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Research Note

Simultaneous Recording with 30 Microelectrodes in Monkey Visual Cortex*

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Summary. A 30-fold multielectrode for extracellular recording of neuronal spikes is described. Single neuronal spikes were isolated simultaneously by about half of the electrodes. The technique has been applied to demonstrate the spatial distribution of ocular dominance and orientation preference in striate cortex.

Key words: Multielectrode – Monkey – Vision – Cortex – Columns

Any higher order brain function is the result of the collaboration of an immense number of neurones. If such a function is not only to be analysed at the level of the final output (e.g., a limb movement) but also at intermediate stages, the simultaneous activity of many neurones must be monitored.

There are several reports on multi-channel recording of action potentials (Blum 1977; Cohen and Salzberg 1978; Gross 1979; Gross et al. 1977; Kuperstein and Whittington 1979; Pine 1980; Pickard 1979; Reitböck et al. 1981; Wise and Angell 1975; Wise et al. 1970) or field potentials (Bantli 1972; Kogan 1974; Mercer and White 1978; Prohaska et al. 1979). This list does not include methods to discriminate several spikes simultaneously at a single electrode, e.g., Abeles and Goldstein (1977). However, to our knowledge there are no reports on experiments dealing with the brain functions of higher animals based on simultaneous single spike recording with techniques using more than a few electrodes.

To study a larger ensemble of neurones in the monkey visual cortex, we built an array of 5 × 6 microelectrodes. The single electrodes (resistances 1–3 megohms) were made from commercially available quartz-glass-coated platinum-iridium wire (dia. 30 and 5 μ, respectively) sharpened by grinding with diamond paste. The electrodes were fixed parallel to each other at mutual distances of 160 μ with tips lying in a plane perpendicular to the electrodes (Fig. 1a). One of our arrays was used for four experiments and all electrodes are still intact. Construction of the device involved only simple techniques but required patience working in small dimensions under the dissecting microscope.

The dimensions of the array (0.64 by 0.8 mm) were designed to encompass one complete set of orientation and ocular dominance columns (Hubel et al. 1978). Using very small stimuli, one could expect a large portion of the visual information processing carried out by the striate cortex to take place within the volume reached by the electrode array (Hubel and Wiesel 1974).

The sum of the cross-sections of the electrodes was 2.8% of the array area. Therefore, tissue damage could be expected to be minimal. This was confirmed by histological examination of Nissl-stained sections, where the recording site could not be recognized without the help of electrolytic lesions which were produced in selected tracks at the end of an experiment.

To introduce the electrode array into the brain, the skull and dura mater were opened under anaesthesia and the pia held by a tangentially inserted three-pronged fork made from fine metal microelectrodes. With this device, excessive depression of the cortical surface was avoided. During penetration, the prongs were located between the rows of the electrodes. The fork was removed thereafter.

Electrode signals were amplified by 30 conventional channels in parallel. Each channel incorporated a hand-adjustable discriminator producing

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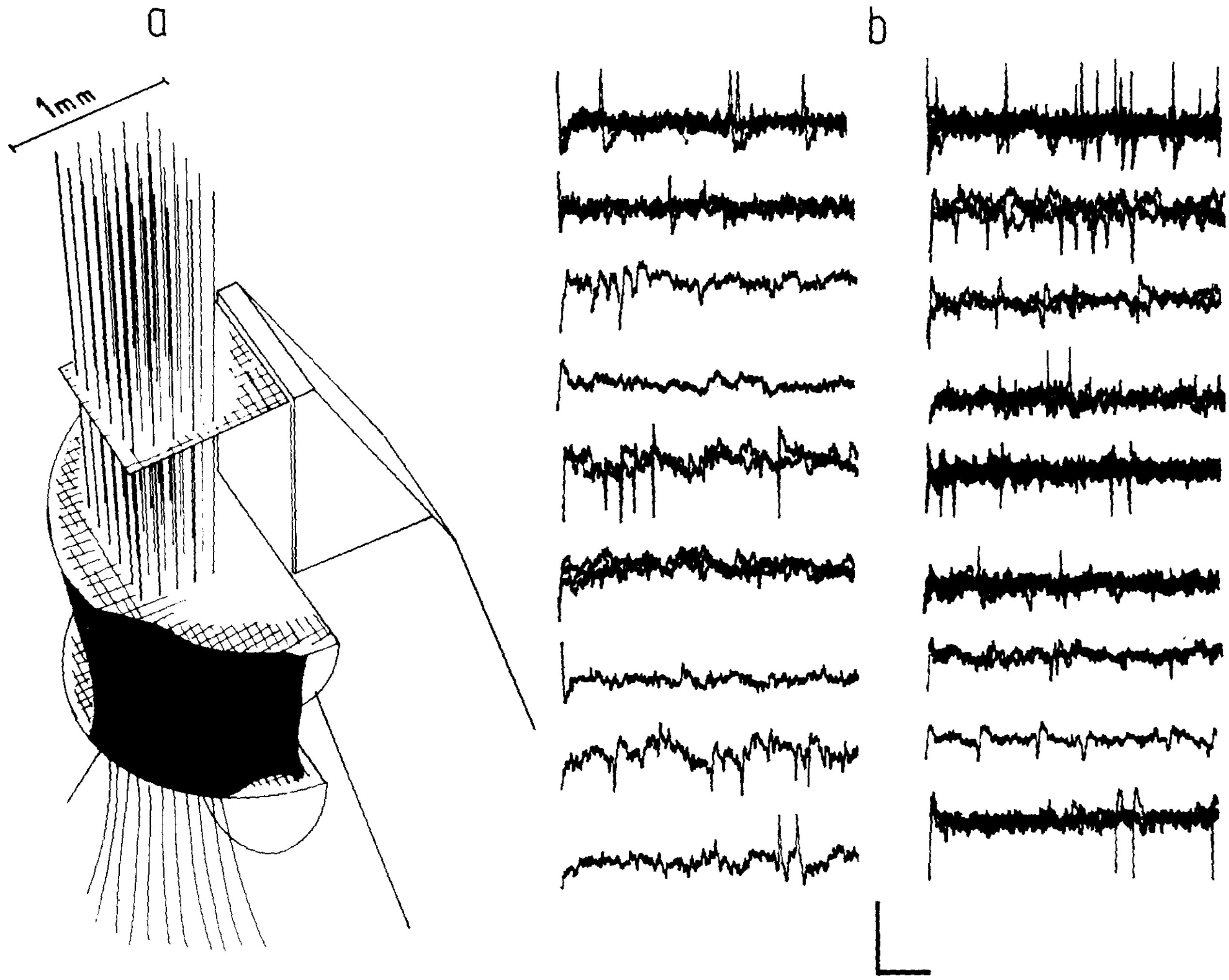

Fig. 1. **a** View of the multi-microelectrode. Three electron-microscope object-holder grids at mutual distances of 2 mm hold the electrodes in place. The grid next to the tips is cut to a rectangular shape. The electrodes are glued to the two remaining grids by pitch (black patch). The electrodes have mutual distances of 160 μ, and their free length is 2.5 mm. At the ends opposite to the tips the wires are spread apart, the glass insulation is removed by molten sodium carbonate and electrical contact made by silver paint. **b** Action potentials in the visual cortex recorded by 18 of the 30 electrodes. The photographs were taken in rapid succession without moving the electrodes. The sweeps were triggered by a spike at left. The calibration mark indicates 100 μV vertically and 10 ms horizontally. Fast flanks of spikes have been retouched. Arrangement of traces in this figure is not related to the matrix positions of the electrodes

standard pulses which were stored on magnetic disc by a computer (Interdata M70) with a time-resolution of 1 ms. Triggered activity was also displayed on a matrix of light-emitting diodes. For auditory monitoring each individual channel or the sum of all channels could be selected.

Although the electrodes could not be moved independently, usually about half of them displayed single unit activity, the maximum so far being 19 single spikes. For many purposes, double or multiple spike activity at the remaining electrodes could also be used. Figure 1b shows action potentials recorded by different electrodes in the visual cortex. Spike train cross-correlograms clearly showed that on no occasion did two electrodes record from the same neurone.

Spike activity was processed off-line by various computer programs which have thus far provided: dot displays of evoked activity (also available during the experiment); peri-stimulus time (pst) histograms (Fig. 2a, left); cross-correlograms between spike trains of pairs of electrodes; cortical maps of preferred orientations (Fig. 2b); spike counts in successive time intervals in order to study neuronal variability and its neighbourhood relations; motion pictures of spatial patterns of activity; histograms from linear combinations of electrode signals to extract stimulus features from ensembles of neurones.

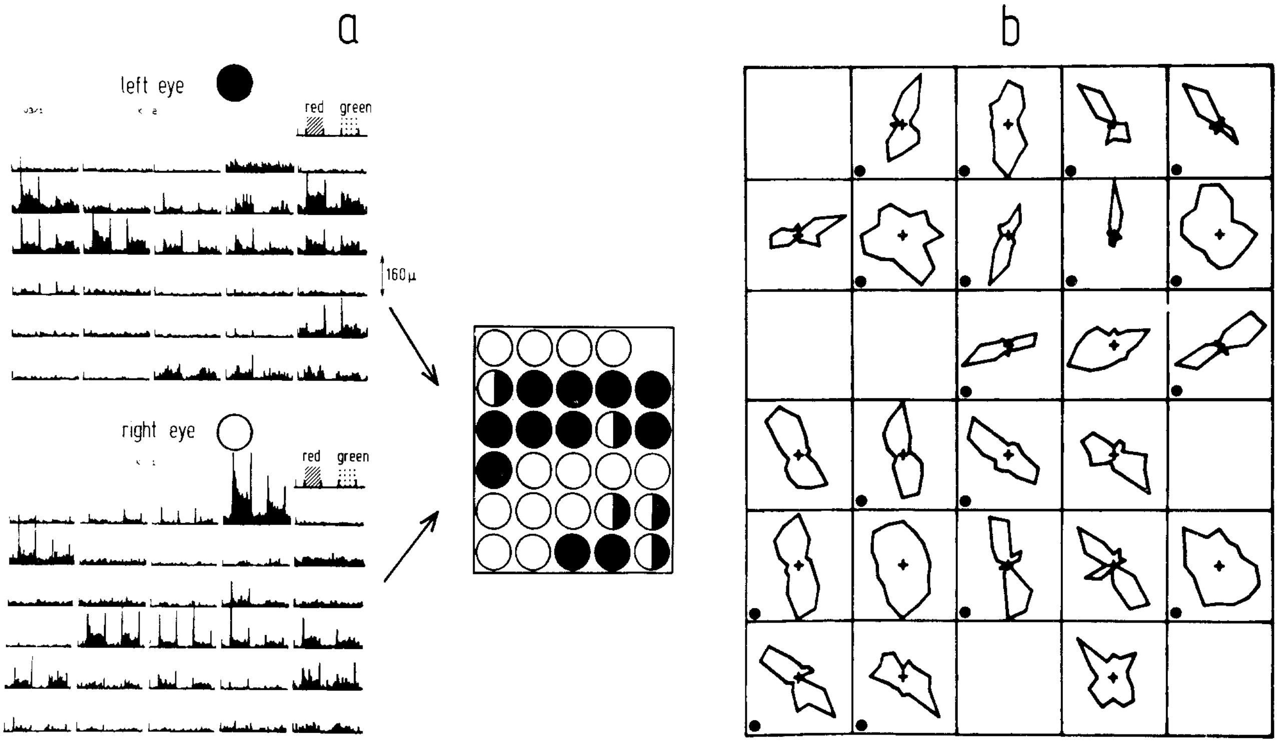

Fig. 2a, b. Distribution of physiological variables in the visual cortex of a vervet monkey. (The animal was paralysed, N_2O/O_2-respired and its EEG continuously monitored.) The arrays of diagrams correspond to the arrangement of microelectrodes in the cortex. The multielectrode was placed in left area 17 near the 17/18 border about 1 cm above the lower tip of the lunate sulcus. The left border of the matrix was parallel to this sulcus. For the diagrams, single as well as multiple spike activity has been utilized. **a** Ocular dominance columns. At left, pst-histograms in response to large red and green lights turned on and off successively are shown. The two eyes were stimulated consecutively (*top:* left, *bottom:* right eye). The vertical distance between histograms corresponds to 100 spikes per s; the stimulation cycles lasted 8 s and were repeated 20 times. The right frame shows at which cortical loci the left eye (black), the right (white) or both eyes (bipartite) yielded strong responses. No neuronal activity was present at the upper right electrode. On this scale, the responses are difficult to recognize in some histograms. This record is from layer IVb. **b** Polar diagrams of responses to moving lines of different orientations. Individual records are from loci 160 μ apart. Responses from both eyes stimulated separately have been combined. Polar diagrams were derived from single unit (marked by dots) or multi-unit activity. Six electrodes (blank squares) did not show responses. A regular progression of preferred orientation angles can be seen in the middle column. This record was obtained in cortical layer VI of another animal than **a**

Results so far obtained are shown in Fig. 2. In Fig. 2a, the responses to red and green fields turned on and off are depicted. There are 30 pst-histograms each for the left (top) and right eyes (bottom). The distribution of ocular dominance in layer IVb abstracted from these histograms is shown at right. In Fig. 2b responses from the two eyes stimulated separately have been combined in order to obtain an array of polar diagrams depicting selectivity for oriented lines. A regular progression of preferred orientations can be seen on scanning the columns vertically. This was recorded in layer VI.

The present report demonstrates that a functional multielectrode can be built without sophisticated technology. In addition to savings of animals and time, otherwise unattainable insights may be gained because of the simultaneity of the recordings. In addition to relations between stimulus and neuronal activity, one can study correlations between the activities of different neurones: Cross-correlations can reveal neuronal network properties, and correlated changes in responsiveness of neighbouring neurones point to extraretinal modulation of visual processing. Experiments along these lines are under way.

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