

DECODING M1 NEURONAL ACTIVITY DURING MULTIPLE FINGER MOVEMENTS.

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Introduction

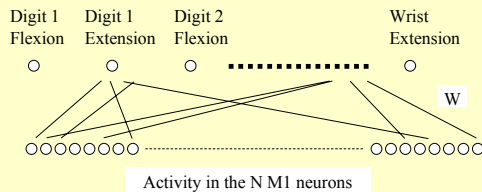
Most studies of neuronal decoding, such as predicting arm trajectories from neuronal activity in M1, deal with situations in which the encoded variable can take only one value at any given time (e.g. the arm can only occupy one location at any given time). This means that the encoded variable can be estimated using techniques such as maximum likelihood, population vectors or optimal linear estimators. These techniques are poorly adapted to the case of finger movements because more than one finger might move simultaneously.

A natural way to deal with this problem is to use a probabilistic framework in which the decoder estimates the *probability* of movement for each of the fingers individually. Here, we decode M1 activity during multiple finger movements using a neural network using a softmax normalization and we compare its performance to decoding using other methods such as population vector and logistic regression.

Methods

Electrophysiological data. The activity of 146 neurons from the primary motor cortex was recorded while monkeys were performing either single or multiple finger movements. Possible finger movements included flexion or extension of any of the digits and of the wrist. Multiple finger movements included flexions or extensions of digits 1 (the thumb) and 2 (the index finger), 2 and 3, or 4 and 5. Spikes were counted in the 100ms interval directly preceding the end of the movement and 9 or more trials were available for each condition.

Logistic regression: We trained a network to estimate independently the probabilities of flexion and extension for all five fingers plus the wrist ((5+1)2=12 output units altogether).

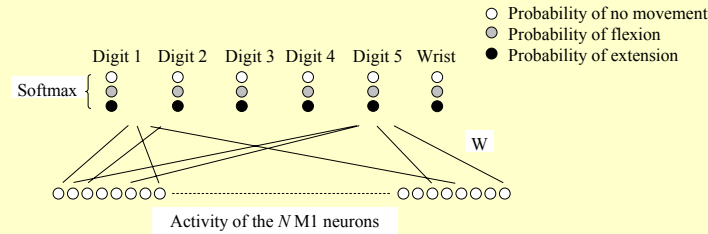


Training Standard gradient descent algorithms were used to train the weights.

Testing. Decoding performance was assessed by testing on 200 novel activity patterns. For single movements, the label of the most active unit was interpreted as the network's prediction, and compared to the actual movement. For pairs of movements, the labels of the two most active units were used and compared to the actual movements.

NOTE: Logistic regression requires prior knowledge of how many fingers have moved on each trial.

Softmax Network. The softmax network was designed to estimate *arbitrary* combinations of finger movements without any prior knowledge, based on the activity of N neurons ($N = 2$ to 146). The input layer encoded the activity of the N neurons on each trial. These units send direct projections to the output layer, itself composed of 6 triplets of units, one for each five fingers and one for the wrist. Each triplet of units encoded the probabilities of flexion, extension or no movement for the corresponding digit. We used a softmax normalization in each triplet to ensure that the probabilities summed to one, since these three possible outcomes were mutually exclusive.



Training. Weights were optimized using standard gradient descent algorithms.

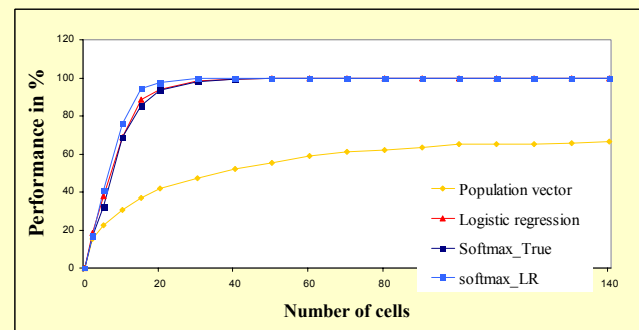
Testing. Decoding performance was assessed by testing on 200 novel activity patterns.

Softmax network: the network was considered to be correct if the predicted and actual movements of the five fingers and wrist were exactly equal.

Softmax_LR: In this variation of the softmax network, we evaluated performance by picking the single most, or two most, active units in the network, depending on whether one, or two, fingers were moved on the trial. This is directly comparable to logistic regression.

Decoding single finger movements.

It only takes 30 cells on average to predict the incoming finger movement with 100% accuracy. Softmax and linear regression networks achieve comparable performances. Softmax_LR performs best for small number of cells, while population vector never reaches 100% correct.



Decoding multiple finger movements

A/ Training on single finger movements

We first tested our network on decoding multiple finger movements after training on single finger movements *only*. We found that the softmax network is completely unable to generalize from single to multiple movements. This indicates that:

- 1- There is a very large overlap in the activity of the single finger movements
- 2- The patterns of activity for multiple movements is unlikely to be simple linear combinations of the patterns for single movements.

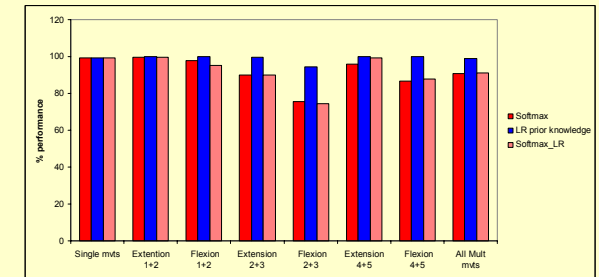
B/ Training on multiple finger movements

The results below show the performance of several networks when trained and tested on both single and multiple finger movements based on the activity of all 146 neurons.

Logistic regression: Near perfect performance (98.98% overall) is obtained for all movements BUT prior knowledge of the number of moving fingers is required.

Softmax: performance varies depending on the finger combination but, overall, the network performs around 90.9% correct.

Softmax_LR: Prior knowledge does not significantly improve performance.



Conclusions

1. Probabilistic decoding can be used to predict finger movements from neural activity with high accuracy.
2. It takes as little as 30 neurons to predict single finger movements with perfect accuracy.
3. Single and multiple finger movements can be predicted almost perfectly with 146 neurons if the total number of fingers moving on each trial is known ahead of time.
4. High performance (100% on single movements, 90.9% on multiple movements) can be obtained without any prior knowledge using a softmax network. This architecture is usable for *arbitrary* combinations of finger movements.
5. The activity patterns for single finger movements are highly overlapping and the patterns for multiple movements are probably not simple linear combinations of the activity for single movements.