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Review

Electrical stimulation of the brain and the development of cortical visual prostheses: An historical perspective

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ABSTRACT

Rapid advances are occurring in neural engineering, bionics and the brain–computer interface. These milestones have been underpinned by staggering advances in microelectronics, computing, and wireless technology in the last three decades. Several cortically-based visual prosthetic devices are currently being developed, but pioneering advances with early implants were achieved by Brindley followed by Dobelle in the 1960s and 1970s. We have reviewed these discoveries within the historical context of the medical uses of electricity including attempts to cure blindness, the discovery of the visual cortex, and opportunities for cortex stimulation experiments during neurosurgery. Further advances were made possible with improvements in electrode design, greater understanding of cortical electrophysiology and miniaturisation of electronic components. Human trials of a new generation of prototype cortical visual prostheses for the blind are imminent.

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1. Introduction

Advances in medicine, surgery and electronics have set the stage for a fusion of the physical and biological sciences; one in which prosthetic devices may restore lost functional capacity to the disabled. The emerging field of neuroprosthetics embodies the totality of this integration, whereby sensory (Carlson et al., 2012; Guenther et al., 2012; Weiland and Humayun, 2014), motor (Hochberg et al., 2012) and even cognitive (Hampson et al., 2012, 2013) deficits may be addressed. A significant share of the worldwide research effort in this regard is directed towards the development of visual prosthetics for the blind. Potential stimulation targets currently being investigated for visual prostheses include the retina (Chow et al., 2004; Dorn et al., 2013; Gerding et al., 2007; Stingl et al., 2013), optic nerve (Brelen et al., 2010; Sakaguchi et al., 2009; Wu et al., 2010), lateral geniculate body (Panetsos et al., 2011; Pezaris and Eskandar, 2009) and the cerebral cortex (Brindley and Lewin, 1968b; Dobelle, 2000; Schmidt et al., 1996). Human testing of implanted cortical electrode arrays for the evocation of visual percepts predates similar attempts at the retinal level by almost 30 years (Brindley and Lewin, 1968b; Humayun et al., 1996; Humayun et al., 1999). Moreover, visual cortical prostheses offering limited functionality were chronically implanted in a number of patients throughout the 1970s (Brindley, 1982; Dobelle et al., 1976; Dobelle et al., 1979). Two retinal devices recently obtained regulatory approval in Europe (Argus II and Alpha IMS), with the Argus II also having obtained regulatory approval in the US (Weiland and Humayun, 2014). Cortical devices remain experimental only. Imminent human trials of a new generation of improved cortical devices render it timely to review the history of their development, including early electrical stimulation of human cerebral cortex and the first pioneering attempts to restore visual sensation to a profoundly blind person over 50 years ago.

2. The electrically excitable brain and occipital cortex as the primary visual centre

The literature on localisation of function in the brain and the discovery that the human brain is electrically excitable has been extensively reviewed, and will be given a relatively brief treatment here. For more detail, the reader is referred to the works of Gross (1998) and Finger (2001).

The end of the 18th century saw the introduction of a electrophysiology as a scientific discipline, beginning with Galvani's 1791 discovery of the electrical excitability of nerves (Galvani and Aldini, 1791; Piccolino, 1997). Interestingly, Le Roy (1755) had unknowingly demonstrated the excitability of the eyes and/or optic nerves previously, reporting flashes of light seen by his patient, while receiving electric shocks to his patient's head as a treatment for blindness (Fig. 1).

In 1800, Volta also noted that electrical stimulation of the eyes and/or optic nerves could induce the sensation of light, commenting that such stimulation may even be useful to reveal “*paralysis of optic nerves*” (Piccolino, 2000, p.151). This notion of electrical excitability was not extended to the cortex until some 80 years after Galvani's experiments on frog's legs. Indeed, despite the mounting evidence to the contrary, throughout the early 19th century there was a persistent belief that the cortex was inexcitable by electrical means (Carlson and Devinsky, 2009; Gross, 1998). Aldini's early 19th century demonstrations of muscular contractions in response to electrical stimulation of the exposed cortex were performed on deceased humans, thus offering little in the way of incontrovertible proof of cortical excitability. The dual questions of cortical functional localisation and electrical excitability were finally settled after the seminal work of Fritsch and Hitzig (1870) prompted further investigations by Ferrier (1874), (Munk, 1881a), Luciani and Tamburini (Rabagliati, 1879) and others (Gross, 2007). The combined works of these investigators provided conclusive evidence that not only did the cerebral cortex demonstrate functional topography, but this topography could be mapped precisely using electrical stimuli.