TEMPORAL, SPATIAL, AND INTENSITY INFORMATION IN CAT VISUAL CORTEX EVOKED BY A RETINA–IMPLANT

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Goal. Assessment of retino–cortical transinformation **T** of multiple retinal inputs and cortical outputs. In particular, we want to apply our three–step–approach of information calculation [1] to data that have been recorded in the context of the development of a retinal prosthesis. By electrical stimulation of the retina we intend to evoke acceptable phosphenes in blinds with photo receptor degeneration but intact retinal ganglion cells. Informative activity in the primary visual cortex is a prerequisite for perception. Thus, we aim at optimized electrical retina stimuli with respect to information transmission to the visual cortex. It is desirable to obtain high resolutions in the spatial, temporal, and intensity domains while minimizing stimulation energy.

Methods. For ethical reasons our basic investigations were not carried out in humans. Instead, we analyzed the primary visual pathway in anesthetized cats by using implant prototype electrode arrays for stimulation. The evoked activities were recorded in the visual cortex. For this we sampled multiple–unit activity (MUA) and local field potentials (LFP, 0.1–140 Hz) from striate cortex (V1) with linear arrays of up to 15 μ–electrodes (350 to 500 μm pitch). Simultaneously, the retina was electrically stimulated at its surface in multiple positions corresponding to the cortical recording locations (correspondence: overlap or close proximity of retinal and cortical receptive fields). Stimulation was either by single dual–polarity impulses (200 μs per phase), short (1 to 3 ms) bursts of them (3 to 5 impulses), or rapid sequences of impulse groups at random intervals and different impulse rates (mimicking natural spike patterns in ganglion cells). Our three step approach to calculate a lower bound of retino–cortical transinformation in case of continuous stimulation is presented elsewhere [1,2]. We separated the representation of temporal, intensity, and spatial aspects of information in the cortical responses [3] and obtained the following results.

Results. (1) *Temporal stimulus information*: The time course of T, following an isolated sti–mulation impulse shows that the first response transient up to 40 ms post stimulus carries the largest part of T (0.1 to 2 bit/impulse; upper bound). The considerable serial correlation within the response, especially in case of LFP, reflects redundancy with respect the the encoding of stimulus information. In case of rapid random sequences of stimulation impulses a maximum rate of T is obtained at high stimulation rates (20 to 140 bit/s at 20 to 40 imp/s). Further, we used amplitude modulated impulse trains with Gamma interval statistics (50 ms mean interval) and found that the temporal stimulus aspect accounts for 50–80% of the total rate of T corresponding to 50–130 bit/s.

(2) *Information about stimulus intensity*: The encoded fraction of stimulus current amplitude information amounted in our measurements to 5–10% (threshold about 20 μA; intensities: 1, 2, 3, or 4 times threshold). In corresponding retino–cortical locations MUA encodes stimulus intensity better than LFP. In this example the respective maxima were 9.3 bit/s and 0.5 bit/stimulus for MUA compared to 4.9 bit/s and 0.25 bit/stimulus for LFP. A quantization of

the stimulus current into more than 2 or 3 steps did not increase the amount of encoded stimulus amplitude information.

(3) *Spatial information:* We found rates of T for electrical and visual stimulation in the same range (20 to 100 bit/s per cortical recording electrode). However, the different cortical recor–ding locations carried different amounts of information from a single retinal location: In the measured examples, their cortical transinformation profiles had widths of about 1 mm corresponding to a resolution of about 1° visual angle at 5° excentricity from the area centralis. With visual stimulation such cortical T–profiles showed multiple maxima so that estimation of spatial resolution is not possible directly, but it can be done by projecting the T–values directly to visual space at the locations of the cortical recordings' RF–positions. When we stimulated the retina within a single mm² in steps from 1 to 7 retinal locations independently, T saturated at about 5 stimulation sites per mm² confirming a resolution of better than 2°.

Discussion: The shortcut of the slow retinal input layers, by directly stimulating the ganglion cells electrically, leaves a retino–cortical pathway of high bandwidth, and thus, higher temporal precision for activating single ganglion cells as is possible with visual stimuli. Thus, the temporal precision of the spike pattern carries the largest amount of transinformation in our examples. This is also due to the activation of volleys of well synchronized single spikes in local groups of simultaneously stimulated ganglion cells. In addition, the single spike activation can also explain the low increase of T b y adding multiple levels of stimulation intensities, because higher suprathreshold intensities also always evoked only single spikes. However, higher stimulation currents lead to a proportional spatial spread of activity in the retina, which may slightly reduce the response variability but mainly impairs the spatial resolution. Spatial aspects of visual information are normally represented at high resolution in V1. A comparable resolution is not present with electrical stimulation as it was used here, because a single small electrode of 30 μm diameter already activates simultaneously local groups of ganglion cells without differentiation between their functional types (like on–, off–, magno– and parvo–).

Outlook: The large amounts of temporal information is functionally related to two visual features in natural retinal coding. The first refers to rate modulations of ganglion cell activity, the other feature is related to precise instances of spike occurrences. Decomposition of these components will be done in future work.

Conclusions. We have shown that large amounts of stimulus information can be transmitted to the striate cortex via electrical stimulation of the retina by using rich spatio–temporal stimulation patterns. The largest fraction in our examples comprises temporal stimulus information. Spatial stimulus aspects are coarsely encoded cortically compared to the acuity achieved with visual stimulation. Stimulus amplitude had the lowest influence on T. A retina implant exploiting these encoding capabilities may guide the design of stimulation–patterns and –array layouts in future tests with blind patients.

References

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