Activation zones in cat visual cortex evoked by electrical retina stimulation

Abstract Background: A retina implant for restoring simple basic visual perception in patients who are blind due to photoreceptor loss requires optimisation of stimulation parameters for obtaining high spatio-temporal resolution. We developed effective low-power epi-retinal stimulation and intracortical recording in semichronically prepared cats. Methods: Individually driveable fibre electrodes were inserted through a small scleral incision and positioned at the area centralis. Polyimide–platinum film electrodes were inserted via a corneal incision and fixed by instillation of perfluorocarbon liquid on the internal limiting membrane. For electrical stimulation we used short charge-balanced current impulses of 100–400 µs duration and amplitudes ranging from 1 to 100 µA. During stimulation we recorded multiple single-cell and population activities from areas 17 and 18. Stimulus–response relations including response strength, cortical activation zones, information transmission, and electrical receptive fields were analysed off-line. Results: We found low-threshold activations with fibre electrodes and polyimide–platinum film electrodes in close mechanical contact to the retina. Retinal stimulation with bipolar charge-balanced impulses resulted in cortical activation zones corresponding to 1–5° visual angle at paracentral locations dependent on the eccentricity of the retinal stimulation point. Retino-cortical transinformation analysis revealed 20–30 bits/s per electrode, corresponding to 10–15 four-level pictures/s. Electrical receptive fields had sizes of 1–3° visual angle. Conclusions: Coarse visuomotor coordination and navigation seems possible with retina implants.

Introduction

Recent success in the development and application of cochlea implants in deaf patients stimulated new efforts in developing visual prostheses. While the first attempts involved electrical stimulation of the primary visual cortex [1, 3, 5, 6, 9, 10, 11, 24, 39], new projects focus on retina implants for restoring vision in blind individuals with photoreceptor degeneration [1, 7, 8, 19, 20, 27, 28, 29, 45, 46, 47, 48].

Ideally, stimulation by a retinal implant should mimic a visual scene by activating the retinal cells properly: electrically evoked spike patterns should be identical to those evoked by visual stimulation of an intact retina. Here we investigate the spatially and temporally achievable resolution of epi-retinal stimulation with fibre electrodes and polyimide–platinum film electrodes by micro-electrode recordings performed in the primary visual cortex of anaesthetised cats. Our results provide coarse estimates of potential perceptual resolutions achievable with epi-retinal implants.
Materials and methods

Surgical and electrophysiological procedures were performed in anaesthetised cats. The procedures were in accordance with the guidelines of the European Communities Council Directive (86/609/EEC) and were approved by an official German Animal Care and Use Committee. In addition we followed the NIH Principles of Laboratory Animal Care (Publication No. 85–23, revised 1985), the OPRR Public Health Service Policy on the Human Care and Use of Laboratory Animals (revised 1986), the US Animal Welfare Act, and the ARVO guidelines.

Semichronic preparation and surgical procedures

For semichronic preparation adult cats (n=7, weight 3–5 kg) received atropine sulphate (0.03 mg/kg) to reduce salivation. Anaesthesia was induced by intramuscular injection of a mixture of ketamine hydrochloride (Ketanest, 10–15 mg/kg) and xylazine hydrochloride (Rompun, 1 mg/kg). After orotracheal intubation, anaesthesia was maintained by ventilation with N₂O/O₂ (70%/30%) and halothane (0.3–0.8%) or isofluorane (0.5–1.5%). Continuous monitoring of rectal temperature (38 °C), end-expiratory CO₂ (3.8–4.2%), ECG, EEG and reflexes was used to control the level of anaesthesia. For head fixation we implanted two bolts in cavities of the forehead using a dental acrylic glue. A craniotomy was performed above visual areas V1 and/or V2, leaving the dura mater intact. In four cats a Teflon recording chamber (5–7 mm diameter) was attached with screws, ensuring easy access to V1 and V2 in the later recording sessions. After the surgical and recording sessions the cats prophylactically received penicillin.

For experiments with fibre electrodes the cats (n=3) were positioned in a standard Horsley-Clarke support. After lateral canthotomy of the left eye the lateral conjunctiva was incised. We performed a sclerostomy about 4 mm posterior to the limbus. An incision of 1.1 mm was sufficient for transscleral positioning of the stimulation electrodes. At the end of the recording and stimulation sessions sclera and conjunctiva were closed with polyglaclin sutures. Atropine, gentamycin sulphate, and dexamethasone were applied topically. Figure 1 shows a schematic drawing of our experimental set-up.

For experiments with polyimide–platinum film electrodes the cats were positioned on the back during eye surgery. Anaesthesia was maintained by ketamine hydrochloride (Ketanest, 1–5 mg/kg i.m.) and/or propofol [Propofol, 0.02–0.05 mg/(kg h)]. During stimulation and recording the cats (n=4) were positioned in a standard Horsley-Clarke support. Anaesthesia was the same as for the semichronic preparations.

In four cats we performed a lentectomy followed by a complete vitrectomy via corneal incisions [25]. Polyimide–platinum film electrodes (24 stimulation sites; 100 µm diam. per site [41]) were inserted and positioned on the internal limiting membrane (Fig. 2) and temporally fixated by perfluorodecalin. Prior to retinal stimulation and cortical recording the incisions were temporarily sealed. After data collection, electrodes and perfluorodecalin were removed. The incisions were closed, and atropine, gentamycin sulphate and dexamethasone ointment was applied.

Fig. 1 Schematic representation of the experimental set-up for testing electrical retina stimulation by cortical responses in the anaesthetised cat

![Schematic representation of the experimental set-up](image)

Fig. 2 Implanted polyimide–platinum film electrode. The film electrode array was placed over the area centralis after removal of the lens and the vitreous body

![Implanted polyimide–platinum film electrode](image)