Supporting Information

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Title: Interfacing Conducting Polymer Nanotubes with the Central Nervous System: Chronic Neural Recording using Poly (3, 4 ethylenedioxythiophene) Nanotubes

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Silicon-Based Chronic Neural Microelectrode Arrays

All recordings described in this study were obtained through chronically implanted Michigan microelectrode arrays. The University of Michigan Center for Neural Communication Technology (CNCT) provided the microfabricated neural electrode arrays. The silicon substrate supports an array of thin film conductors that are insulated above and below by deposited dielectrics of silicon dioxide and silicon nitride. Openings in the upper dielectrics along the probe define vertical connections to underlying polysilicon traces that are then sputtered with gold over regions of the top dielectrics for interfacing to the tissue. At the rear of the probe, gold bond pads facilitate connections with off-chip instrumentation. Single neural probes were used in our research with gold-coated electrode sites (1250 μm^2 in area).[1]

Implantation of chronic electrodes

All animal procedures were approved by the University of Michigan University Committee on Use and Care of Animals and were in accordance with the National Institutes of Health guidelines. Three 300 gram, three month old Sprague Dawley rats were chronically implanted with silicon substrate multi-site microelectrode arrays in the barrel cortex. Surgery was done as previously described.[1, 2]

Each rat was implanted with two microelectrode arrays each having one penetrating shank with eight recording sites at the shank tips separated by 200 μm (Center for Neural Communication Technology, University of Michigan, Ann Arbor). Each electrode site had a surface recording area of 1250 μm^2. Both electrodes were implanted the right barrel cortex (region of cortex responsive to whisker movement). The coordinates used for all barel cortex implantations spanned 1-2 mm anterior to bregma, 4-6 mm lateral from bregma, and 1.5 mm deep from the surface of the brain.[3]

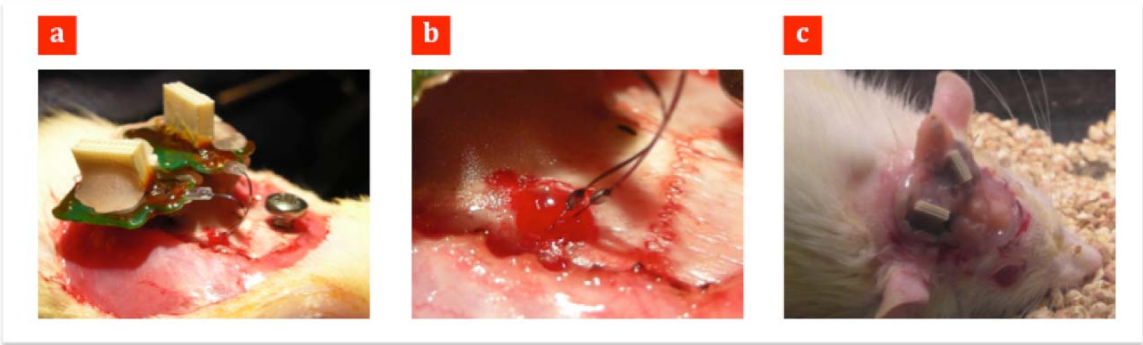

Figure S1. Two chronic electrodes were implanted in barrel cortex of rat (total of six electrodes in three animals)

Table S1. Summary of impedance results across days

	PEDOT NTs [kΩ]	Control [kΩ]
Day 0 before implantation	17 ± 4	841 ± 7
Day 0 after implantation	87 ± 8	908 ± 5
Day 1-3 (AV)	105 ± 7	960 ± 9
Day 3-9 (AV)	530 ± 17	1220 ± 15
Day 8	546 ± 30	1250 ± 43
Day 15-49 (AV)	509 ± 8	1133 ± 19
Day 49	521 ± 18	980 ± 15

Neural Recordings & Data Analysis

Recorded neural signals were acquired using a Multi-channel Neural Acquisition Processor (MNAP; Plexon Inc, Dallas, TX). Neural electrophysiological data for all 16 recording channels were amplified and bandpass filtered; single and multi-unit recordings were sampled at 40 kHz and bandpass filtered from 450-5000 Hz, while local field potentials were sampled at 1 kHz and bandpass filtered from 1-500 Hz. During recording sessions, animals were placed in an electrically shielded recording booth and multiple 30-second segments of continuous neural recordings were taken. After initial electrical

referencing to a stainless steel groundscrew, a common average reference was utilized in software to reduce correlated sources of noise as outlined in Ludwig et al.[4]

Neural recording segments were analyzed offline using custom automated MatLab (Mathworks Inc., MA) software, as described in detail elsewhere [5]. In summary, an amplitude threshold window was set 3.5 standard deviations above and below the mean of the sample distribution. For each peak exceeding the threshold window, a 2.4 ms candidate waveform snippet centered on the absolute minimum of the waveform was removed from the recorded segment and stored. The amplitude of the noise voltage for every recording site in each recorded segment was calculated after all candidate waveforms had been removed.

After initial principal component analysis and fuzzy C-means clustering [5], waveforms with a cluster membership index of greater than 0.8 were used to determine a mean waveform for a cluster. Signal amplitude for a cluster was defined as the peak-to-peak amplitude of the mean waveform for each cluster.

The signal-to-noise ratio (SNR) for a given cluster was defined as follows:

SNR = Signal Amplitude / (2 * Calculated RMS Noise Voltage for Recording Site)

Clusters were then separated into one of four categories based on calculated SNR. Clusters with an SNR of greater than 4 were categorized as quality units. Clusters with an SNR between 3 and 4 were categorized as moderate units. Clusters with an SNR between 2 and 3 were categorized as poor units, while clusters with an SNR of less than 2 were not considered units. These four categories correspond well with observations of unit quality based on signal-to-noise ratio made in similar recording studies [5, 6].

Isolating action potentials from an individual neuron using an individual recording site is inherently prone to classification errors [7, 8]. The methodology employed in this study is intended to minimize these errors, and should accurately parallel the true number of underlying neural sources. The sorting routine produces similar results to manual sorting performed by experienced researchers over the same data sets, but with the advantage of being objective and automated [5].

References:

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