Analysis of Functional Magnetic Resonance Imaging Time Series by Independent Component Analysis

Dissertation

zur Erlangung des akademischen Grades

doctor rerum naturalium

(Dr. rer. nat)

von Dipl.-Statistikerin Mandy SOHR

geb. am 20.02.1980 in Lutherstadt Wittenberg

genehmigt durch die Fakultät für Mathematik

der Otto-von-Guericke-Universität Magdeburg

Gutachterin: Frau Prof. Dr. Waltraud KAHLE

Gutachter: Herr Priv.Doz. Dr. Siegfried KROPF

eingereicht am: 26.02.2007

Verteidigung am: 22.06.2007

Contents

List of Figures iv

List of Tables vi

Index of Symbols vii

Index of Abbreviations x

1 Introduction 1

2 Fundamentals 6

2.1 Probability Spaces, Random Variables, and Stochastic Processes 6

2.2 Independence and Correlation 8

2.3 Measures of Independence and Nongaussianity 11

2.3.1 Measuring Independence by Information-Theoretic Functions 11

2.3.2 Measuring Nongaussianity by Kurtosis 18

3 Functional Magnetic Resonance Imaging 20

3.1 Functional Magnetic Resonance Imaging 20

3.2 FMRI Time Series 22

3.3 FMRI Time Series Regarded as Stochastic Processes 23

3.4 Analyzing fMRI Data 24

4 Classical Methods for Analyzing fMRI Time Series 26

4.1 General Linear Model 26

4.2 Principal Component Analysis 27

4.3 Time Series Analyzing Methods 30

4.3.1 Stationary Process 31

4.3.2 Autocovariance and Autocorrelation Function 32
4.3.3 Test for White-Noise Process 32
4.3.4 Test for Gaussian Distribution 33
4.3.5 Frequency Analysis 34
4.3.6 Histograms and Probability Density Estimation 35

5 Independent Component Analysis **37**
5.1 Definition of ICA 37
5.1.1 Identification and Restriction of ICA Algorithms 39
5.1.2 Preprocessing the Data 41
5.2 Relation between PCA and ICA 42
5.3 Algorithms for ICA 44
5.3.1 Jutten-Hérault Algorithm 45
5.3.2 Algorithms for Maximum Likelihood Estimation 46
5.3.3 ICA by Minimization of Information 48
5.3.4 The Infomax Principle 49
5.3.5 The FastICA Algorithm 51
5.3.6 Molgedey and Schuster Approach 53
5.3.7 Nonparametric ICA 54
5.3.8 Further ICA Algorithms 55
5.4 Performance of ICA Algorithms 56
5.5 ICA Applied to fMRI Data 58

6 Simulation Studies **63**
6.1 Modelling the Signals 64
6.1.1 Modelling the Hemodynamic Response Function 64
6.1.2 Variations in the Hemodynamic Response Function 66
6.1.3 Further Contributing Signals 69
6.2 Performing the Programming 70
6.3 Illustrative Results of ICA Decomposition 73
6.4 Simulation Studies with Variations in the HRF 76
6.5 Over- and Underestimation of the Number of Independent Components . . . 85
6.6 Comparing the results of GLM analysis of mixed signals with and without included ICA 88
6.7 Illustrative Results of Time Series Decomposition 91

7 An Auditory Working Memory fMRI Study and ICA-Results **96**
7.1 Material and Method 96
7.2 Data Analysis 99
7.3 Results 103
7.3.1 Behavioral Results 103
7.3.2 ICA-Results and Time Series Analysis 103
7.4 Comparing ICA Time Courses to HRF Time Courses in Correlation Analysis 109
7.5 Discussing the Shape of BOLD Responses 111

8 Conclusions **113**

Bibliography **114**

A Properties of Information-Theoretic Functions **I**
A.1 Information I
A.2 Differential Entropy III
A.3 Negentropy IV
A.4 Approximation of Information-Theoretic Functions VI