EEG/ERP Analysis

METHODS AND APPLICATIONS

EEG/ERP Analysis

Methods and Applications

EDITED BY

Nidal Kamel

Centre for Intelligent Signal & Imaging Research (CISIR)
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS, Malaysia

Aamir Saeed Malik

Centre for Intelligent Signal & Imaging Research (CISIR)
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS, Malaysia

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20140915

International Standard Book Number-13: 978-1-4822-2471-9 (eBook - PDF)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

List of Tables vii
Preface ix
Acknowledgments xiii

1. **Introduction** 1
   Humaira Nisar and Kim Ho Yeap

2. **The Fundamentals of EEG Signal Processing** 21
   Nidal Kamel

3. **Event-Related Potentials** 73
   Zhongqing Jiang

4. **Brain Source Localization Using EEG Signals** 91
   Munsif Ali Jatoi, Tahamina Begum, and Arslan Shahid

5. **Epilepsy Detection and Monitoring** 123
   Arslan Shahid and John K.J. Tharakan

6. **Neurological Injury Monitoring Using qEEG** 143
   Waqas Rasheed and Tong-Boon Tang

7. **Quantitative EEG for Brain–Computer Interfaces** 157
   Anton Albajes-Eizagirre, Laura Dubreuil-Vall, David Ibáñez, Alejandro Riera, Aureli Soria-Frisch, Stephen Dunne, and Giulio Ruffini

8. **EEG and qEEG in Psychiatry** 175
   Likun Xia and Ahmad Rauf Subhani

9. **Perspectives of M-EEG and fMRI Data Fusion** 195
   Jose M. Sanchez-Bornot and Alwani Liyana Ahmad

10. **Memory Retention and Recall Process** 219
    Hafeez Ullah Amin and Aamir Saeed Malik

11. **Neurofeedback** 239
    Mark Llewellyn Smith, Thomas F. Collura, and Jeffrey Tarrant

12. Future Integration of EEG-fMRI in Psychiatry, Psychology, and Cultural Neuroscience 269
Mohd Nasir Che Mohd Yusoff, Mohd Ali Md Salim, Mohamed Faiz Mohamed Mustafar, Jafri Malin Abdullah, and Wan Nor Azlen Wan Mohamad

13. Future Use of EEG, ERP, EEG/MEG, and EEG-fMRI in Treatment, Prognostication, and Rehabilitation of Neurological Ailments 287
Jafri Malin Abullah, Zamzuri Idris, Nor Safira Elaina Mohd Noor, Tahamina Begum, Faruque Reza, and Wan Ilma Dewi Putri Wan Burhanuddin

Index 311

List of Tables

Table 1.1 Characteristic Properties of Bioelectric Signals 14

Table 2.1 Some Common Windows and Their Properties 40

Table 4.1 Localization Ability Comparison for Three Algorithms 111

Table 4.2 Summary of Different Techniques for Solution of EEG Inverse Problem 112

Table 4.3 Comparisons between Various Localization Algorithms 114

Table 4.4 Feature-Based Comparison of Methods 115

Table 5.1 Summary of Seizure Event Detectors 131

Table 5.2 Summary of Seizure Onset Detectors 134

Table 5.3 EEG Features for Epileptic Seizure Detection 137

Table 6.1 Clinical Evaluation Tests 146

Table 6.2 Clinical Schemes of Severity Assessment of Brain's Neuronal Dysfunction 146

Table 6.3 Regional Deficits 147

Table 6.4 Alpha Rhythm and Sleep-Spindle Frequencies Observed in Preteen Children 151

Table 10.1 Summary of Traditional Models 224

Table 10.2 Summary of Factors Affecting Memory Retention and Recall 232

Table 11.1 Band-Pass Filters Used for Neurofeedback 247

Table 11.2 Neurofeedback Learning Mechanisms 248

Table 11.3 Goals of Neurofeedback 248

Table 11.4 Standard Inhibit/Enhance Protocols 252

Preface

The first recording of the electric field of the human brain was made by Hans Berger, the German psychiatrist, in 1924. These recordings came to be known as electroencephalogram (EEG). Since then, the EEG has been a useful tool in understanding and diagnosing neurophysiological and psychological disorders.

Recent advances in digital recording and signal processing, together with the leaps in computational power, are expected to spawn a revolution in the processing of measurements of brain activities, primarily EEGs and event-related potentials (ERPs). This will enable the implementation of more complicated denoising techniques of ERP than ensemble averaging and the implementation of more complicated EEG quantification analysis methods (qEEG) than the amplitudes and frequencies, including nonlinear dynamics and higher-order statistics. Furthermore, this will help in the implementation of various techniques describing the interactions between different regions of the brain, which offer more insights into the functional neural networks in the brain.

This book provides an introduction to both the basic and advanced techniques used in EEG/ERP analysis and presents some of their most successful applications. Before we present EEG/ERP methods and applications, in Chapter 1 we introduce the physiological foundations of the generation of EEG/ERP signals and their characteristics. This chapter first explains the fundamentals of brain potential sources and then describes the various rhythms of the brain, the different electrode cap systems, EEG recording and artifacts, and finally outlines the application of EEG in neurological disorders.

In Chapter 2, the basic digital signal processing topics are first explained, including time-domain, frequency-domain, and signal filtering; stochastic processes; power spectrum density, autoregressive modeling of EEG; and the joint time-frequency methods for EEG representation including the short-time Fourier transform and the wavelet. Next, the nonlinear descriptors of the EEG signal are explained, including the higher-order statistics; chaos theory and dynamical analysis using correlation dimension and Lyapunov exponents; and dynamical analysis using entropy. In addition, motivated by research in the field over the past two decades, techniques specifically used in the assessment of the interaction between the various regions of the brain, such as the normalized cross-correlation function, the coherency function, and phase synchronization, are explained. MATLAB® code is provided in order to enable the reader to run the presented techniques with his or her EEG/ERP data.

Chapter 3 explains the extraction of event-related signals using the multi-trials-based ensemble averaging technique and the recently proposed single-trial subspace-based technique, outlining their implementation. In addition, this chapter explains brain activity assessments using ERP signals, including the applications of P100 in the assessment of the functional integrity of the visual system and some psychophysiological disorders, the application of N200 in the assessment of attention-deficit/hyperactivity disorder (AD/HD), and the application of P300 as a biomarker of the severity of alcoholism, Alzheimer's disease, and Parkinson's disease.

Chapter 4 gives a brief description of the forward and the inverse problem, and then outlines the different EEG source localization methods, including the minimum norm, the weighted minimum norm (WMN), low resolution brain electromagnetic tomography (LORETA), standardized LORETA, recursive multiple signal classifier (MUSIC), recursively applied and projected MUSIC, shrinking LORETA-FOCUSS, the hybrid weighted minimum norm method, recursive sLORETA-FOCUSS, and standardized shrinking LORETA-FOCUSS (SSLOFO).

Chapter 5 presents the successful clinical applications of qEEG in the detection and monitoring of epileptic seizures. This chapter describes the various proposed techniques for epileptic seizure onset detection and epileptic seizure event detection and compares them. In addition, it describes a recently proposed method that relies on the singular value decomposition of the EEG data matrix for feature extraction and the support vector machine (SVM) for classification.

The brain undergoes several types of dysfunctions caused by internal or external stimuli. The cause may be an injury or a neurodegenerative disease. Chapter 6 discusses the issue of monitoring a neurological injury with the qEEG. It describes the assessment criteria of a neuronal injury, the post-concussion syndrome (PCS), and common evaluations of functional connectivity, including functional homogeneity, differentiation, or topographic reciprocities. The monitoring process of a brain injury using the qEEG is also outlined, and a review of the various entropy measures, such as information entropy, mutual entropy, and approximate entropy, is given.

The brain–computer interface (BCI) is an emerging field of study where qEEG techniques are used as a direct nonmuscular communication channel between the brain and the external world. In Chapter 7, the different neurotechnologies for the brain–computer interface based on the detection of ERPs such as the P300 or the steady-state visual evoked potentials (SSVEPs) are described. Moreover, the different parameters of the P300 waveform that can be used to quantify attentional processes are outlined in addition to the different technologies for the measurement of arousal, valence, and stress. Experimental work conducted in the field is also provided.

Chapter 8 reviews the use of qEEG in psychiatry and presents its applications as a biomarker for stress, unipolar depression, and alcohol addiction. A case study on stress assessment is included and discussed.

EEG is known to have a high temporal resolution but a low spatial resolution. On the contrary, functional magnetic resonance imaging (fMRI) is known to have a high spatial resolution but a low temporal resolution. Combining EEG with fMRI may provide high spatiotemporal functional mapping of brain activity. Chapter 9 reviews EEG and fMRI fusion techniques, addresses the theoretical and practical considerations for recording and analyzing simultaneous EEG-fMRI, and describes some of the current and emerging applications. Furthermore, it introduces some integrative models for solving the multimodal fusion.

Chapter 10 provides an introduction to memory-related processes. Two important processes are memory retention and memory recall, and these two processes are discussed in this chapter. Various memory models are presented that describe the cognitive loads and memory. The brain anatomical regions associated with memory retention and recall processes are discussed. Both short-term and long-term memory processes are described. Memory experimental design issues are discussed while keeping in view the various factors affecting memory.

Chapter 11 is intended as a general survey of neurofeedback and is written to help the reader understand neurofeeback in a general way. It provides a starting point for deeper investigation by giving a short history of the field and offering an introductory description of the existing clinical modalities that are developed as a result. It also describes basic clinical processes and neurofeedback interventions, including biological, technical, and scientific considerations.

With the advancements in technology, researchers are attempting to combine various modalities to reap the benefits of all those modalities. One example is the combination of EEG with fMRI, which can provide both spatial and temporal resolution. Chapter 12 discusses the EEG-fMRI data fusion and analysis with respect to psychiatry, psychology, and cultural neuroscience. The chapter begins by giving an introduction to cultural neuroscience. One section in the chapter is dedicated to psychopathy and criminal behavior. The final section describes the role of EEG-fMRI in the rehabilitation of developmental and psychological disorders such as autism and obsessive compulsive disorder.

Chapter 13 discusses the future of EEG, ERP, and EEG-fMRI. These modalities can result in better treatment, prognostication, and rehabilitation for various neurological ailments. This chapter provides an insight into how EEG technology can be used in neurosurgery. In addition, clinical applications of EEG are also discussed. Future clinical applications of EEG-fMRI and EEG-MEG are presented with a specific emphasis on epilepsy, stroke, and traumatic brain injury.

Dr. Nidal S. Kamel and Dr. Aamir S. Malik
Editors
Universiti Teknologi PETRONAS
Tronoh, Malaysia

The MathWorks, Inc.
3 Apple Hill Drive
Natick, MA, 01760-2098 USA
Tel: 508-647-7000
Fax: 508-647-7001
E-mail: info@mathworks.com
Web: www.mathworks.com

Acknowledgments

The editors thank all the contributors for their professional support in developing this book. The editors thank especially Prof. Jafri Abdullah from Universiti Sains Malaysia; Dr. Mark Smith from Neurofeedback Services of New York; Dr. Aureli Soria-Frisch from Starlab Barcelona; Prof. Zhongqing Jiang from Liaoning Normal University, China; and Dr. Humaira Nisar from Universiti Tunku Abdul Rahman, Malaysia.

The editors also acknowledge the support of Mission Oriented Research Biomedical Technology, Centre for Intelligent Signal and Imaging Research, and Department of Electrical and Electronic Engineering at Universiti Teknologi PETRONAS, Malaysia.

Finally, the editors express their appreciation for CRC for the opportunity to edit this book and also thank the entire staff of CRC for their professional support during all the phases of development of this book.

Nidal Kamel and Aamir Saeed Malik

1

Introduction

Humaira Nisar and Kim Ho Yeap
Universiti Tunku Abdul Rahman

CONTENTS

1.1 Introduction to EEG and ERP Signals 2
1.1.1 History 2
1.1.2 Source of Neural Activities 3
1.1.2.1 Human Brain 3
1.1.2.2 Structure and Function of the Neuron 4
1.2 Brain Rhythms and Wave Patterns 6
1.3 Techniques of EEG and ERP Recording 8
1.3.1 Electrodes 8
1.3.2 Montages 10
1.3.2.1 Bipolar Montage 10
1.3.2.2 Referential Montage 10
1.3.2.3 Average Reference Montage 10
1.3.2.4 Laplacian Montage 10
1.4 Recording and Artifacts 11
1.4.1 Biological Artifacts 11
1.4.1.1 Electrooculographic Artifacts or Ocular Artifacts 11
1.4.1.2 Electromyogram Artifacts 11
1.4.1.3 Electrocardiogram Artifacts 13
1.4.1.4 Other Bio-Artifacts 13
1.4.2 Technical Artifacts 14
1.4.2.1 AC or Power Line Artifacts 14
1.4.2.2 DC Noise 14
1.4.2.3 Artifacts due to Improper Placement of Electrodes 14
1.4.2.4 Artifacts due to High Impedance 14
1.5 Properties of EEG and ERP Signals 15
1.6 Application of EEG in Neurological Disorders 16
References 18

1.1 Introduction to EEG and ERP Signals

1.1.1 History

Electroencephalography (EEG) is the recording of electrical activity along the scalp. The flow of current due to firing of neurons in the brain results in a voltage fluctuation that is measured as EEG. The measurement of the brain's response to a stimulus is called event-related potential (ERP). The stimulus can be sensory, motor, or cognitive in nature.

Richard Caton (1842–1926), a physician, deserves credit for the discovery in 1877 of the fluctuation potentials in rabbits, cats, and monkeys that constitute the EEG. However, the first measurement and pictorial demonstration of EEG was performed by Vladimir Pravdich-Neminsky. He measured the electrical activity in the brains of dogs in 1912 and named it *electrocerebrogram* [1,2].

Hans Berger (1873–1941), a neuropsychiatrist, started his study of human EEG in 1920. The first human EEG tracings were shown in his first report in 1929. Berger used a bipolar technique and photographic paper to record electrical activities of the brain and named it *electroenkephalogram* [3]. This term later evolved into electroencephalogram or EEG.

In the United States, the first EEG work was reported in Harvard at Boston in 1934 by Hallowell Davis [1]. During the years 1935 and 1936, Pauline and Hallowell Davis recorded the first known ERPs on conscious humans. They published their findings in 1939. In 1964, Grey Walter and his colleagues reported the first cognitive ERP component, contingent negative variation (CNV) [4].

The development of clinical and experimental EEG work reached a high point around 1960. The interest of electroencephalographers in academic institutions shifted from tracing to automatic data analysis because of computerization. By 1967, people thought that the traditional EEG reading would soon become obsolete, being eventually replaced by fully automatic interpretation. In the 1970s, studies on the evoked potential progressed greatly. The introduction of the pattern changer in the visually evoked potential (VEP) technique by Speckrejse and Spehlmann made this method very reliable [1]. The 1970s and 1980s saw the emergence of structural neuroimaging techniques, computed tomography, and magnetic resonance imaging.

For 30 years after its discovery, EEG was primarily used for assistance in clinical diagnostics, the study of neurological disorders, and brain function assessments. Different areas of the brain involved in specific neurological activities were studied. In 1973, Jacques J. Vidal from the University of California introduced a new concept of brain–computer communication [5,6]. In his study, he proposed the concept of VEP and the route for the future of the brain–computer interface (BCI).

Currently, ERP is the most widely used method in cognitive neuroscience research. It is used to study the physiological correlation associated with the processing of information, such as sensory, perceptual, and cognitive activity [7].

1.1.2 Source of Neural Activities

To understand the origins of the EEG signal, a brief introduction to the human brain and the neuron, the most fundamental cell in neuropsychology, has been presented in the following sections.

1.1.2.1 Human Brain

The human brain may be divided into three major parts: cerebrum, cerebellum, and brain stem. Here, we will only consider the actions of the cerebrum and cerebellum. The cerebellum mainly controls complex body movements, involving coordination and muscle tone modulation. The cerebrum may be subdivided into six parts: frontal lobe, parietal lobe, temporal lobe, occipital lobe, insular lobe, and limbic lobe. The parietal lobe perceives pain and taste sensations, and is involved in problem-solving activities. The temporal lobe is concerned with hearing and memory. The occipital lobe mainly contains the regions used for vision-related tasks. The frontal lobe is mainly associated with emotions, problem solving, speech, and movement. It contains the primary motor cortex located anterior to central gyrus as shown in Figure 1.1 [8,9].

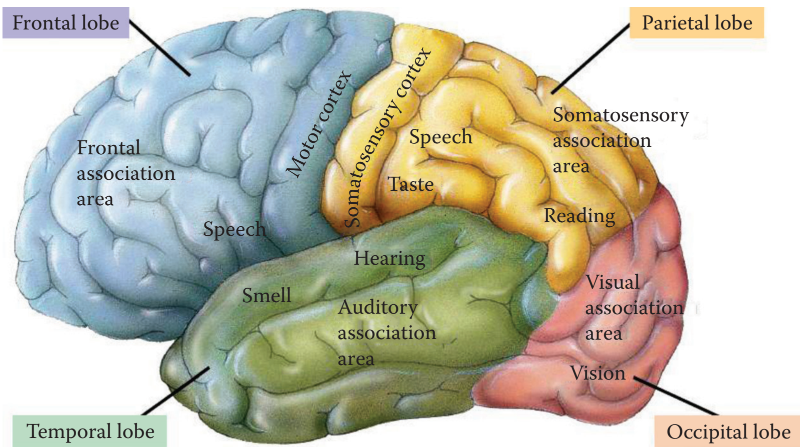

FIGURE 1.1
Functional diagram of brain lobes. (From Chen, P. 2011. Principles of biological science. Accessed September 28, 2013. http://bio1152.nicerweb.com/Locked/src/chap48_g.html.)