such as pharmacological medications e g Amantadine or Zolpidem and brain stimulations e g transcranial direct current stimulation or repetitive transcranial magnetic stimulation *Statistical Methods for FMRI Data Analysis* Jing Xia,2011 Since the early 1990s functional magnetic resonance imaging fMRI has dominated the brain mapping field and it has been proved a powerful tool for mapping human brain functions The fMRI is a high spatial temporal resolution medical imaging modality which means the data structure is complicated and the data size is huge These features of fMRI data pose some challenges to traditional statistical methods which focus on data with small sample size and simple data structure The functional activation detection and functional connectivity network analysis by using fMRI are two important research topics in the neuroscience In this work we present three different statistical methods corresponding to three chapters for the activation detection and network discovery In the first part we present a spatial Bayesian method for simultaneous activation detection and hemodynamic response function HRF estimation in the second part we propose a model based clustering method to detect the functional connectivity network in the third part we present a general and novel statistical framework for robust and more complete estimation of brain functional connectivity based on correlation analysis and hypothesis testing The complicated data features are taken into account in the three algorithms **Nutrients, Neurotransmitters and Brain Energetics** Adriana Ximenes-da-Silva,Rubem C. A. Guedes,2021-09-28

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