Identifying Intra-Cortical Recording Instabilities

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1 OBJECTIVES

Cortical multielectrode-arrays (MEA) offer some of the highest resolution technology for detecting clinical user intent for controlling prosthesis, such as robotics and functional electrical stimulation. The long term performance of these neuron-machine-interfaces (NMI) depends on both neural directional tuning stability and signal recording stability (Wang et al., 2014). Having more functional channels to decode from a larger neural ensemble however, can effectively compensate for directional tuning fluctuations (Nuyujukian et al., 2014).

To improve MEAs to retain more stable channels, it is critical to prioritize engineering requirements, as the biological vs. non-biological causes of instability/ failure may require opposite design strategies. For example, reducing gliosis may necessitate enhanced biomimicry and softer substrates, while reducing hardware failure may benefit from adsorption-repelling and robust substrates.

This project aims to discern hardware vs. tissue degradations that underlie recording instability, and quantify MEA stability without relying on spike sorting − as sorting is not essential to NMI, labour intensive and/or has uncertainies (Einevoll et al., 2012). To accomplish this we analysed chronic Utah array recordings from inferotemporal and prefrontal cortices of adult macaque monkeys, focusing on individual channel trends.

2 METHODS

Existing recordings obtained from eight-months of visual system studies on an adult macaque monkey (monkey F) was used. MEAs were Iridium oxide Utah arrays implanted in the left inferotemporal (implant 1) and right prefrontal (implant 2) cortices. Before each experiment an 8-minute baseline recording was made with the same series of visual stimuli (10 repetitions of 100 images per session) and fixation point as previous sessions. These baseline recordings are used in our stability analysis.

Data collected at 30Khz was digitally filtered at 250Hz-7.5KHz and thresholded at -4.5RMS for spike detection. Channel spike rate distributions were tabulated per session, fitted to gamma distribution, and verified with chi-square goodness-of-fit test.

3 RESULTS

3.1 Stability Quantification

The most active channels were selected (based on mean spike rate over all sessions), and analysed individually. To examine channel data in detail, spike counts within each 8-minute recording was tabulated per second into histogram form (Figure 1). Since the stimuli sequence included a wide variety of images, each distribution represents a general range of behaviour of the neurons at that electrode. If these ranges change significantly between sessions (under the same stimuli) the channel's neural population has likely changed, and is defined as unstable.
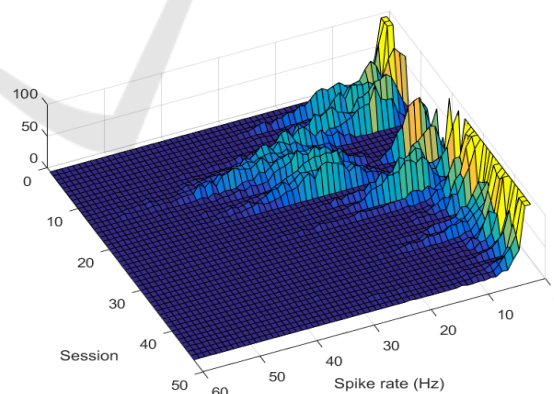

Figure 1: Spike rate histograms per session from channel 23, which showed notable discrepancy between sessions.

The spike rate histograms were found to fit gamma distributions. Since each session contained 10 repetitions of identical stimuli, distribution parameters extracted from single repetitions could serve as a standard for nominal variability within a stable period. This enables, for example, comparing

the parameters' percent change between sessions vs. within sessions as a criterion of channel stability. We intend to further this analysis and quantify stability over time for both implants.

3.2 Biological vs. Non-biological Causes

Intra-cortical recordings consist of high-amplitude action potentials and a dense core of device and biological noise. The latter is the larger component (Lempka et al., 2011), and contains the overlapping activity of a sea of distant neurons. Hence if the loss of spike detection is due to hardware degradation, a change should also be reflected in the below-threshold portion of the recording. Inspection of representative sessions (Figure 2) show that when spikes are absent, the core portion is unaffected, and signal loss is reversible. Thus hardware failure is not the cause of this form/instance of instability.
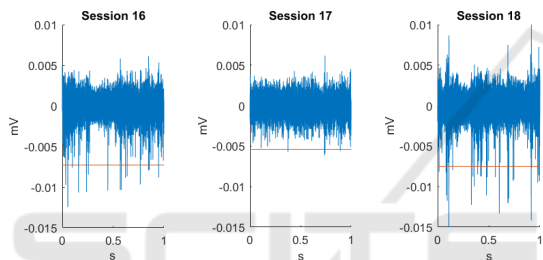

Figure 2: Time domain signal from channel 23, sessions 16 to 18; red line is the spike detection threshold (-4.5RMS).

Histograms of waveform amplitudes distinguish the bulk that is biological noise (Figure 3). Measuring the low-amplitude side of this distribution quantifies noise consistency, hence hardware stability across sessions. A simple colour map visualization of all sessions also implicates instances of hardware failure (unusual distributions at the core signal component).
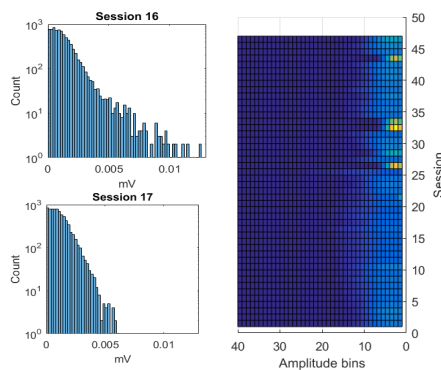

Figure 3: A) Un-thresholded signal amplitude histogram showing noise consistency regardless of spike stability. B) Top view of the stack of histograms for channel 23.

4 DISCUSSION

It is helpful for new NMI design and evaluation to have simple methods to assess recording stability and distinguish tissue or hardware induced signal loss.

Typically, stability is quantified from combined activity of all channels. Such statistics are compelling but hide the profile of single channels, which suggest underlying mechanisms of failure. Also common is to apply thresholding to eliminate noise and isolate units prior to analysis, but this imposes a zone around the electrode where only neural activity within is kept as data, and more distant activity is discarded as noise (or heavily filtered for LFP). This "biological noise" holds robust information on hardware performance unaffected by the state of local neurons.

We examined long term intra-cortical recordings from sensory & processing areas of macaque cortex - where neural activity can be regulated by stimuli - and analysed individual channel spike rates and biological noise: 1) Quantifying and fitting the distribution of spike rates per session gave an illustrative statistic of channel stability. This method does not rely on spike sorting, which is non-trivial to perform and the margins of error are harmful to stability assessment. 2) Tabulating all peaks in the recording showed that the "core" of the amplitude distribution (comprised of biological noise and system noise) can remain constant when the spike count is low, indicating cellular causes such as poor health of a neuron. This analysis also identified sessions with abnormal signal core shape, suggesting true hardware failure.

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