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Case Report

Preserved evoked conscious perception of phosphenes with direct stimulation of deafferented primary visual cortex☆,☆☆

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ABSTRACT

The premise of neuro-rehabilitation after injury is to access the residual capacity of the nervous system to improve function. We describe a patient who developed a quadrantopsia and drug-resistant focal epilepsy after an arteriovenous malformation hemorrhage. Thirty years later, he underwent placement of subdural electrodes for seizure mapping. Phosphenes were elicited in the blind right visual field with stimulation of occipital cortex. This case demonstrates that visual cortex may retain functional organization after a partial subcortical visual pathway injury. This persistent conscious mapping suggests that disconnected visual cortex could serve as a region for interfacing with neural prosthetic devices for acquired blindness.

1. Introduction

Neuroprosthetic restoration of lost neurologic function has become a reality, including for vision. One class of visual prostheses creates percepts in blind individuals by direct stimulation of visual cortex [1–3]. Other neuro-restorative strategies have been contemplated through direct cortical stimulation, as in the sensorimotor system [4].

An important question is whether deafferented cerebral cortex retains enough of its original mapping and connectivity, and ability to generate relevant conscious perceptions, to be a viable candidate for use that can successfully interface with a prosthetic device. Cortex that has lost its immediate afferent projections may reorganize, and widespread alterations in cortical maps have been described after injury [5]. In sensorimotor cortex, deafferented cortex changes its field, yet preserved conscious perception of an amputated limb can be created through stimulation of sensory cortex, despite years of absent input from this body part [6]. This suggests that the organization of the somatosensory cortex remains stable and viable though time and would be amenable to interface with a chronically implanted prosthesis.

In the visual system, primary visual cortex organization remains stable long-term in completely blind individuals [2,3]. Partial injury to the primary visual cortex or proximal visual pathways leads to a conscious defect in the contralateral visual field and is followed by a period of variable recovery of the field. Some studies have supported reorganization of the primary visual cortex following retinal or optic radiation lesioning, [5–9,11], while others have not supported reorganization [13,14]. We report a patient with a long-term visual field deficit from subcortical injury who, nevertheless, generated conscious perception of a visual sensation within the affected field from contralateral occipital cortex stimulation.

2. Case Report

2.1. Presentation

The patient was a 45-year-old right-handed man with epilepsy and a dense upper right quadrantopsia after the hemorrhage of a left occipital arteriovenous malformation (AVM) at age 15. Focal aware seizures

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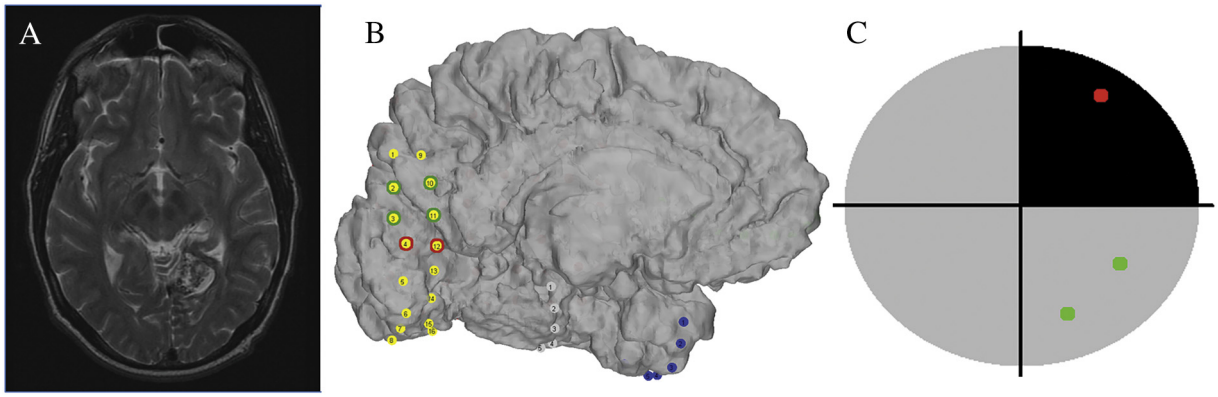

Fig. 1. A: Preoperative MRI demonstrating the left occipital subcortical infarct and associated AVM. B: Reconstructed three-dimensional cortical montage with overlay of electrocorticography grids. Stimulation contact pairs are highlighted on the left occipital grid. C: Representative illustration of the patient's visual fields with dots in the lower right quadrant representing phosphenes from stimulation across contacts 2–10 and 3–11. The dot in the blind upper right quadrant represents phosphenes generated from stimulation across contacts 4 and 12.

originally began with a blinking white light in the right visual field, but later became focal impaired awareness seizures without visual aura. Video-EEG monitoring demonstrated left basal-temporal origin and MRI demonstrated the AVM and surrounding changes in the posterior temporal lobe and temporal-occipital regions including the optic radiations, but sparing primary visual cortex (Fig. 1).

2.2. Cortical Mapping and Surgical Treatment

A left craniotomy for placement of subdural electrodes was performed with stereotactic navigation to assess occipital and medial temporal involvement. Informed consent was obtained for the surgery and subsequent seizure focus mapping. Electrodes placed included a 16 contact array (Ad-Tech, Racine, Wisconsin, USA) of 4 mm diameter platinum contacts with 1 cm center-to-center spacing over the surface of the medial occipital lobe (Fig. 1). More than 100 spontaneous subclinical seizures and focal aware seizures (over 1 week) arose from around the arteriovenous malformation, the left inferior temporooccipital region, and the medial temporal lobe.

Extra-operative cortical mapping (biphase square wave pulses of 1 ms in 60 Hz trains) of the left occipital array with bipolar stimulation of visual cortex (OCS-2, Integra LifeSciences Corporation, Plainsboro, New Jersey, USA) evoked visions of flashing light in the right lower quadrant from contacts 2–10 at 10 mA (peak-to-peak amplitude) and also from contacts 3–11 at 6 mA. Stimulation across contacts 4–12 at 11 mA resulted in flashes in the blind right superior quadrant. Other than a brief period following the initial injury in which he had seizures with visual hallucinations, the patient had not noted any visual percepts in that region since the rupture of his AVM.

Resection of the medial temporal lobe and cortex adjacent to the AVM resulted in long-term seizure freedom and demonstrated histopathology of an embolized occipital AVM with gliosis around the lesion and in the hippocampus.

3. Discussion

Phosphenes generated by direct electrical stimulation of the visual cortex were first reported by Foerster in 1929 and later by Krause and Schum in 1931 [17,18]. The first cortical visual prosthesis (Brindley and Lewin in 1968) involved a wireless array which created phosphenes which were distinguishable between different electrode pairs [7]. Later, stimulation of blind adult patients [3,21] allowed detection of simple horizontal and vertical lines and a chronically implanted system allowed for recognition of letters and numbers [2]. Today both retinal and central visual implants are under development to restore vision in the visually impaired [16,23].

Visual pathway reorganization occurs, but is variable. After a proximal visual pathway lesion, monkey and cat studies find persistent silent areas in the lateral geniculate nucleus and reorganization is provided by synaptic connections in primary visual cortex rather than more proximal fibers [8,11]. Neurons in the region of primary visual cortex which map to an area of lesioned retina undergo an immediate expansion of their receptive field and begin to respond to stimuli in the visual field adjacent to the scotoma, possibly from an unmasking of pre-existing synaptic connections [5,6,8,11,25]. Studies in humans show variable increase of receptive fields from only border effects, [22] to more extensive fill-in, possibly from long-range horizontal connections from adjacent functional visual cortex [23,24]. Cortical reorganization may occur from the development of feedback connections from higher level visual areas to primary visual cortex and the larger receptive field sizes in these areas may help to guide long-term topographical reorganization [28–30]. This plasticity, while desirable from a rehabilitation standpoint, could theoretically alter the underlying organization of the visual cortex to prevent neuroprosthetic restoration of the original cortical function.

In this patient, we do not know what specific factors may have allowed preserved cortical perception. Possible contributing factors include the subcortical nature of the lesion, any incomplete preservation of visual field, impact of seizures, reorganization related to early damage from the AVM, or even an altered visual map from birth given the presumed presence of the AVM. Though bipolar cortical stimulation appears to be limited to the region stimulated [28], downstream spread of stimulation cannot be excluded.

In contrast to visual input to the brain, little is known about the output from cortex that is impacted by subcortical injury. The idea that perception as a conscious phenomenon can occur from sensory cortex, even cortex with no normal input, has served as a theoretical basis to explain phantom pain [5]. Direct neuroprosthetic stimulation of cortex would not be effective if such cortex lost the ability to induce conscious phenomenon in response to upstream injury. The finding in this patient adds to the small evidence present in humans that such conscious phenomenon, long since absent, can be evoked long after initial injury.

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