Chapter 6
The Convergence of AI and BCIs:
A New Era of Brain–Machine Interfaces

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ABSTRACT

BCIs and AI converge for enhanced brain-machine interaction. AI optimizes signal processing and control algorithms, fueling applications like movement restoration and mind-driven communication. This comprehensive review underscores AI's vital role in BCIs, tackling translation hurdles and fostering innovation. It explores AI-boosted BCIs for motor control, sensory feedback, and research. Transformative outcomes encompass disability empowerment, performance enhancement, and deeper brain insights. Challenges include quicker training and improved sensor accuracy. This partnership heralds a dynamic future, revolutionizing human-device interaction and advancing neurotech. As AI and neurotechnology advance, BCIs promise impactful transformations, enriching lives, and capabilities.

INTRODUCTION

The rapid advancement of technology has ushered in a convergence between humans and machines, blurring the once-distinct boundaries. The visionary science fiction narratives of "mind control" are

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gradually becoming a reality with the emergence of brain-computer interfaces (BCIs) and artificial intelligence (AI) (Wolpaw et al., 2002). Traditionally developed and applied independently, experimental paradigms for BCIs and AI are now merging, presenting a remarkable opportunity to harness the brain's electric signals to control external devices efficiently (Carmena et al., 2003).

For individuals with severe disabilities, the development of BCIs holds immense promise as a transformative technological breakthrough. BCIs, as technologies designed to communicate with the central nervous system and neural sensory organs, offer a muscle-independent communication channel for people affected by neurodegenerative diseases or acquired brain injuries (Yang et al., 2019). The evolution of BCIs is closely tied to the continual effort to develop new electrophysiological techniques, enabling the recording of extracellular electrical activity generated by differences in electric potential carried by ions across neuron membranes (Saa & Çetin, 2012).

BCIs can be broadly classified into invasive and non-invasive recording systems. Invasive BCIs involve electrode implantation directly into the brain, while non-invasive BCIs rely on external sensors placed on the scalp (Ušćumlić & Blankertz, 2016). The latter techniques, including electroencephalography (EEG), magnetoencephalography, functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy, present lower risks of tissue damage and ease of implementation (Müller-Putz et al., 2015).

While BCIs hold great potential, they face challenges related to the efficient transfer of vast amounts of neural information. Neuroscientists grapple with discerning a person's intentions from background electrical activity recorded in the brain, especially when matching these intentions to actions performed by robotic arms (Li et al., 2019). The complexity and ambiguity of neural correlates for psychological phenomena present further limitations (Ang & Guan, 2017).

Fortunately, recent advances in AI methodologies have shown significant progress, with AI surpassing human performance in decoding and encoding neural signals (Schirrmeister et al., 2017). As a result, AI can serve as an ideal collaborator, efficiently processing brain signals before they reach prosthetic devices.

AI encompasses a set of general approaches that model intelligent behavior using minimal human intervention, ultimately matching or even surpassing human performance in task-specific applications. In the context of BCIs, AI algorithms continuously receive internal parameters, such as pulse durations, stimulation frequencies, and electrical properties of neural tissues, enabling the identification of relevant information and logic to produce desired functional outcomes.

The convergence of BCIs and AI has captured considerable attention in the technological transformation. This review focuses on current applications of BCIs based on AI, exploring the state of BCIs, the role of AI, and the future directions of this exciting field.

What Are Brain-Computer Interfaces (BCIs)?

Brain-computer interfaces (BCIs) are also known as brain-machine interfaces (BMIs). They are communication systems that establish a direct connection between the human brain and external devices, such as computers or prosthetics, without requiring any muscular or peripheral nerve involvement (Mason et al., 2009). BCIs allow individuals to control external devices, communicate, or interact with their environment using only their brain activity.

BCIs function by detecting and interpreting neural signals or brain activity patterns, which are then translated into specific commands or actions that can be executed by the external device. These neural signals can be acquired using various techniques, including invasive methods such as microelectrode