 DOI:10.3217/978-3-85125-260-6-93

Comparison of Invasive Chronic Electrodes for Brain-Computer Interface Applications

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Abstract. Invasive chronic micro-electrodes are capable of recording high quality neural signals at the cellular level and are widely used in animal Brain-Computer Interface studies. However, human implantations remain very limited due to potential risks. Thus, development of electrodes that optimally sample neural signals is an important area of scientific research. In this study we compare two promising electrode technologies: the Neurotrophic Electrode (NE) and the Utah Array (UA). We found that both electrode types recorded task-related LFP signals in a saccade task. The UA recorded many more single- and multi-unit spikes than the NE identified by standard spike sorting techniques, probably due to recording sites being closer to cell bodies. The UA also showed less correlation between signals on nearby channels, resulting in bigger decoding improvements when more channels are considered. These results provide valuable guidelines for further electrode development for BCI applications.

Keywords: Electrophysiology, Invasive BCI, Utah Array, Neurotrophic Electrode, Monkey, Eye Movements, PFC

1. Introduction

Invasive Brain-Computer Interfaces (BCIs) are the only BCI type capable of recording neural signals at the level of individual cells and thus hold much promise for restoration of motor functions in severely paralyzed individuals. To date, there have been only two chronic intra-cortical electrode types approved by the FDA to for implantation in a human brain: the Neurotrophic Electrode (NE) and the Utah Array (UA). These electrode technologies have a number of differences. The NE [Bartels et al., 2008] is hand-made of several micro-wires glued inside a glass cone. The cone is coated with nerve growth factor which stimulates neural growth inside the cone for weeks after implantation. The UA [Maynard, 1997] is a machine-manufactured silicon-based planar microarray, commercially available from Blackrock Microsystems. Its electrode tips are exposed and record from existing cortical tissue. An in-depth comparison of these two electrode technologies can be valuable for guiding further electrode development for BCI applications.

2. Material and Methods

Building on our previous work [Guenther, 2009] we modified the NE design to increase its channel capacity since low channel capacity is one of its primary weaknesses for use in high-throughput BCIs. The resulting cone electrode had 2-3 stereotrodes and higher channel count and was termed the Neurotrophic Array (NA). To test these electrodes we implanted them in a macaque monkey: one cone with 8 wires in pre-frontal cortex (PFC) and another cone with 6 wires in ventral pre-motor cortex (vPMC). We recorded from these electrodes while the monkey performed a delayed center-out saccade task for 6 months after implantation. On each trial the animal was briefly presented with one of 48 possible target locations, followed by a delay period when the monkey needed to hold the target position in working memory. Finally, after a go cue the monkey made a saccade to the remembered location.

A second monkey was implanted with three 32-channel UAs in PFC, supplementary eye fields (SEF), and frontal eye fields (FEF). We recorded neural data from this monkey performing a similar delayed saccade task for one year so far and are continuing the recordings.

3. Results

In the collected NA data, spikes on only two channels and only in two sessions could be reliably separated from noise using standard spike sorting techniques. One of these channels contained a single unit and one potentially included a multi-unit source. In contrast, 50-60% of UA channels recorded clear spiking signals, with about 15-20% recoding isolated single-units. Many channels carried several units simultaneously.

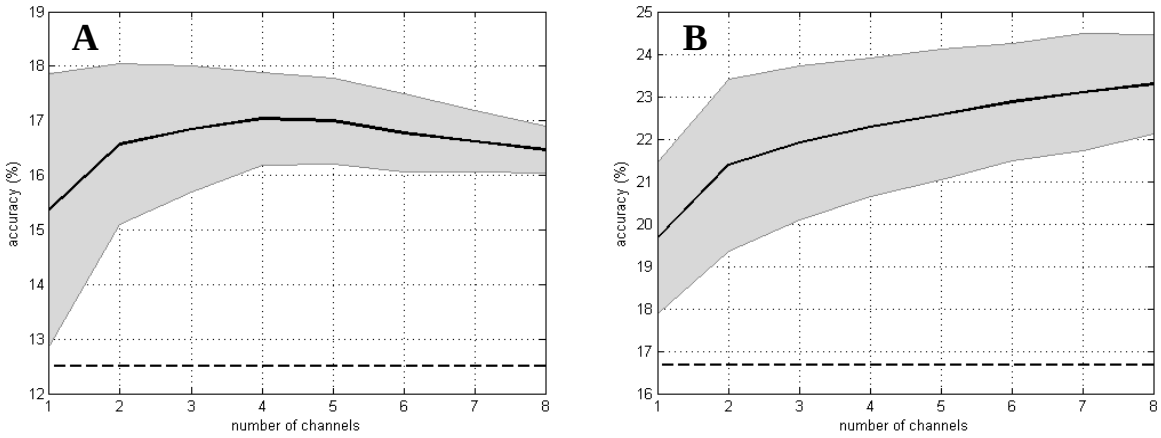

Figure 1. *Accuracy of decoding saccade directions from 15-25Hz LFP band power of PFC electrodes during the delay period across the number of used channels: (A) Neurotrophic Array results for 8 saccade directions; (B) Utah Array results for 6 saccade directions. Dashed lines depict chance performance. Using signals from SEF significantly improves decoding accuracy of the Utah Array (reaching approximately 80% correct), but we restrict analysis in the current abstract to comparing common implantation areas.*

In the current study we focused on comparing signals from PFC where both monkeys (and implant types) had arrays. The UA had 4-5 dB higher power in high gamma frequency range (> 100 Hz) than the NA, while their beta band LFP power was at about the same level. Nearby channels in the NA had significantly higher LFP signal correlation than adjacent channels in the UA.

Both PFC arrays carried significant information (ANOVA, $p < 0.01$) about saccade direction in the LFP beta band (15-25 Hz) during the delay period (8/8 NA channels and 12/32 UA channels). To further investigate information content of recorded PFC beta band we ran a cross-validated linear discriminant decoder on randomly selected subsets of significant channels, with 1 to 8 channels in each set. The resulting decoding accuracies are plotted in Figure 1 as a function of number of channels used for decoding. As we can see from the figure, decoding accuracy peaks around 4 channels for the NA while continuing to monotonically grow for the UA. This result is likely related to higher signal correlation between NA channels, which limits the contribution of additional channels.

4. Discussion

Signals from both the NA and UA contained significant information concerning saccade direction. The NA recorded relatively little clear single- or multi-unit spiking activity. This is likely due in large part to the glass cone design which, although improving mechanical stability, puts recording sites next to cell axons and dendrites instead of somas. This causes a decrease in spike amplitude compared to the UA (which records near somas) and can result in redundant information appearing on different channels that record from the same axon. As a result, in the NA most of the useful information in the signal comes from LFPs. Signals on NA channels are more correlated with each other than those on the UA; such correlations negatively impact the NA's information capacity when considering more than one recording site, as demonstrated by the decoding analysis.

Acknowledgements

This study is supported in part by CELEST, a National Science Foundation Science of Learning Center (NSF OMA-0835976).

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