NEUROSCIENTIFIC BASIS FOR THE DESIGN AND DEVELOPMENT OF A BIOINSPIRED VISUAL PROCESSING FRONT-END

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Abstract: **The development of a bioinspired reconfigurable Sw/Hw platform able to transform the visual information into parallel trains of signals is essential for applying adequate stimulus patterns to the visual cortex of blind persons. To establish adequate transfer functions for digital signal converters requires adjoining individual cell types classes to the responses obtained in recordings multi-electrode from multielectrode arrays. It has become clear that visual features are represented by the correlated activity of ganglion cells rather than by a mosaic-like assemblage of single channels. Therefore we are investigating various approaches to the characterization of local photoreceptors and neuron populations in retinas from human donors and pig retinas.**

Keywords: **Neuroprosthesis, multiarray-recording microstimulation, Photoreceptors, Retinal ganglion cells, Artificial Vision, Visual cortex,.**

Introduction

Several important research efforts are currently focusing on the development of retinal implants for patients suffering from retinal diseases. [1].

However these approaches require substantial elements of the functional retinal circuitry or at least the retinal output layer (ganglion cells) to be preserved. Thus these prostheses cannot be used after complete degeneration or traumatic loss of eye function when no more visual signals reach the central visual system along the optic nerve.

We have decided to start research for providing higher visual centers directly with information based on a bio-inspired artificial vision system [2]. The digital reconstruction of afferent visual stimuli requires a thorough knowledge about their coding by the essential processing streams inside the retina and about the output, spatially and temporally [3].correlated action potential series of ganglion cell clusters

Materials and Methods

Material

At the initial stage of this approach we cannot hope to reconstruct maximum visual functions as provided by the central macular region. Therefore patches of peripheral retina representing paracentral sectors of the visual field are chosen as adequate models to study principles of visual processing.

Presently human donor retinas, pig and rodent retinas are chosen for different experimental approaches. While human donor retinas are evidently the best subject their use is evidently limited by ethical restrictions and availability. Pig retinas share many similarities with human/primate peripheral retinas such as size, vascularization, cone photoreceptor shape and density and are already used for retinal implant testing.. We therefore focus on the characterization of the different retinal levels of pig's cellular inventory, in particular on the ganglion cells. Finally rat and mouse retinas are suitable to test retrograde dye application.

Morphology and intraretinal tracing

Antibodies against cone-photopigments, calcium-binding proteins and other marker molecules are used to visualize specific cell populations either in whole-mount retinas or in cryosections, light- and electron microscopy. The spatial relations between chromatic cone subtypes and interneurons at the first synaptic level of investigation - in particular horizontal cells - are investigated.

For visualization of the entire ganglion cell population we applied retrograde tracers such as DiI or Neurobiotin to freshly eyecups that were kept in suitable medium and oxygenation to prolong metabolic capacities.

Electrophysiology

We used arrays of 100 or 25 penetrating silicon electrodes (Utah Electrode Array, UEA), specifically designed to focally stimulate or record retinal ganglion cells from human donor retinas and pigs. The arrays were positioned on the vitreous surface of retinas isolated from human transplant donor eyes or anaesthetized animals.

Results

As in other mammals a regular mosaic of medium-wavelength-sensitive cones provides the major population while short wavelength sensitive cones add ca. 10% leading to maxima of 30.000/mm^2 Studying the cone topography along the pigs' high density indicates a interesting specialization of considerable interest for the present project. Within the elongated visual streak there are two peaks – one in the temporal and another in the

nasal region (Fig. 1). This is manifest in the density of long wavelength sensitive cones as well as in the thickness of inner retinal layers indicating varying complexity of post-receptoral processing.

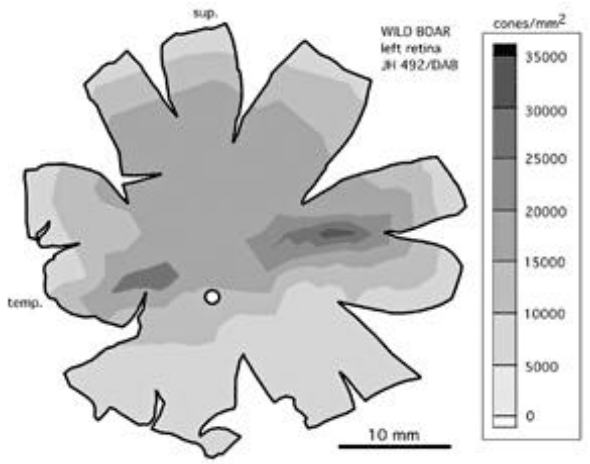

Figure 1: Map of cone photoreceptor topography of wild pig retina.

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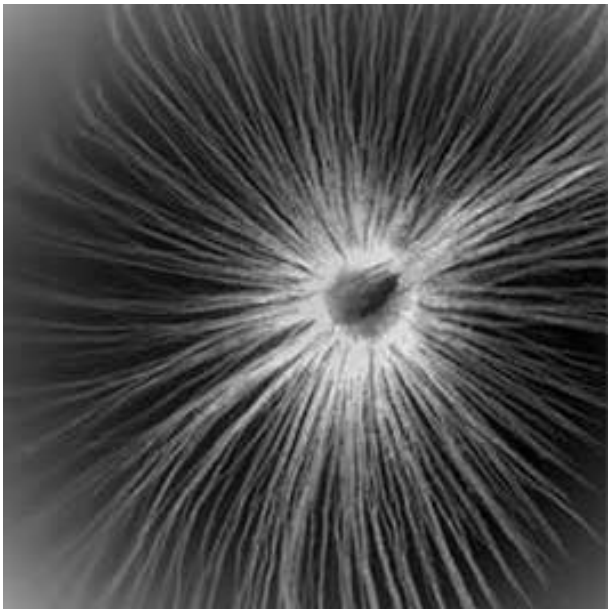

Figure 2 Light micrographs of rat retina ganglion cell axons labeled for 3 weeks with the retrograde passive tracer DiI. At least the majority of axons appears to be labeled and at higher magnification the individual somata are discernible in the retinal periphery

Retrograde labeling studies for ganglion cell characterization have so far led to results of variable quality. DiI appears to label at least the majority of axons and associated cell bodies, especially in rat retina (Fig. 2). The quality of dendritic labeling is however often insufficient for cell typification and will require further improvements of the applied procedures.

Discussion

The preliminary results indicate that it may be possible to achieve a comprehensive assignment of basic signals to particular cell populations and their specific parameters. Further procedural improvements will be required however for identification of the processing modules leading to a basic achromatic representation of spatio-temporal contrast changes and motion. These cannot expected to be transmitted along entirely separate channels as opposed to chromatic or stereo-information. Therefore even establishing basal transfer functions requires comprehensive identification of output neurons within recording sites.

Conclusions

In order to characterize the basic units required to reconstruct features of the image projected on the retina we have to understand which sets of ganglion cells process incoming signals to code it in parallel series of spike trains. In pig retina comparison between the neuronal sets in th seemingly monocular nasal peak and the binocular temporal peak e in addition to identification of color related pathways may allow to isolate the basic circuitry for transmittance essential information based mainly on spatiotemporal contrast channels.

We will have to learn more about what properties create this variance of the single cell outputs to seemingly identical stimuli while reliably transporting information via cross correlation. Comparing the shapes of intertwined dendritic fields, the varying fractalization, radial stratification and intercellular connection of identified ganglion cells with their spike train variances may help to isolate essential parameters of. This should allow establish arrays of interrelated transfer functions for mimicking the retinal output coding.

While there are many obstacles to be solved in both, assembling a viable biological model as well as in its technical implementation it seems possible to reconstruct the activity of optic nerve axon bundles as a source for the cortical neuroprosthesis.

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