Writing to the mind's eye of the blind

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Abstract

The implantation of electrodes on the visual cortex of blind individuals could lead to the restoration of a rudimentary form of sight. In this issue of Cell, Beauchamp et al. use electrical stimulation of the visual cortex to create visual perception of shapes.

Main text

Scientists have long dreamt of restoring vision in blind individuals by stimulating the visual cortex, bypassing malfunctioning eyes to directly deliver information to higher visual centers (Bosking et al., 2017). In this issue of *Cell*, Beauchamp et al. (2020) used electrical stimulation of the visual cortex to produce visual percepts. They took the next step on a path that was started by Giles Brindley at the University of London in the 1960s. His team implanted arrays of electrodes on the visual cortex of a small number of blind people. The electrodes were connected to an array of coils under the skin so that they could be stimulated with a coil held above the skin. The subjects perceived dots of light upon stimulation, known as phosphenes, and Brindley studied the properties of these percepts. The visual cortex contains a two-dimensional map of visual space, and phosphene location depended on the stimulation point on the cortical sheet (Brindley and Lewin, 1968). The remarkable achievement of creating a wireless interface with the brain more than fifty years ago should not be understated. It set the stage for the scientists who subsequently attempted to produce percepts of shapes by creating patterns of phosphenes, akin to lighting up the bulbs on a stadium display to show letters and numbers. One of these scientists was William Dobelle, who implanted electrodes on the surface of the visual cortex in a larger number of blind individuals between 1970 and 2000 (Dobelle, 2000). However, the useful lifespan of his devices was short and patients appeared to receive little overall benefit in their daily lives, leading to diminished enthusiasm for cortical prosthetics.

After Dobelle's experience, many researchers had turned away from the visual cortex and focused on the retina as the site for implantation. The most successful retinal prosthesis is the Argus II, produced by the company Second Sight Medical Products, which received FDA approval under a Humanitarian Device Exemption for patients diagnosed with retinitis pigmentosa, and has been implanted in more than 350 patients. The Argus II helps blind individuals to localize objects, but its utility for the recognition of shapes is limited (Stronks and Dagnelie, 2014). Last year, Second Sight Medical Products suspended the production of the Argus II and decided to focus on cortical implants, signaling renewed interest in the visual cortex as the site of implantation. One advantage of cortical compared with retinal devices is that patients with damage to the retina or early visual pathways are still candidates for cortical implantation.

Beauchamp et al. (2020) now report the results of a study in which they implanted silastic sheets containing multiple embedded electrodes on the surface of the visual cortex. They tested sighted individuals who were implanted as part of their treatment for epilepsy, as well as two blind individuals. One of the blind subjects was implanted with a prototype of a new visual cortical prosthetic device with 60 electrodes, the Orion, built by Second Sight.

As expected, electrical stimulation of individual electrodes elicited phosphenes with locations that corresponded to the retinotopic map in the visual cortex. Beauchamp et al. also tested if the perception of shapes could be induced by the stimulation of multiple electrodes. However, when multiple electrodes were stimulated at the same time, the degree to which the phosphenes combined into recognizable shapes was unpredictable. Typically, they merged into larger phosphenes, making shape recognition impossible. The current required for a single phosphene with surface stimulation is in the order of a few milliamperes, and the total current produced by the stimulation of multiple electrodes may combine to activate neurons in poorly controlled constellations.

Beauchamp et al. developed two clever methods to circumvent this limitation. The first was the creation of phosphenes at locations intermediate between those produced by individual electrodes. The method is called current steering and has also been used for cochlear implants (Townshend et al., 1987). Suppose that stimulation of electrode A at a certain base current produces a phosphene at the visual field at location L_A and that electrode B produces a phosphene at location L_B. The surprising result was that concurrent stimulation of both A and B, both at 70% of the base current, elicits a “virtual” phosphene at a point between L_A and L_B. With different current proportions they could control the location of the virtual phosphene on a line through L_A and L_B. Hence, it is possible to address more locations in the visual field than the number of implanted electrodes.

The second trick was rapid successive stimulation to produce a sequence of phosphenes that traces out the shape of letters (Figure 1). This approach does not require simultaneous stimulation of multiple electrodes and the surprising result was that the subjects readily recognized and reproduced the shape that had been written to their visual cortex. Both seeing and blind subjects recognized letters and the study thereby presents the first clear demonstration of shape perception with electrical stimulation of the visual cortex in the blind.

Current steering and sequential stimulation will help to improve the utility of visual cortical prostheses, but there are still a number of challenges to be overcome. For example, dynamic stimulation that is limited to only one cortical location at a time limits the bandwidth of the shape generation process, because viewing time increases with the number of phosphenes necessary for shape perception. It would be useful to know if multiple items can be dynamically presented, e.g. one per hemifield or one per quadrant. Another limitation of dynamic stimulation is that it might prove difficult to convey information about visual objects that move or change shape because drawing a single shape takes time.

Fortunately, further improvements may be on their way. One approach that could convey more information per unit time is the use of thinner electrodes that penetrate the visual cortex instead of laying against its surface (Normann and Fernandez, 2016). Penetrating electrodes require orders of magnitude less current and produce smaller phosphenes (Schmidt et al., 1996). It might therefore be possible to simultaneously stimulate multiple nearby electrodes, enhancing the resolution of artificial vision. Researchers are also developing other methods to stimulate neuronal tissue with a high bandwidth, such as optogenetics with up to single cell resolution (Marshel et al., 2019). It is an exciting time for novel methods to write to and read from the brain (Roelfsema et al., 2018), and these developments bring us closer to fulfill Brindley's dream of restoring vision for blind people.

Competing interest statement

The author is co-founder of Phosphoenix, a startup company aiming to develop a visual cortex prosthesis as a treatment for blindness.

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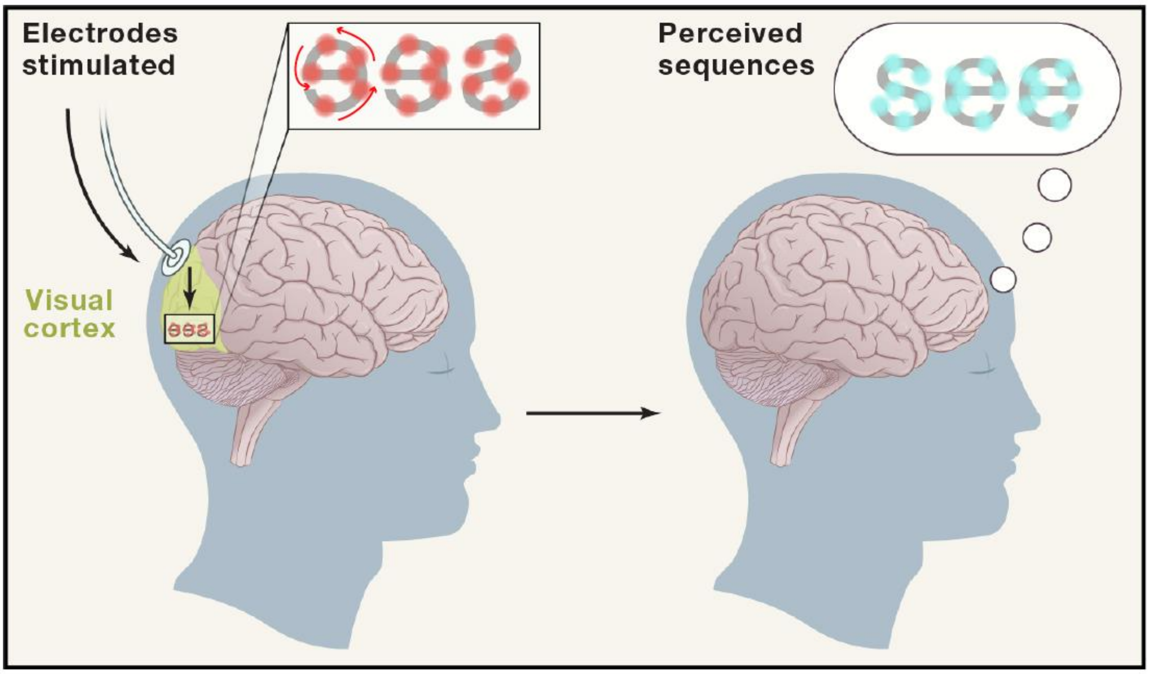

Figure 1. Dynamic writing of shapes to the visual cortex.

Beauchamp et al. (2020) created letters in the perception of their subjects by successively stimulating a number of electrodes laying on the surface of the visual cortex. The subjects perceived sequences of phosphenes (dots of light), which traced the letters, and they could recognize or redraw them. Note that the figure is schematic and does not take the shape of the retinotopic map of visual cortex into account, which requires stimulating electrodes with a mirrored and deformed version of the word “see” on the visual cortex.

References

Beauchamp, M., Oswalt, D., Sun, P., Foster, B., Magnotti, J., Niketeghad, S., Pouratian, N., Bosking, W., and Yoshor, D. (2020). Dynamic stimulation of visual cortex produces form vision in sighted and blind. Cell *XX*, XXX-YYY.

Bosking, W.H., Beauchamp, M.S., and Yoshor, D. (2017). Electrical Stimulation of Visual Cortex: Relevance for the Development of Visual Cortical Prosthetics. Annu. Rev. Vis. Sci. *3*, 141–166.

Brindley, B.Y.G.S., and Lewin, W.S. (1968). The sensations produced by electrical stimulation of the visual cortex. J. Physiol. *196*, 479–493.

Dobelle, W.H. (2000). Artificial Vision for the Blind by Connecting a Television Camera to the Visual Cortex. ASAIO J. *46*, 3–9.

Marshel, J.H., Kim, Y.S., Machado, T.A., Quirin, S., Benson, B., Kadmon, J., Raja, C., Chibukhchyan, A., Ramakrishnan, C., Inoue, M., et al. (2019). Cortical layer-specific critical dynamics triggering perception. Science (80-.). DOI: 10.1126/science.aaw5202.

Normann, R.A., and Fernandez, E. (2016). Clinical applications of penetrating neural interfaces and Utah Electrode Array technologies. J. Neural Eng. *13*, 061003.

Roelfsema, P.R., Denys, D., and Klink, P.C. (2018). Mind reading and writing: the future of neurotechnology. Trends Cogn. Sci. *22*, 598–610.

Schmidt, E.M., Bak, M.J., Hambrecht, F.T., Kufta, C. V, O’Rourke, D.K., and Vallabhanath, P. (1996). Feasibility of a visual prosthesis for the blind based on microstimulation of the visual cortex. Brain *119*, 507–522.

Stronks, H.C., and Dagnelie, G. (2014). The functional performance of the Argus II retinal prosthesis. Expert Rev. Med. Devices *11*, 23–30.

Townshend, B., Cotter, N., Compernolle, D. Van, and White, R.L. (1987). Pitch perception by cochlear implant subjects. J. Acoust. Soc. Am. *82*, 106–115.