STANFORD UNIVERSITY

Neural Prosthetics Translational Laboratory

Brain Computer Interfaces for Communication

Erin M. Kunz, MS

Department of Electrical Engineering
Stanford University

About me

Hayward, CA

B.S. MechE,
Minor: EECS

Software/Controls Engineering
Autonomous Vehicle Development

2018
Admitted to MS in EE

Joined NPTL w/ advisors:
Krishna Shenoy,
Jaimie Henderson,
Shaul Druckmann

2020
Admitted to PhD in EE

2024:
PhD Defense(!)
&
Start PostDoc

The need to restore movement and communication

Christopher Reeve at MIT, 2003

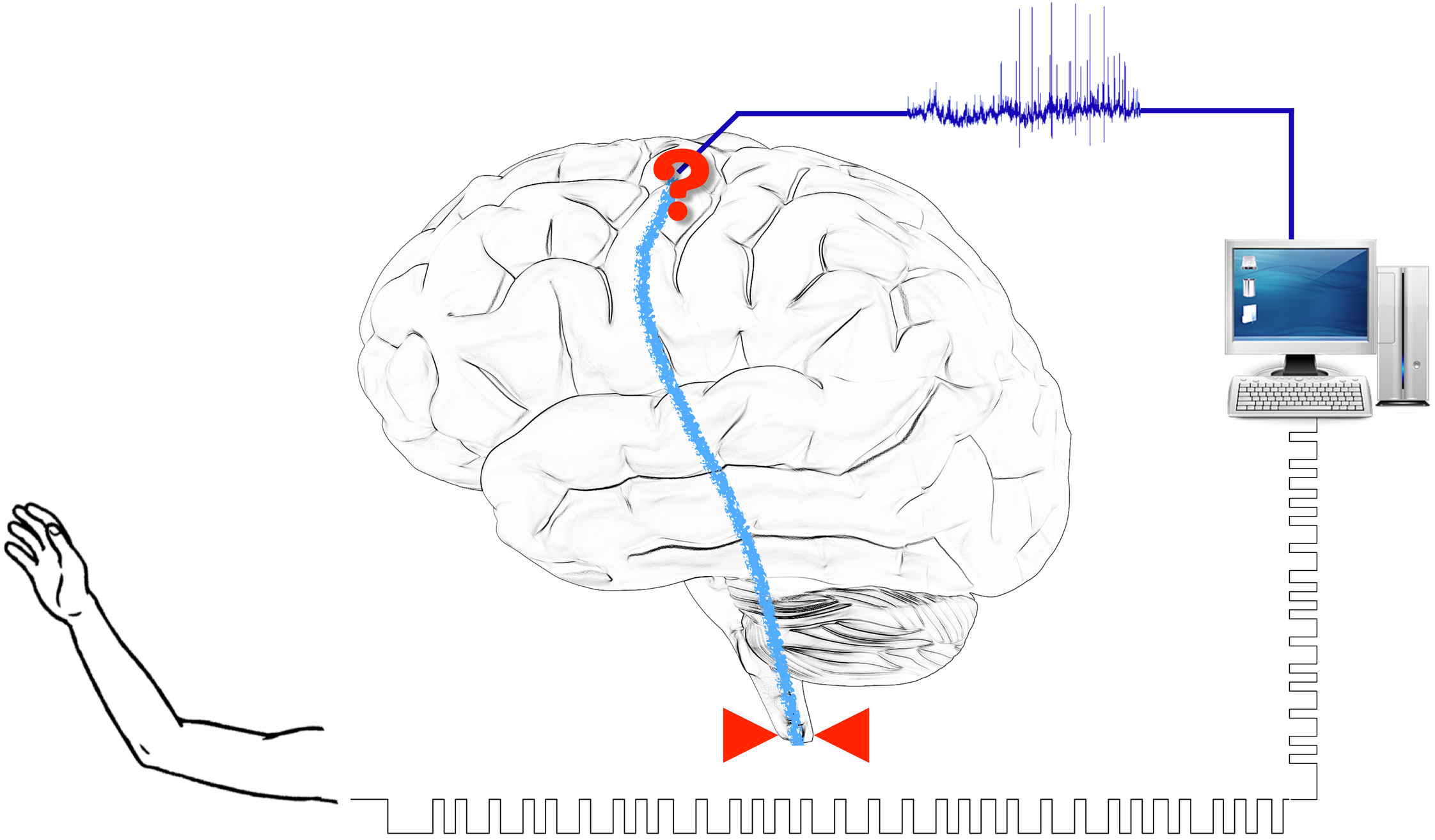
The need to restore movement and communication

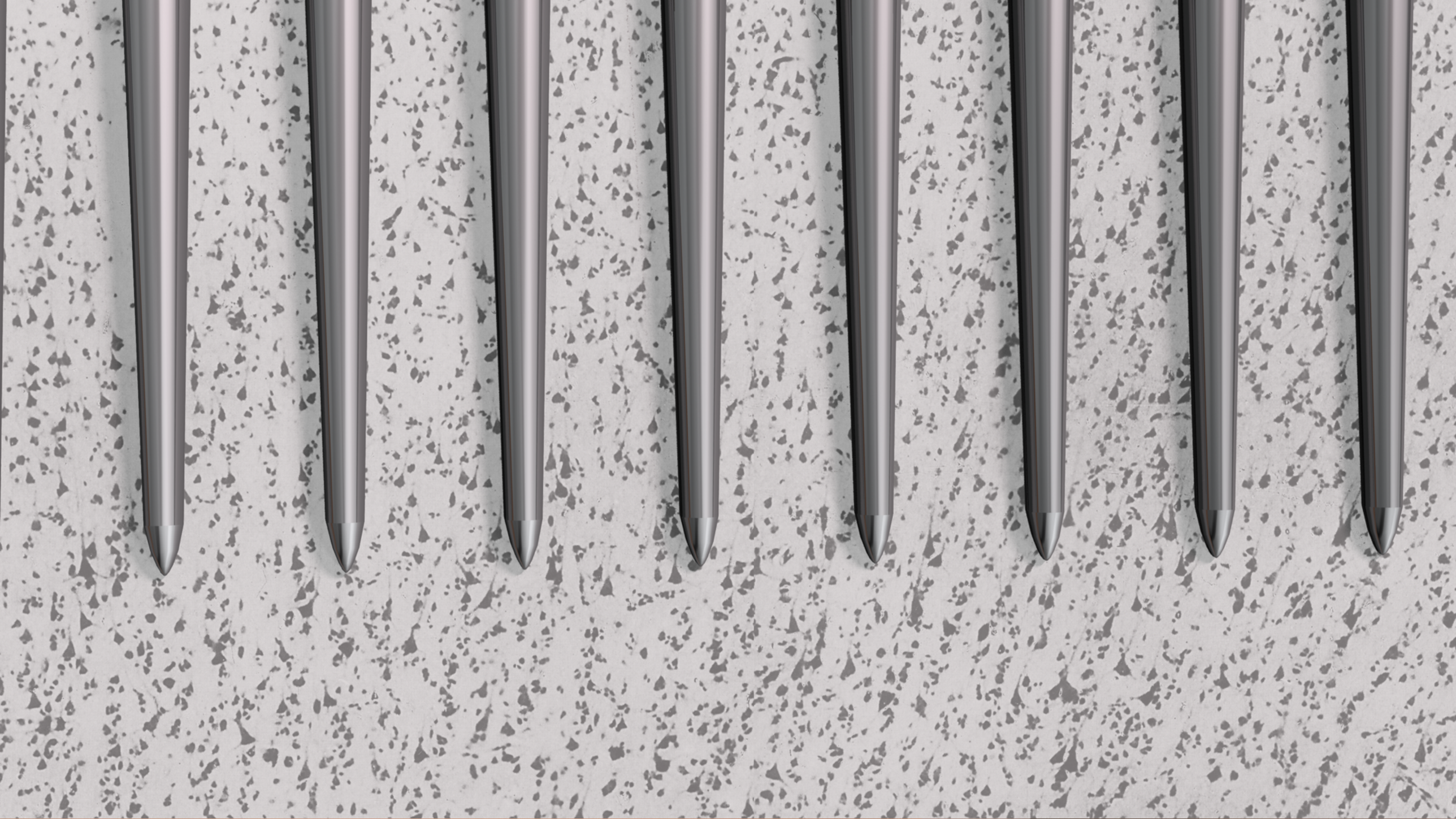
ALS: ~15,000 individuals in the U.S. (CDC, 2016)

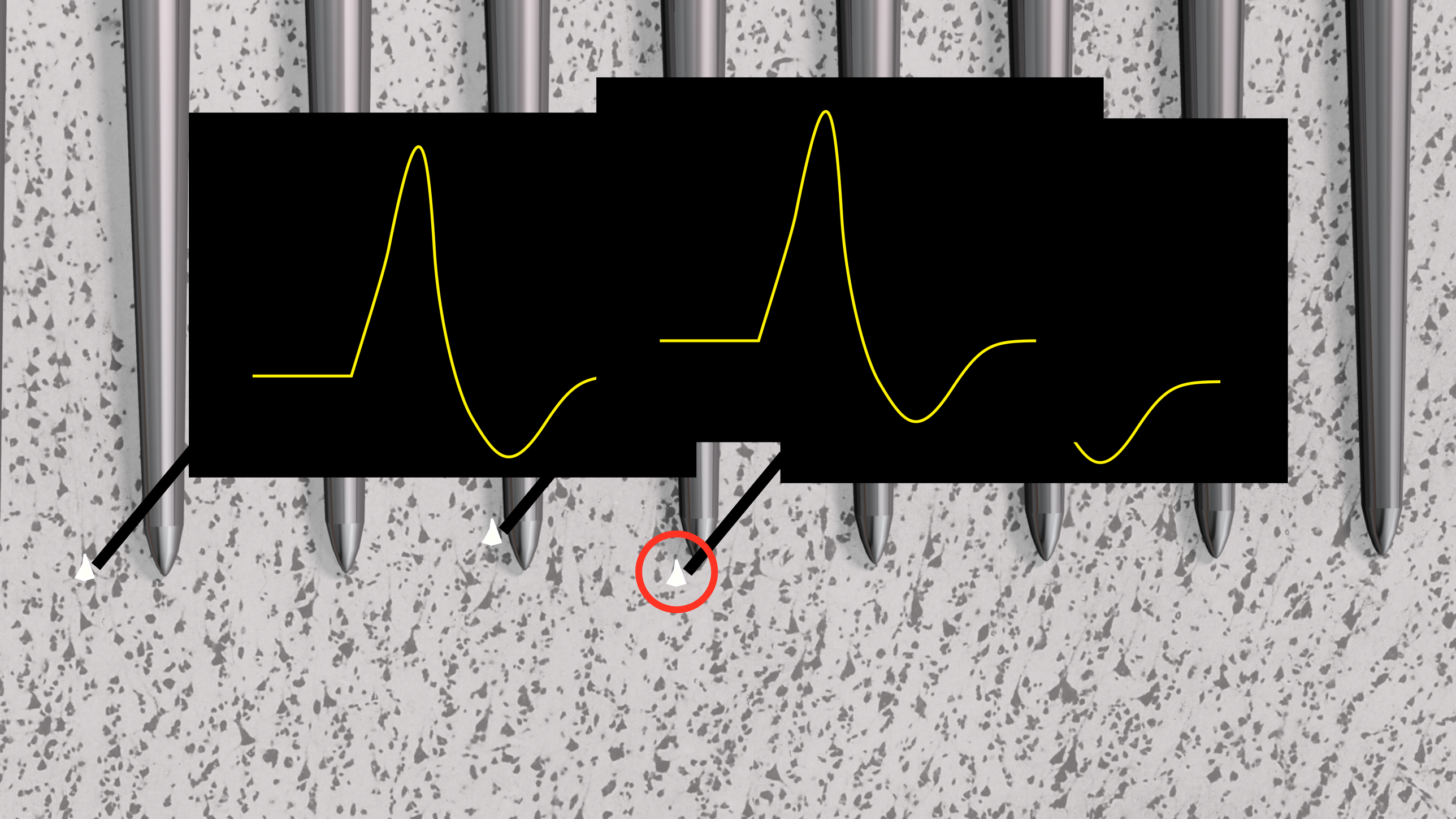
Hundreds of thousands of individuals with tetraplegia (NSCISC, 2018)

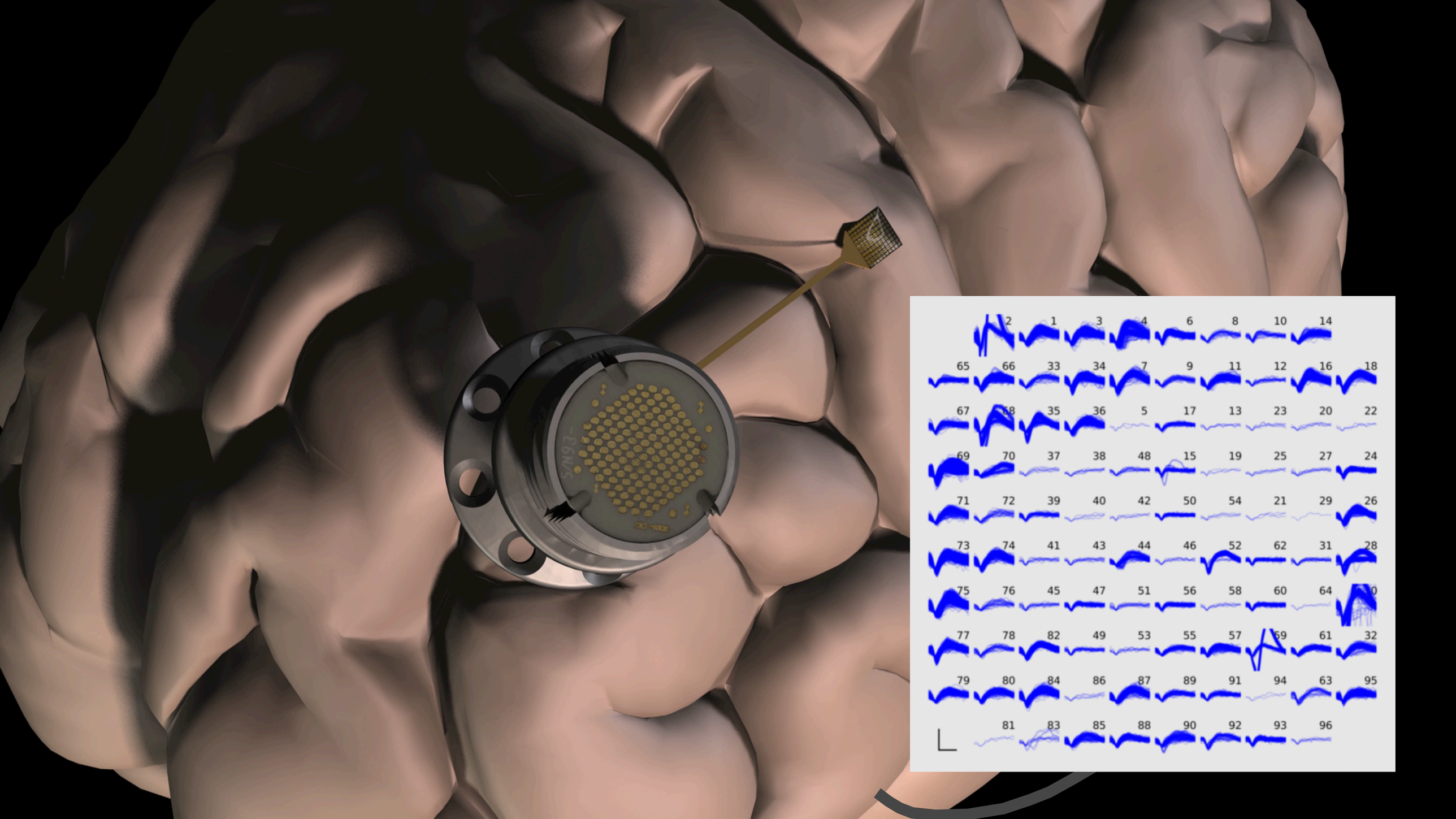
Today: essentially no treatments

Stephen Hawking at Imperial College London, 2016

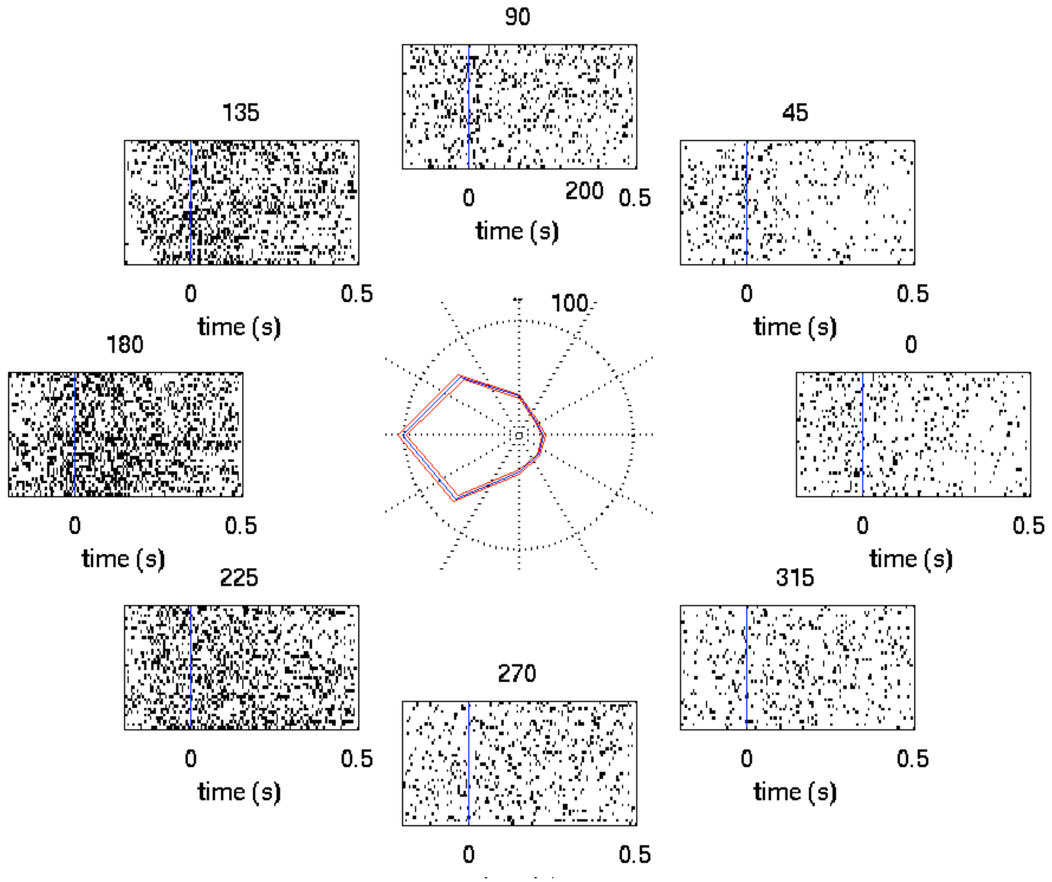


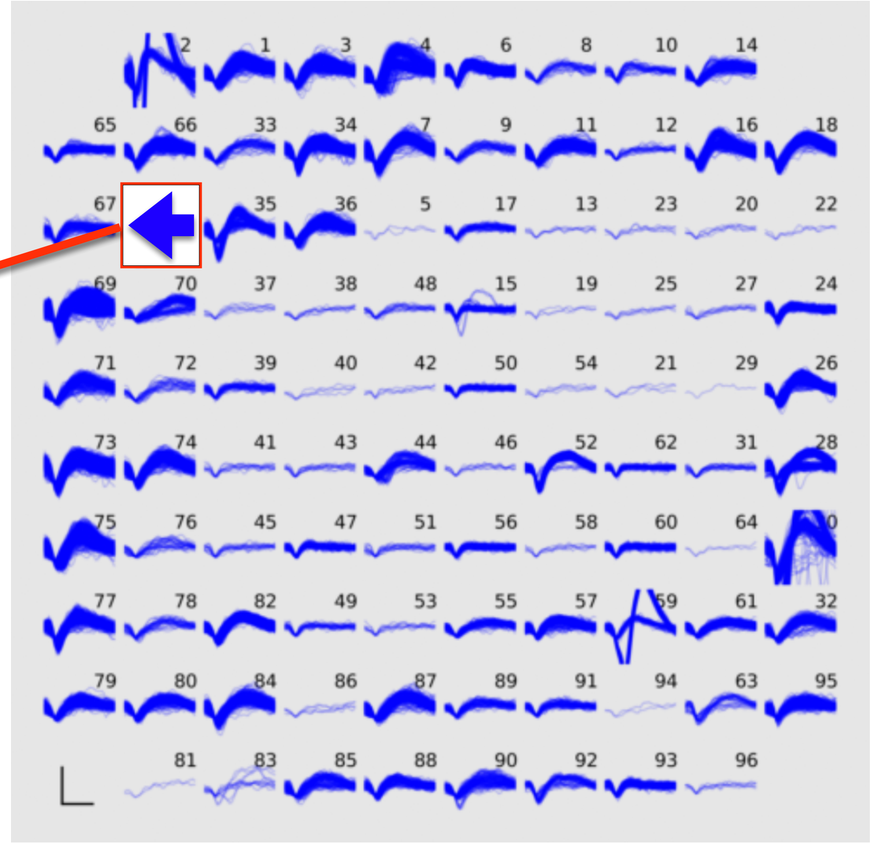


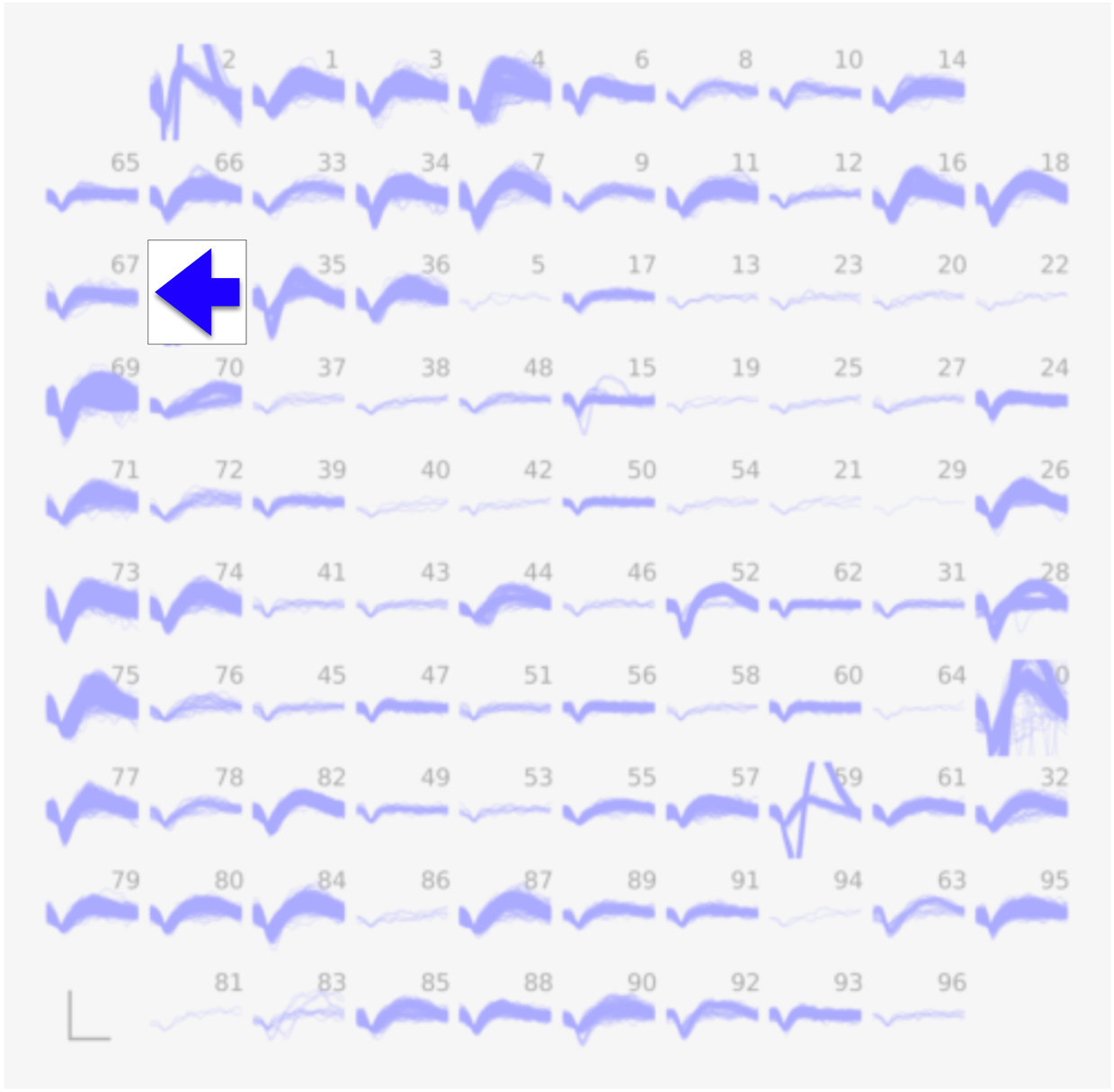


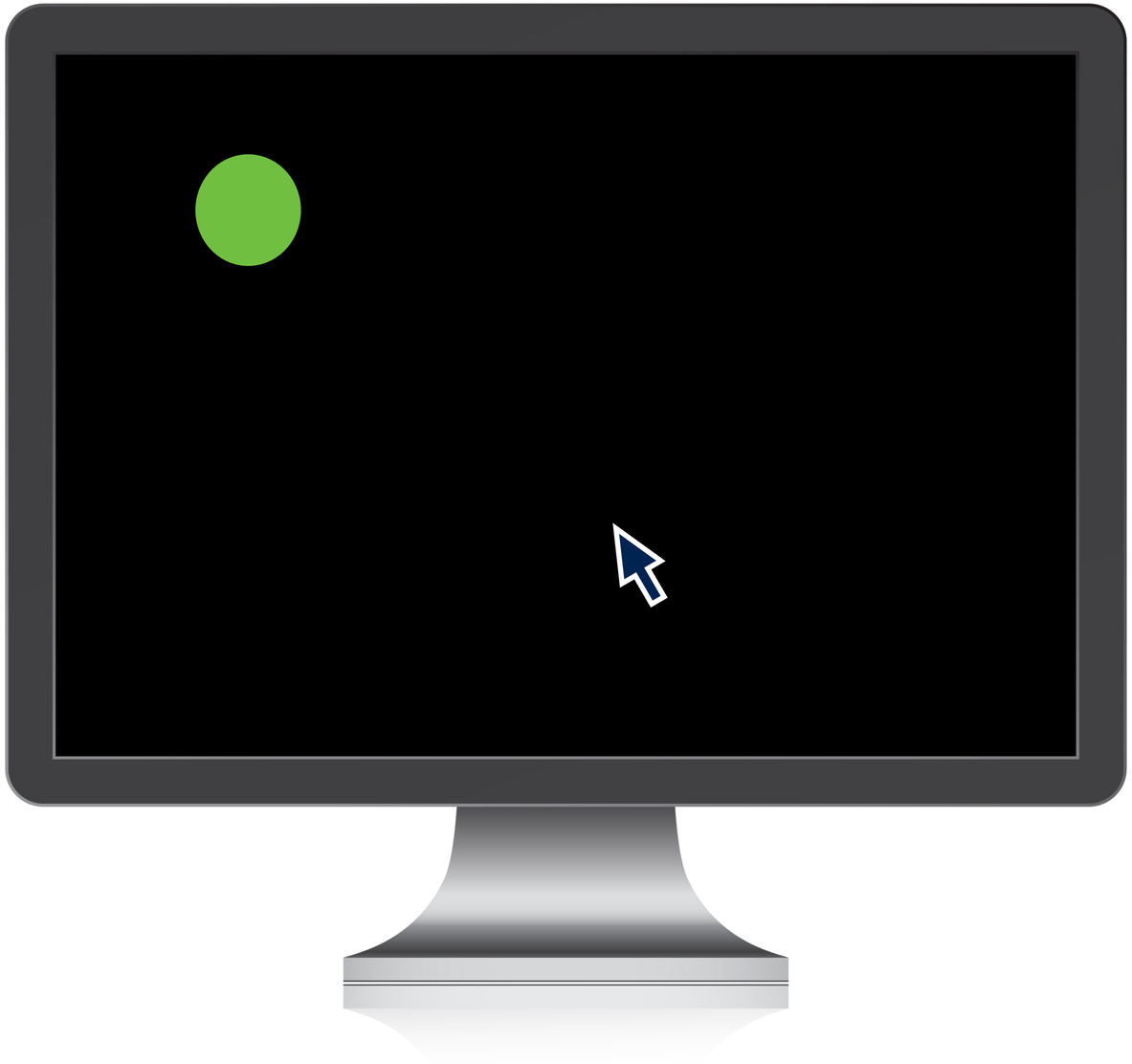

2 1 3 4 6 8 10 14
65 66 33 34 7 9 11 12 16 18
67 68 35 36 5 17 13 23 20 22
69 70 37 38 48 15 19 25 27 24
71 72 39 40 42 50 54 21 29 26
73 74 41 43 44 46 52 62 31 28
75 76 45 47 51 56 58 60 64
77 78 82 49 53 55 57 59 61 32
79 80 84 86 87 89 91 94 63 95
81 83 85 88 90 92 93 96

Georgopoulos et al. (1986) *Science*



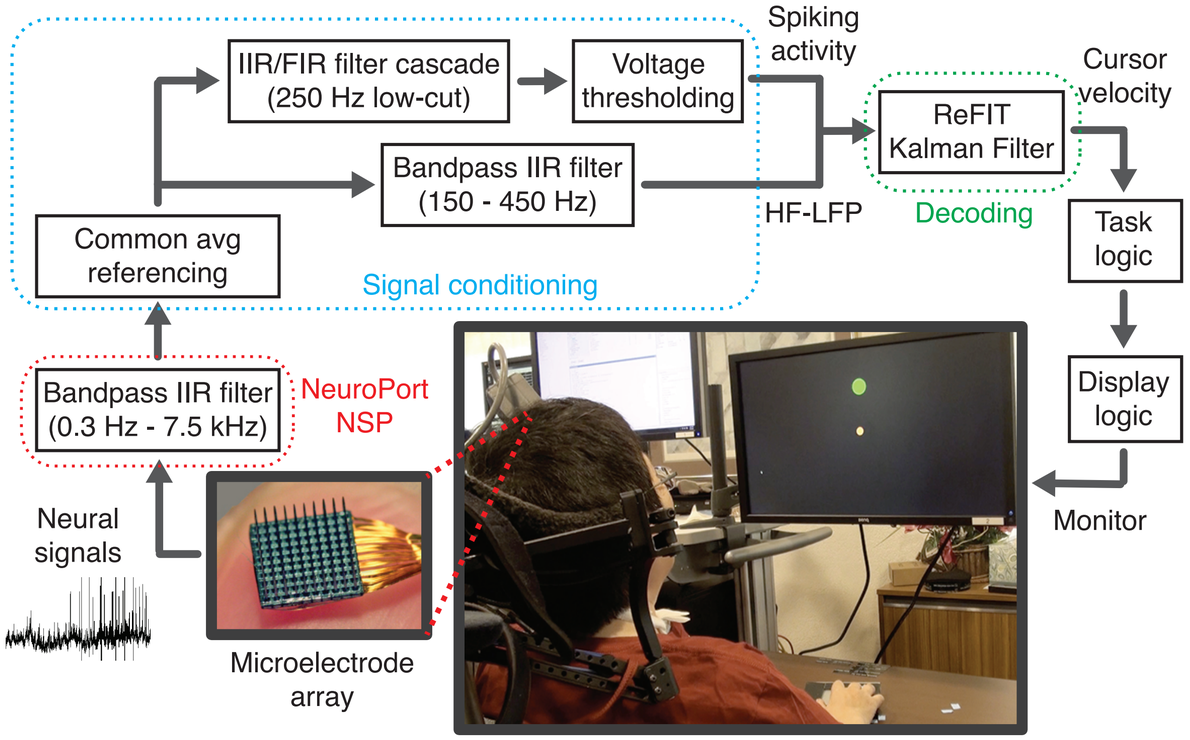


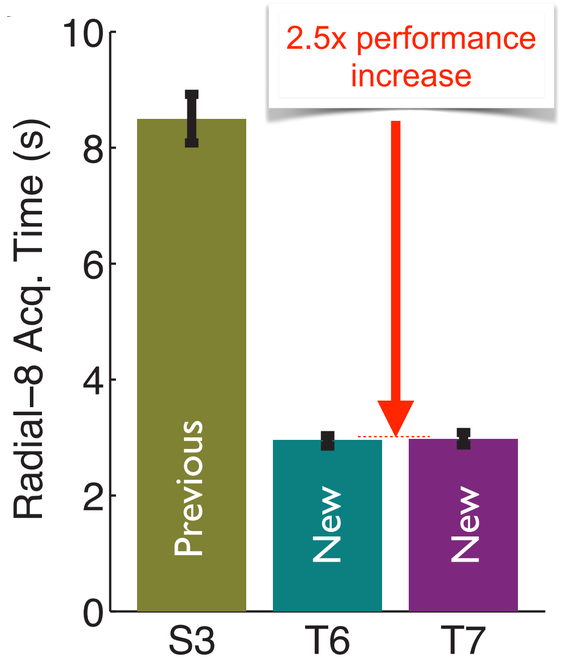

2 1 3 4 6 8 10 14
65 66 33 34 7 9 11 12 16 18
67 35 36 5 17 13 23 20 22
69 70 37 38 48 15 19 25 27 24
71 72 39 40 42 50 54 21 29 26
73 74 41 43 44 46 52 62 31 28
75 76 45 47 51 56 58 60 64
77 78 82 49 53 55 57 59 61 32
79 80 84 86 87 89 91 94 63 95
81 83 85 88 90 92 93 96



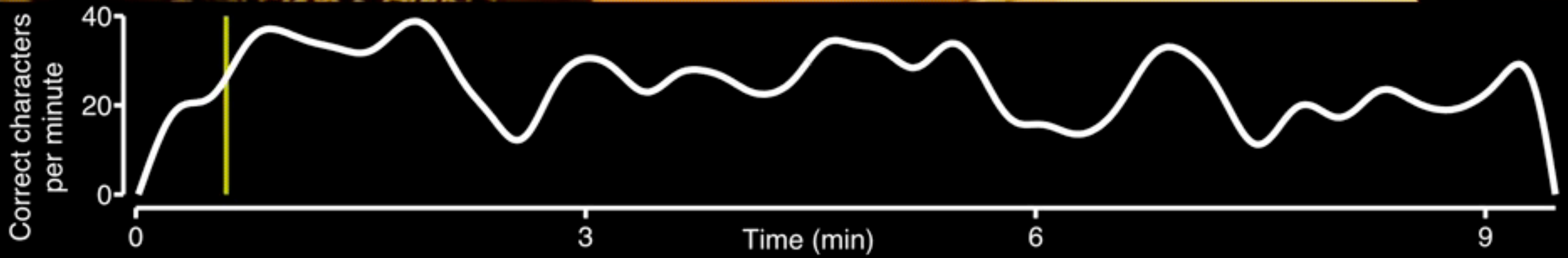
Translating Communication BCI

Design of signal conditioning, decoders and real-time systems





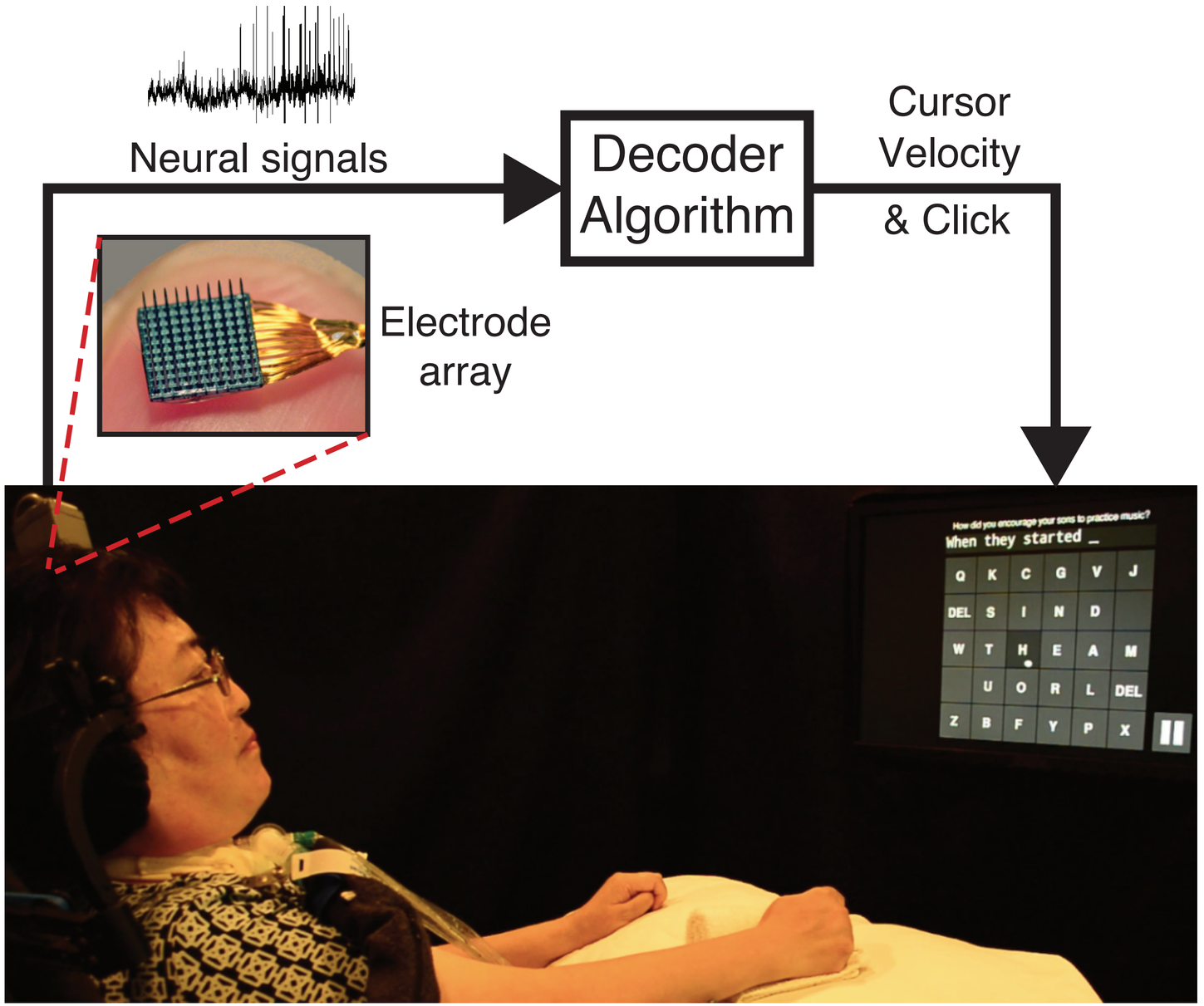
Gilja*, Pandarinath*, …, Hochberg, Shenoy**, Henderson** (2015) *Nature Medicine*
Jarosiewicz, …, Henderson, Shenoy, Donoghue, Hochberg (2015) *Science Translational Medicine*
BrainGate2 pilot clinical trial. CAUTION: Investigational device. Limited by federal law to investigational use.



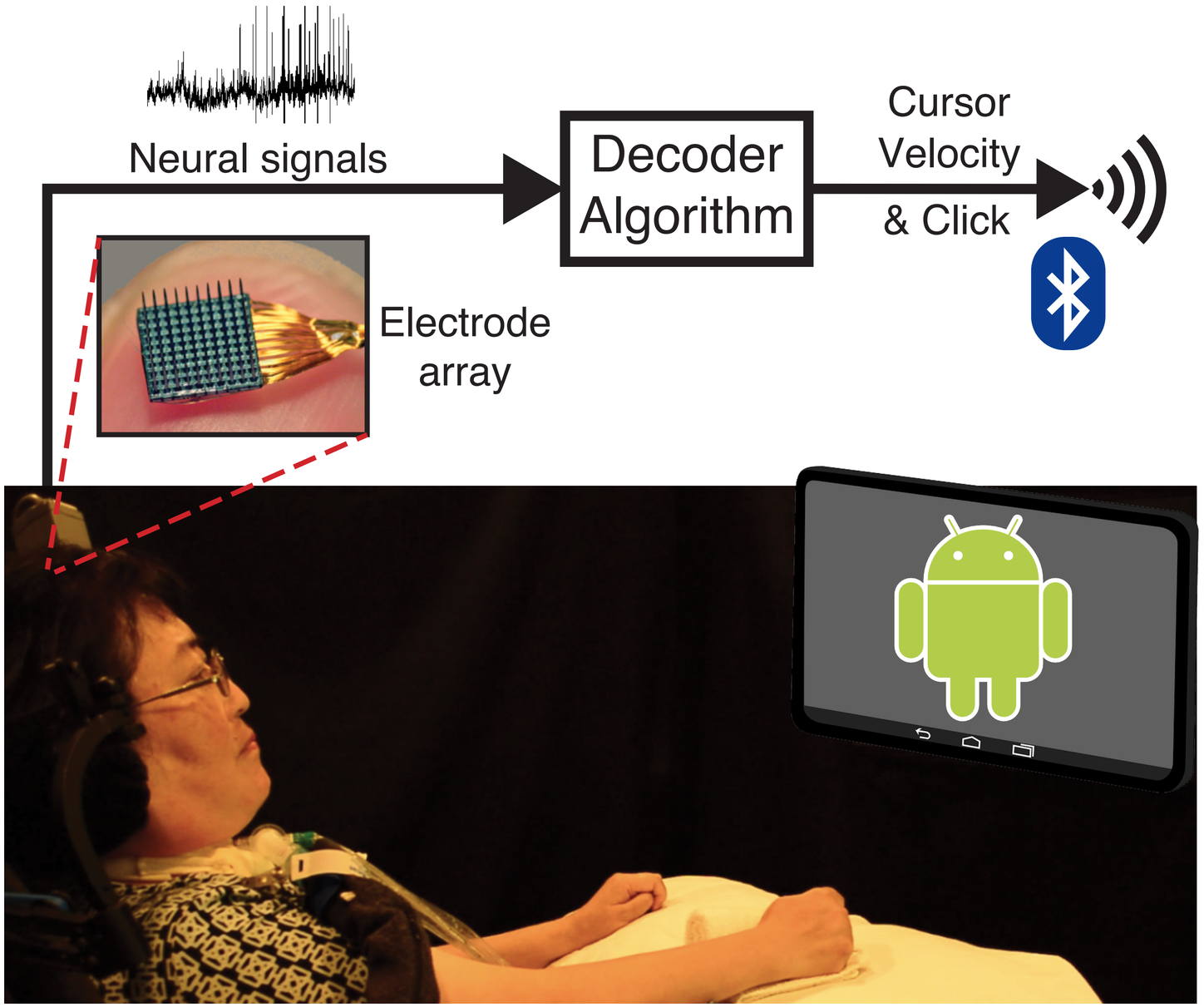
Pandarinath*, Nuyujukian*, et al. (2017) *eLife*

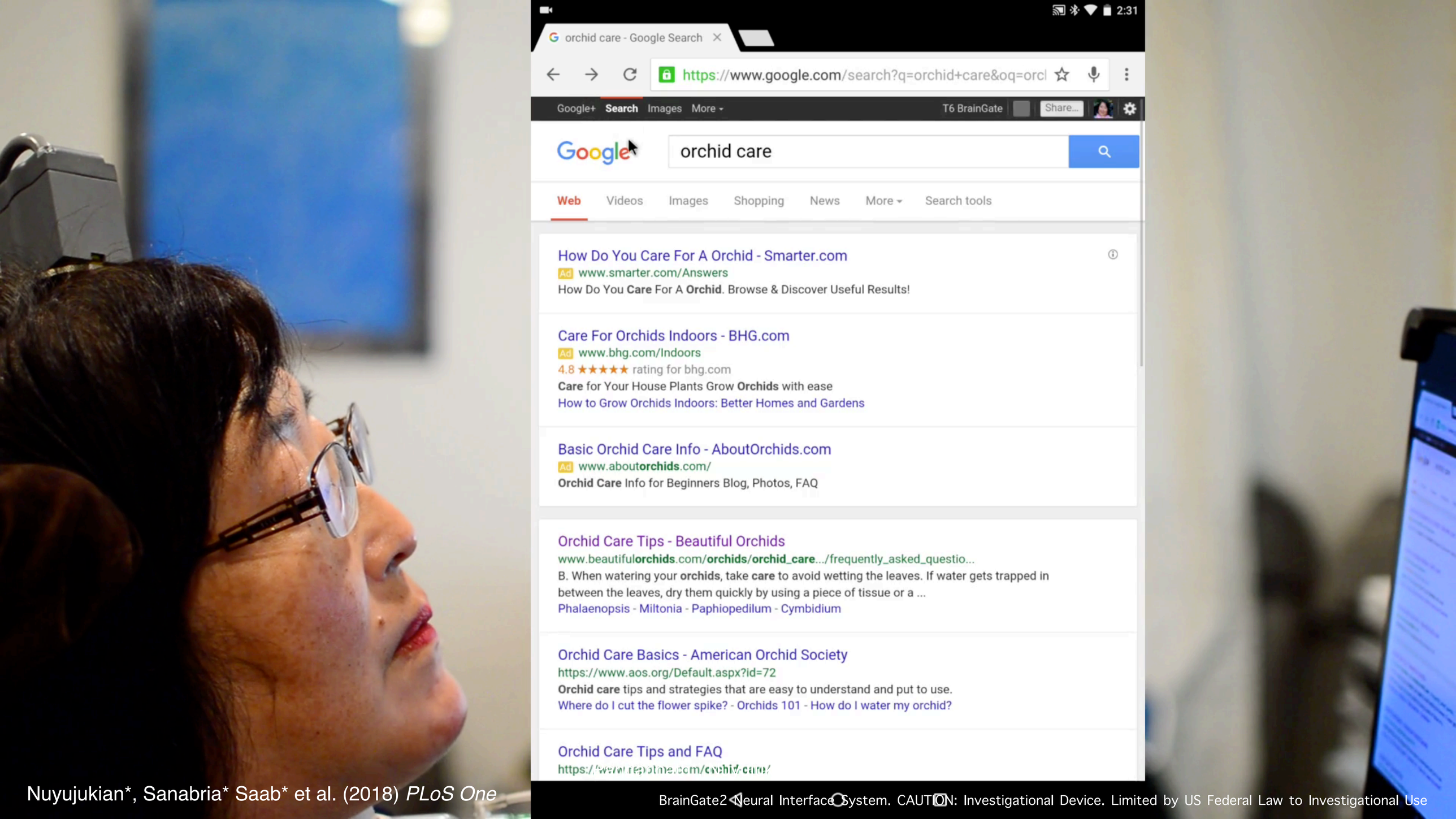
BrainGate2 Neural Interface System. CAUTION: Investigational Device. Limited by US Federal Law to Investigational Use

Existing setup



Android Interface

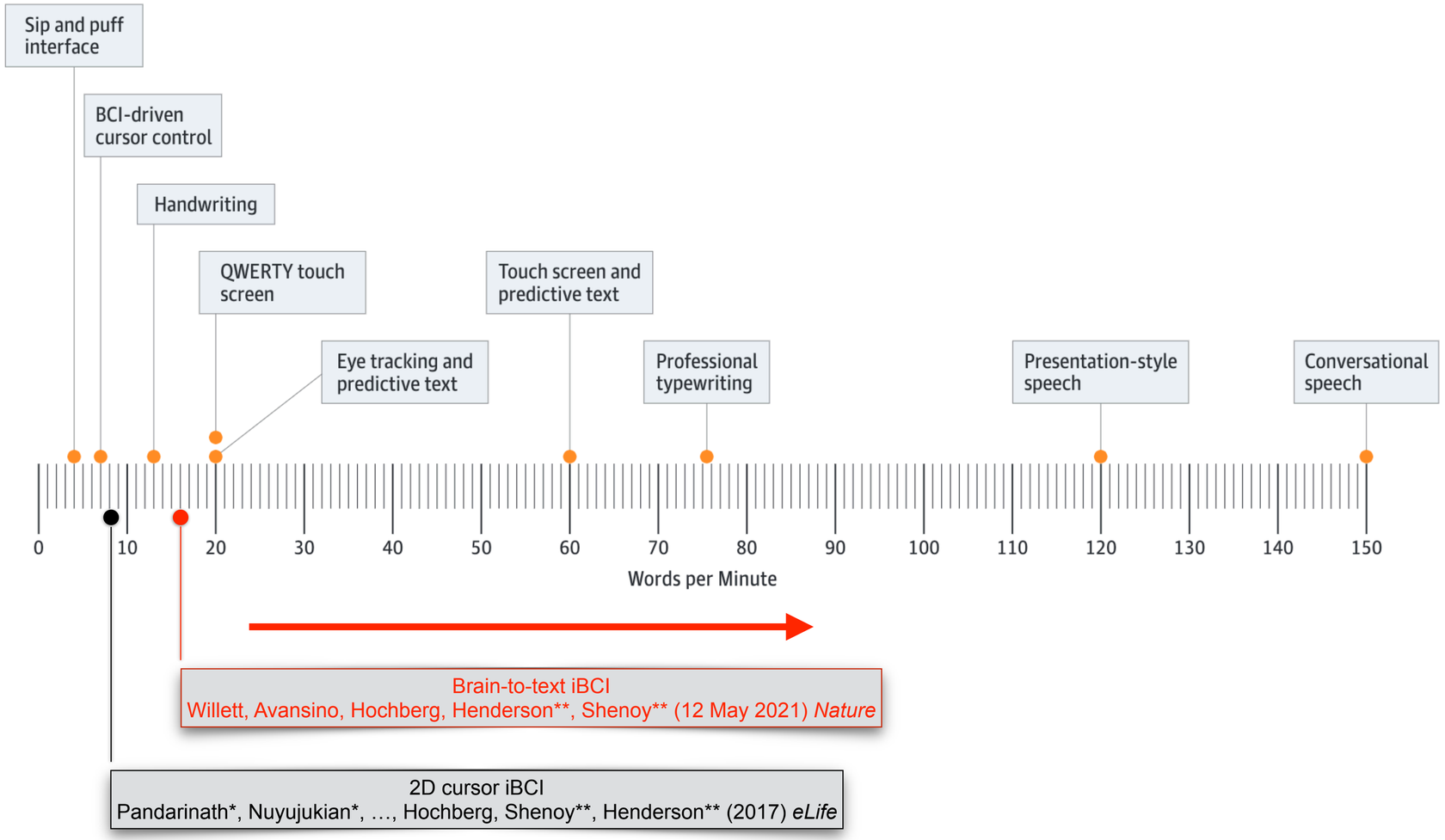




Nuyujukian*, Sanabria* Saab* et al. (2018) *PLoS One*

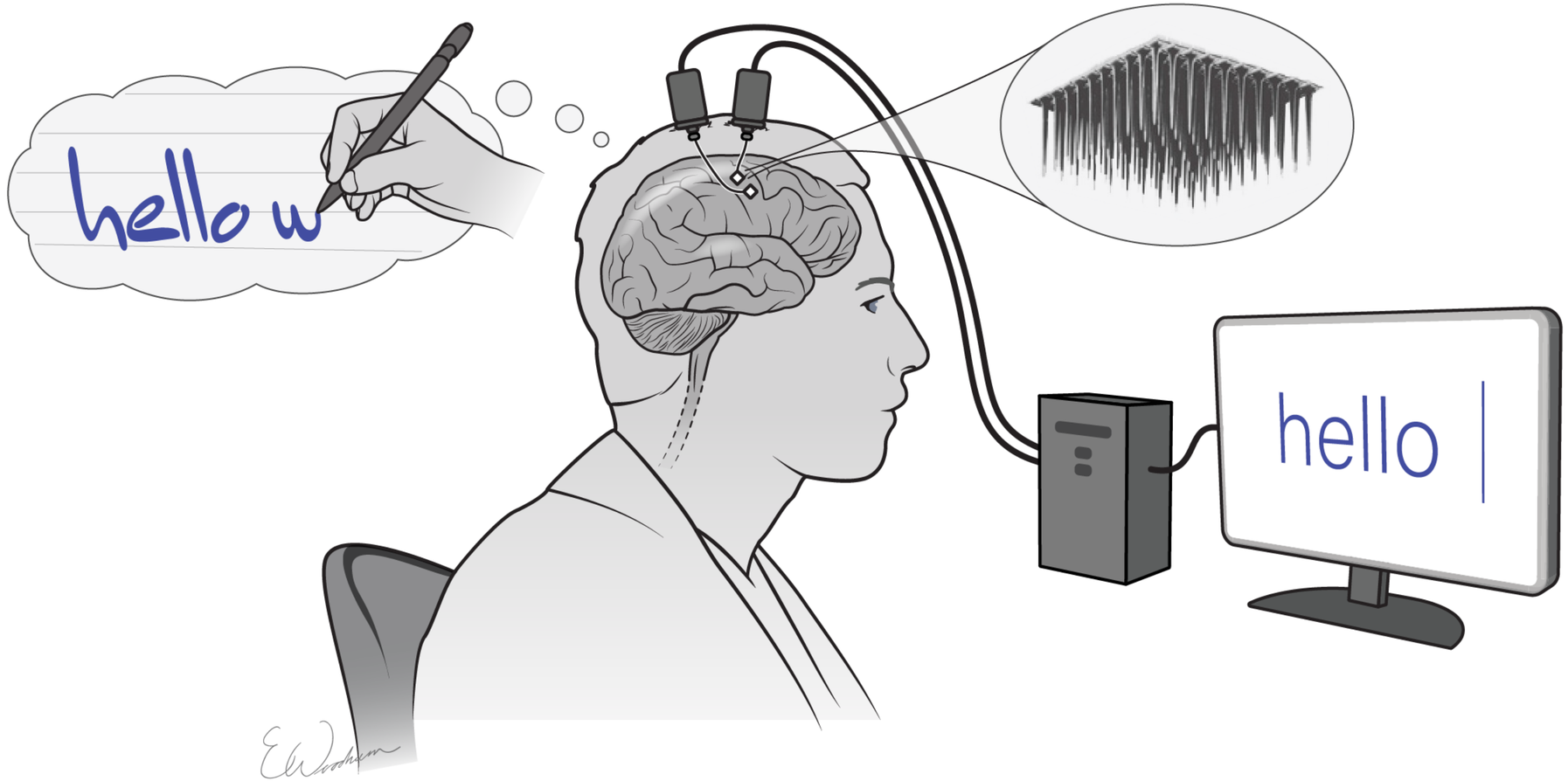
BrainGate2 Neural Interface System. CAUTION: Investigational Device. Limited by US Federal Law to Investigational Use

Increasing the performance of iBCIs with rapid and dexterous behaviors



Chang & Anumanchipalli (2019) *JAMA*

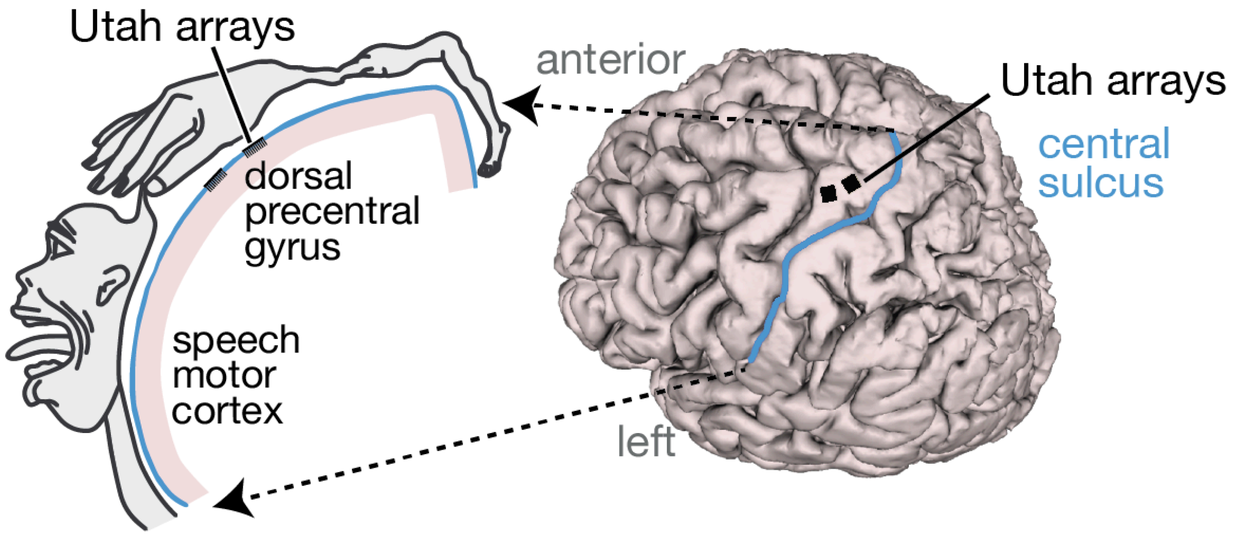
System Overview

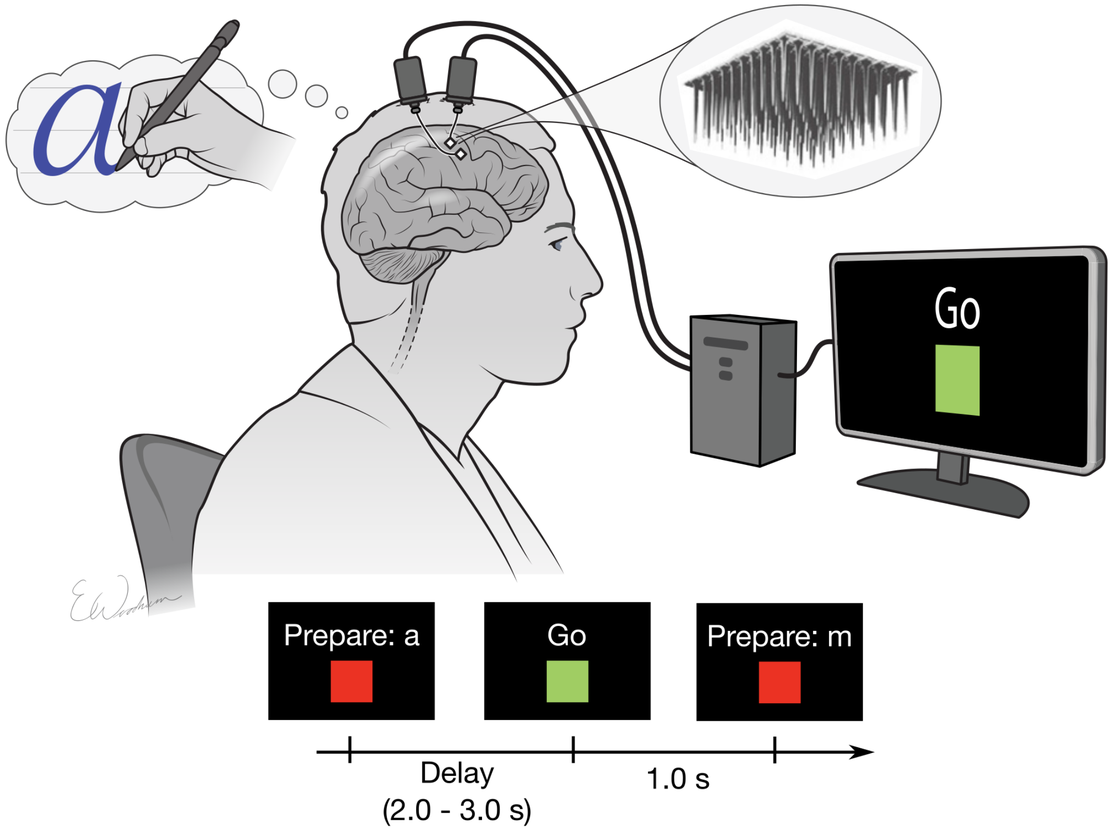


Willett, Avansino, Hochberg, Henderson**, Shenoy** (2021) High-performance brain-to-text communication via imagined handwriting. *Nature.*

Neural Representation of Handwriting

Does the neural representation of handwriting remain intact years after paralysis?



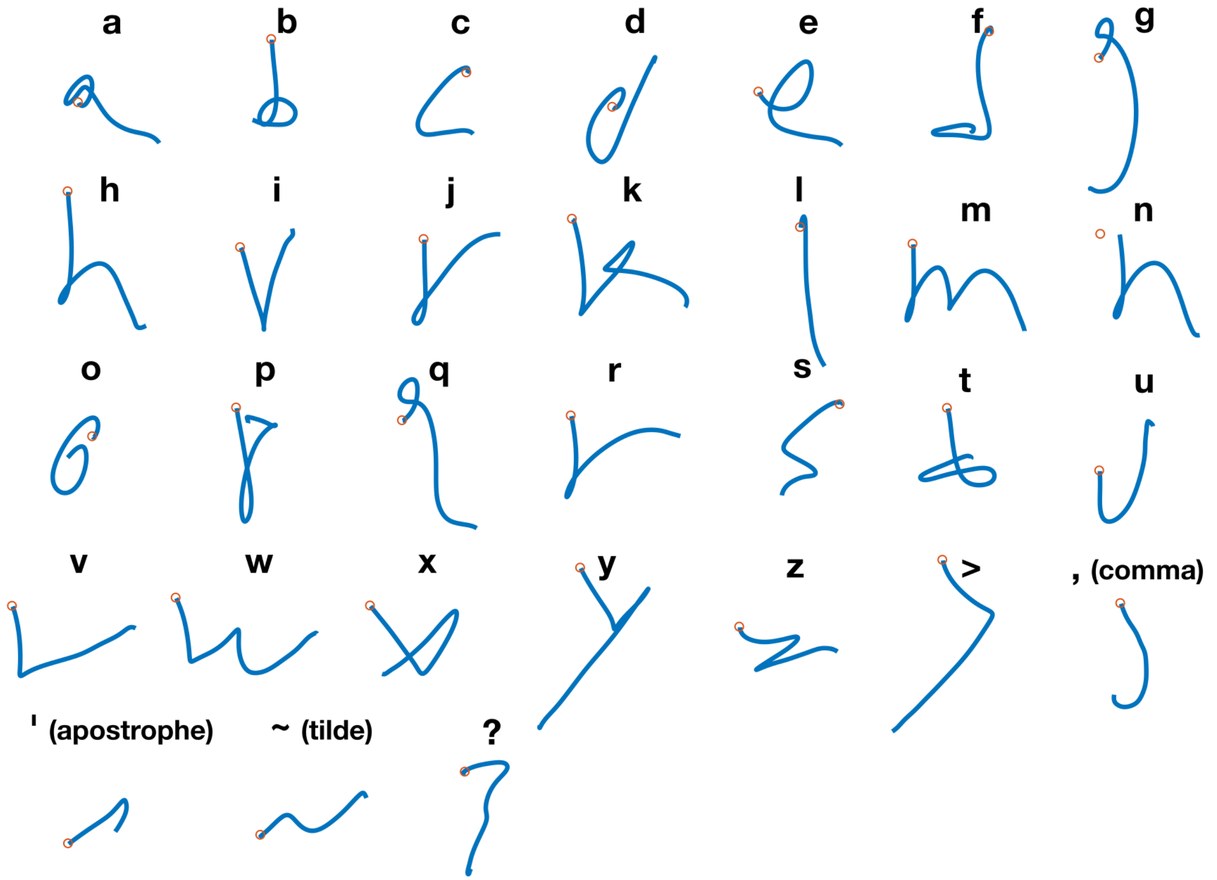


Neural Representation of Handwriting

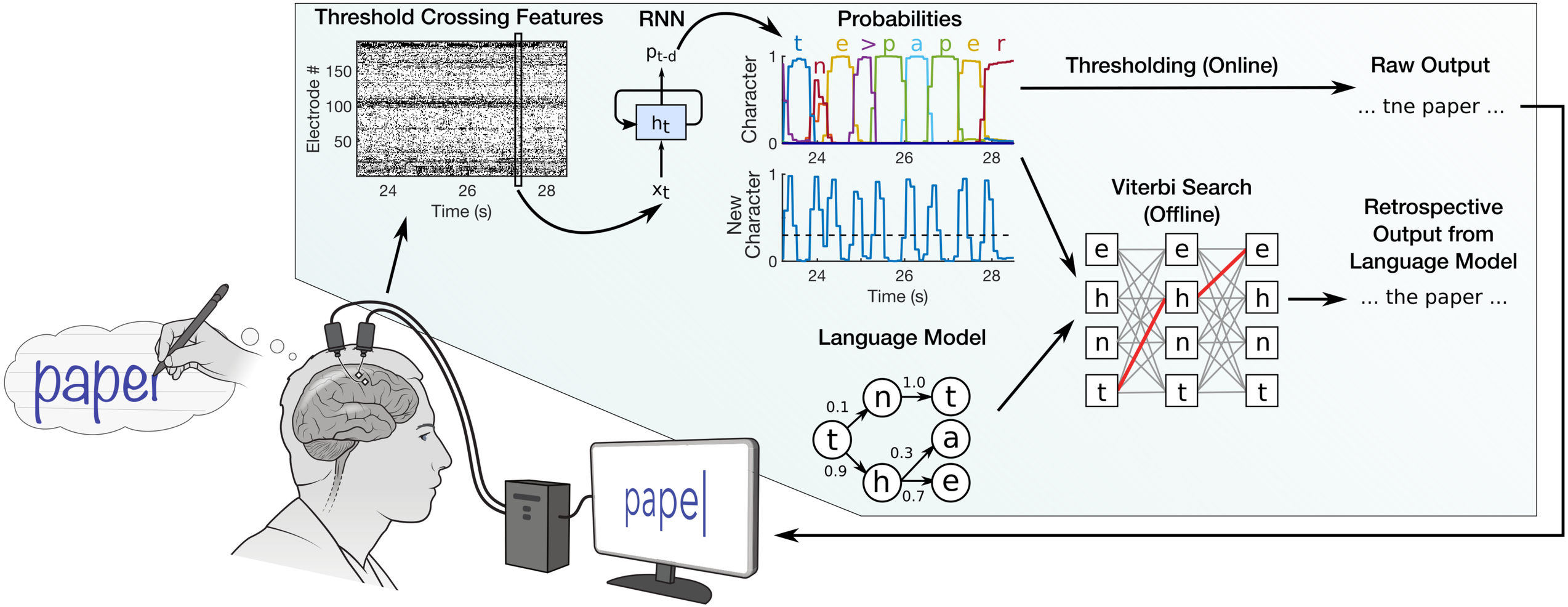
Can we reconstruct the imagined pen tip trajectory from the neural activity?

$$v_t = D f_t$$

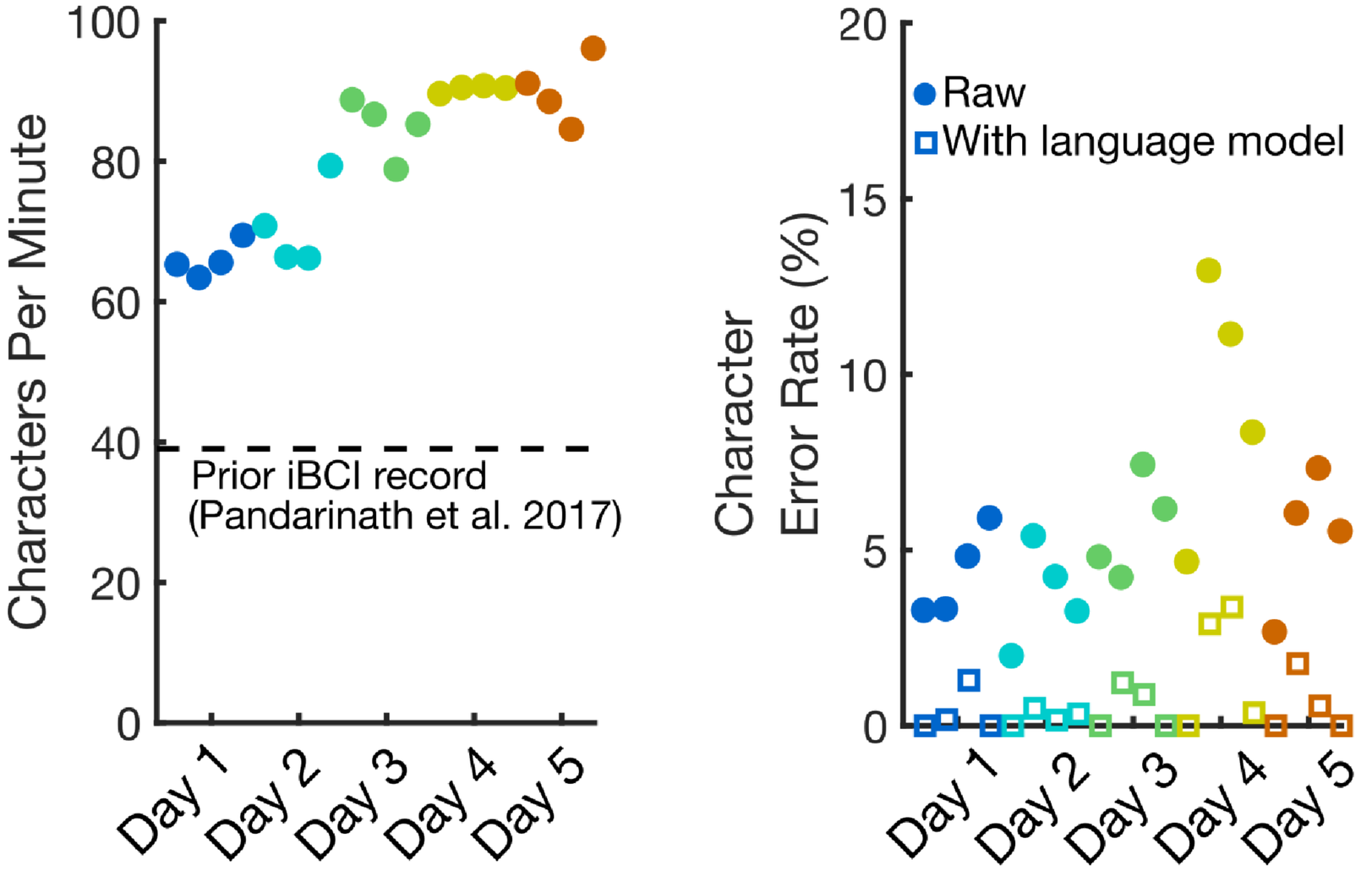
Pen tip velocity Vector 2 x 1	Linear decoding Matrix 2 x 192	Firing rate vector 192 x 1



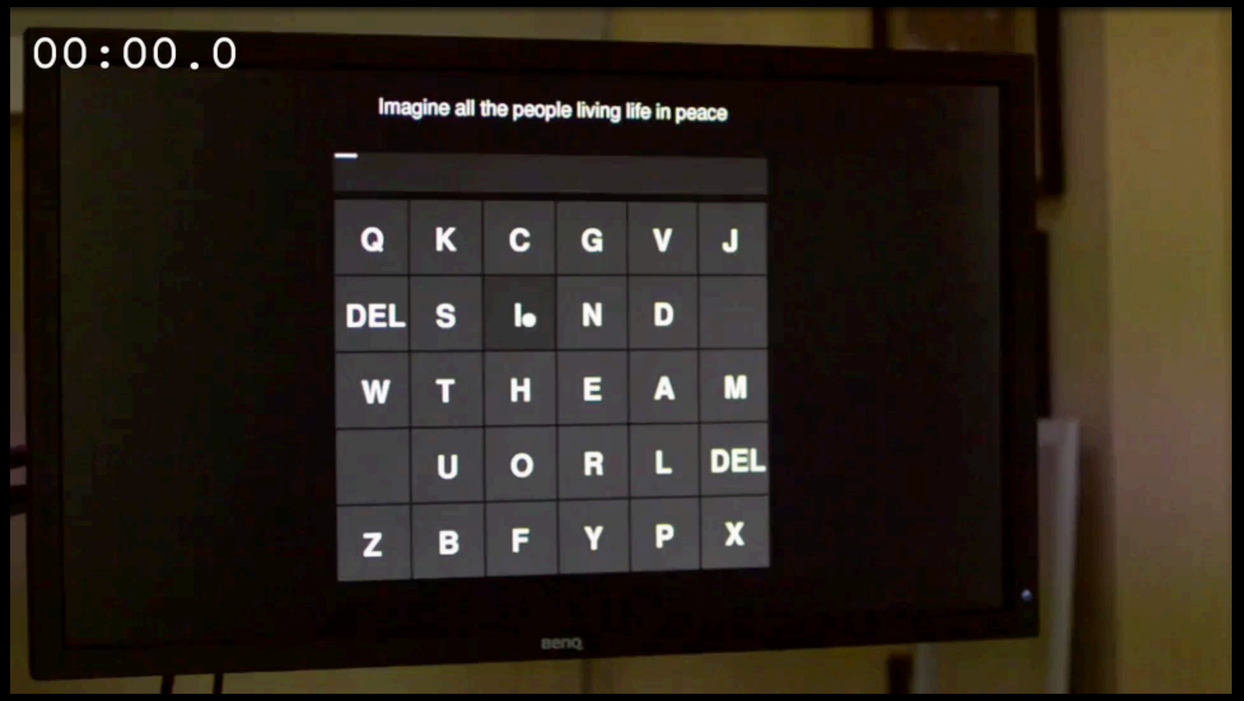
Handwriting iBCI System Diagram

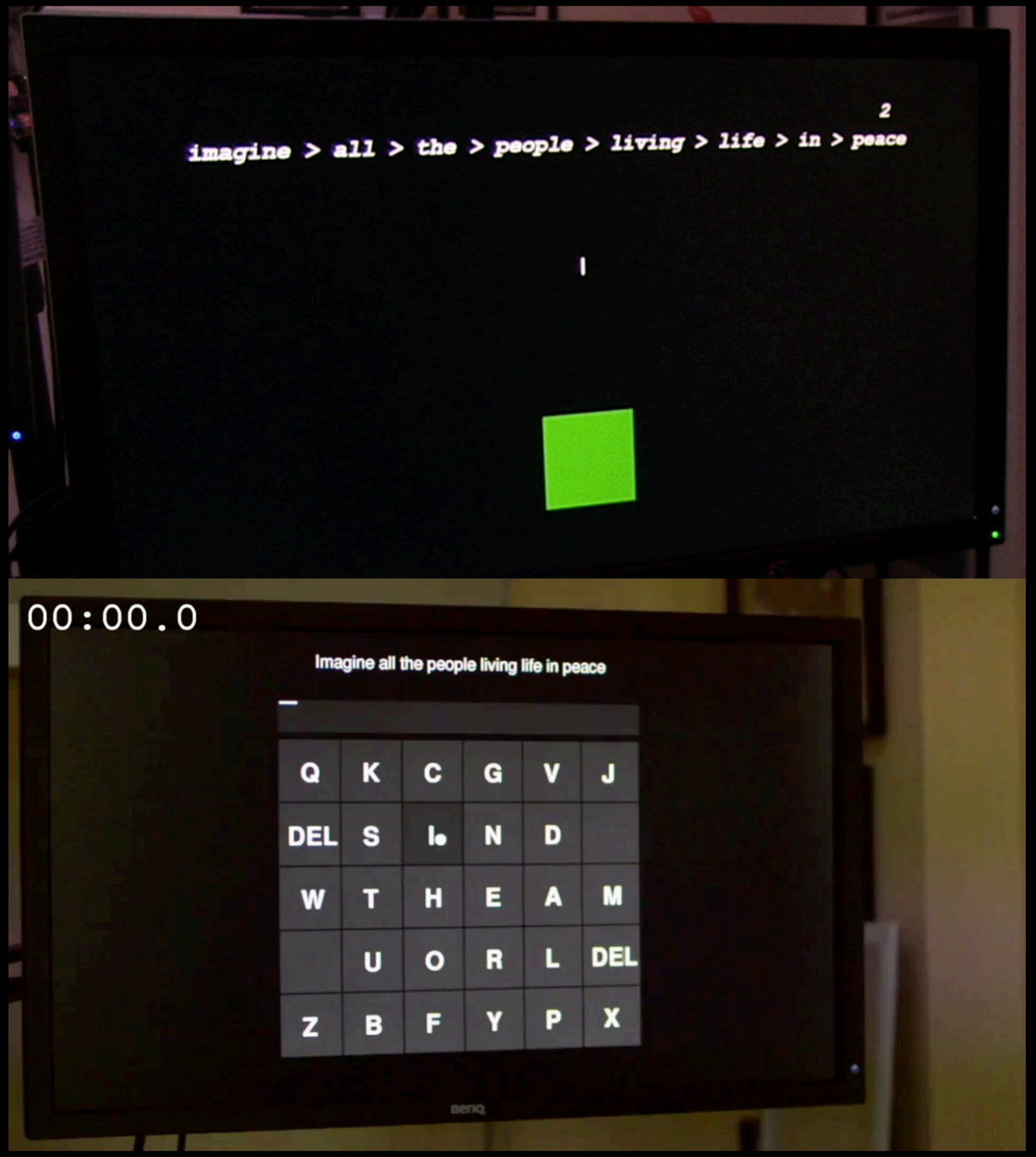


Copy Typing Performance

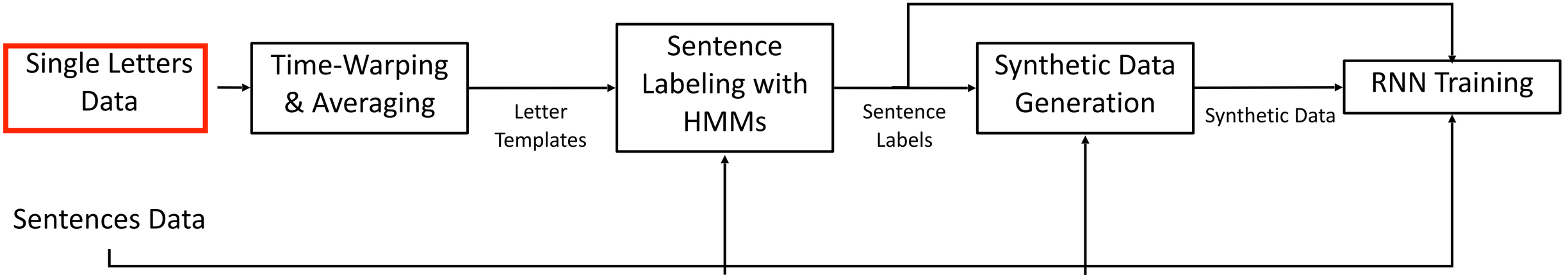


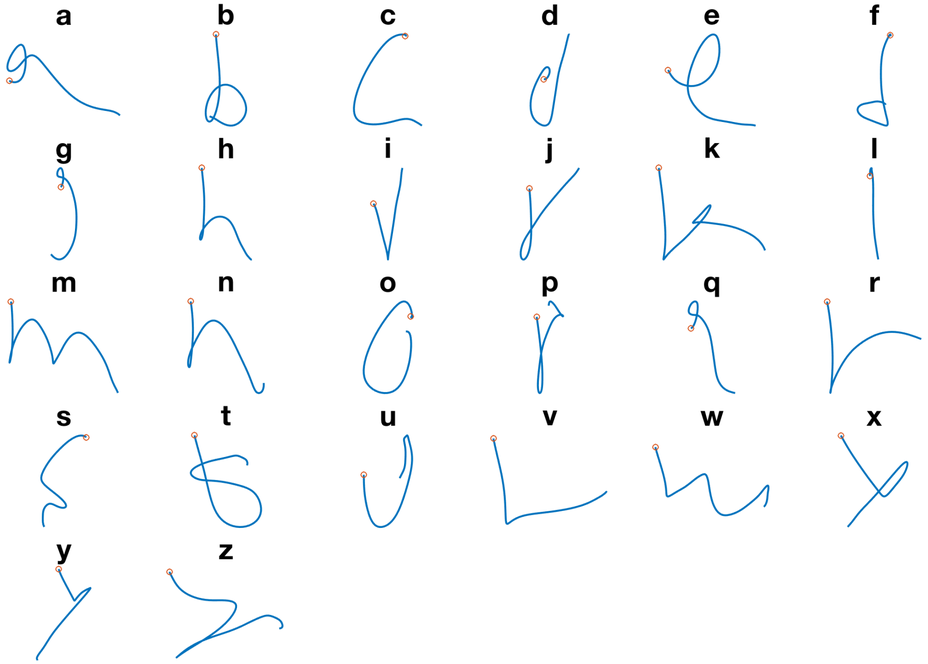
Willett, Avansino, Hochberg, Henderson**, Shenoy** (2021) High-performance brain-to-text communication via imagined handwriting. *Nature.*


00:00.0
Imagine all the people living life in peace
Q K C G V J
DEL S I N D
W T H E A M
U O R L DEL
Z B F Y P X
benq

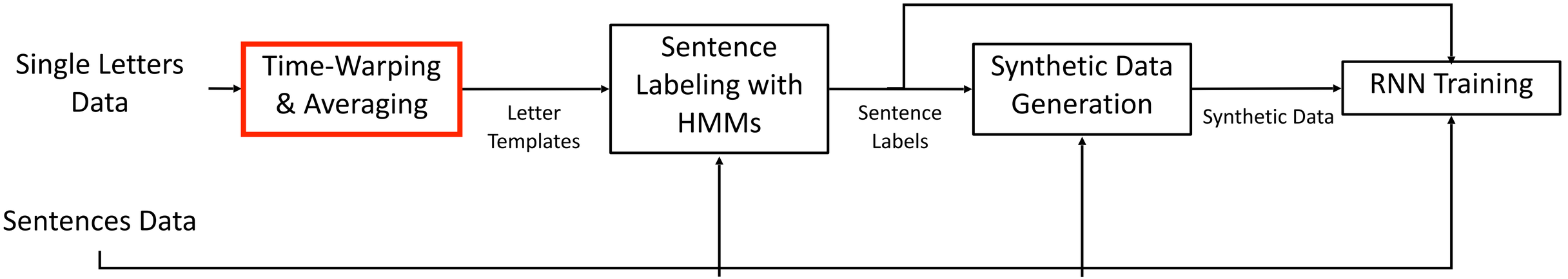

2
imagine > all > the > people > living > life > in > peace
I
00:00.0
Imagine all the people living life in peace
Q K C G V J
DEL S I N D
W T H E A M
U O R L DEL
Z B F Y P X
benq

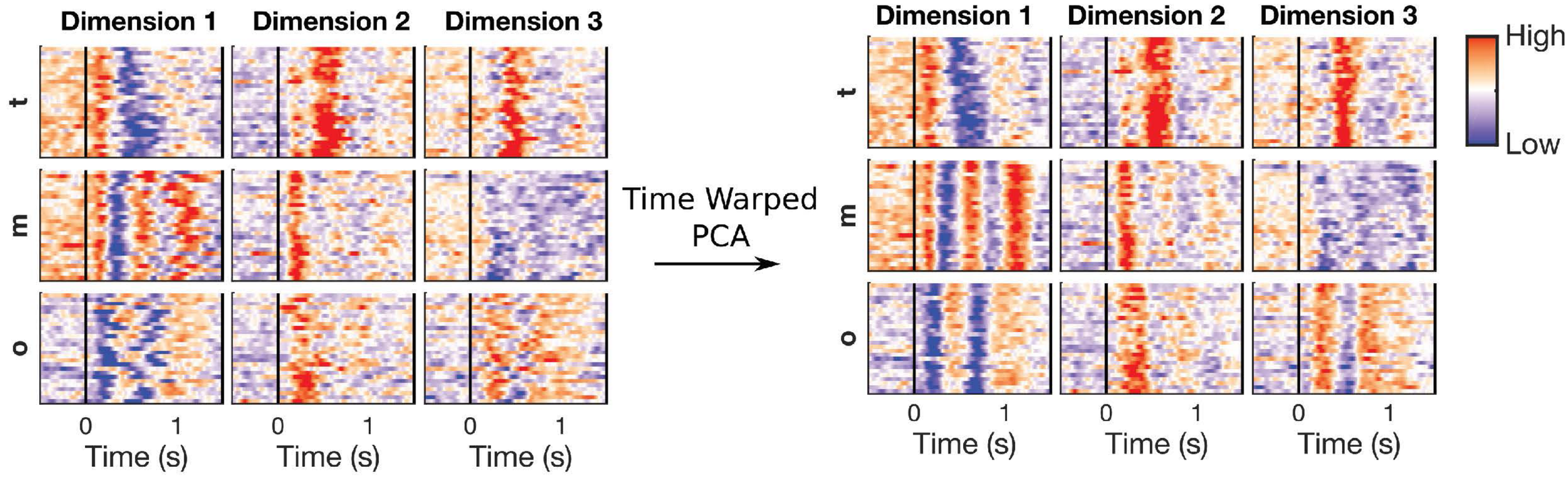
Data Processing Pipeline



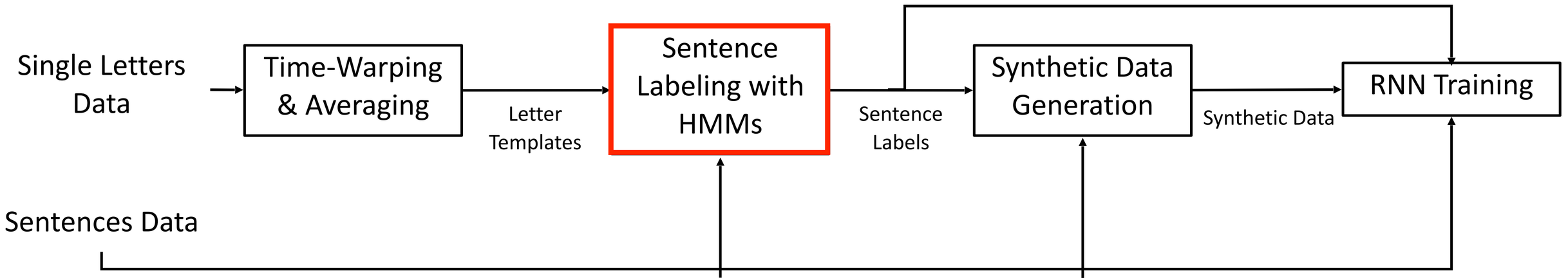


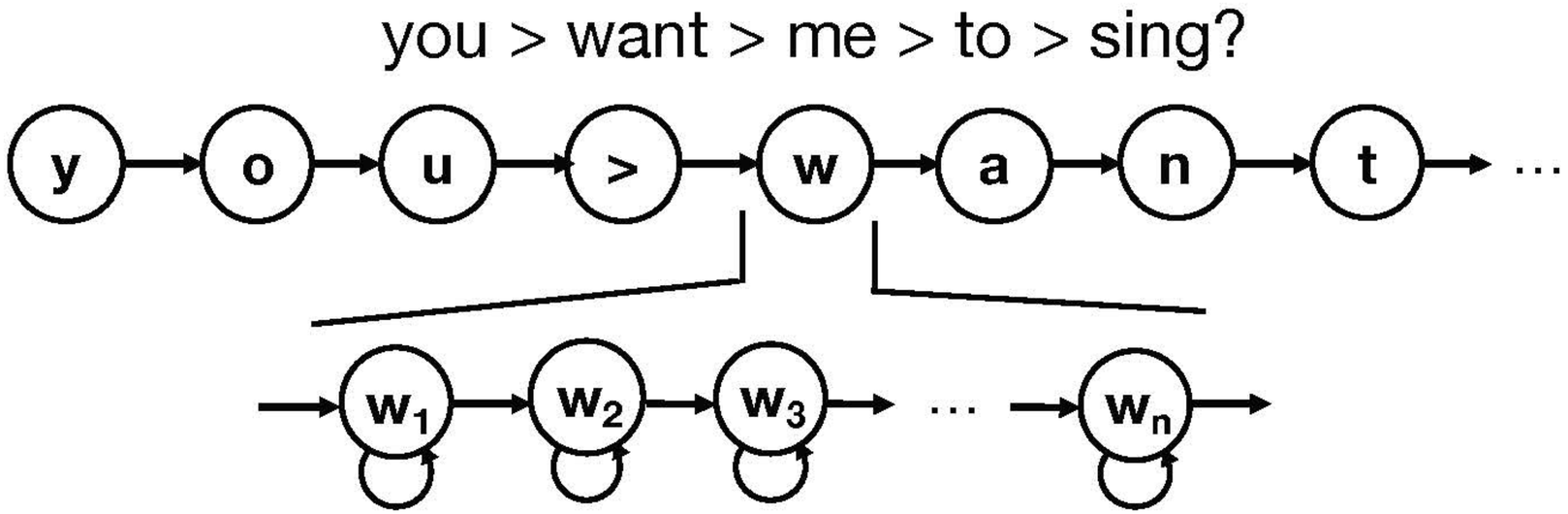
Data Processing Pipeline



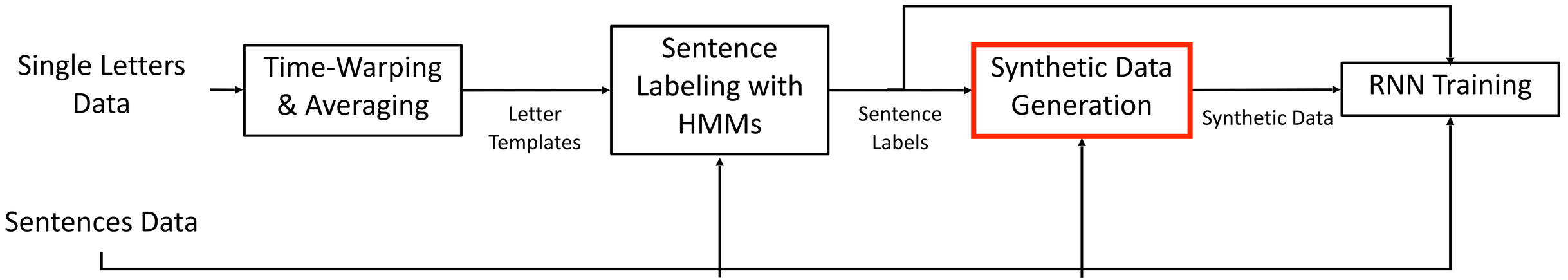


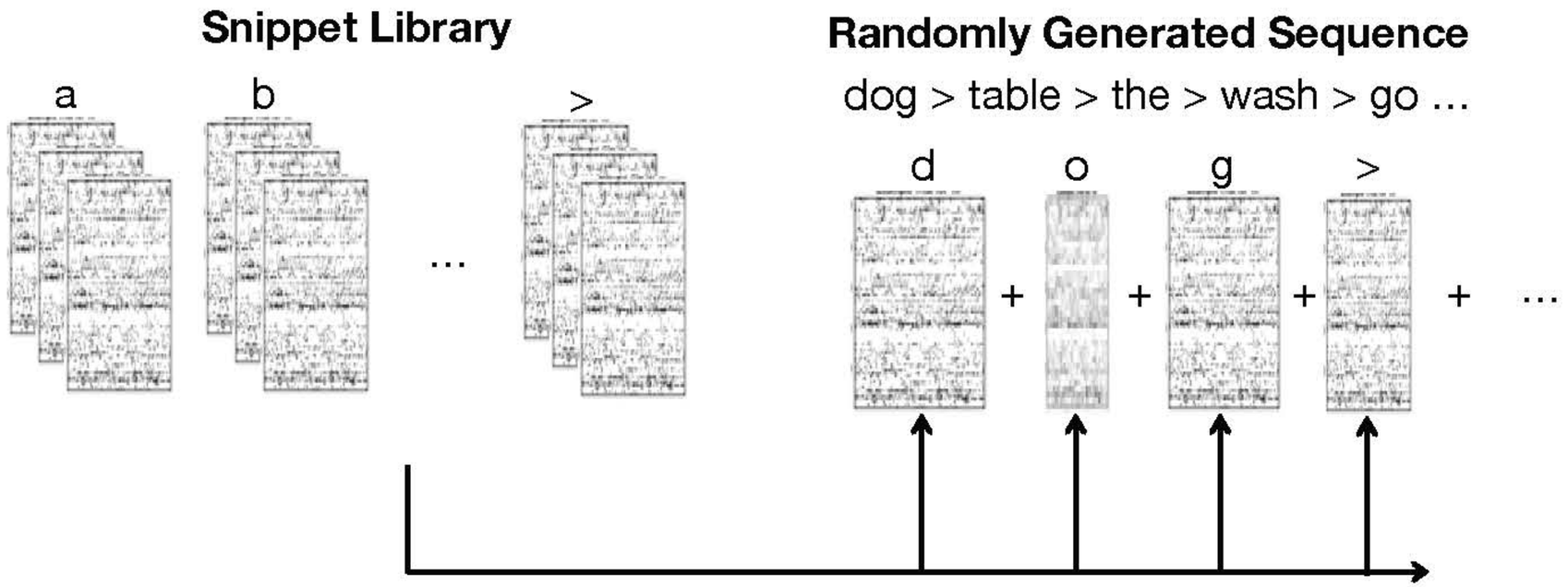
Data Processing Pipeline



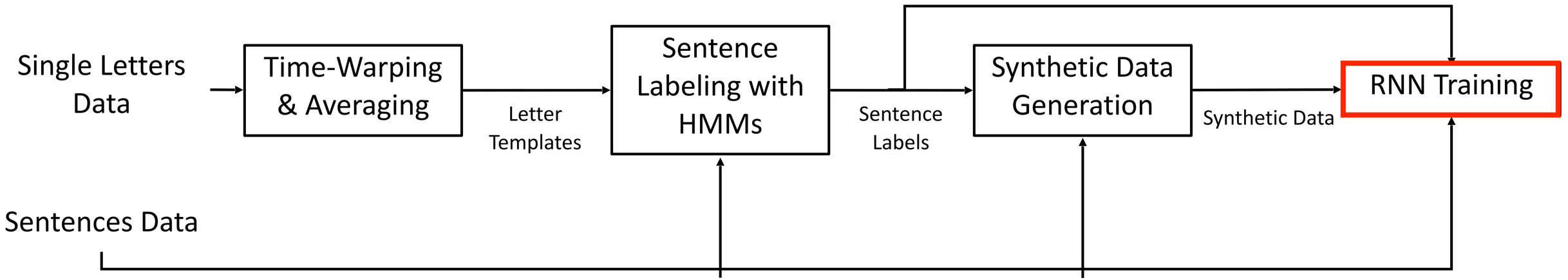


Data Processing Pipeline

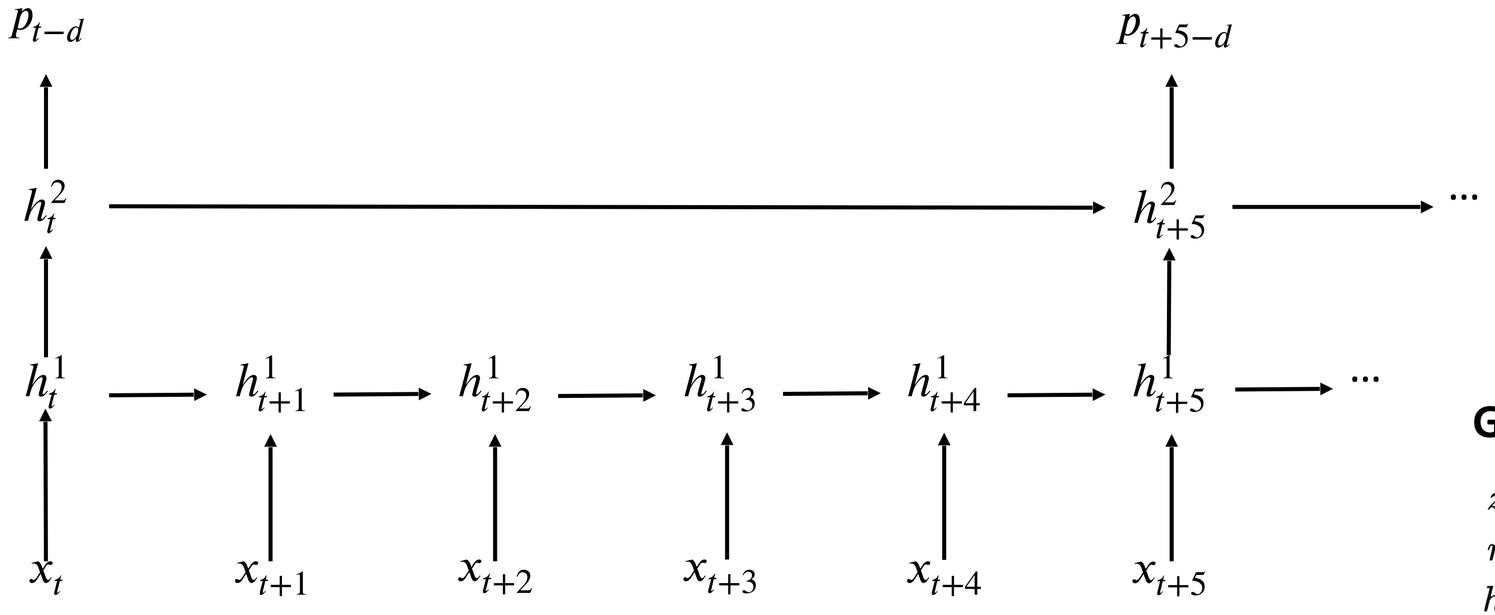




Data Processing Pipeline



RNN Architecture



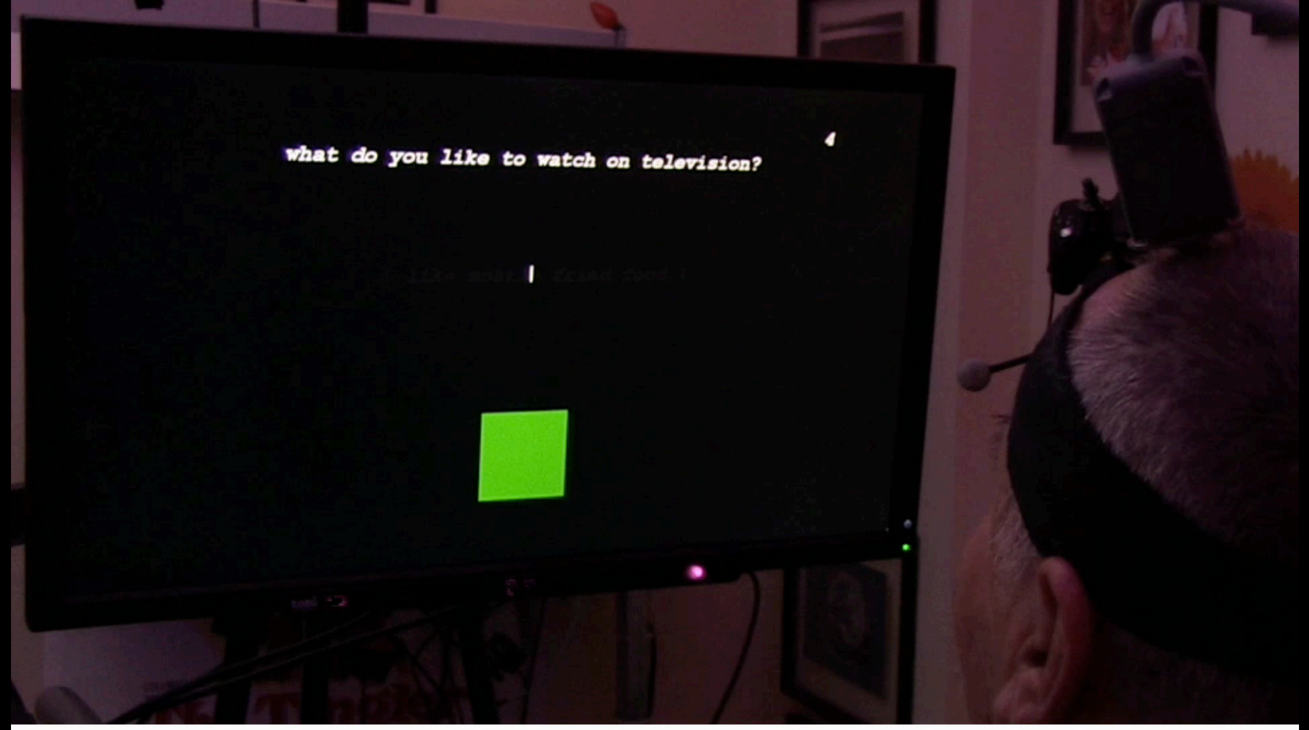
x_t : binned firing rate vector (20 ms)

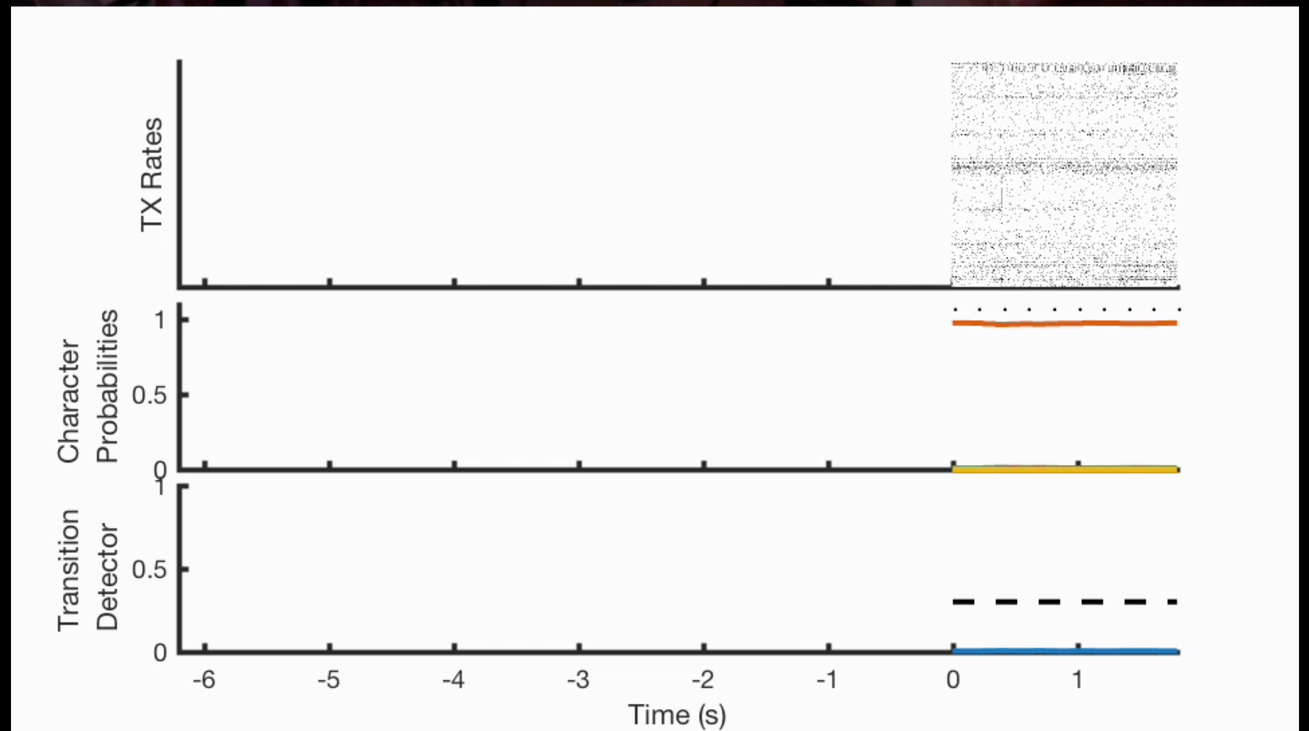
h_t : hidden unit vector (512 units)

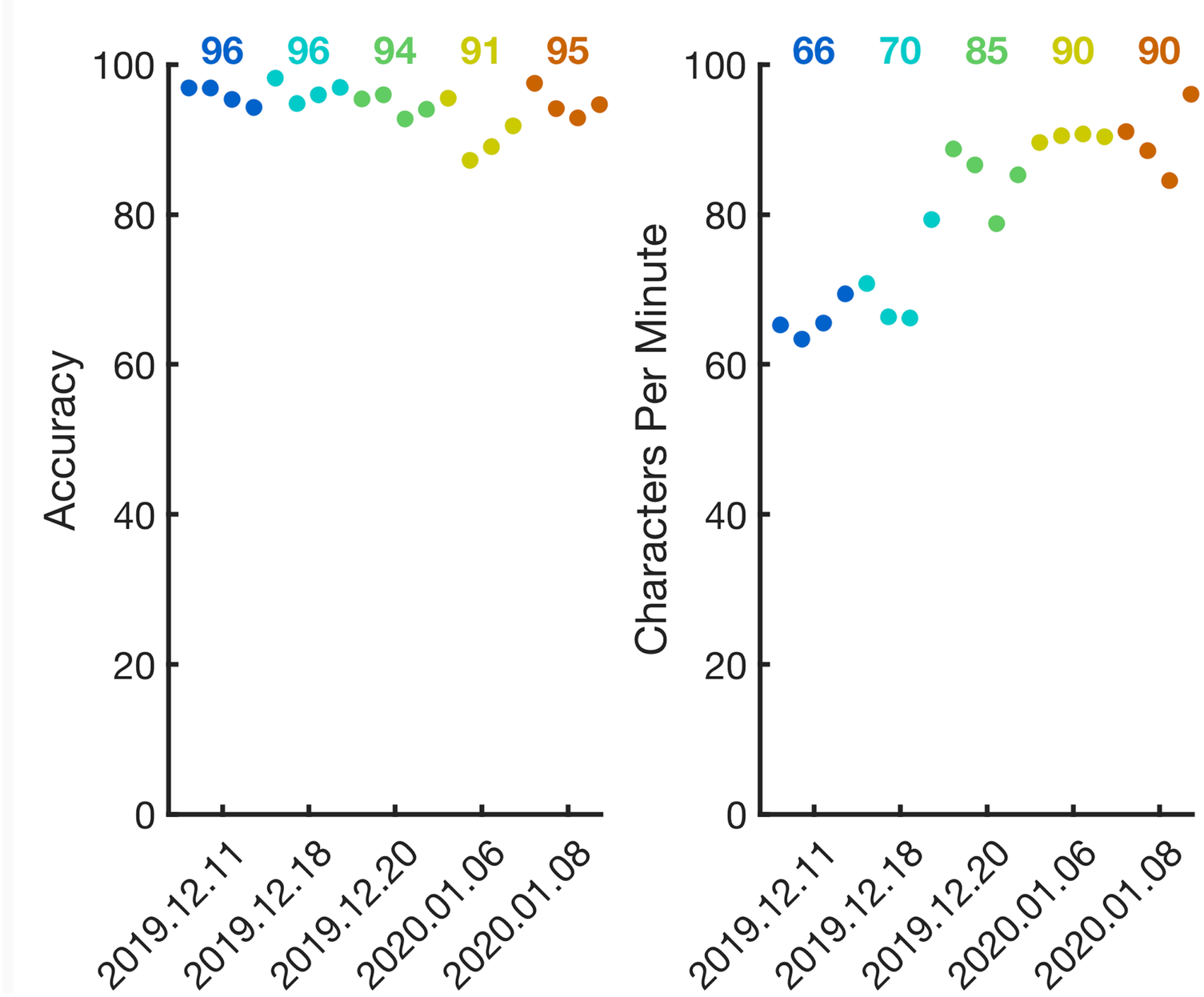
p_{t-d} : delayed character probabilities (1 s delay)

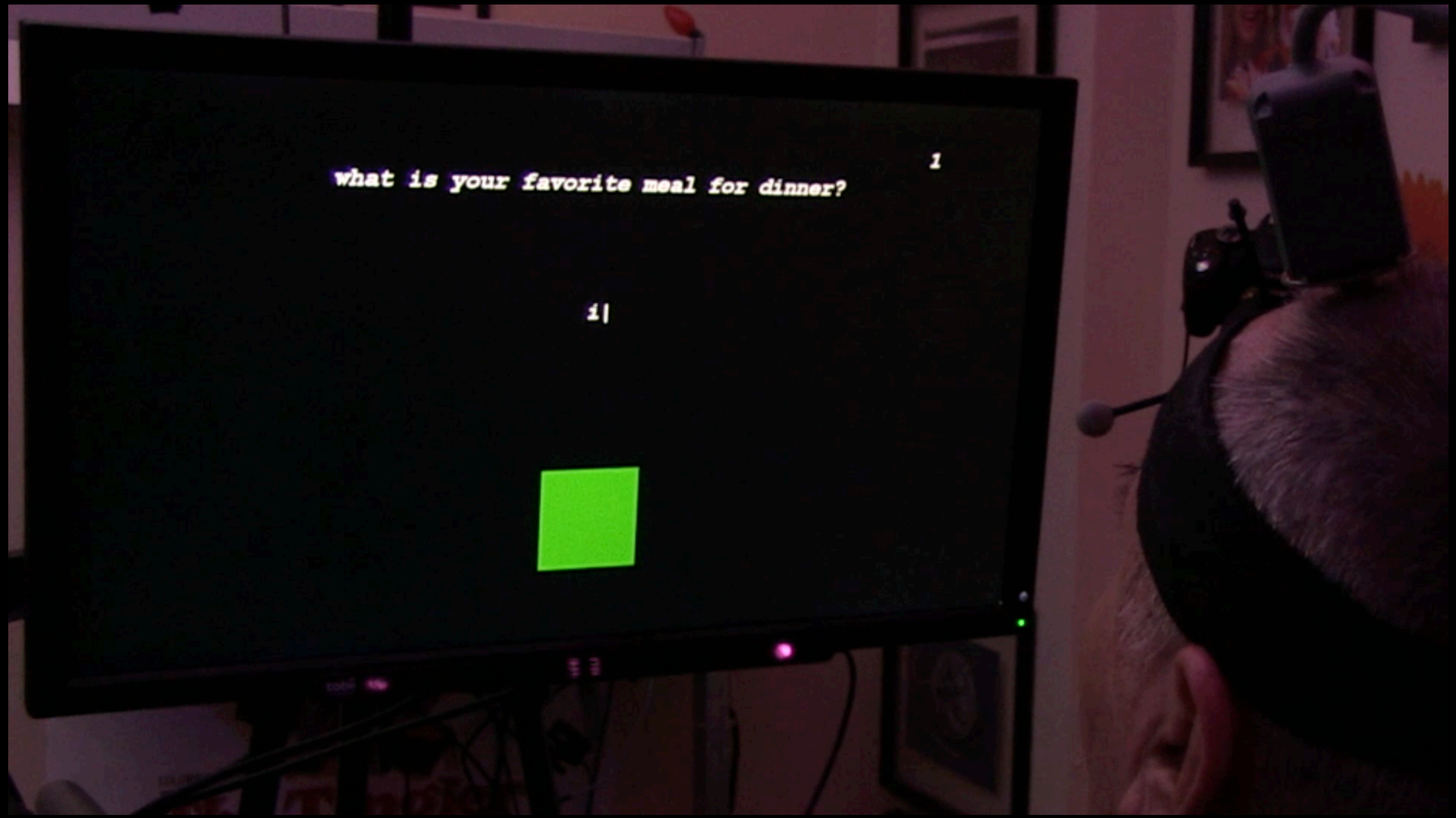
Gated Recurrent Unit:

$$z_t = \sigma_g(W_z x_t + U_z h_{t-1} + b_z)$$
$$r_t = \sigma_g(W_r x_t + U_r h_{t-1} + b_r)$$
$$h_t = (1 - z_t) \circ h_{t-1} + z_t \circ \sigma_h(W_h x_t + U_h(r_t \circ h_{t-1}) + b_h)$$


what do you like to watch on television?


TX Rates
Character Probabilities
1
0.5
0
Transition Detector
1
0.5
0
-6
-5
-4
-3
-2
-1
0
1
Time (s)


96
96
94
91
95
Accuracy
100
80
60
40
20
0
2019.12.11
2019.12.18
2019.12.20
2020.01.06
2020.01.08
66
70
85
90
90
Characters Per Minute
100
80
60
40
20
0
2019.12.11
2019.12.18
2019.12.20
2020.01.06
2020.01.08

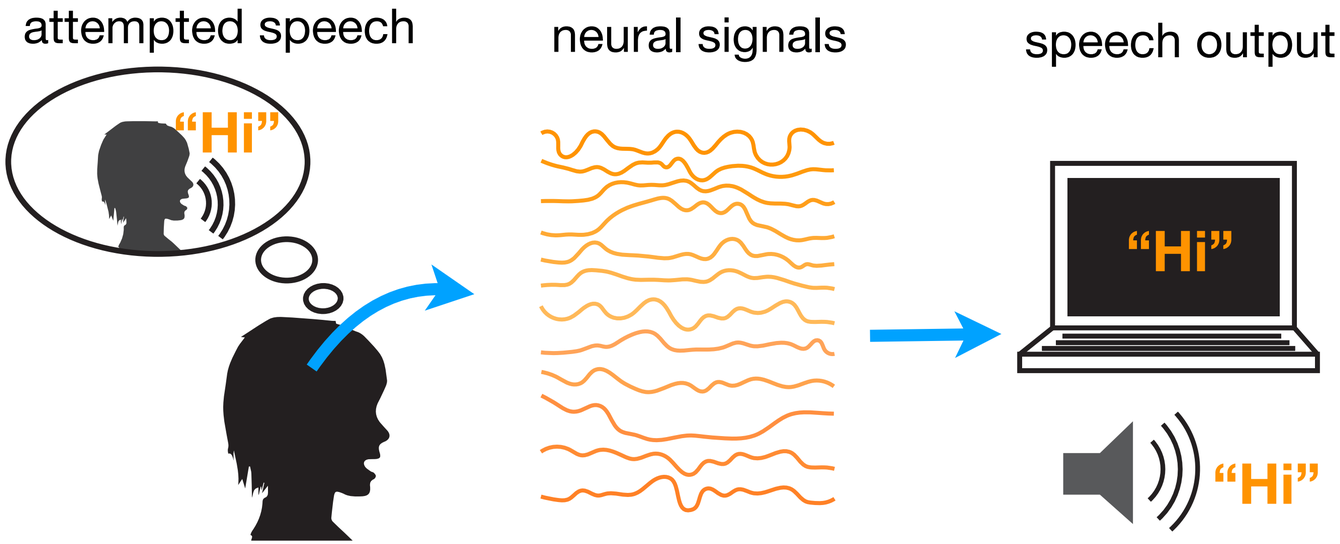

1
what is your favorite meal for dinner?
i

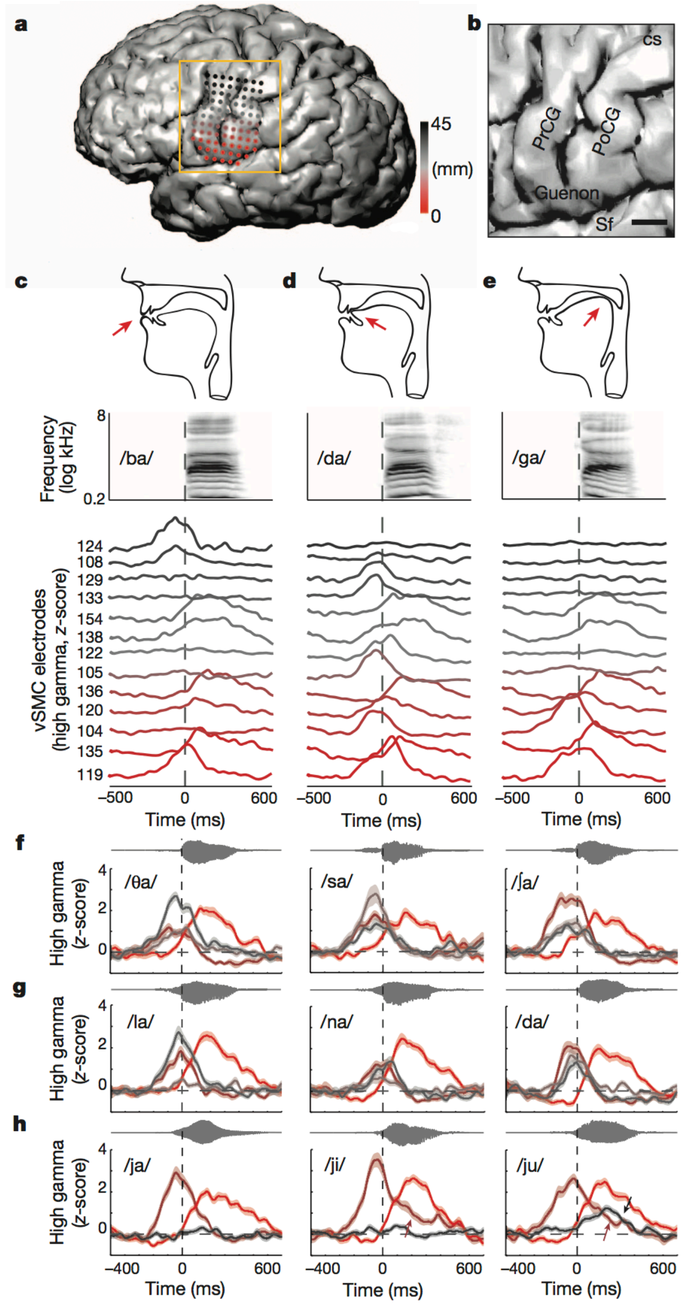
Studying the Neural Bases of Speech in People

1. Fundamental neuroscience of an exquisite motor control problem.

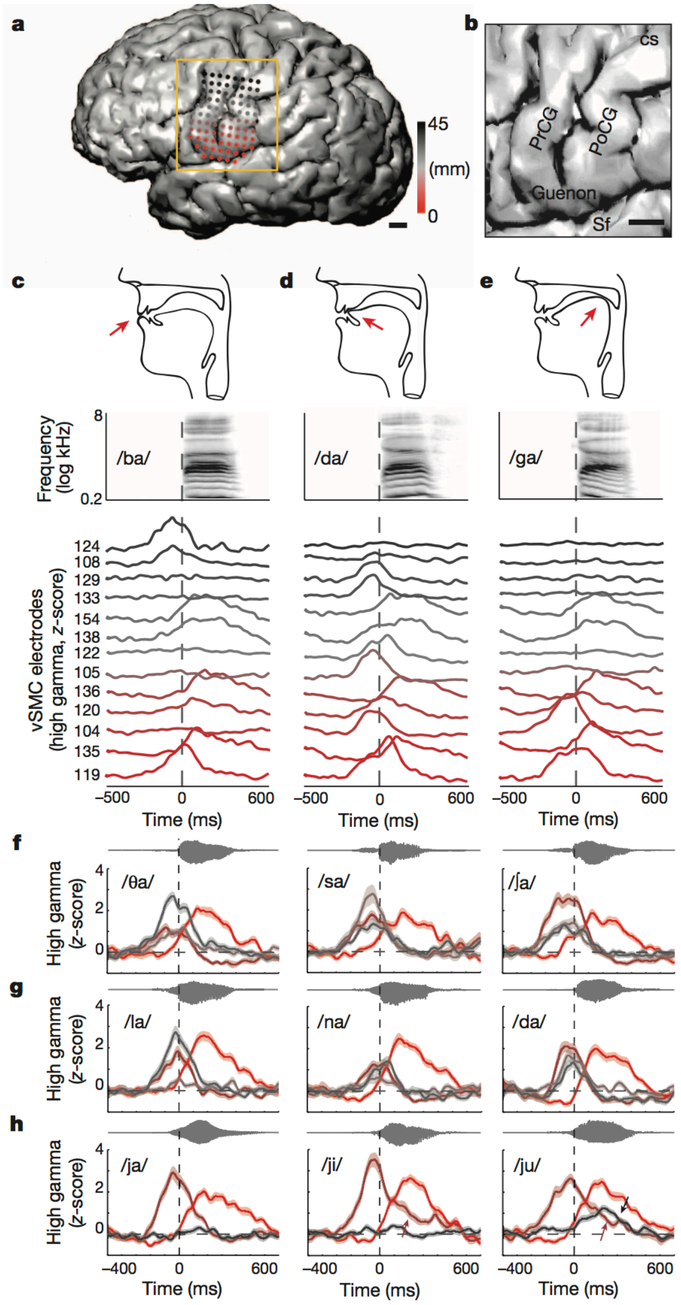
Uecker et al. (2010) *NMR in Biomed.*

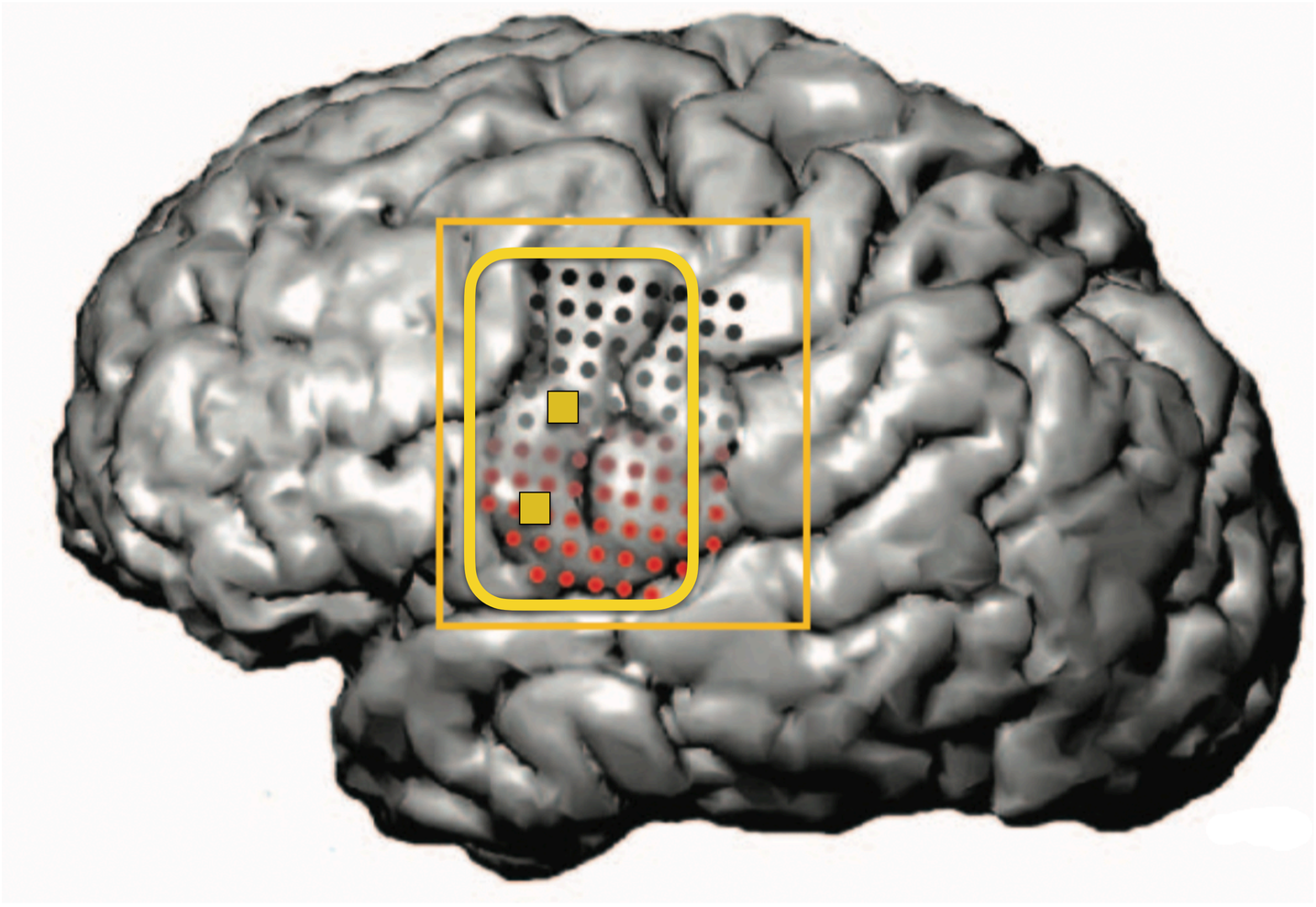
2. Translational need for speech BMIs for patients who cannot speak.



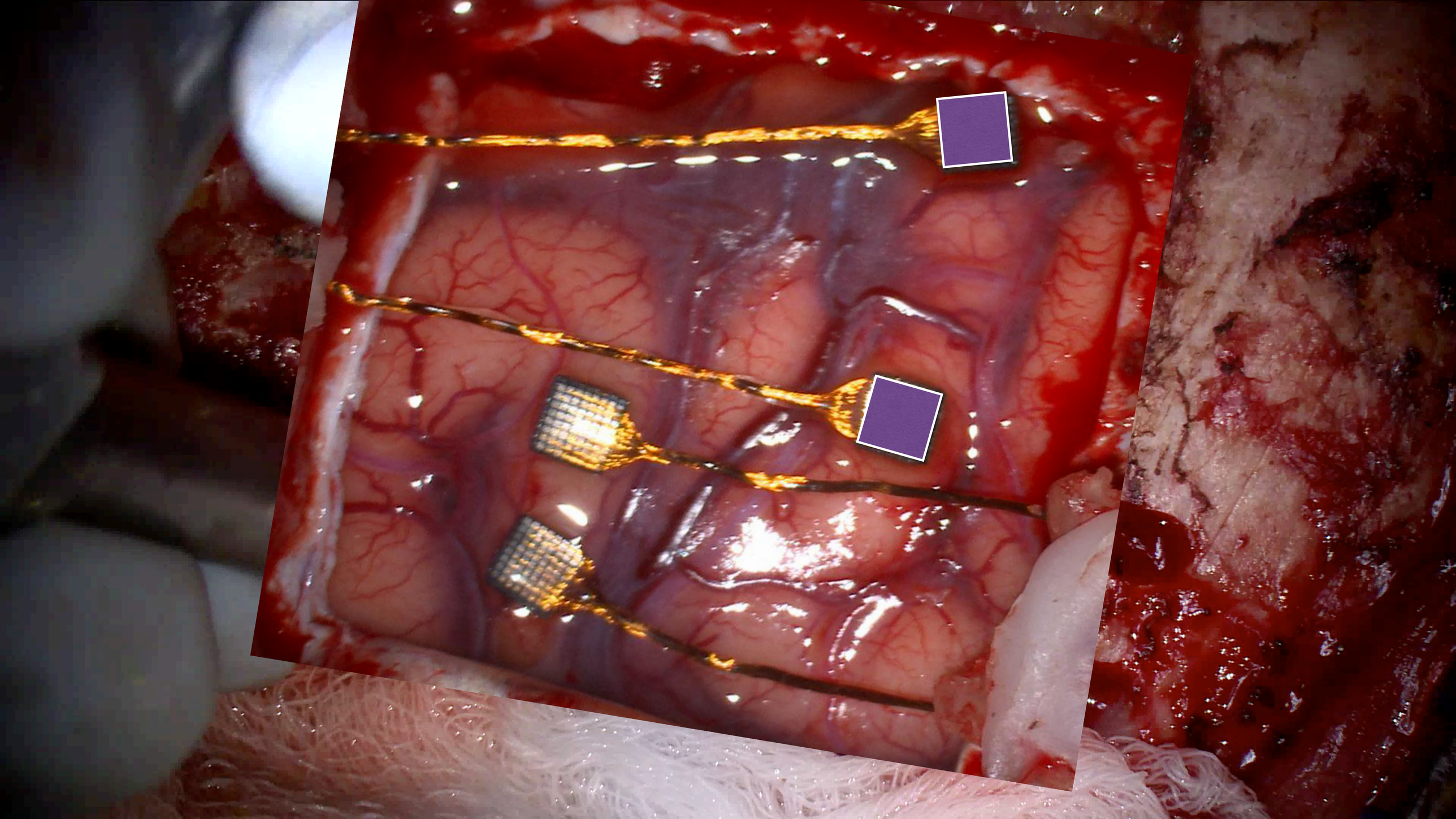


Bouchard et al. (2013) *Nature*

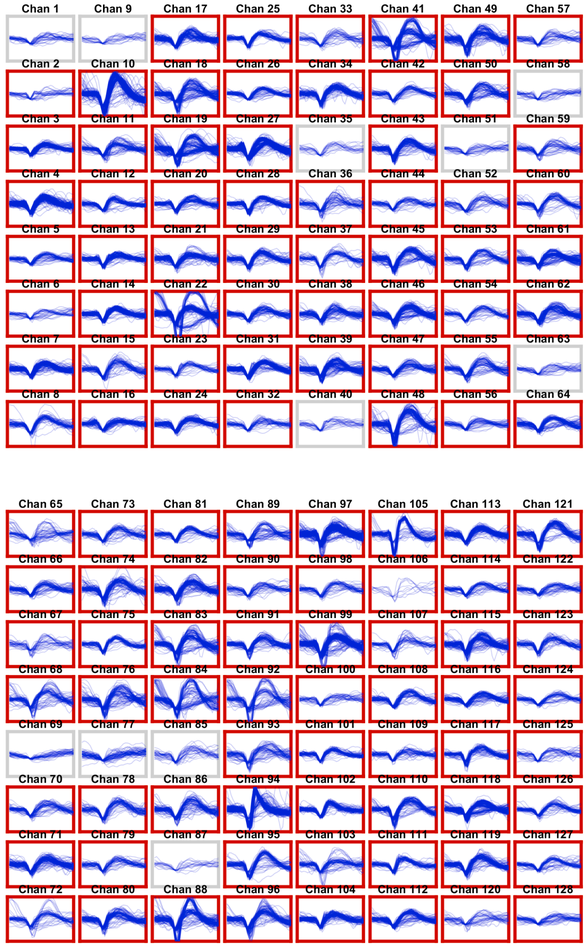


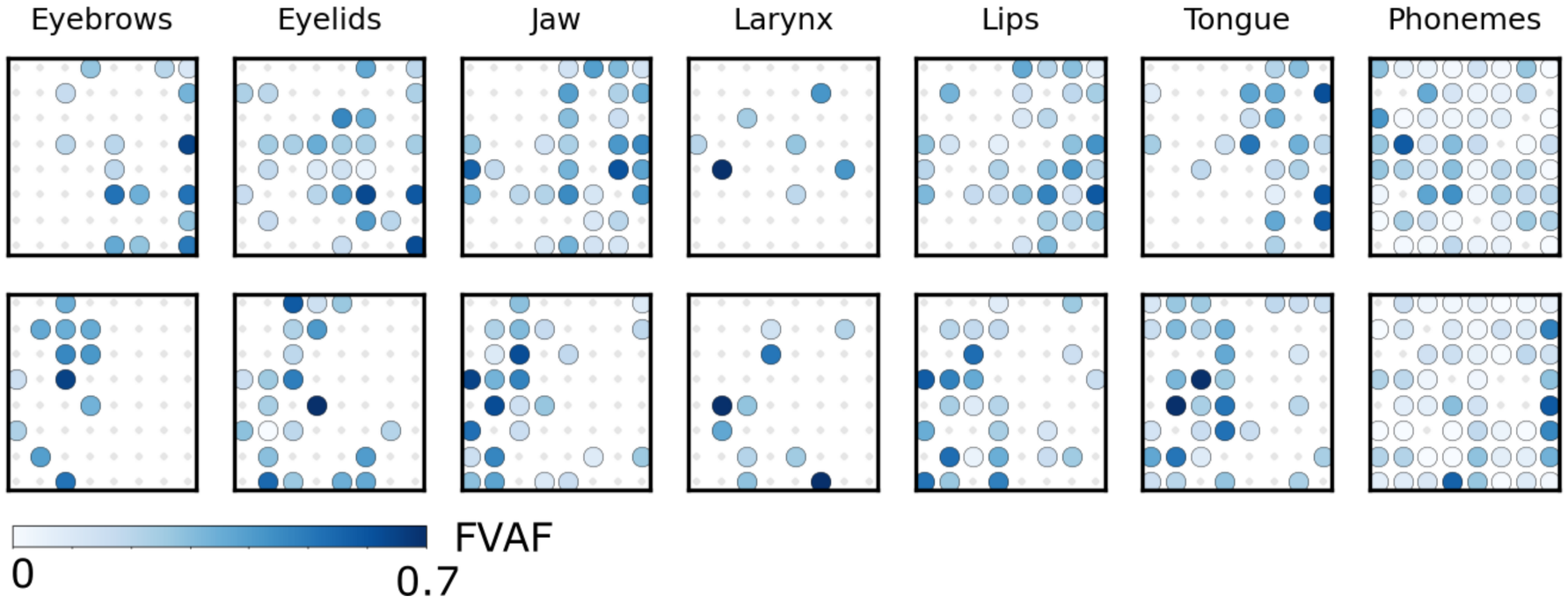


Bouchard et al. (2013) *Nature*

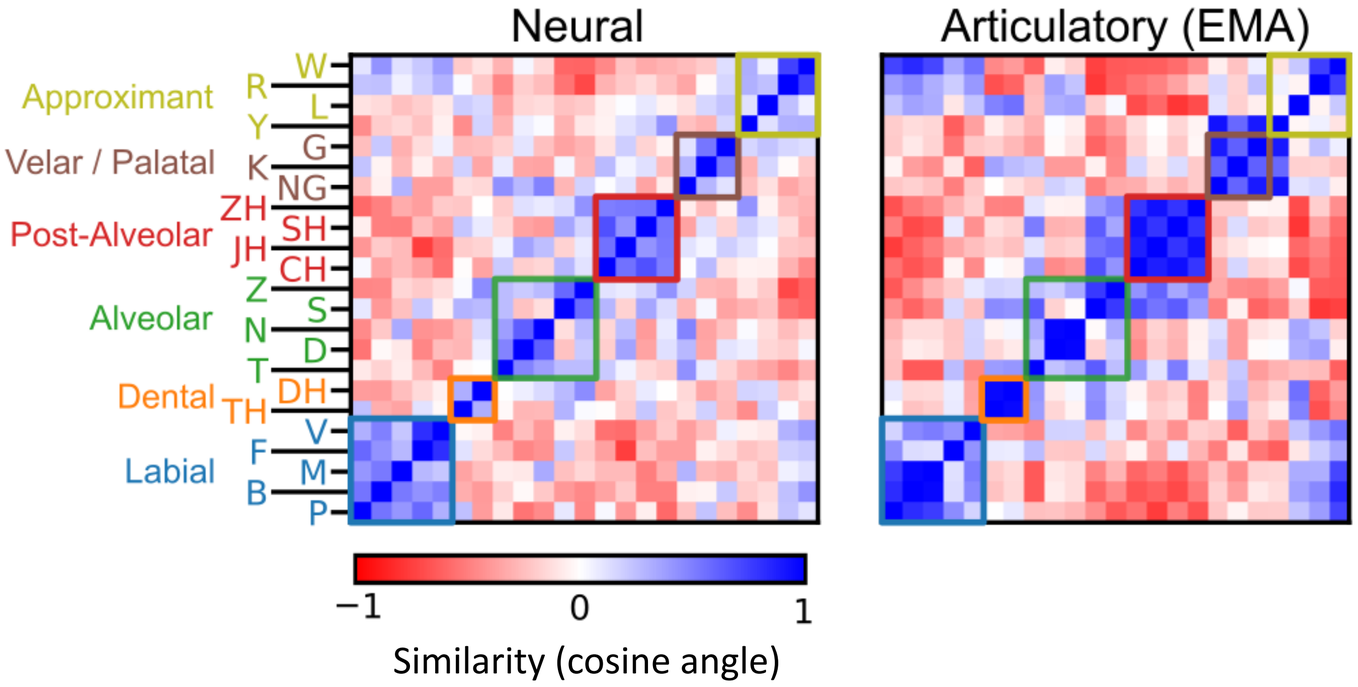


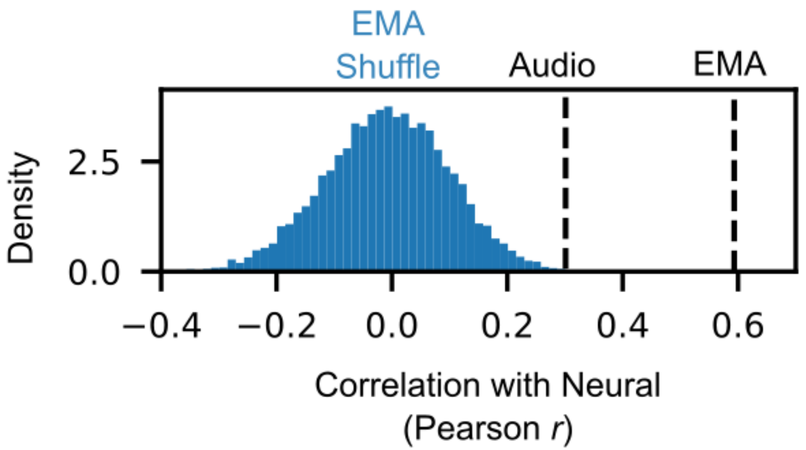
Dense Spatial Intermixing

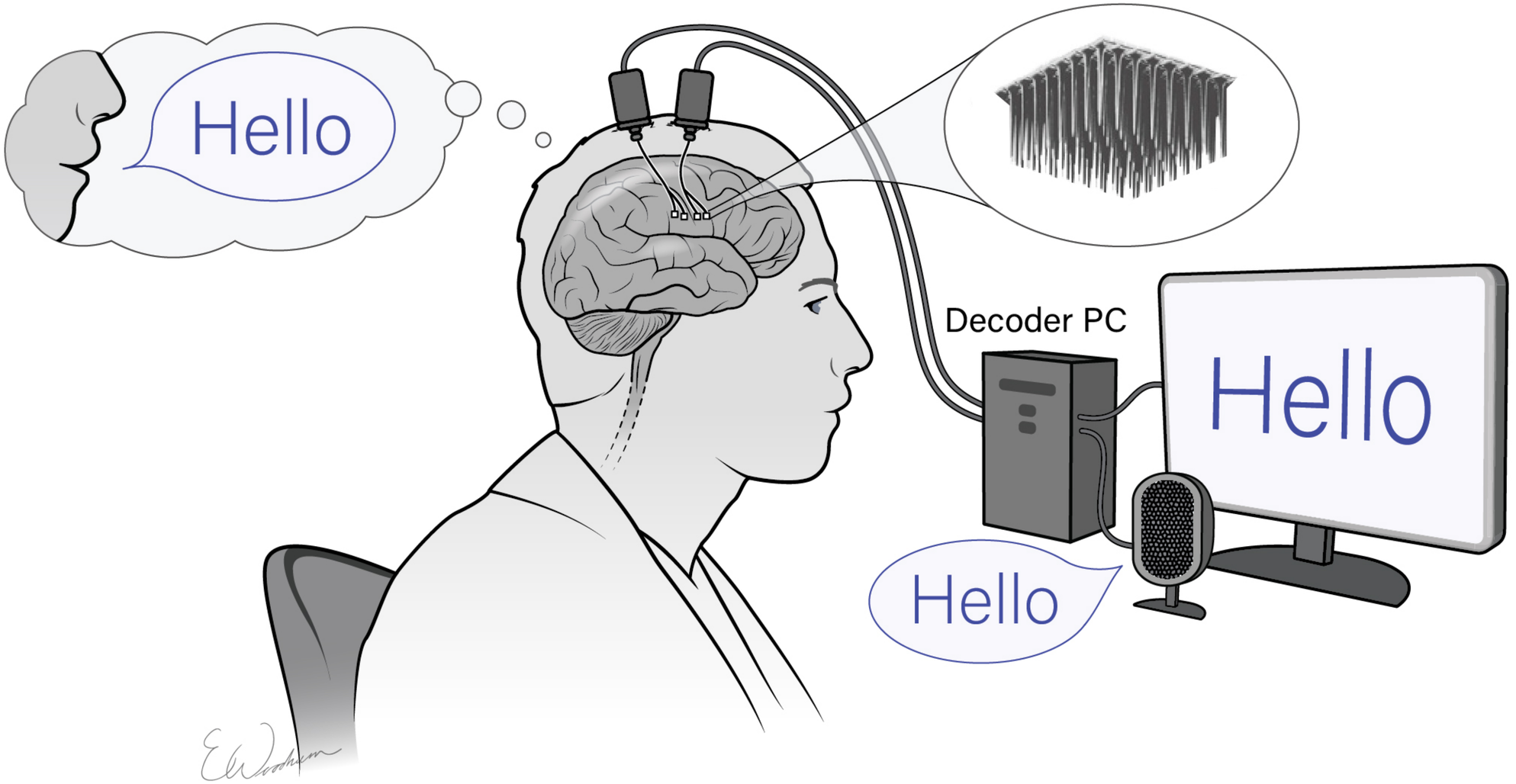




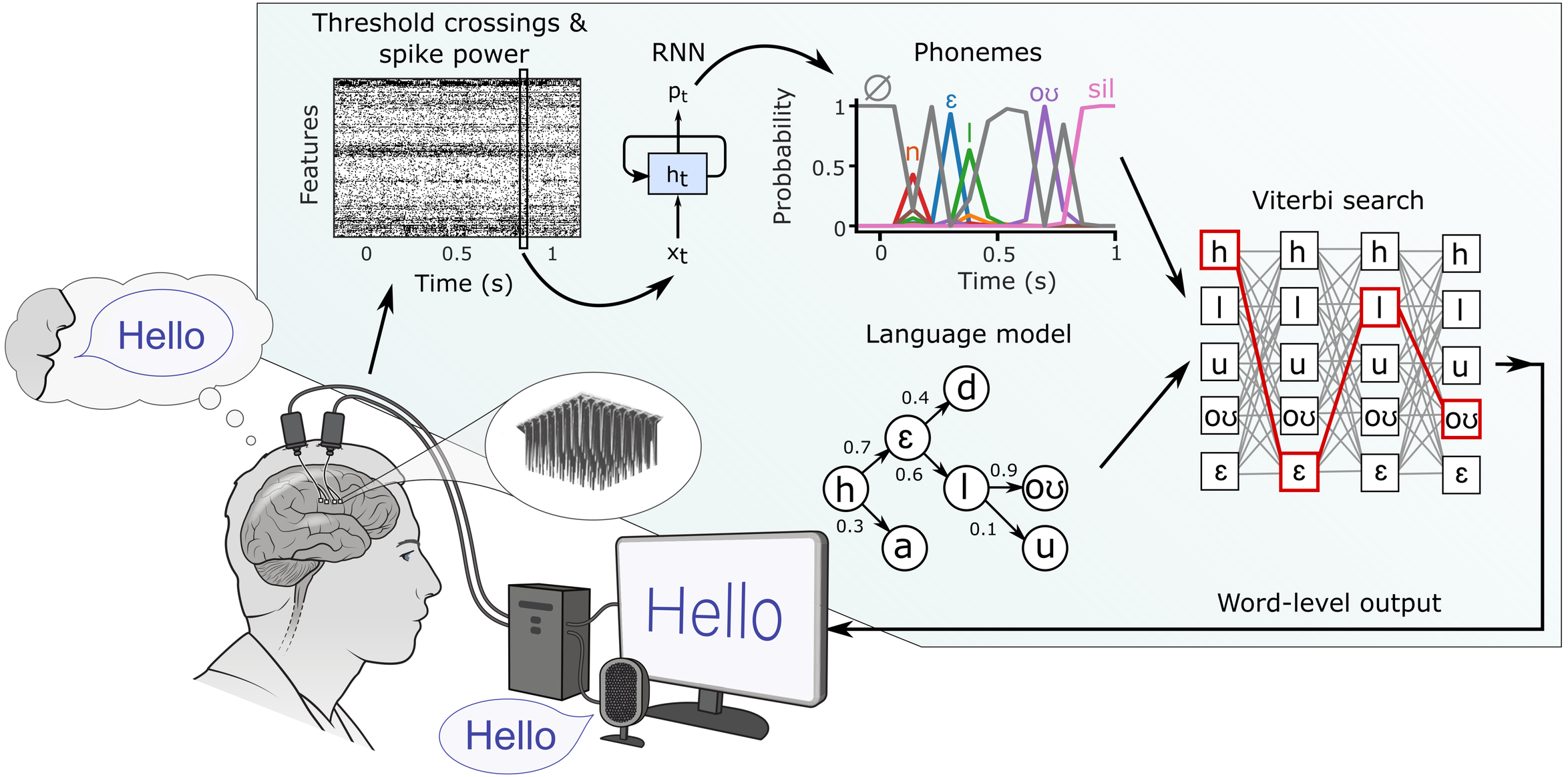
Preserved Articulatory Representation



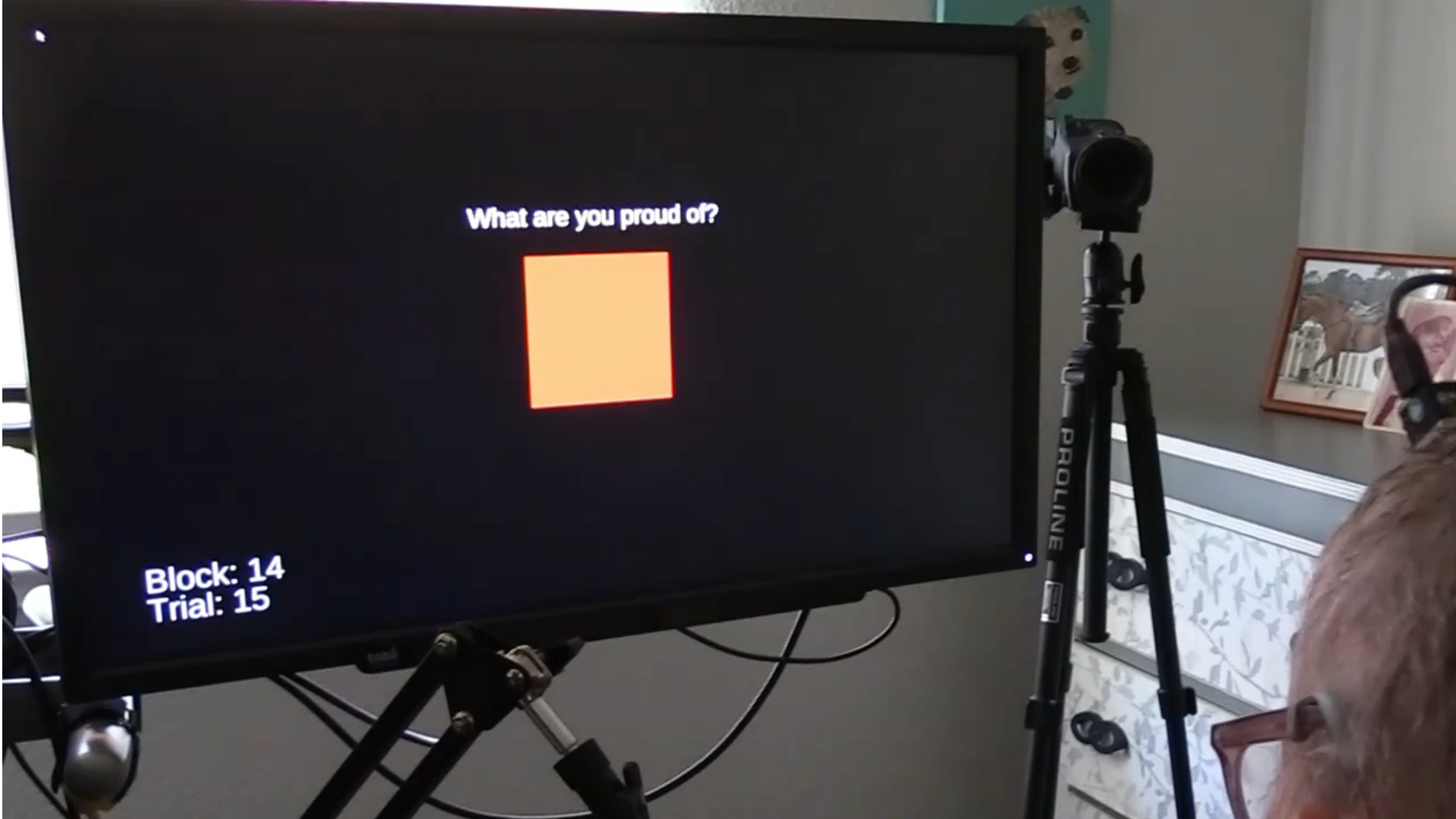



Hello
Decoder PC
Hello
Hello

Decoding Methods

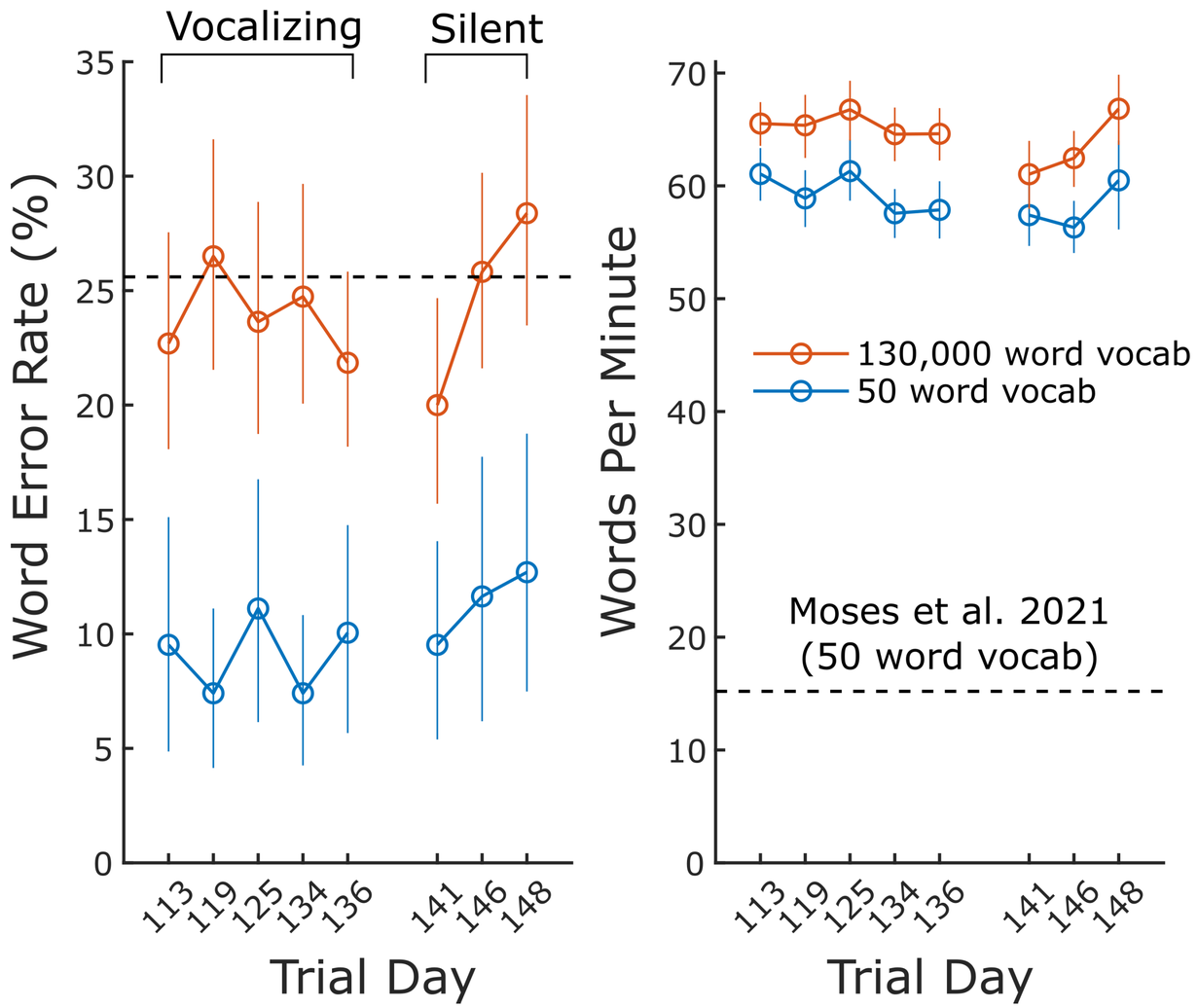


I don't want to call her a baby sitter.
Block: 17
Trial: 32
Canon

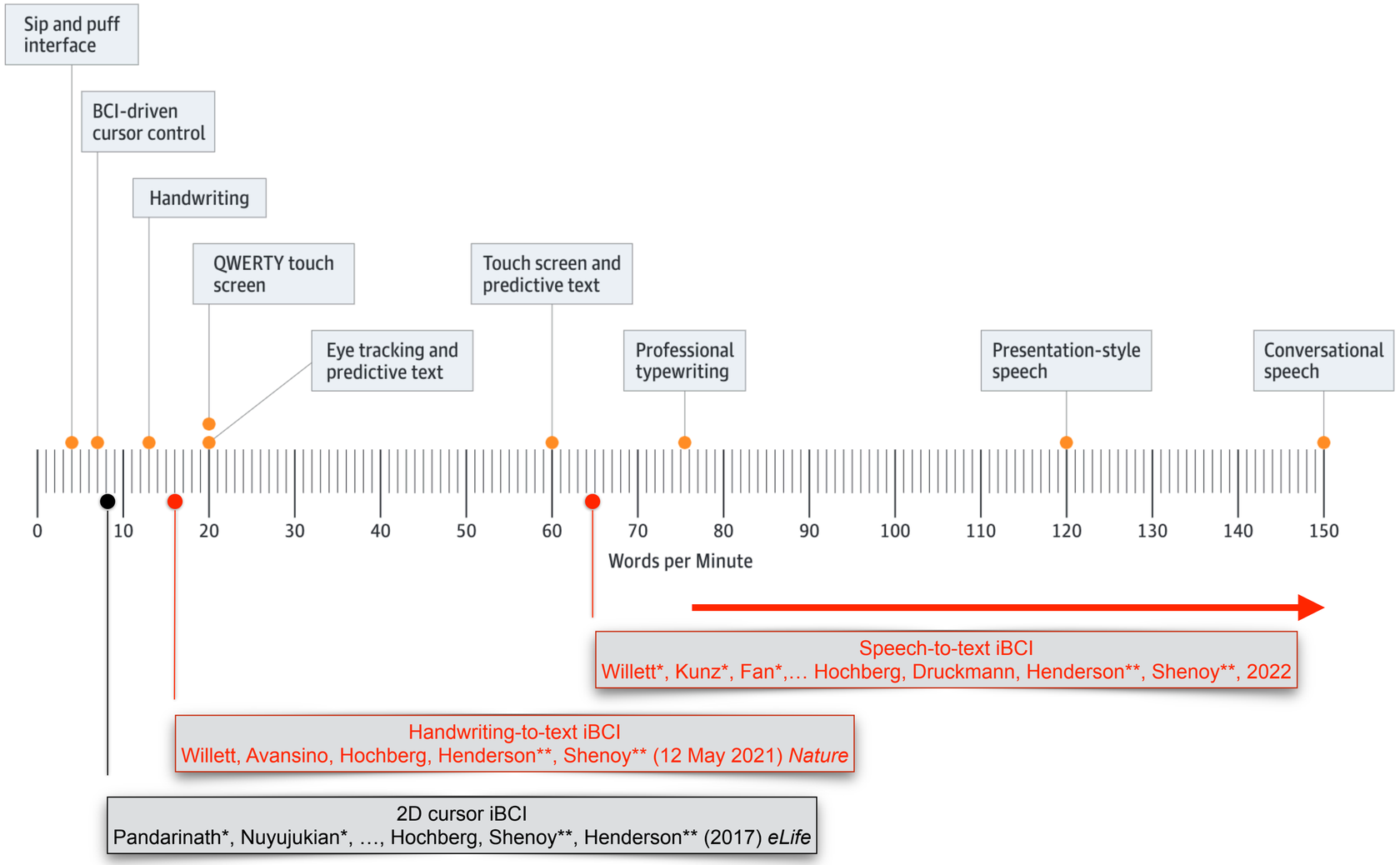

What are you proud of?
Block: 14
Trial: 15
PROLINE

I do not have much to compare it to.
Block: 17
Trial: 29

A New Record for Speech Decoding



Increasing the performance of iBCIs with rapid and dexterous behaviors (including speech)



Chang & Anumanchipalli (2019) *JAMA*

Toward Full Clinical Implementation

- Improving ease of use
  - Elimination of patient cable and pedestal
  - Fully-implantable wireless system
- Improving performance
  - Higher channel count - more neurons
  - Improved decoders
  - “Always on” capability

Toward Full Clinical Implementation

- Improving ease of use
  - Elimination of patient cable and pedestal
  - Fully-implantable wireless system
- Improving performance
  - Higher channel count - more neurons
  - Improved decoders
  - “Always on” capability

Brain-to-Text ’24

- Neural recordings of 12,100 Sentences

Rank	Participant team	WordErrorRate (↑)
1	NPTL Pytorch Baseline (5gram + OPT6B)	9.76
2	NPTL Baseline (RNN + 5-gram + OPT) B	11.06
3	Zhao_Zhengtuo-Group (OPT-2.7b)	11.25
4	innerspeech-wyl	11.57
5	SNU-NLP2023 (Bi-GRU + 3-gram + GPT-2)	13.33
6	FATE (baseline)	15.43

Conclusions

- Brain-computer interfaces are moving closer to clinical reality
- BCI research enables insights in fundamental human neuroscience
- We will soon have systems that can provide real assistance to people with communication disorders and paralysis
- The future is very exciting!

Shenoy Undergraduate Research Fellowship in Neuroscience (SURFiN)

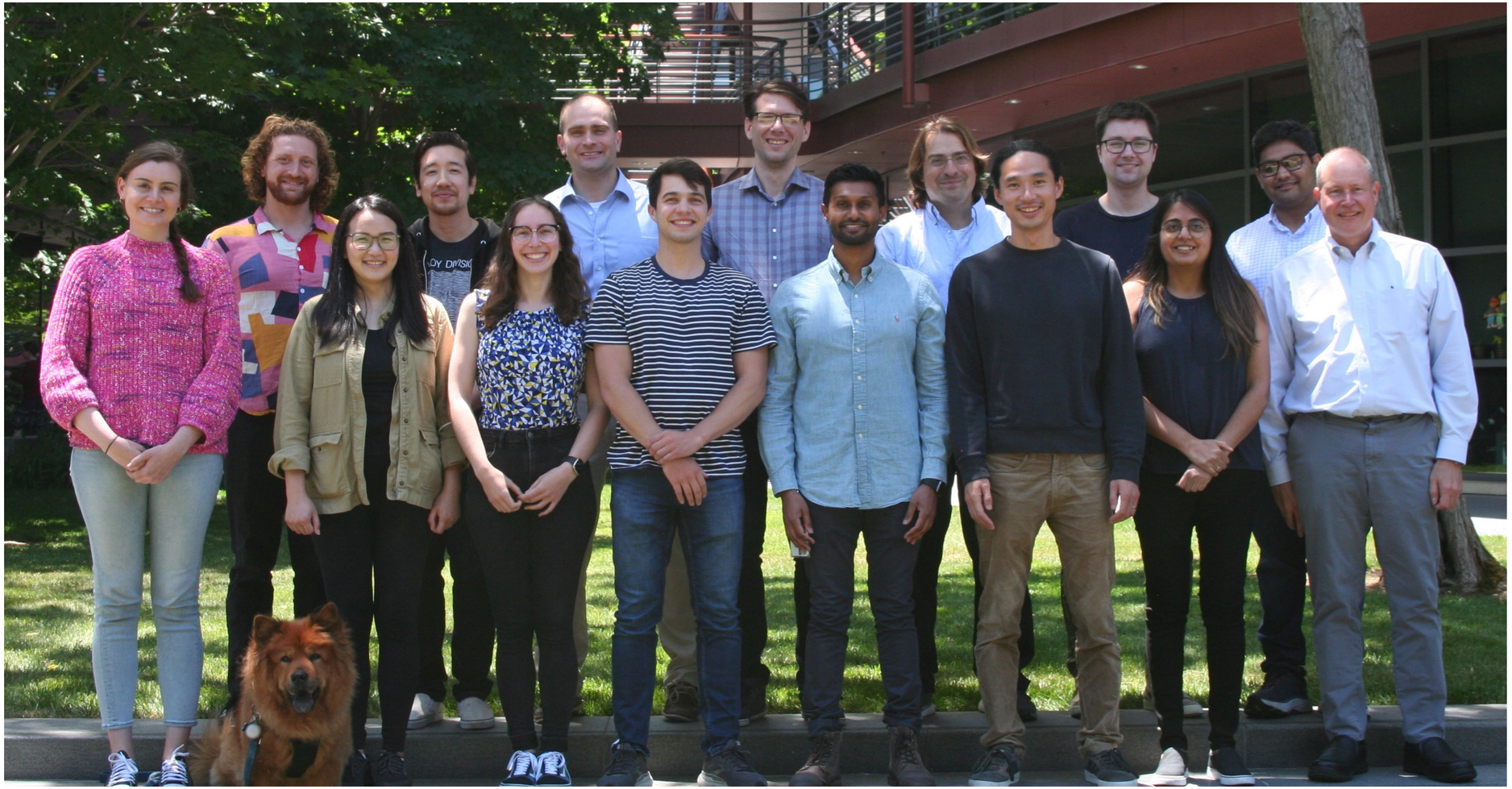
Positions at NPTL as well as our collaborators UC Davis Neuroprosthetics Lab!

Krishna Shenoy

(9/3/1968 - 1/21/2023)

hhmi
Howard Hughes Medical Institute

Participants
T5, T6 and T12



Stanford Neural Prosthetics Translational Lab (NPTL)

Funding

ALS Association
Stanford: Bio-X, Wu Tsai Neuroscience, OPA

NIH: NINDS, NIDCD, NICHD
VA Rehab. R&D Service
Mass. General Hospital ECOR

Larry and Pamela Garlick
Samuel and Betsy Reeves
John Gunn