BRAIN RESEARCH 1595 (2015) 51–73

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Brain Research

Review

Restoration of vision in blind individuals using bionic devices: A review with a focus on cortical visual prostheses

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ARTICLE INFO

Article history:
Accepted 8 November 2014
Available online 15 November 2014

Keywords:
Bionics
Vision
Bionic eye
Cortical implant
Blindness

ABSTRACT

The field of neurobionics offers hope to patients with sensory and motor impairment. Blindness is a common cause of major sensory loss, with an estimated 39 million people worldwide suffering from total blindness in 2010. Potential treatment options include bionic devices employing electrical stimulation of the visual pathways. Retinal stimulation can restore limited visual perception to patients with retinitis pigmentosa, however loss of retinal ganglion cells precludes this approach. The optic nerve, lateral geniculate nucleus and visual cortex provide alternative stimulation targets, with several research groups actively pursuing a cortically-based device capable of driving several hundred stimulating electrodes. While great progress has been made since the earliest works of Brindley and Dobelle in the 1960s and 1970s, significant clinical, surgical, psychophysical, neurophysiological, and engineering challenges remain to be overcome before a commercially-available cortical implant will be realized. Selection of candidate implant recipients will require assessment of their general, psychological and mental health, and likely responses to visual cortex stimulation. Implant functionality, longevity and safety may be enhanced by careful electrode insertion, optimization of electrical stimulation parameters and modification of immune responses to minimize or prevent the host response to the implanted electrodes. Psychophysical assessment will include mapping the positions of potentially several hundred phosphenes, which may require repetition if electrode performance deteriorates over time. Therefore, techniques for rapid psychophysical assessment are required, as are methods for objectively assessing the quality of life improvements

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http://dx.doi.org/10.1016/j.brainres.2014.11.020

obtained from the implant. These measures must take into account individual differences in image processing, phosphene distribution and rehabilitation programs that may be required to optimize implant functionality. In this review, we detail these and other challenges facing developers of cortical visual prostheses in addition to briefly outlining the epidemiology of blindness, and the history of cortical electrical stimulation in the context of visual prosthetics.

Contents

1. Introduction

Neurobionics is the direct interfacing of electronic devices with the nervous system. This interface may be exploited to facilitate exogenous stimulation of the nervous system or for single and multi-unit recording of neural activity. The significant therapeutic potential offered by neural recording is evident in recent reports of multi-electrode prostheses implanted in the motor cortex of humans and non-human primates, enabling the dextrous operation of a robotic arm and hands (Collinger et al., 2013; Hochberg et al., 2012). This dexterity will undoubtedly be greatly enhanced by the integration of sensory feedback (e.g. mechanosensation), which has already been demonstrated in macaques via microstimulation of somatosensory cortex (Berg et al., 2013; O'Doherty et al., 2011; Tabot et al., 2013). Beyond the experimental domain, electrical stimulation of the brain, spinal cord and peripheral nerves via implanted electrodes is in use clinically for the treatment of movement disorders (Williams and