Chapter 5
Are We the Robots?
Man–Machine Integration

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ABSTRACT

We experience and interact with the world through our body. The founding father of computer science, Alan Turing, correctly realized that one of the most important features of the human being is the interaction between mind and body. Since the original demonstration that electrical activity of the cortical neurons can be employed to directly control a robotic device, the research on the so-called Brain-Machine Interfaces (BMIs) has impressively grown. For example, current BMIs dedicated to both experimental and clinical studies can translate raw neuronal signals into computational commands to reproduce reaching or grasping in artificial actuators. These developments hold promise for the restoration of limb mobility in paralyzed individuals. However, as the authors review in this chapter, before this goal can be achieved, several hurdles have to be overcome, including developments in real-time computational algorithms and in designing fully implantable and biocompatible devices. Future investigations will have to address the best solutions for restoring sensation to the prosthetic limb, which still remains a major challenge to full integration of the limb into the user's self-image.

INTRODUCTION

At the beginning of the third millennium the development of a revolutionary approach to rehabilitation radically improved the integration between apparently separated fields of research and heavily reshaped the traditional intervention protocols. Building on the last century's most promising technological innovations, this inspired trend confirmed the importance of neuroprosthetics as an interdisciplinary specialty aiming at merging advances in neuropsychology, cognitive neuroscience, and biomedical engineering for creating adaptive devices to overcome the impairments resulting from traumatic or degenerative loss of sensorimotor functionality.

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Following long-established procedures, manual interventions have been widely employed in conventional rehabilitation protocols. However this approach is extremely task-specific and time-consuming for both patients and therapists, requires elaborate schemes, and depends drastically both on therapists' experience and patients' compliance (del-Ama et al., 2012). In addition, these procedures do not always address some of the most important features of a proper sensorimotor rehabilitation, including systematic control of feedback and difficulty (Popovic et al., 2003) and monitoring patients' achievements (Dietz, 2009). Thanks to the most recent technological advances in mechanics, control, and attachment, neuroprosthetics has rapidly grown (Zlotolow and Kozin, 2012). Thus by increasing repeatability, automation, and quantification, robotic-assisted rehabilitation represents one possibility to solve these issues (Prange et al., 2006).

Despite the broad implementation of robotic devices in clinical practices (Marchal-Crespo and Reinkensmeyer, 2009), robotic assistance does not always cope with the difficulties of severe clinical conditions characterized by complete loss of body segments or neural connections, e.g. amputation or spinal cord injury, respectively. As some visionary artists imagined in forward-looking master pieces such as the song "The Robots" realized by the band Kraftwerk in 1978, pioneering studies showed that the signal originating from the neural activity in the brain can be recorded, encoded, and used to control external devices (Fetz and Finocchi, 1971; Fetz, 1969). This innovative methodology triggered a huge amount of scientific investigations and clinical applications, establishing in fact an innovative field in neuroprosthetics and a new era in rehabilitation. Thus the so-called Brain-Machine Interfaces (BMIs) have been applied to a wide collection of clinical conditions (Lebedev and Nicolelis, 2006) and radically transformed the expectations of both patients and medical doctors, quantitatively increasing the range of possibilities for coping with the patients' needs and qualitatively improving the rehabilitation protocols. However before BMI techniques can be fully implemented into clinical environments, some important issues have to be clarified and further investigations are necessary.

The main aim of this chapter is to provide detailed information on the state-of-the-art progresses and future directions of neuroprosthetics and BMIs, highlighting the advantages and disadvantages of each technique. In the first section of this chapter we will introduce how BMI systems can provide users with communication and control capabilities independently of muscular activity, explaining that translating the electrical brain activity into commands is a way to restore lost motor functions by allowing the communication between the brain and an external device. In the second section we will summarize the advances in invasive and non-invasive neuroprosthetics, both for rehabilitation and motor substitution, according to the type of disability towards which the intervention is addressed. Here we will review the progresses in innovative prosthetic technology and we will further discuss the future key challenges aimed at improving the life of disabled people. The third section of the chapter will be dedicated to illustrate the development of the BMIs which made it possible to control prosthetic limbs, giving birth to the research and application of neuroprosthetics, including external as well as implanted components. We will take into account recent evidence showing new methodology for accurately predicting and reconstructing natural kinematics from non-invasively recorded brain activity during movements. In addition, we will focus on the therapeutic implementation of functional electrical stimulation, combined with neuroprostheses, as a possibility for restoring lost motor functions by stimulating muscles with either intramuscular or surface electrodes. In the fourth section of the chapter we will mention the significant emerging challenges to implementation of advanced neuroprostheses. Furthermore, we will elucidate the work on the elaboration of biologically-derived