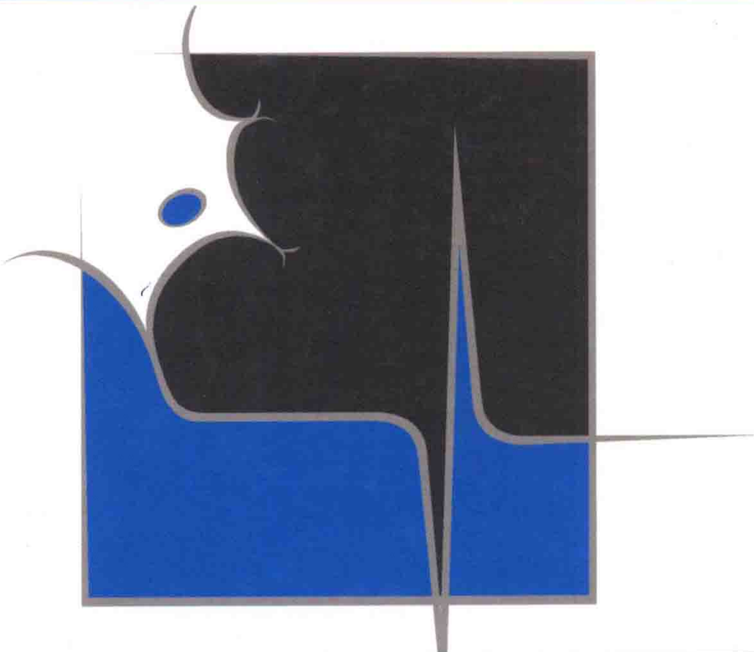
Introduction to Neural Engineering for Motor Rehabilitation



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PREFACE

Neural engineering is an interdisciplinary research area that brings to bear methods from neuroscience and engineering to analyze neurological functions and to design solutions to problems associated with neurological limitations and dysfunctions (definition by the Editorial Board of the *Journal of Neural Engineering* [Durand, 2007]). Despite neural engineering's being a relatively new research area, the field is developing rapidly. This development requires continuously updated didactic material for the increasing number of undergraduate, graduate, and Ph.D. courses on the topic. The applications of neural engineering to rehabilitation of movement cover a broad range of engineering challenges, from electrode design to signal processing and from the neurophysiology of movement to robotics.

The three main approaches of neural engineering used for rehabilitation of impaired motor functions are restoration, replacement, and neuromodulation. Restoration consists in retaining existing neural and anatomical structures and in controlling them for reestablishing a motor function. An example of such an approach is functional electrical stimulation (FES). Replacement consists in substituting the impaired motor apparatus with an artificial one, controlled by residual, but still functional, neural or muscular structures. An example of these methods is the control of artificial limbs (active prostheses). The aim of neuromodulation is (re)training the central nervous system to induce plasticity through artificial stimulation of afferent pathways and/or by artificial enhancement of efferent neural and muscular signals provided as feedback. Examples of such an approach are the application of patterned peripheral electrical neuromuscular stimulation (e.g., transcutaneous electrical nerve stimulation, TENS), mechanical stimulation using robots, or repetitive transcranial magnetic stimulation for retraining the diseased central nervous system.

The aim of this book is to present the state of the art in technologies for motor neurorehabilitation and to give an overview of the current challenges and recent advances within neural rehabilitation technology. The book is intended for undergraduate, graduate, and Ph.D. students as well as senior researchers who work in the field of biomedical engineering, and it is organized in five parts. Part I reviews aspects related to injuries of the nervous system that determine motor impairments. It is considered as a prerequisite that the reader is familiar with the physiology of the neuromuscular system, which is not included in this book. Part II reviews engineering methods for interfacing the neuromuscular system and for conditioning and processing neural and muscular signals. The methods described in Part II are also used in the last three parts of the book, which describe examples of neurotechnologies within the areas of restoration, replacement, and neuromodulation. The topics in each part are collected with the focus on the application (e.g., replacement of function) rather than on the principle on which such application is exploited. Therefore, for example, the principle of brain-interfacing is used in applications described in both Parts III (replacement) and V (neuromodulation), according to the different uses of brain-interfacing in these two sections. Each part begins with a short introduction that serves to put into perspective the topics addressed in that part and to guide the reader to the research areas detailed there. The book's parts comprise introductory chapters, which provide a broad perspective (review chapters), and chapters with a strong focus on more specialized topics (focused chapters), as indicated at the beginning of each chapter.

The book is intended to provide a broad perspective within the field of motor neurorehabilitation engineering by including several topics that in most other books are treated separately. At the same time, the book does not intend to provide an exhaustive treatment of all methods and approaches for motor neurorehabilitation. Rather, the topics presented have been selected to be representative of the field and thus to provide the reader with a general broad overview and understanding of the research area. Readers who approach neural rehabilitation engineering for the first time will find the review chapters as an overview of the state of the art, whereas senior researchers or experts within the field may have further interest in the focused chapters that provide a detailed analysis of specific topics with recent solutions. As indicated, the physiology of the neuromuscular system is not presented in this book, which has as its starting point the injuries of the system. Therefore, readers approaching neural engineering for the first time are advised to first consult references on human physiology.

The editors are very grateful to all the contributing authors for enthusiastically accepting the invitation to contribute to this project and to Dr. Antonietta Stango (University Medical Center Göttingen, Germany) for the important contribution of assisting with the editorial tasks.

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Dario Farina
Winnie Jensen
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REFERENCE

Durand D.M. (2007). What is neural engineering? *J Neural Eng*. 4. http://dx.doi.org/10.1088/1741-2552/4/4/E01.

CONTENTS

PART I

INJURIES OF THE NERVOUS SYSTEM

Part I contains three chapters that examine the type of neural injuries that may lead to sensory–motor impairment, as well as aspects of plasticity, as a relatively novel conceptual theme in the field of neural rehabilitation. Damage to the nervous system is typically associated with the loss of motor drive and of afferent input to the central nervous system. The severity of the neural damage depends on the location of the injury, which may lead to adaptation of the movement pattern, paresis, or complete paralysis. Plasticity has been defined as changes in the strength, number, and location of synaptic connections in response to either an environmental stimulus or an alteration in synaptic activity in a network; our fundamental understanding of what underlies neural plasticity is believed to be one of the key elements in devising strategies for rehabilitation or repair of injuries.

Chapter 1, by Popović and Sinkjær, provides a review of the incidence and the pathology of major diseases and injuries within the central nervous system that lead to impairment of the sensory–motor system, such as stroke and spinal cord injury. The chapter also briefly introduces the types of injuries that lead to loss of sensory–motor functions at the peripheral level.

Chapter 2, by Navarro, more specifically examines injuries at the peripheral level that may result in partial or total loss of motor, sensory, and autonomic functions. Functional deficits may be compensated by reinnervation of denervated targets by regenerating the injured axons, by collateral branching of

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undamaged axons, or by remodeling of nervous system circuitries. Plasticity of central connections may compensate functionally for the lack of adequate target reinnervation; however, plasticity has limited effects on disturbed sensory localization or fine motor control after injuries, and it may even result in maladaptive changes, such as neuropathic pain and hyperreflexia.

Obtaining evidence for spinal or cortical plasticity in the human is very difficult without using invasive recording techniques. Chapter 3, by Ivanenko and collaborators, reports on motor primitives to provide a novel perspective on how the neural control system operates under locomotion in healthy subjects and in patients. They find that building blocks with which the central nervous system constructs motor patterns can be preserved in patients with various motor disorders despite the fact that they often modify their muscle activity and adopt *motor equivalent* solutions. Our understanding of these motor primitives may be useful in driving neuroprostheses or entraining locomotor circuits in disabled people in the future.

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REVIEW CHAPTER

DISEASES AND INJURIES OF THE CENTRAL NERVOUS SYSTEM LEADING TO SENSORY–MOTOR IMPAIRMENT

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SUMMARY

Damage to the central and peripheral nervous systems is associated with a loss of motor drive and a defective afferent input to the central nervous system (CNS). Depending on the location and severity of the neural damage this leads to anything from a complete paralysis to a paresis and a maladaptation of the movement pattern. This chapter starts with a presentation of neuron injury. Such injuries are categorized based on the extent and type of damage to the nerve and the surrounding connective tissue. This chapter addresses sensory–motor deficits that are caused by neuron injury or disease: (a) cerebrovascular accident (CVA), or stroke, which causes impairments due to changes in blood supply to the brain; (b) spinal cord injuries (SCIs), which result in total or partial obstruction of flow of both sensory and motor information between the peripheral and central nervous systems; (c) nontraumatic disorders of the CNS (amyotrophic lateral sclerosis and multiple sclerosis); and (d) cerebral palsy. At the end of the chapter we present the incidence of CNS diseases.

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