The relationship between activity of neurons recorded simultaneously in primary motor cortex

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Introduction

• Neurons in the arm area of primary motor cortex (M1) have been characterized at the level of single unit activity.

• Learn more about the relationship between the activity of these neurons recorded simultaneously.

• **Aim:** Determine what information about reaching is encoded by a population of M1 neurons.
Reaching Task
Example of a Neuron
Cosine Tuning
Cosine Tuning

FiringRate = Baseline + k \cos(\theta - \alpha)
Cosine Tuning
Example of a Neuron
Kalman filter
Correlation between pairs of neurons in M1

During movement:

\[
 r = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}
\]
Correlation between pairs of neurons in M1

Baseline: During movement:

Neurons with similar preferred directions exhibit correlations during the movement but not during baseline conditions.
Neural Information Coding

• Hypothesize that the control signal from M1 will have information content modulated by directional activity.

• Compare interspike intervals from spike trains from trials
  • Nearest preferred direction
  • Opposite direction

• Will use Approximate Entropy (Pincus, 1991) to assess information content of the interspike intervals during target-on condition.

Repeated pattern:
- new data
- doesn’t add new information

ApEn: Lower values indicate more patterns in the data

Time Series – Mock Data

<table>
<thead>
<tr>
<th>Random</th>
<th>Sine function</th>
<th>Random</th>
<th>Sine function</th>
</tr>
</thead>
<tbody>
<tr>
<td>small amplitude</td>
<td>small amplitude</td>
<td>large amplitude</td>
<td>large amplitude</td>
</tr>
</tbody>
</table>

ApEn(m, r, N) = $\Phi^m(r) - \Phi^{m+1}(r)$

\[
\Phi^m(r) = (N - m + 1)^{-1} \sum_{i=1}^{N-m+1} \log C_i^m(r)
\]

Where $C^m(r)$ is the count of similar patterns of length $m$, and similarity is defined by radius $r$. 

<table>
<thead>
<tr>
<th>Range</th>
<th>ApEn</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>2.02</td>
</tr>
<tr>
<td>10.0</td>
<td>0.18</td>
</tr>
<tr>
<td>50.0</td>
<td>2.02</td>
</tr>
<tr>
<td>50.0</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Results

- Kolmogorov-Smirnov goodness-of-fit test finds no significant difference between the two distributions.
Approximate Entropy not so useful

• May need to optimize ApEn parameters
  – Radius to determine similarity (r)
  – Word length (m)

• A different information measure may perform better.

• Maybe information measures from individual neurons simply doesn’t tell us that much…
Information theory

1. Mutual Information

\[ M_{IJ} = \sum p(i, j) \log \frac{p(i, j)}{p(i)p(j)} \]

2. Transfer Entropy

\[ T_{I \rightarrow J} = \sum p(i_{n+1}, i_n^{(k)}, j_n^{(l)}) \log \frac{p(i_{n+1} \mid i_n^{(k)}, j_n^{(l)})}{p(i_{n+1} \mid i_n^{(k)})} \]
Functional connectivity clusters by direction
Functional connectivity clusters by direction
Functional connectivity clusters by direction

Reach in non-PD
Reach in PD
Less mutual information among neurons with similar tuning when reaches made in preferred direction.
Conclusions

• Kalman filter is a valid tool to predict trajectories based on activity recorded from M1

• Neurons with similar preferred directions exhibit correlations during the movement

• Approximate entropy is not sensitive to control information contained in primary motor cortex spike trains

• Less shared information among neurons with similar tuning when reaches made in preferred direction
THANK YOU!