Deep Multi-State Dynamic Recurrent Neural Networks Operating on Wavelet Based Neural Features for Robust Brain Machine Interfaces

Caltech

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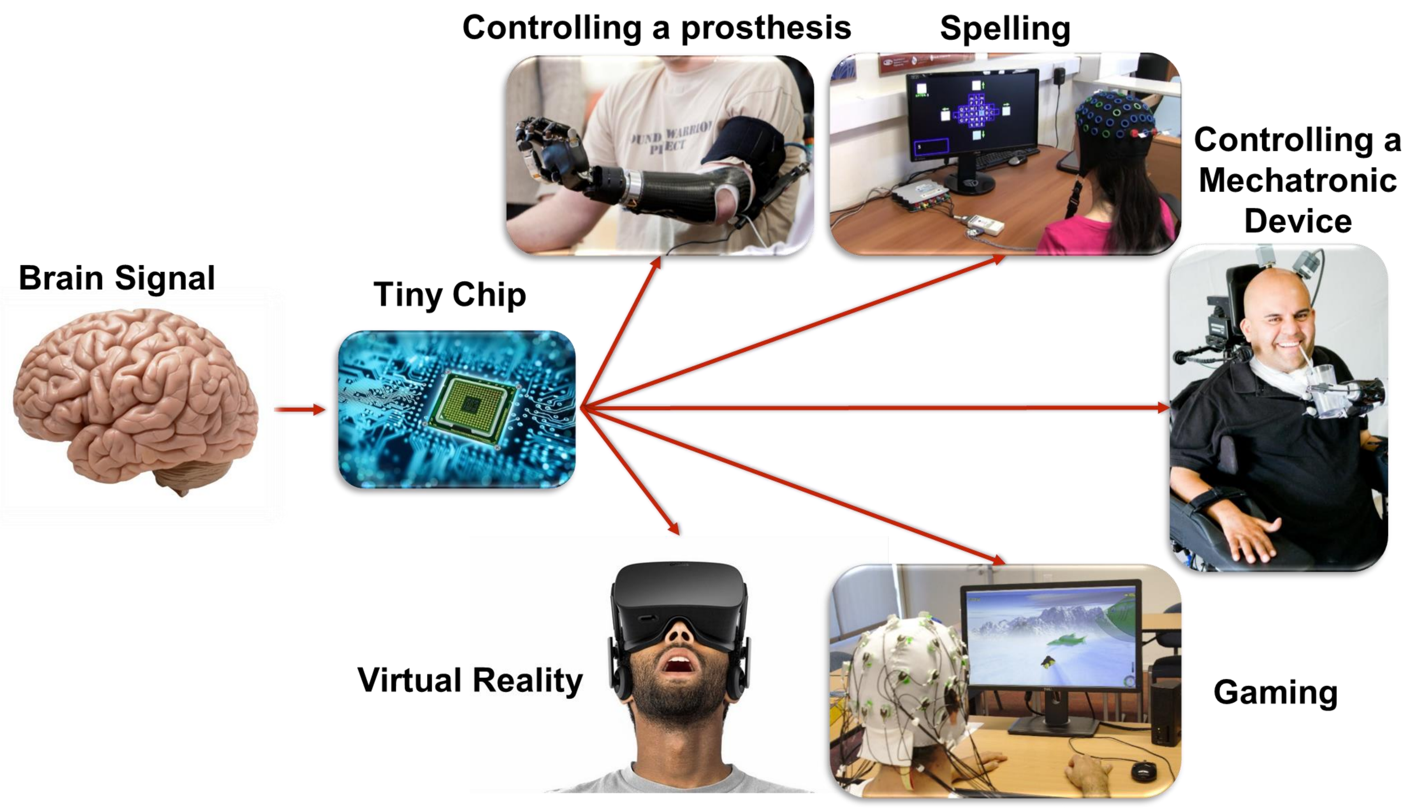
Motivating Problem

Spinal Cord Injuries > 250,000 patients per year

Treatment Costs ~ $ 9.7 billion per year

Applications of BMI



Goals

Minimize Treatment Cost | Robustness

Low Power/Area Chip | High Performance

Challenges

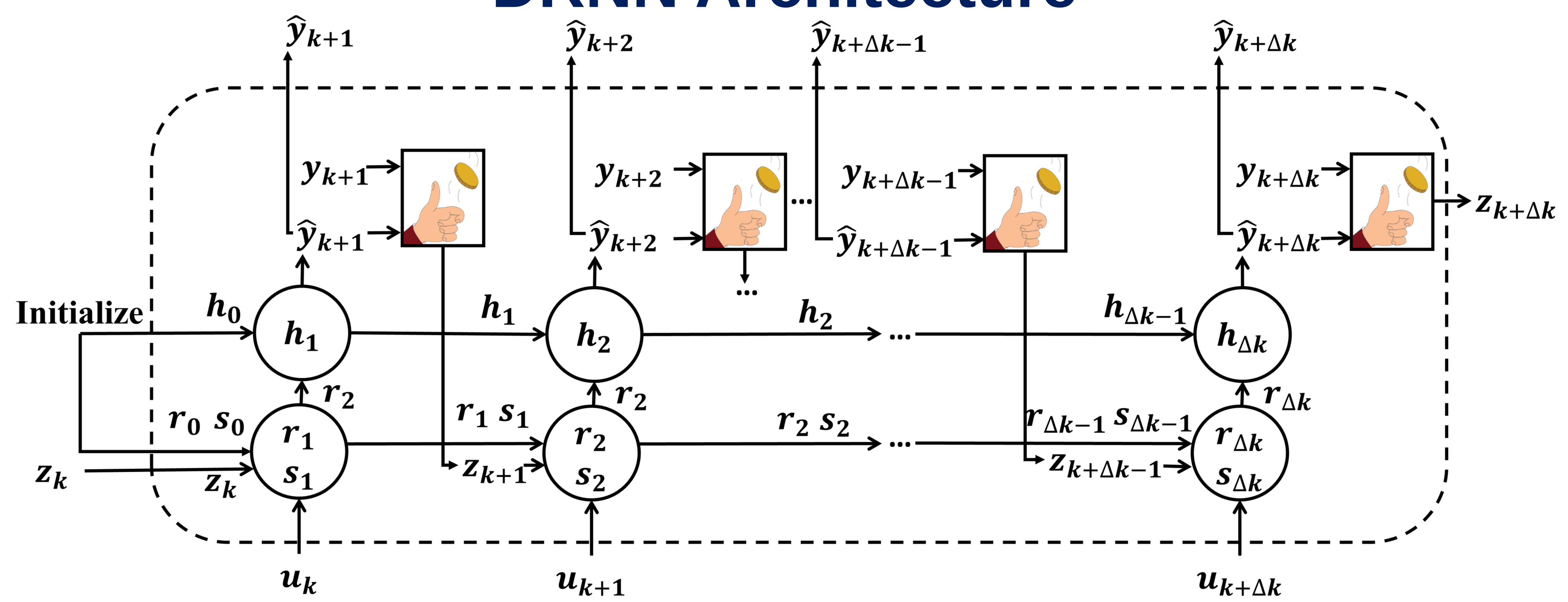
Achieving High Speed Design | Noise

Non-Stationarity of Neural Data | Limited Data

Deep Multi-state DRNN

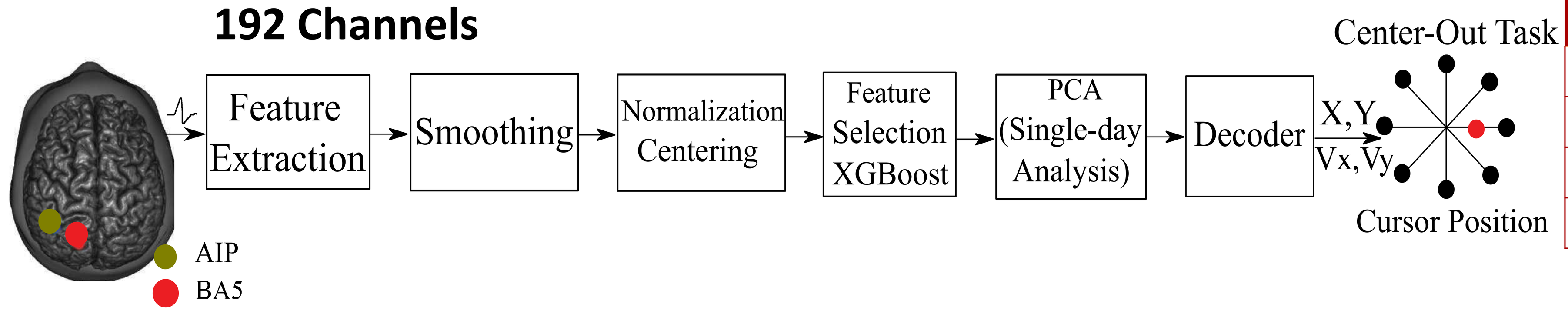
$$
\begin{cases}
s_k = W_{ss}s_{k-1} + W_{sr}r_{k-1} + W_{si}u_k + W_{sf}z_{k-1} + b_s \\
r_k = \tanh(s_k) \\
h_k^{(1)} = \tanh\left(W_{h^{(1)}h^{(1)}}h_{k-1}^{(1)} + W_{h^{(1)}r}r_k + b_{h^{(1)}}\right) \\
h_k^{(i)} = \tanh\left(W_{h^{(i)}h^{(i)}}h_{k-1}^{(i)} + W_{h^{(i)}h^{(i-1)}}h_k^{(i-1)} + b_{h^{(i)}}\right) \\
\hat{y}_k = W_{yh^{(l)}}h_k^{(l)} + b_y \\
\hat{y}_k = tanh(\hat{y}_k) \quad |\hat{y}_k| > 1 \\
z_k \leftarrow \hat{y}_k \text{ or } y_k \text{ (Scheduled Sampling)}
\end{cases}
$$

DRNN Architecture



BMI System Architecture

- 32 year-old tetraplegic (C5-C6) human
- FDA- and IRB-approved
- Sampling Rate: 30 KHz
- Utah electrode arrays



Features	Frequency Range
HWT, HFT, HPF	> 3.75KHz
TCs, LFADS	250Hz – 5KHz
MWT, MFT, MUA	234Hz – 3.75KHz
LWT, LFT, LPF	< 234HZ

Single-day Analysis with Mid-Wavelet Feature

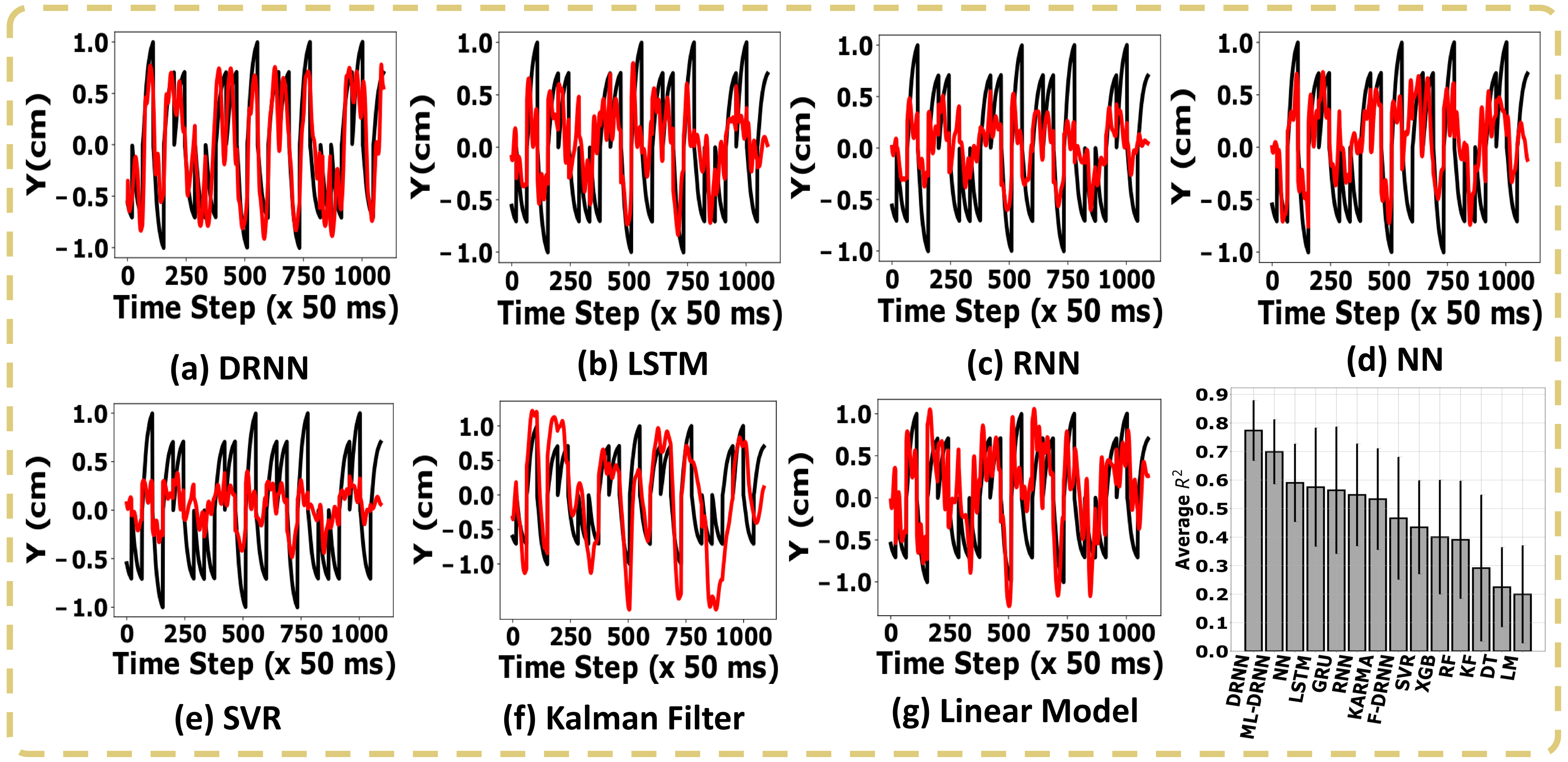


Fig.1. Regression of different algorithms on test data from the same day 2018-04-23: true target motion (black) and reconstruction (red)

Multi-day Performance

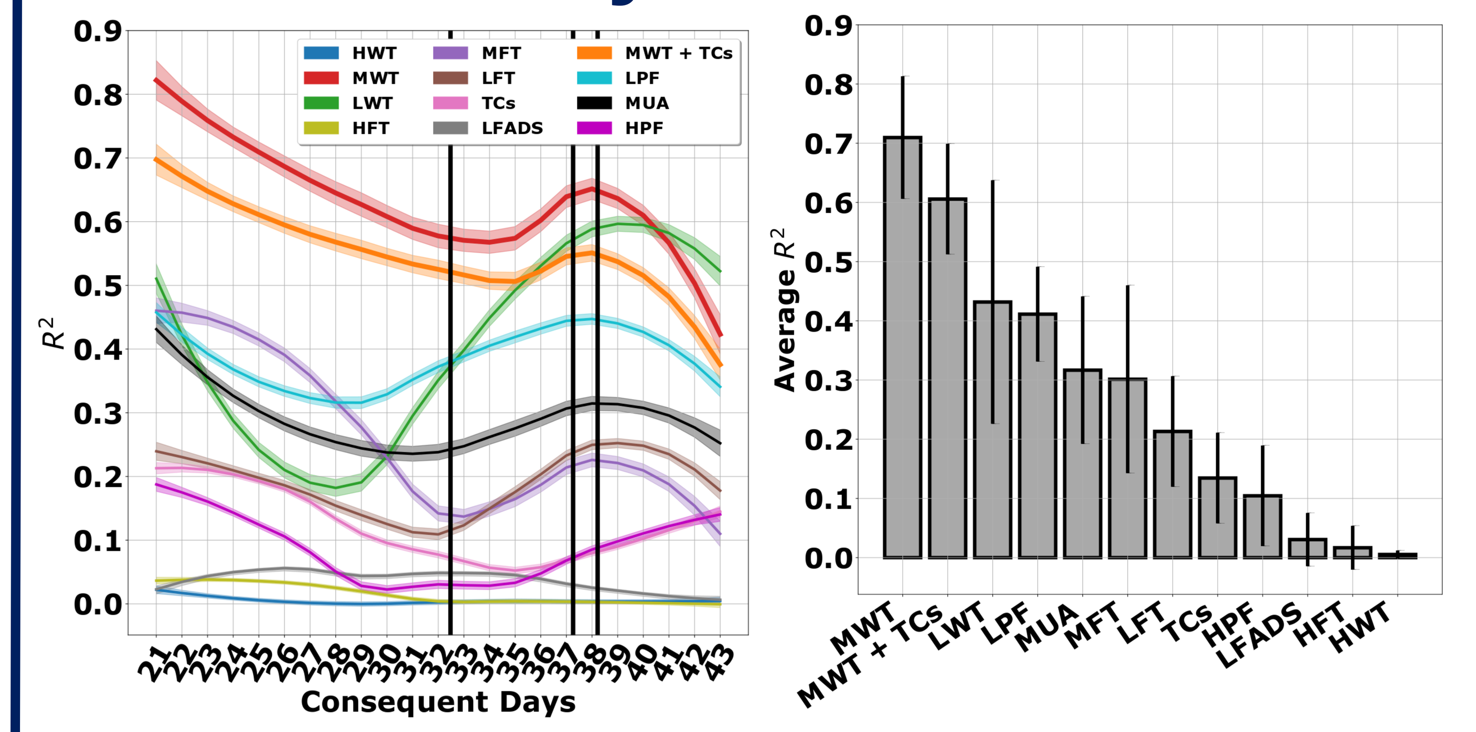


Fig.2. The DRNN operating on different features.

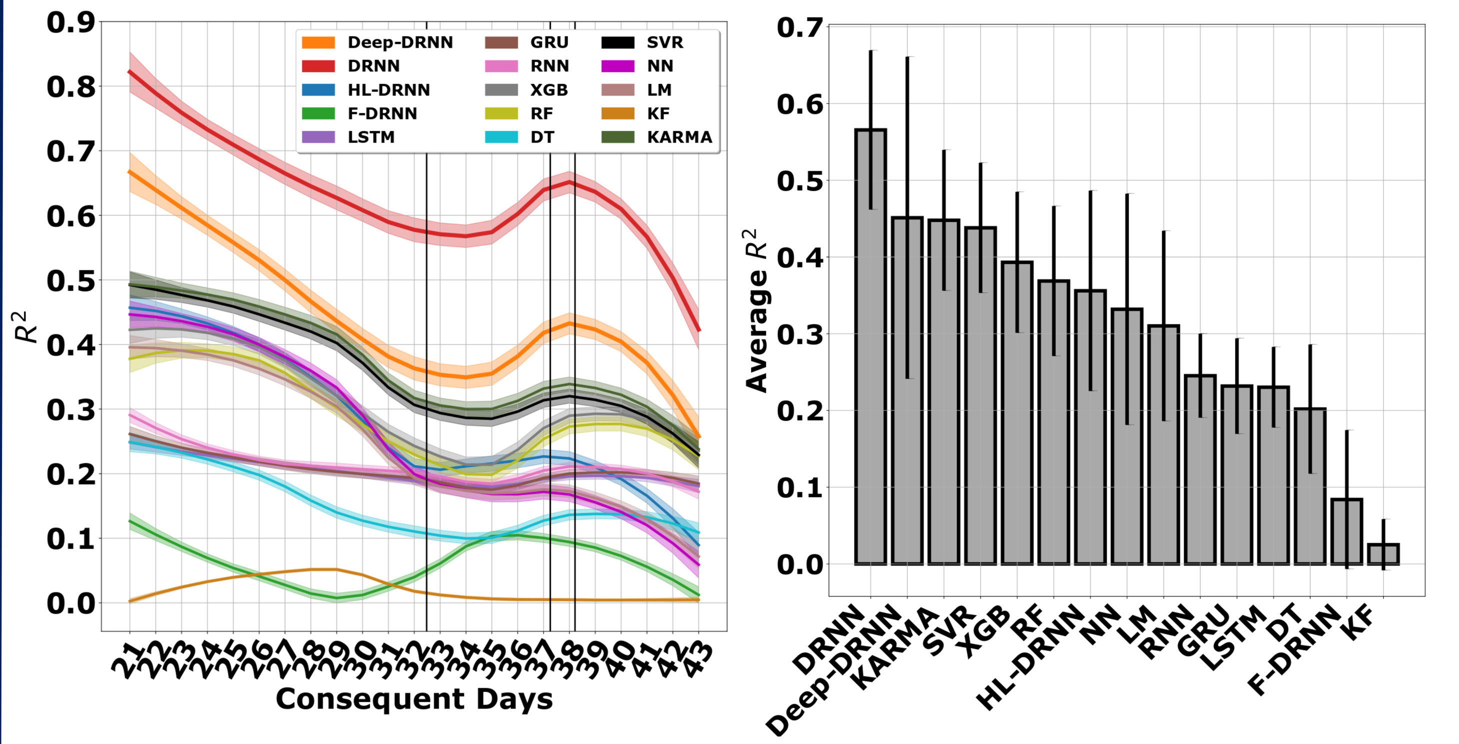


Fig.3. Multi-day performance of the decoders.

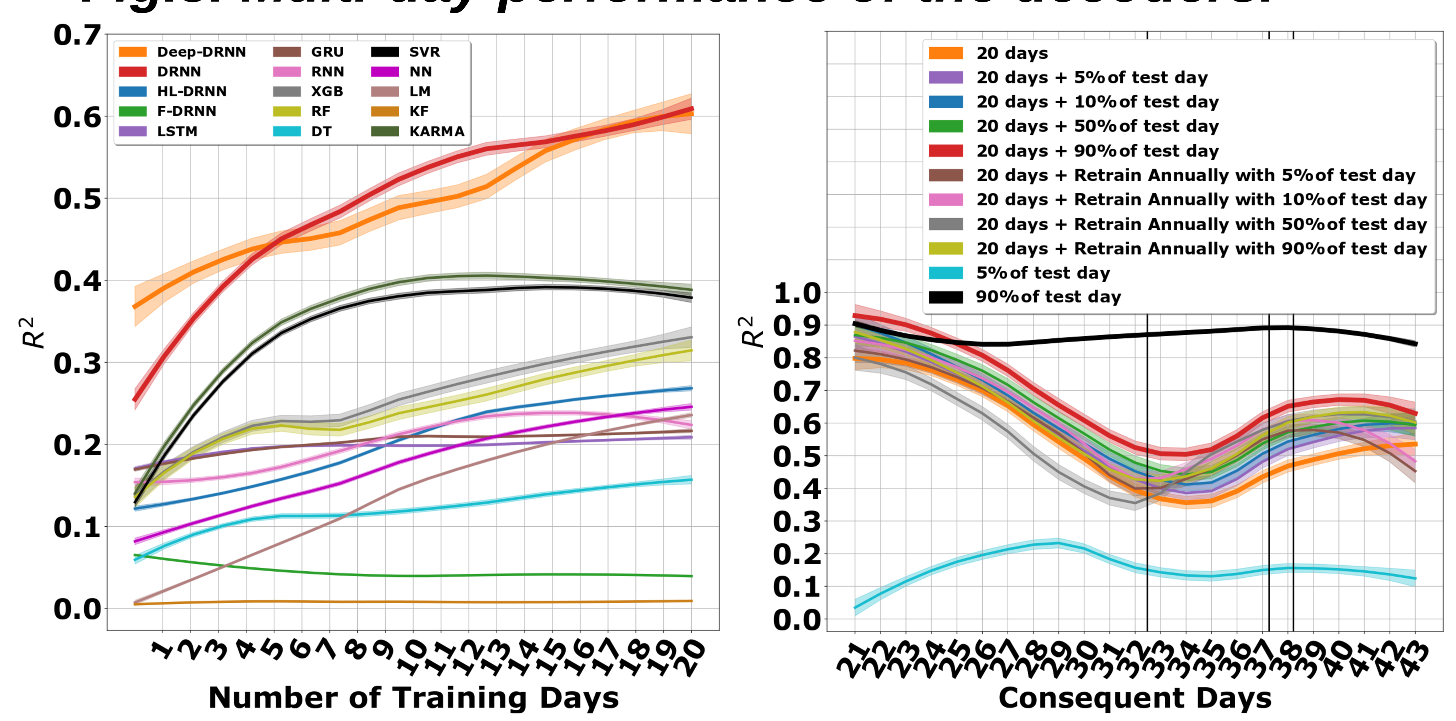


Fig.4. (Left) Effect of number of training days on the performance of the decoders. (Right) The DRNN operating in different training scenarios.

References

[1] B. A. Haghi, S. Kellis, S. Shah, M. Ashok, L. Bashford, D. Kramer, B. Lee, Ch. Liu, R. A. Andersen, and A. Emami, *"Deep Multi-State Dynamic Recurrent Neural Networks Operating on Wavelet Based Neural Features for Robust Brain Machine Interfaces"*, NeurIPS 2019, Vancouver, Canada (bioRxiv)

[2] S. Shah, B. A. Haghi, S. Kellis, L. Bashford, D. Kramer, B. Lee, Ch. Liu, R. A. Andersen, and A. Emami, *"Decoding Kinematics From Human Parietal Cortex using Neural Networks*, NER 2019, San Fransisco, CA, USA

Acknowledgement: T&C Chen Brain-Machine Interface Center at Caltech, USC Neurorestoration Center