Tracking Nonstationarity in Multi-Day Intracortical Neural Recordings During iBCI Use By a Person with Tetraplegia

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BRAINGATE
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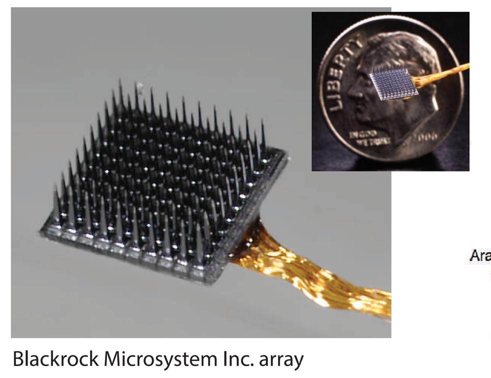
INTRODUCTION

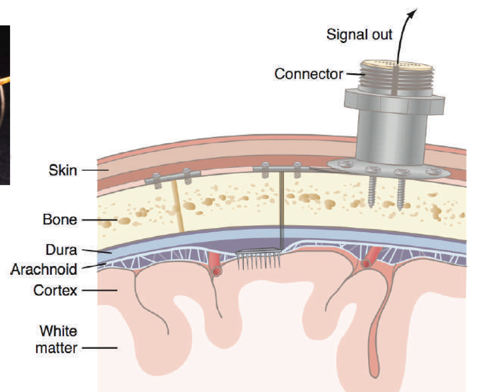
- Intracortical brain-computer interfaces (iBCIs) have enabled individuals with tetraplegia to control external devices via decoding movement intentions from neural recordings.
- However, neural activity underlying consistent motor intentions varies over time due to changes in recording conditions, individuals' cognitive states, etc.
- Within- and across-day nonstationarity in the relationship between recorded neural activity and intended movements can lead to a drop in performance if the decoder is fixed or not robust against such changes (Perge et al, 2013).
- To translate iBCIs for practical everyday use, we propose an approach to track nonstationarity, when a participant with tetraplegia controls a computer cursor through an iBCI with a fixed decoder.
- A distance metric is used to monitor the changes in the distribution of neural ensemble activities and decoder outputs, without the knowledge of target location or performance

BACKGROUND & METHODS

Participant (enrolled in BrainGate2 pilot clinical trial, IDE*)

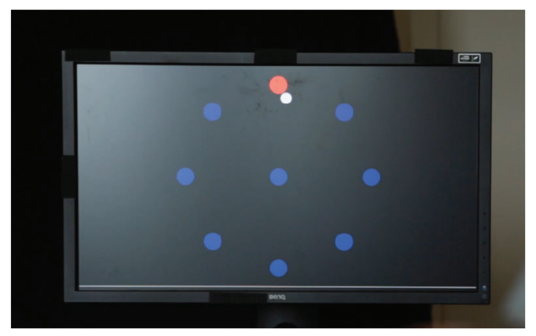
- T11: 37 year-old male with tetraplegia due to C4 AIS-B spinal cord injury
- Two 96-channel microelectrode arrays implanted both on left precentral gyrus (PCG)





Data Acquisition

- Intracortical neural recordings via a wireless broadband iBCI (Simeral et al, 2021)
- Extracted threshold crossing events and power in the spike band (250 - 5kHz)
- 5 -10 mins closed-loop cursor control of a radial-8 task per session
- Collected 1832 trials over 15 sessions spanning across 142 days



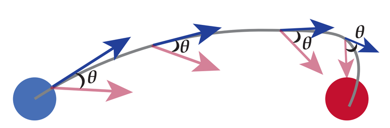
Radial-8 task on a computer monitor, T11 is controlling the cursor (in white) from center to outer target (in red)

Fixed RNN Decoder for decoding kinematics

- LSTM is a variant architecture of recurrent neural network (RNN) with gated input features
- Outperforms linear Kalman filter-based decoder in offline analysis (Hosman et al, 2019)
- Train and validate using point-and-select data from 20 most recent sessions prior to the first session in this study (8441 trials spanned across 70 days - trial day 576 to 646)
- Only trials with a median angular error less than 45° were included for training
- 30% of trials were reserved for validation

TABLE I. LSTM TRAINING HYPERPARAMETERS

Hidden units	Batch size	Learning rate	Unrolled steps	# Features	Drop out	Loss
100	1024	5E-4	25	384	50%	Mean sq. err

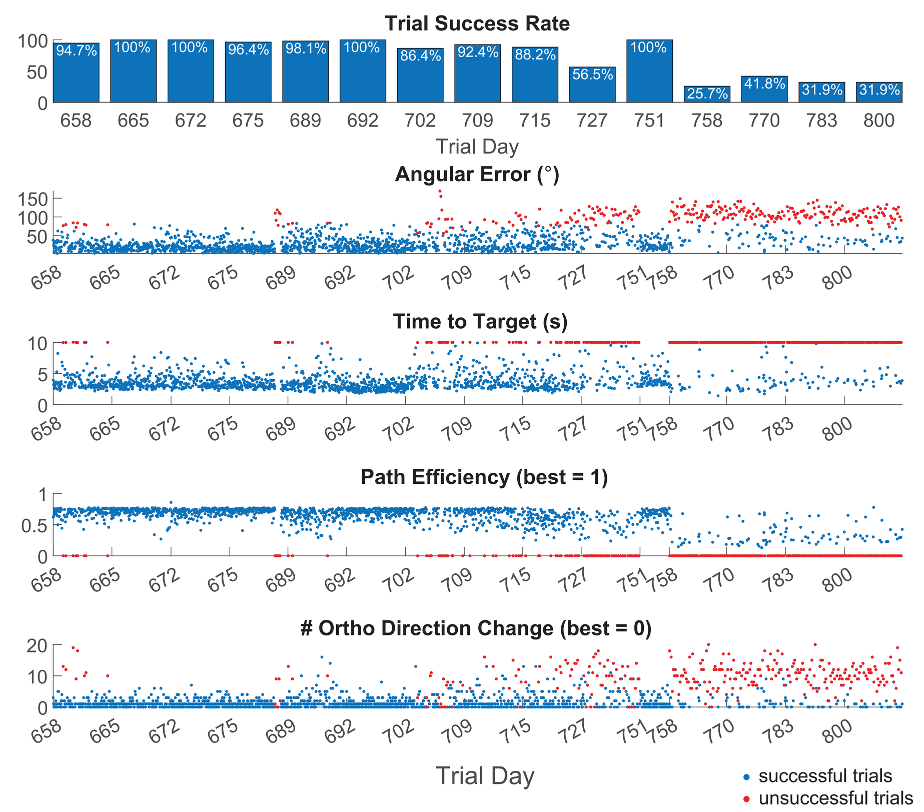


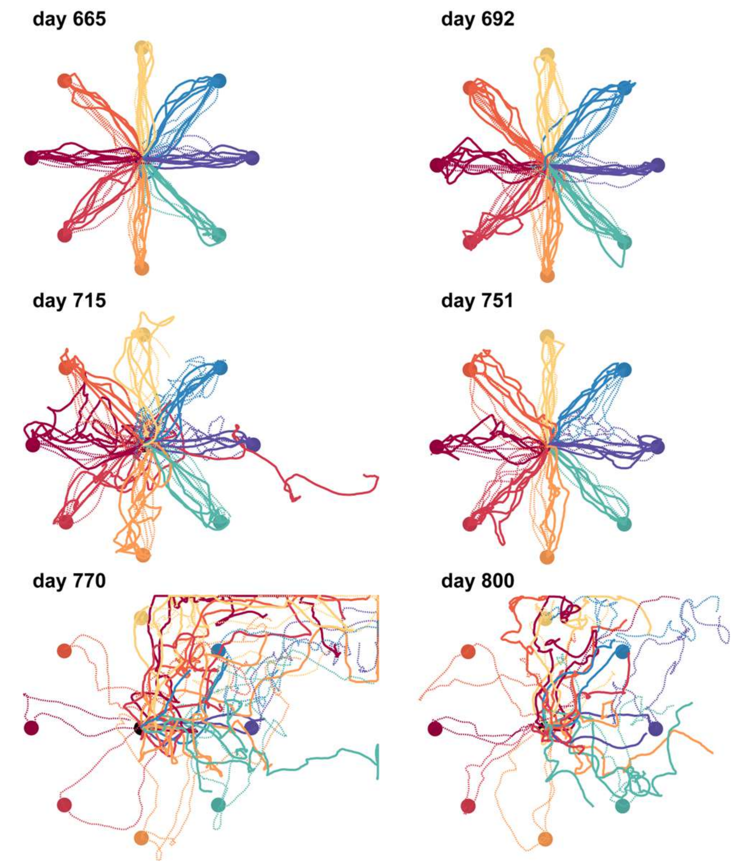
An example of instantaneous angular error (AE) during a trial; (best: 0°, worst: 180°)

ONLINE PERFORMANCE

Fixed RNN decoder provides long-term high performance

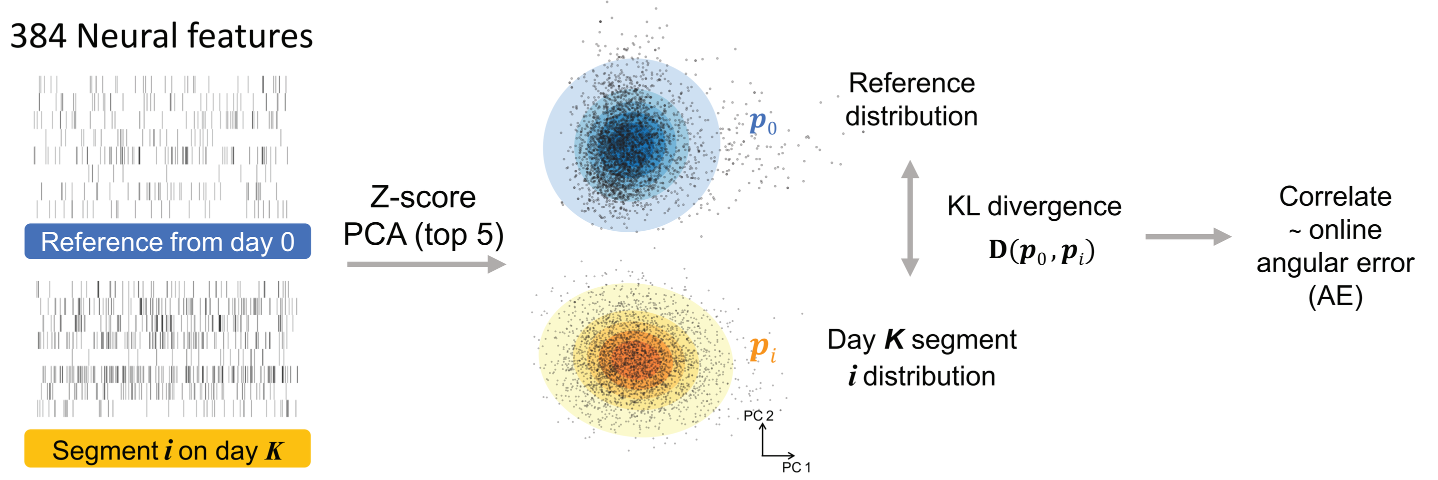
- 93.8% mean success rate in the first 3 months without any parameter updates, but subsequently degraded to 33.1% in later sessions



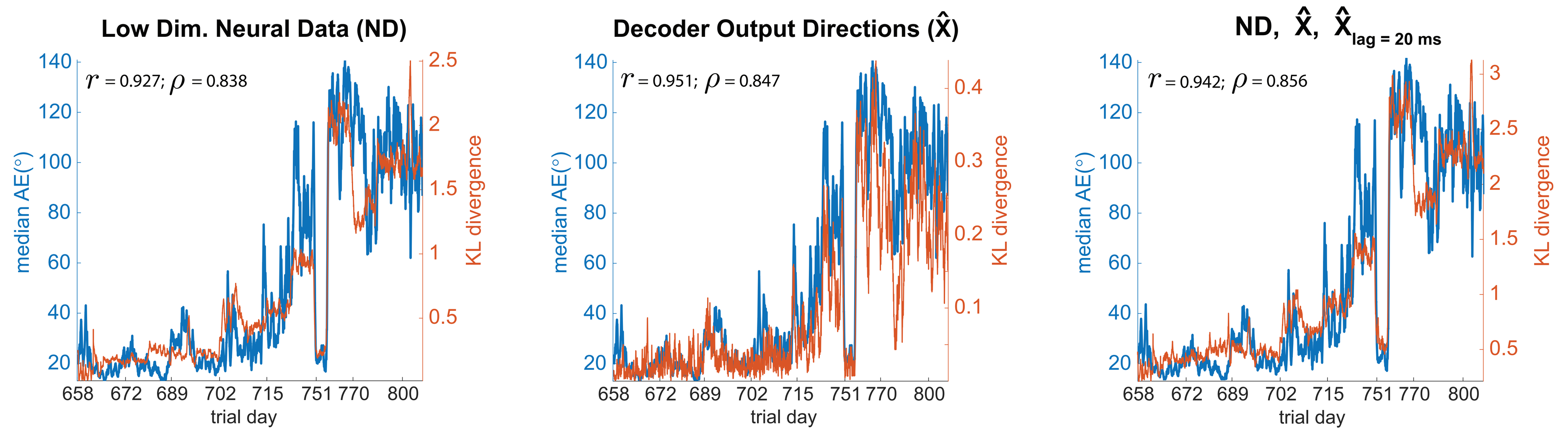


METHODS: DATA PROCESSING AND METRIC

- Evaluate nonstationarity by measuring the change between distributions
- Estimate reference multivariate Gaussian distribution from data when decoder was first tested on day 0 and subsequent time segments from other days and calculate KL divergence between them
- Calculate correlation coefficients with online performance across all session days

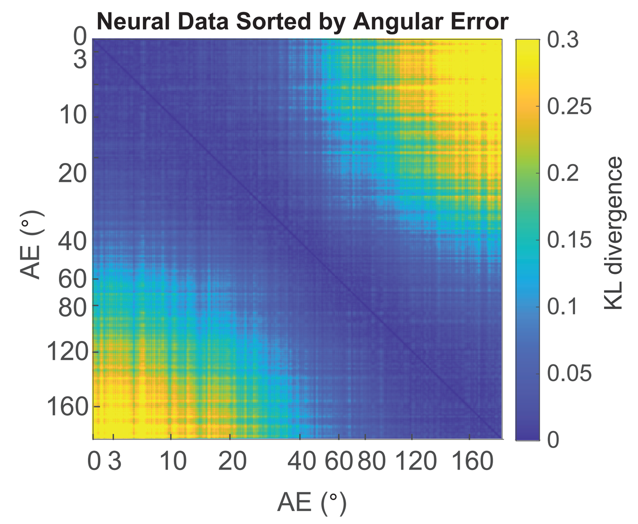


RESULTS: Distance metric highly correlates with online performance over 142 days



- Estimated distribution is updated every 0.2 second over a 60-second sliding window, no smoothing is applied
- r - Pearson's correlation coefficient (assess linear relationship)
- ρ - Spearman's rank correlation coefficient (assess monotonic relationship)

RESULTS (CONT.)

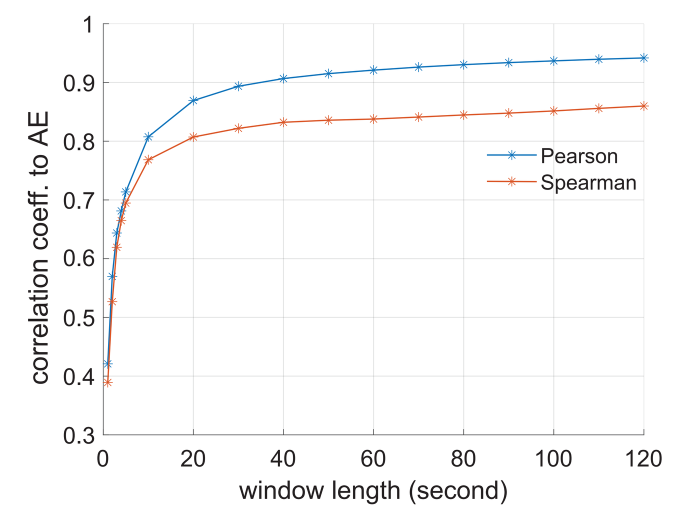


Performance depends on similarity in neural feature ensembles

- Decoder is expected to perform well when neural patterns in testing are similar to neural patterns used for training
- When sorting neural data (ND) time series by angular error (AE)
  - When AE are in similar ranges, ND are more similar
  - When AE are in different ranges, ND are more dissimilar
- Distance metric between ND distributions reflects ND similarity, which should also reflect similarity in decoder performance

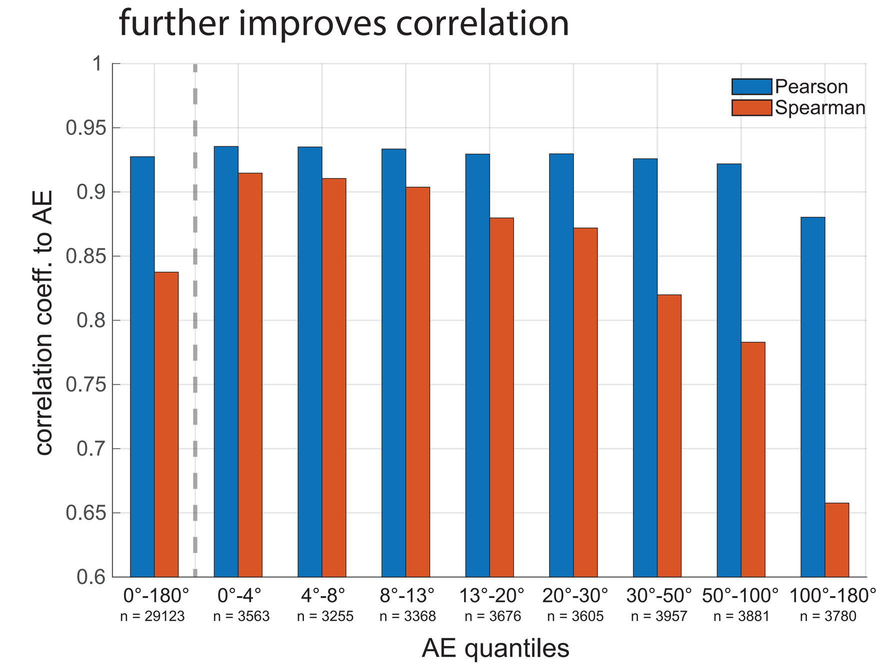
Window length

A long enough window length is required to obtain better estimation of neural data; 30 second + is sufficient to track online AE



Subselect data for reference

Selecting only time steps with low angular error from the first session as reference data further improves correlation



CONCLUSIONS & FUTURE WORK

- KL divergence of neural data relative to epochs of good performance is an effective metric to track nonstationarity over a long period without requiring labels of the target location
- Towards online application, it might be useful for triggering either a user-engaged or background update as the decoder begins to degrade
- Future work includes
  - validating this approach with other datasets to evaluate how well it generalizes to other participants and other tasks
  - online implementation for tracking nonstationarity during kinematic control with an iBCI

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