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,
Frank Willett



2020
Admitted to PhD in EE

2025:
PhD Defense(!)
&
Start PostDoc

The need to restore movement and communication

Christopher Reeve at MIT, 2003

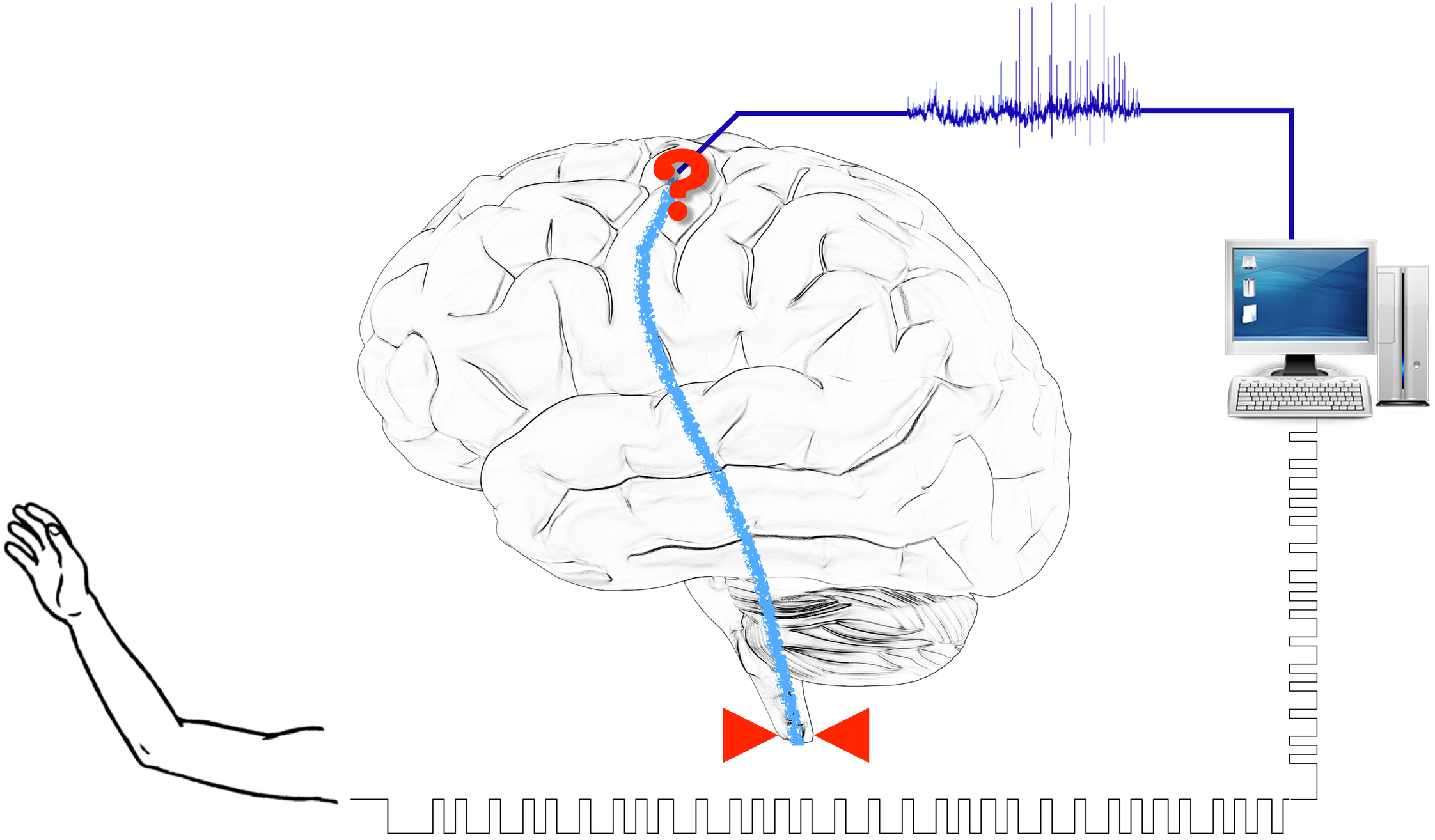
The need to restore movement and communication

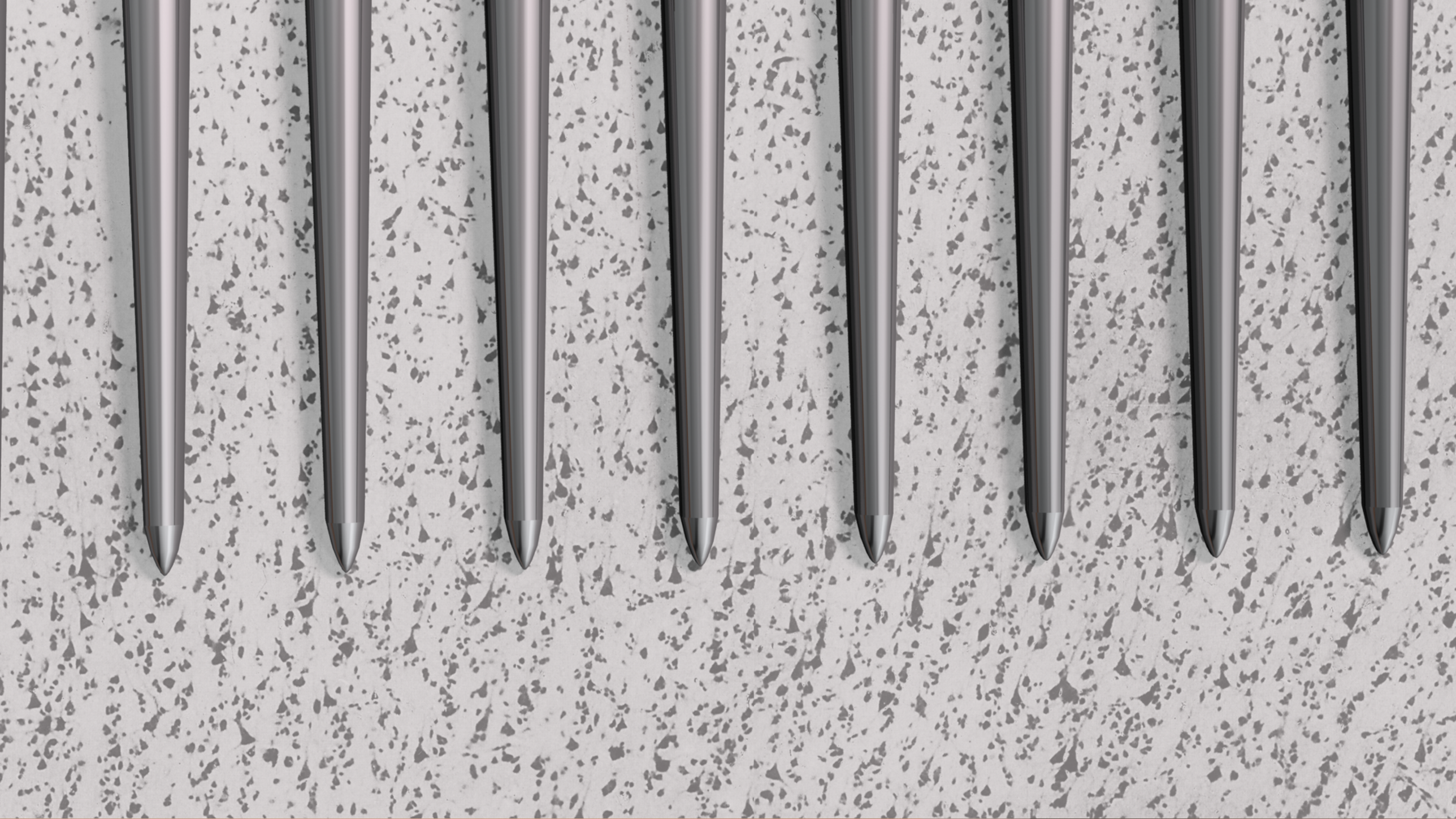
ALS: ~30,000 individuals in the U.S. (CDC, 2018)

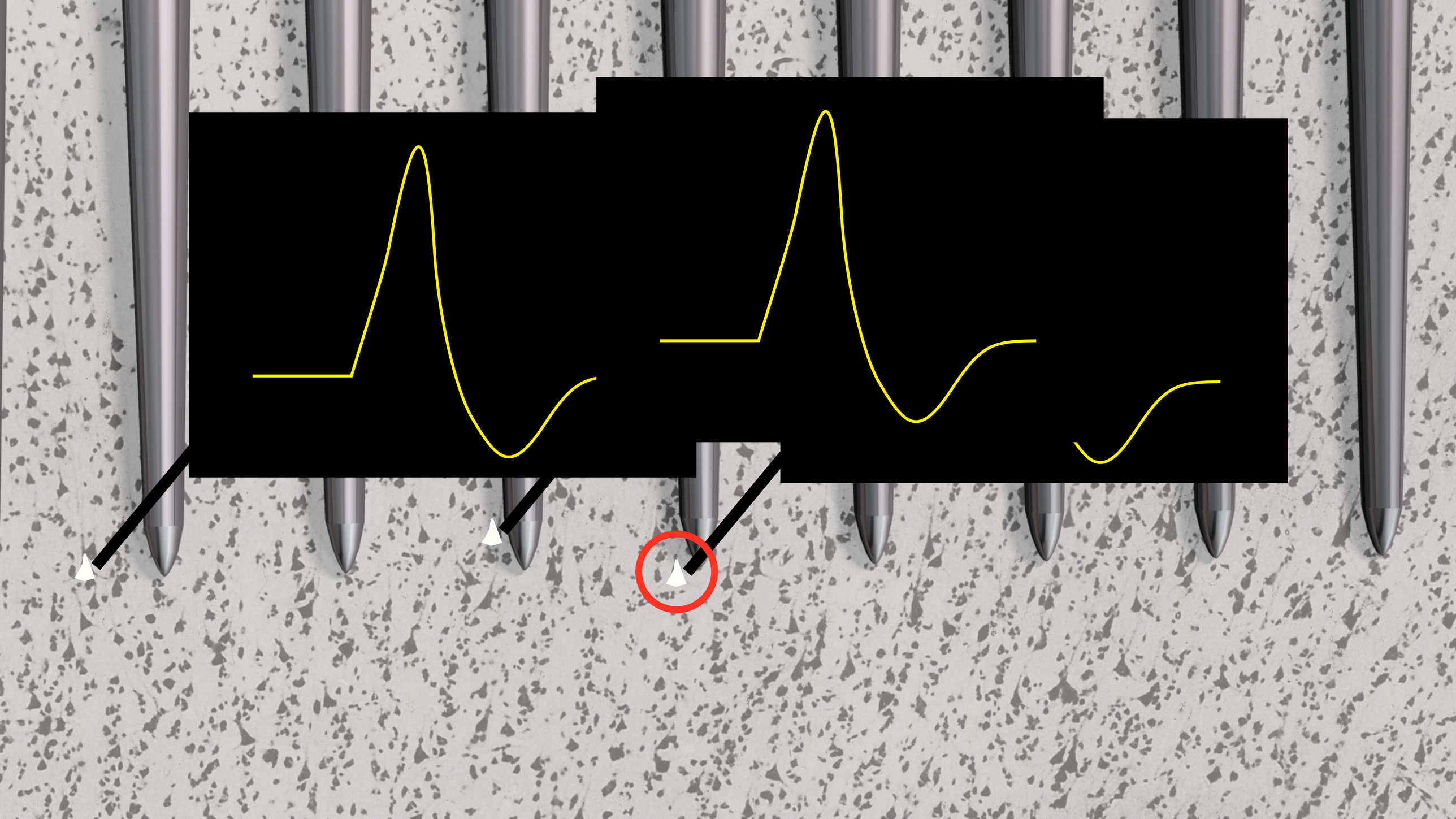
Hundreds of thousands of individuals with tetraplegia (NSCISC, 2018)

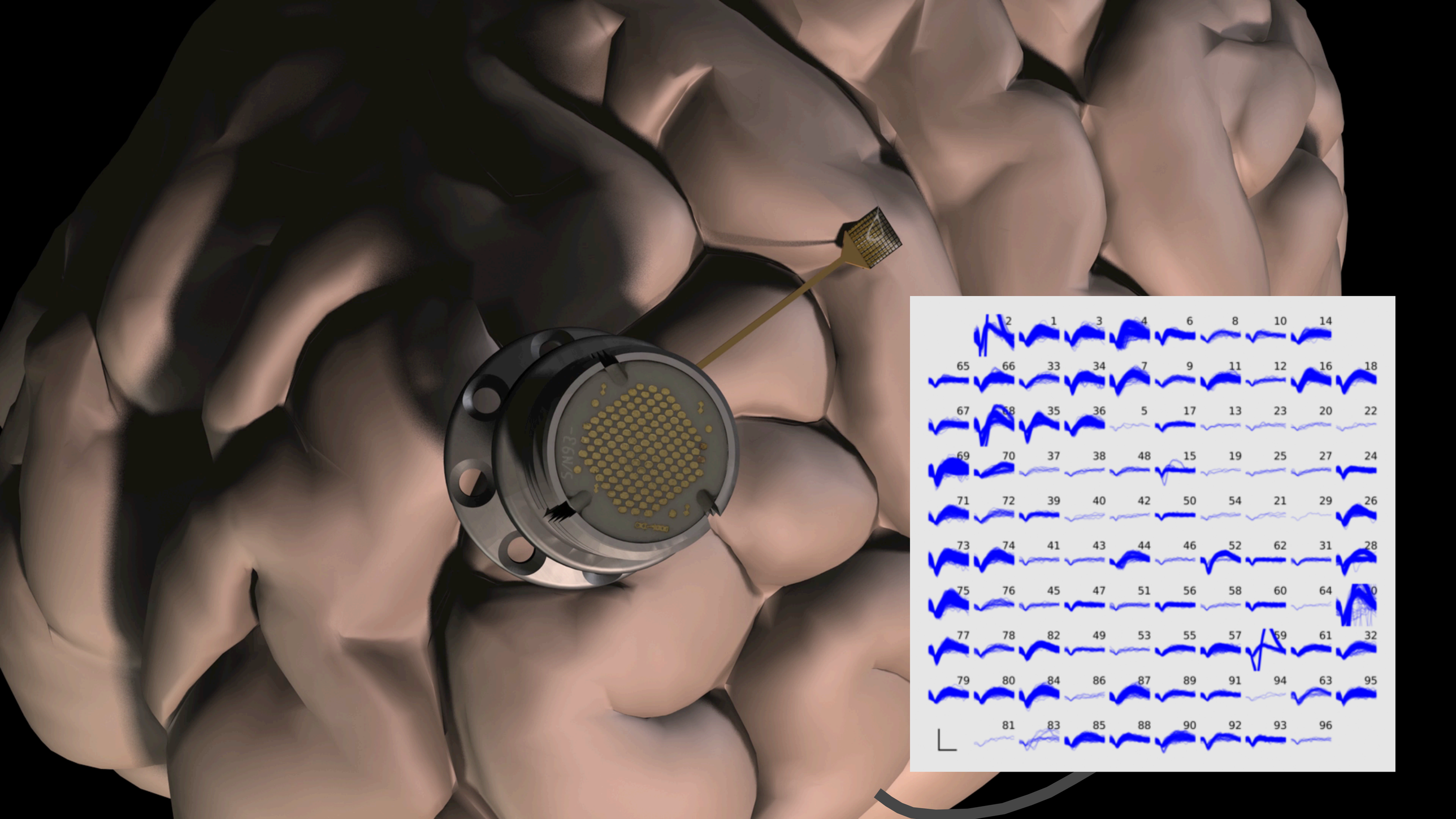
Today: essentially no treatments

Stephen Hawking at Imperial College London, 2016





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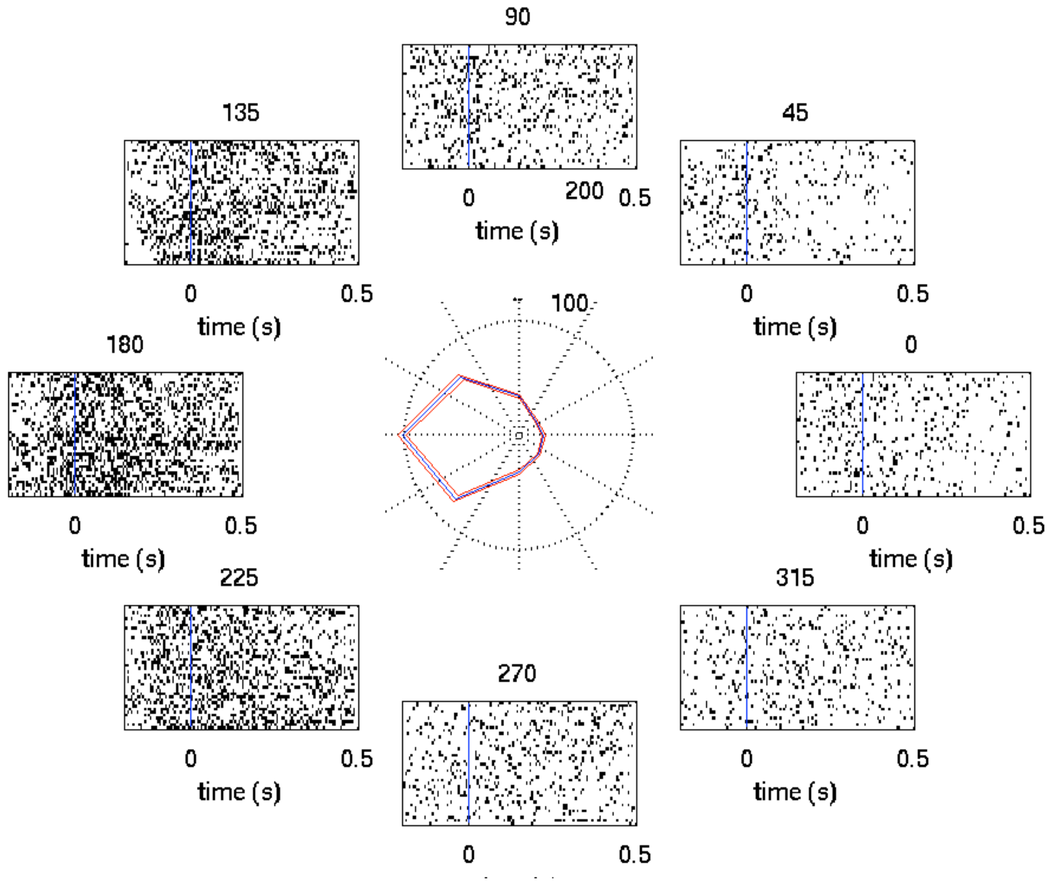
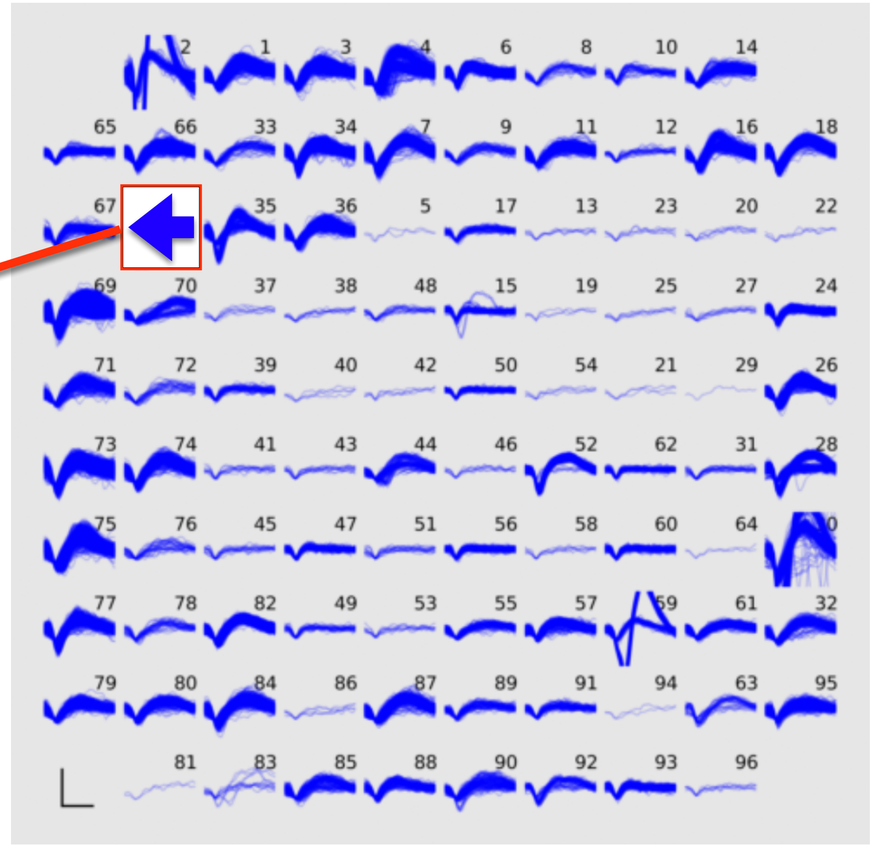
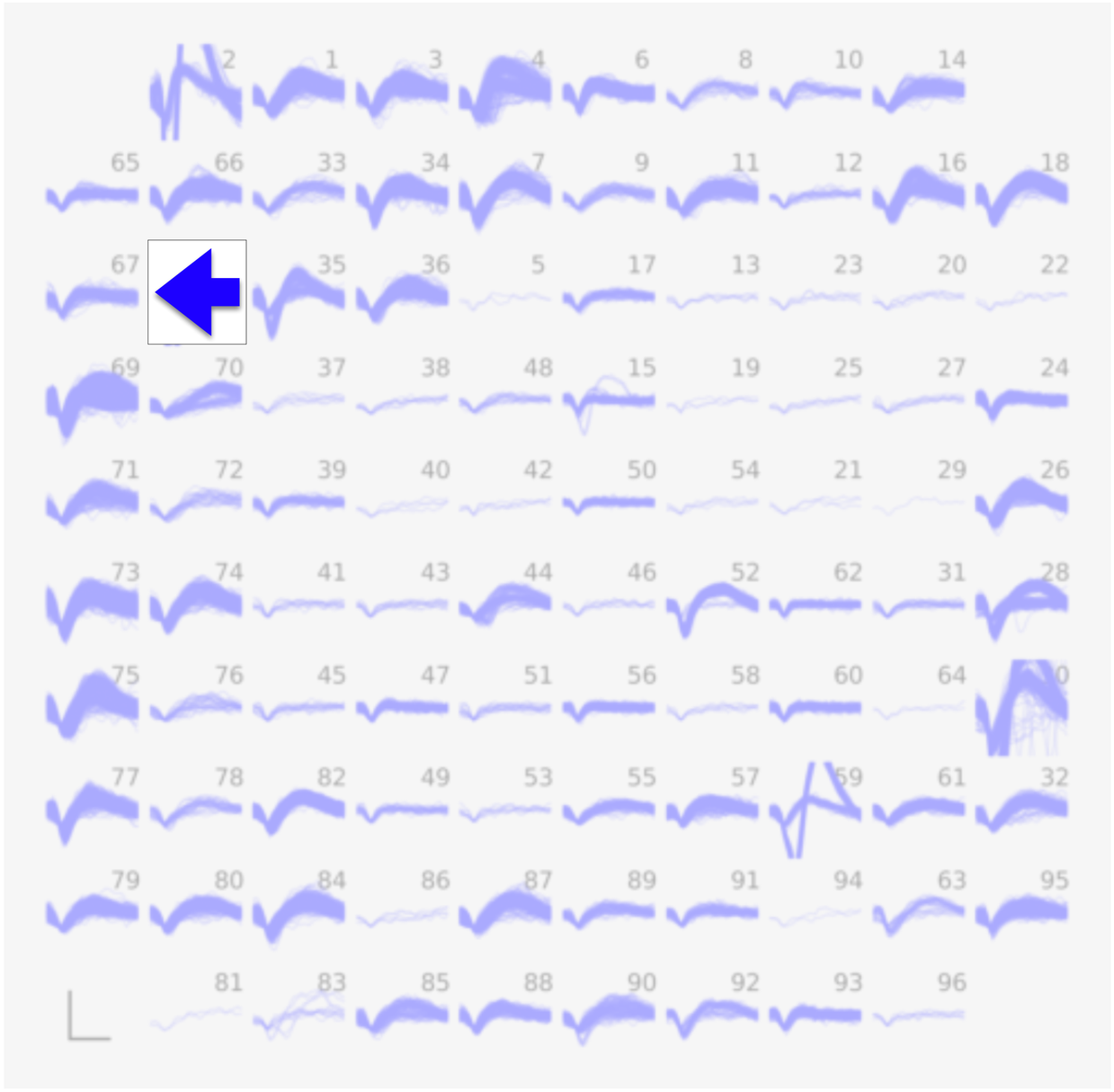
65 66 33 34 7 9 11 12 16 18
67 68 35 36 5 17 13 23 20 22
69 70 37 38 48 15 19 25 27 24
71 72 39 40 42 50 54 21 29 26
73 74 41 43 44 46 52 62 31 28
75 76 45 47 51 56 58 60 64
77 78 82 49 53 55 57 59 61 32
79 80 84 86 87 89 91 94 63 95
81 83 85 88 90 92 93 96

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
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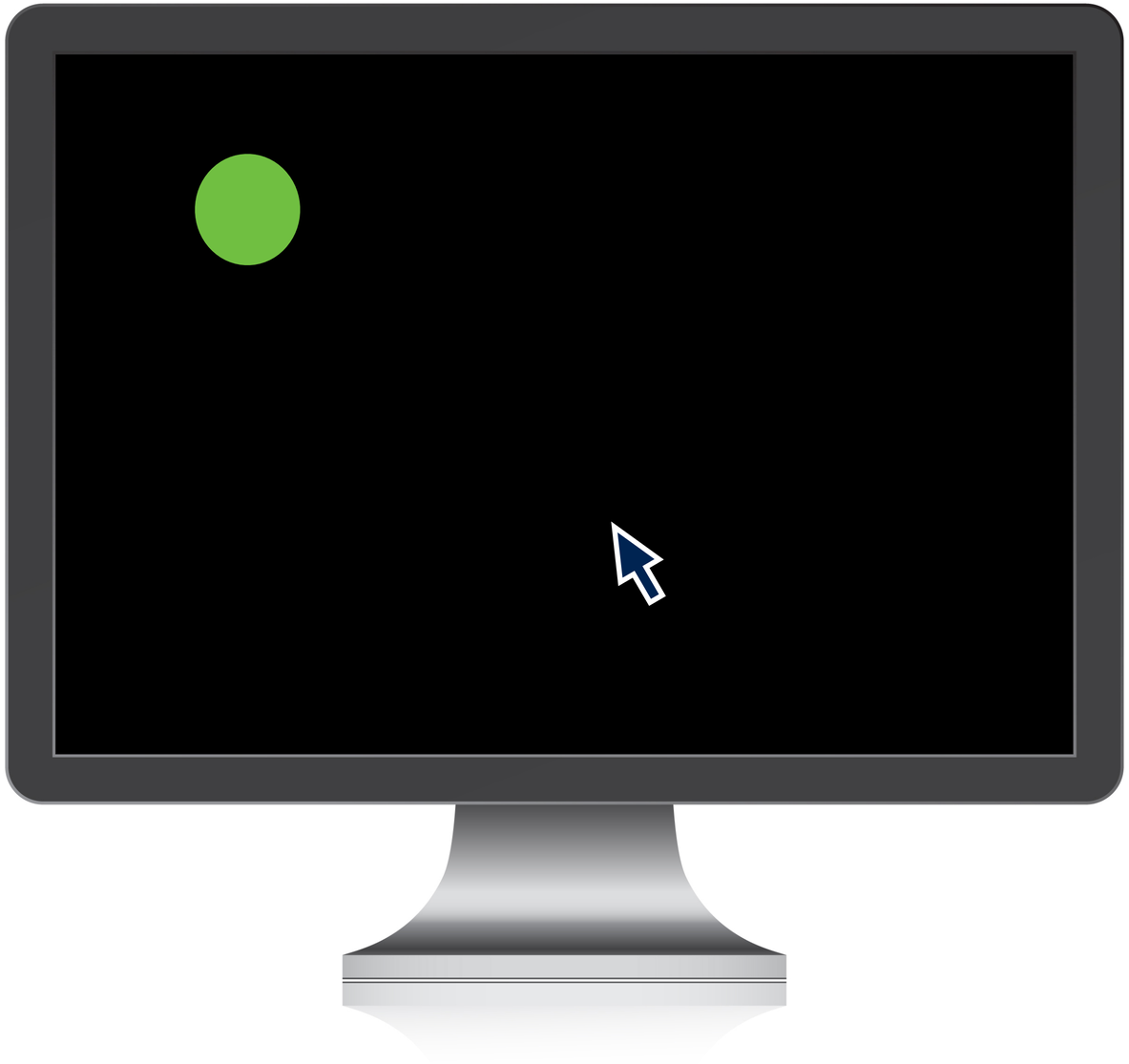
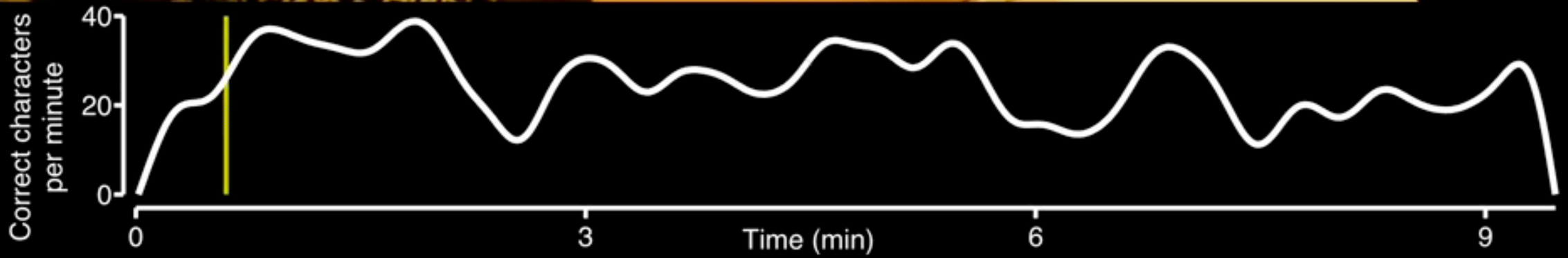
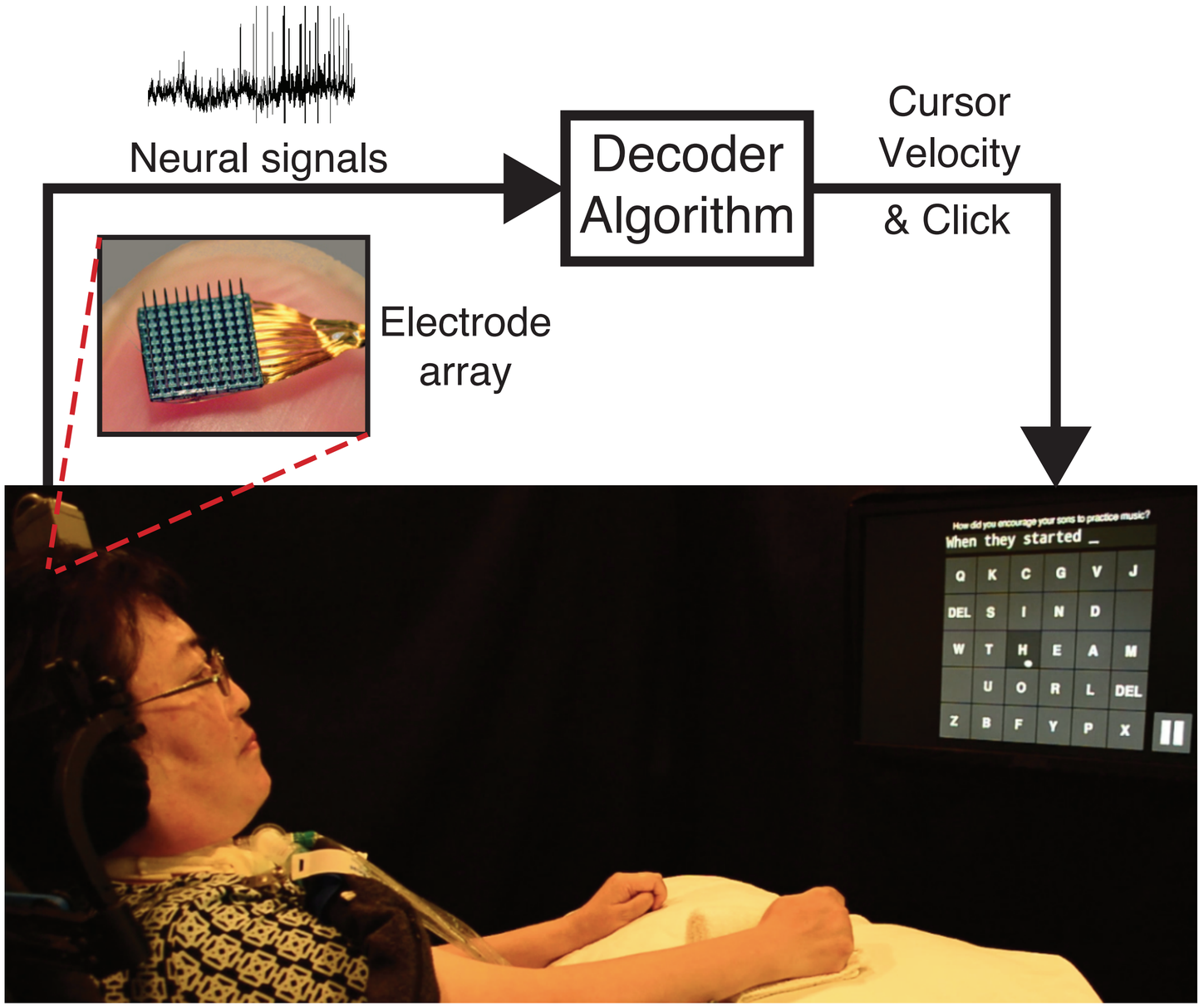


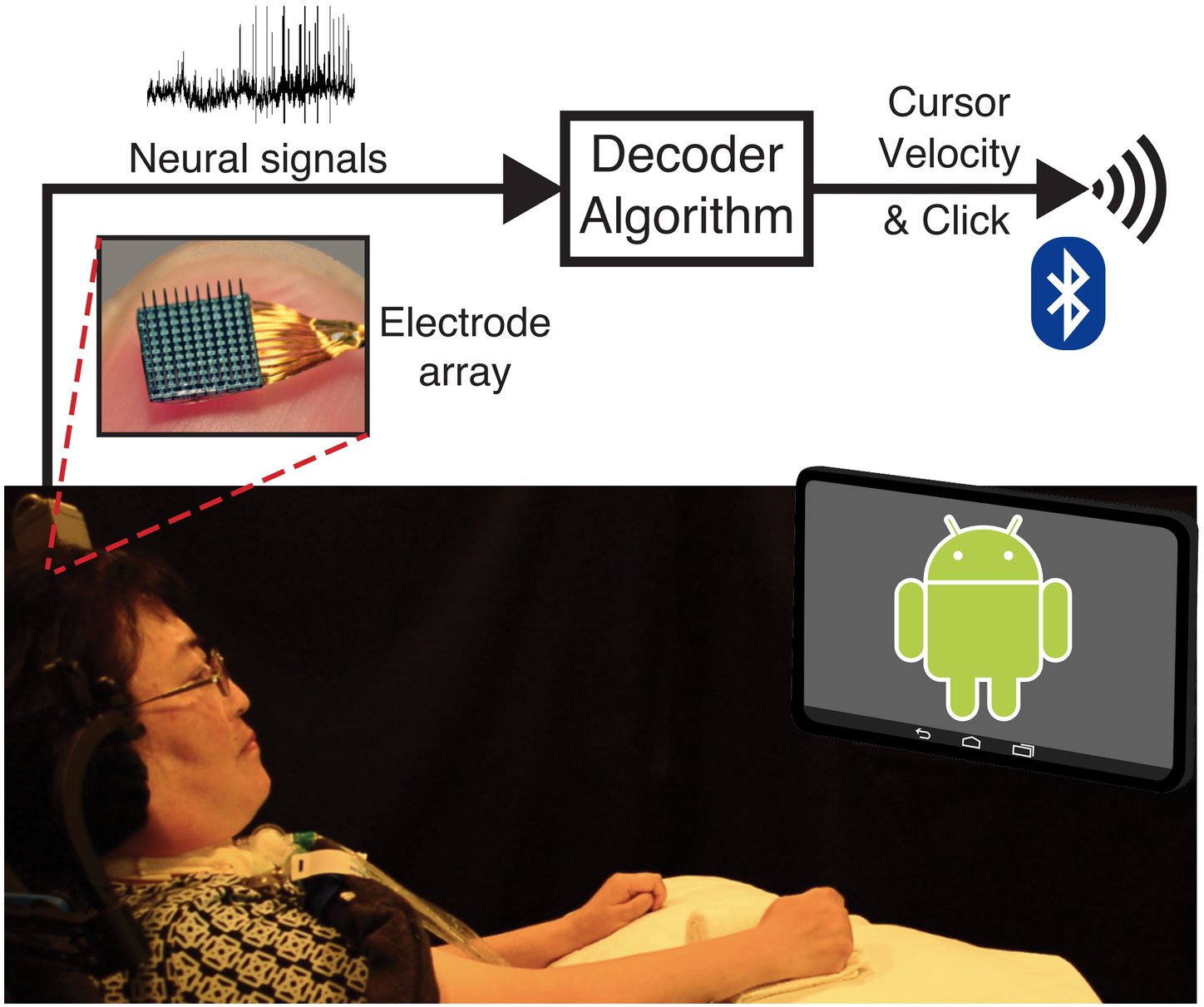


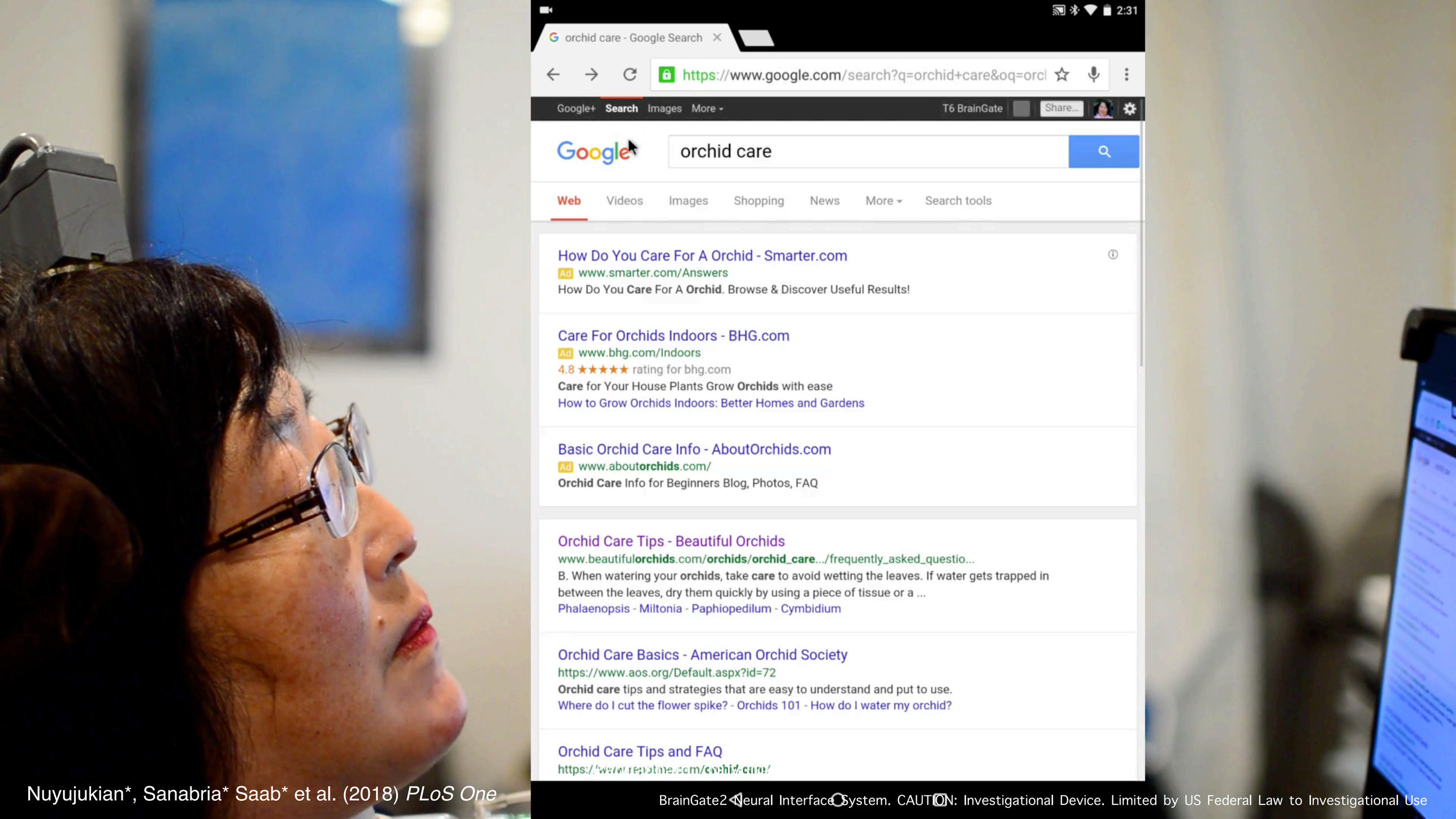
Pandarinath*, Nuyujukian*, et al. (2017) *eLife*

Existing setup



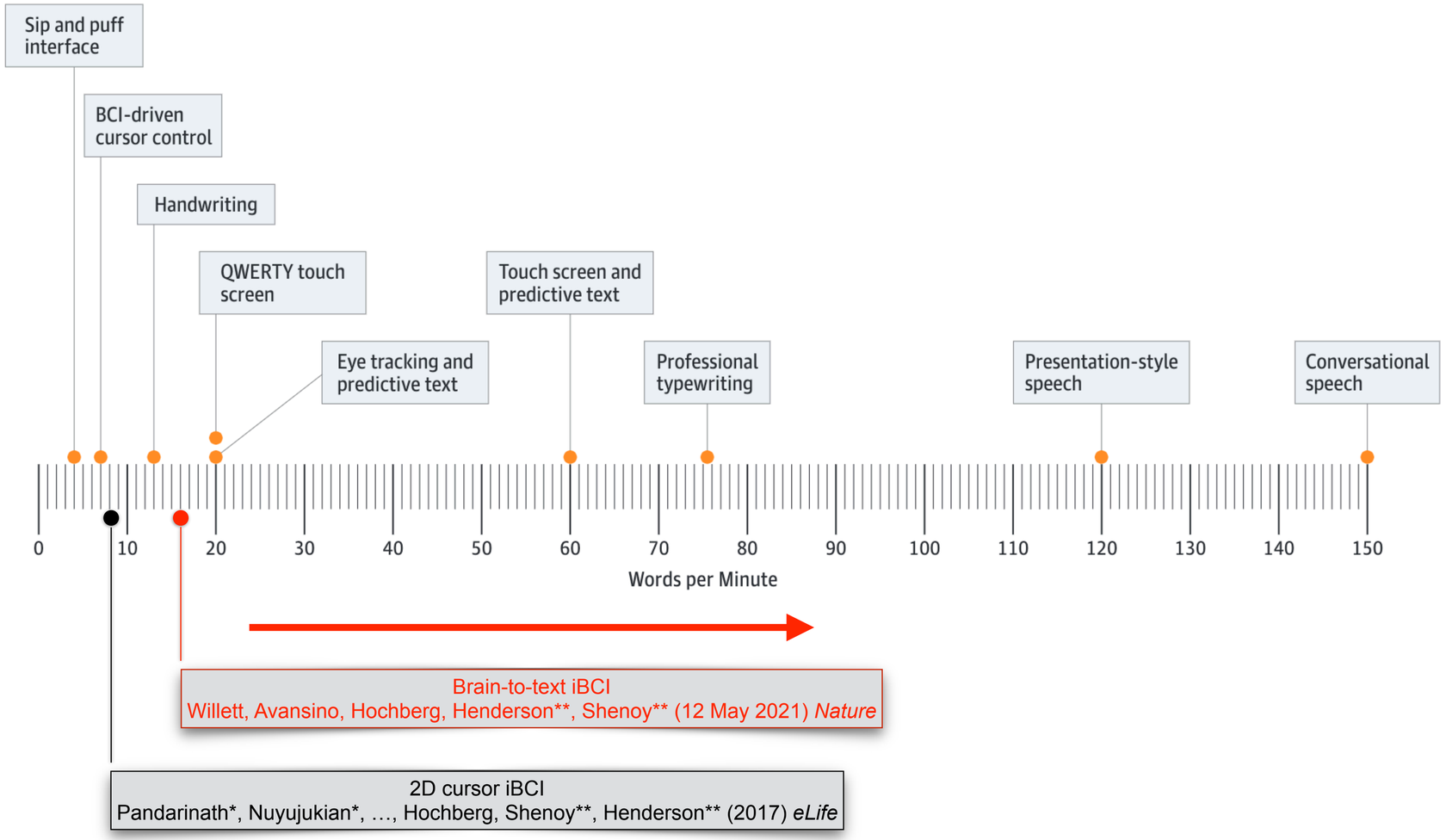
Android Interface





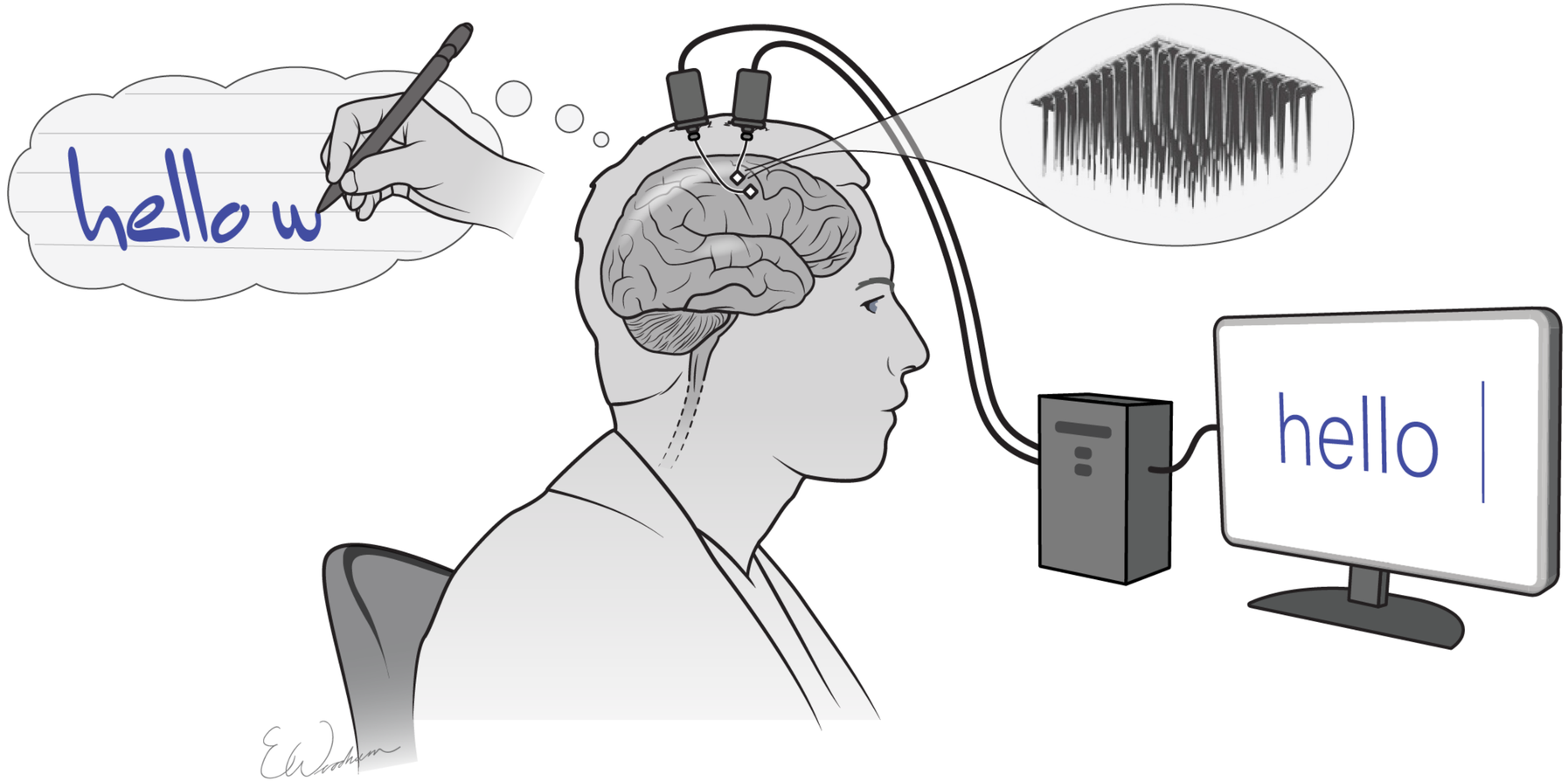
Nuyujukian*, Sanabria* Saab* et al. (2018) *PLoS One*

Increasing the performance of iBCIs with rapid and dexterous behaviors

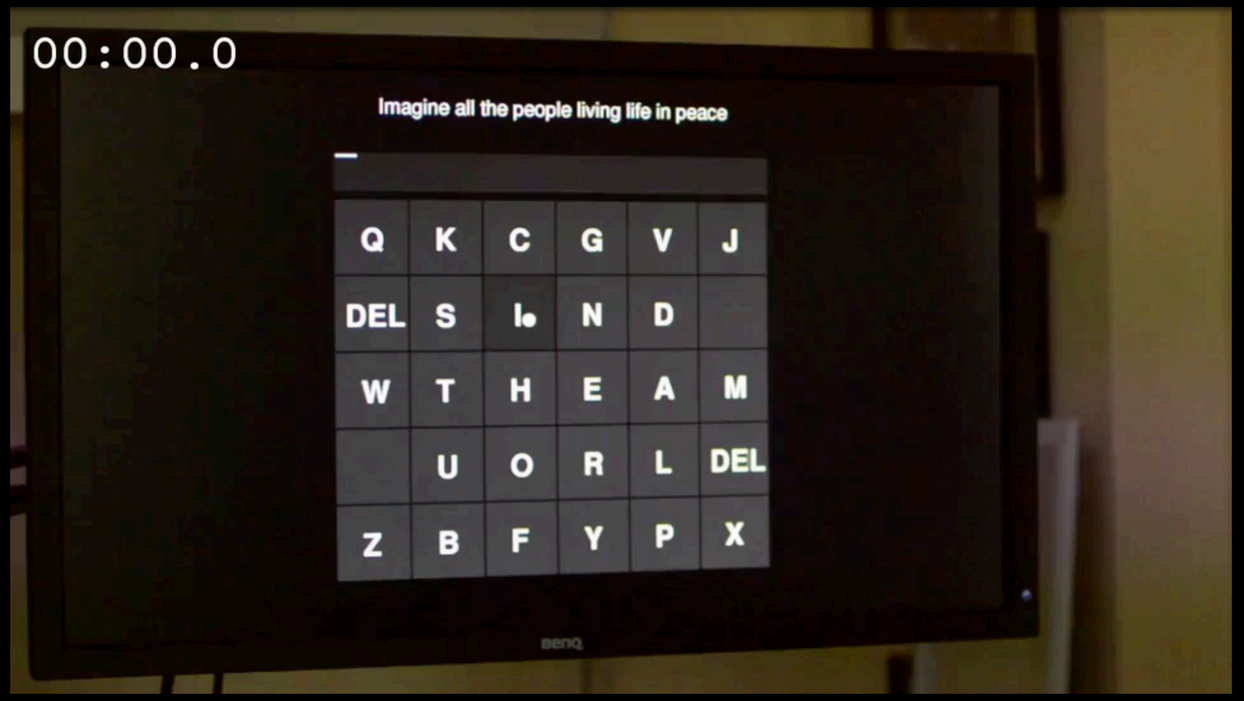


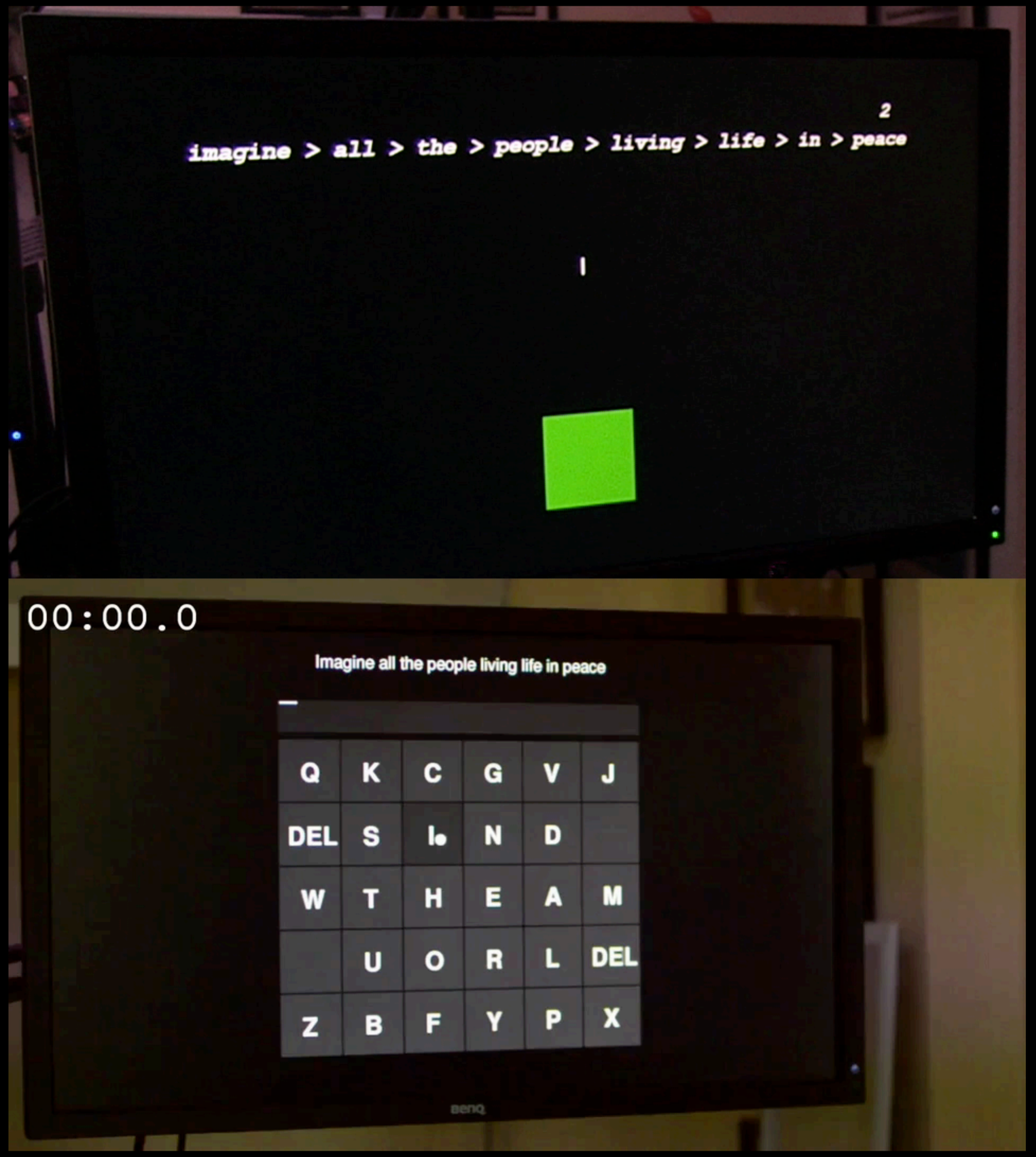
Chang & Anumanchipalli (2019) *JAMA*

System Overview

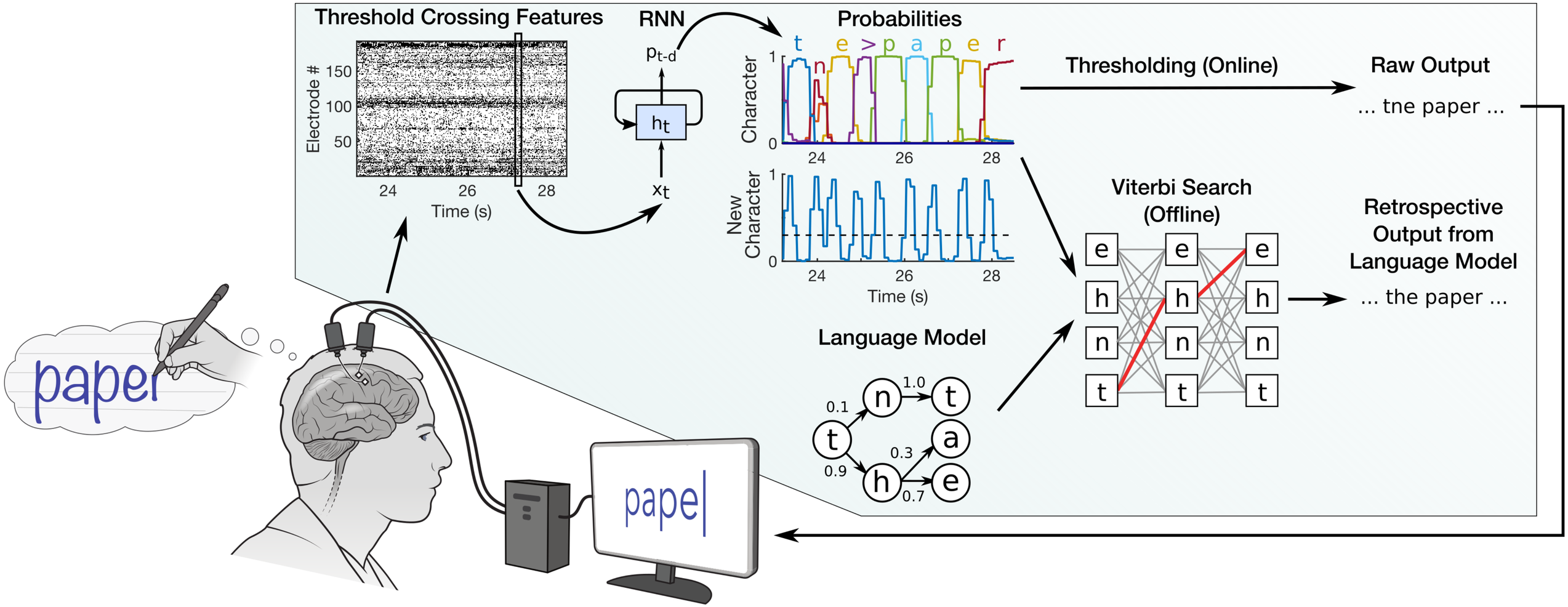


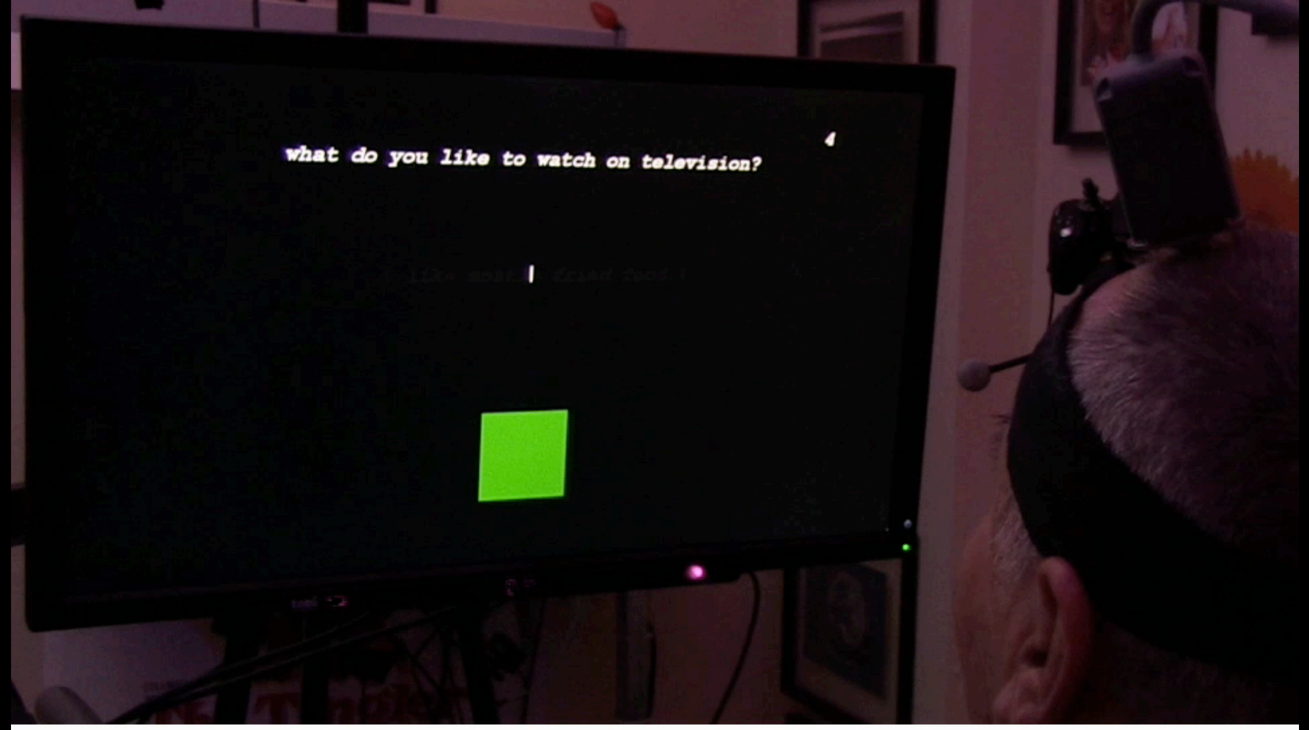
Willett, Avansino, Hochberg, Henderson**, Shenoy** (2021) High-performance brain-to-text communication via imagined handwriting. *Nature.*

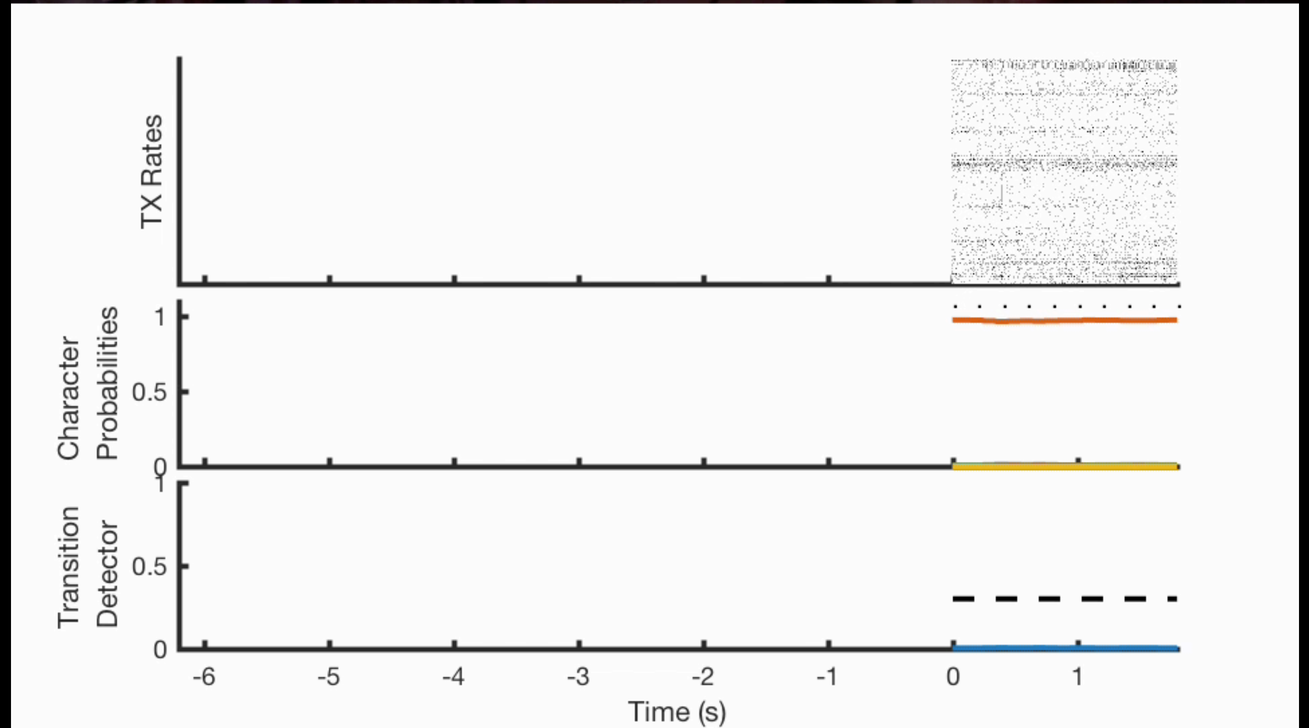

00:00.0
Imagine all the people living life in peace
Q K C G V J
DEL S I N D
W T H E A M
U O R L DEL
Z B F Y P X
benq

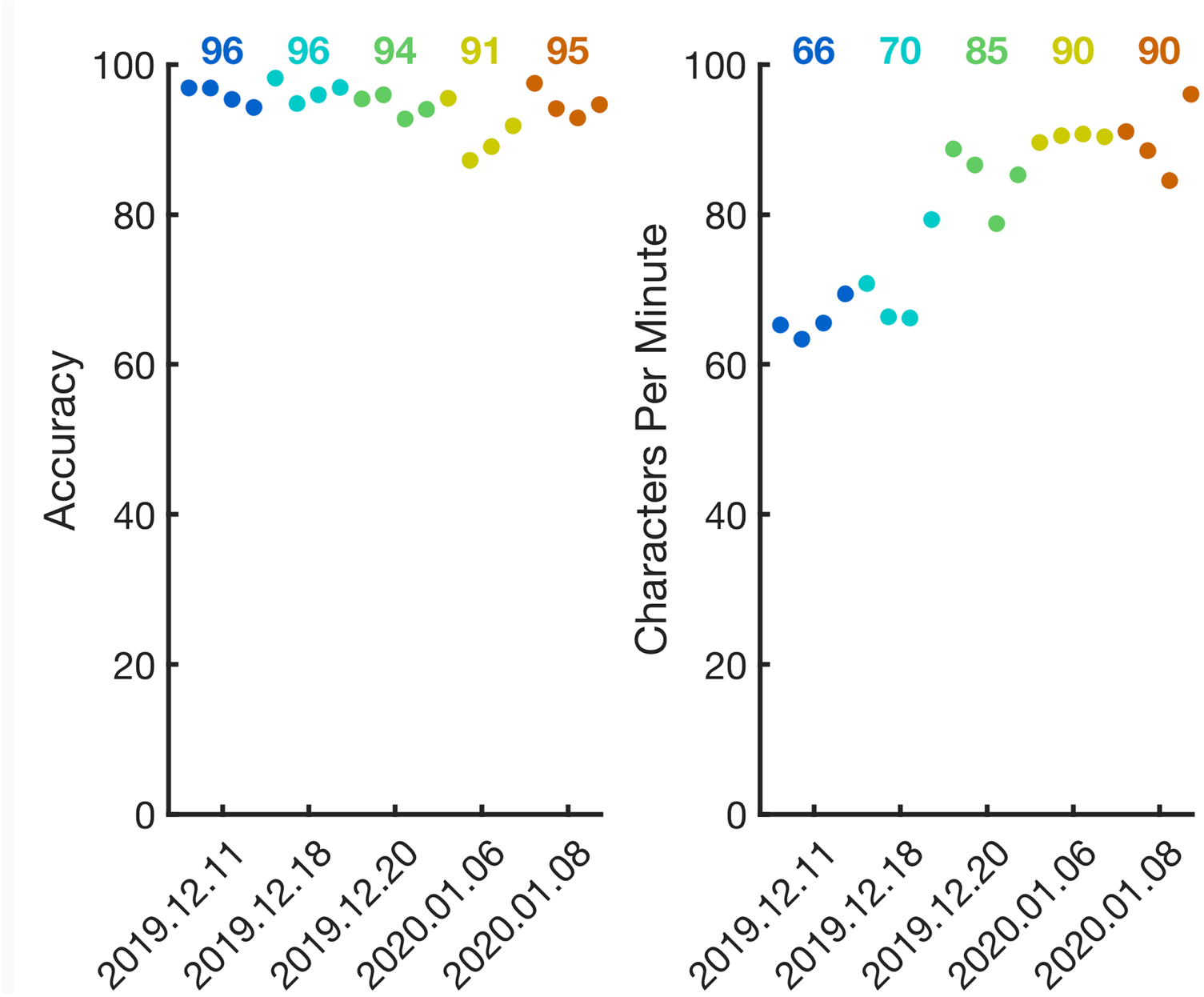

2
imagine > all > the > people > living > life > in > peace
I
00:00.0
Imagine all the people living life in peace
Q K C G V J
DEL S I N D
W T H E A M
U O R L DEL
Z B F Y P X
benq

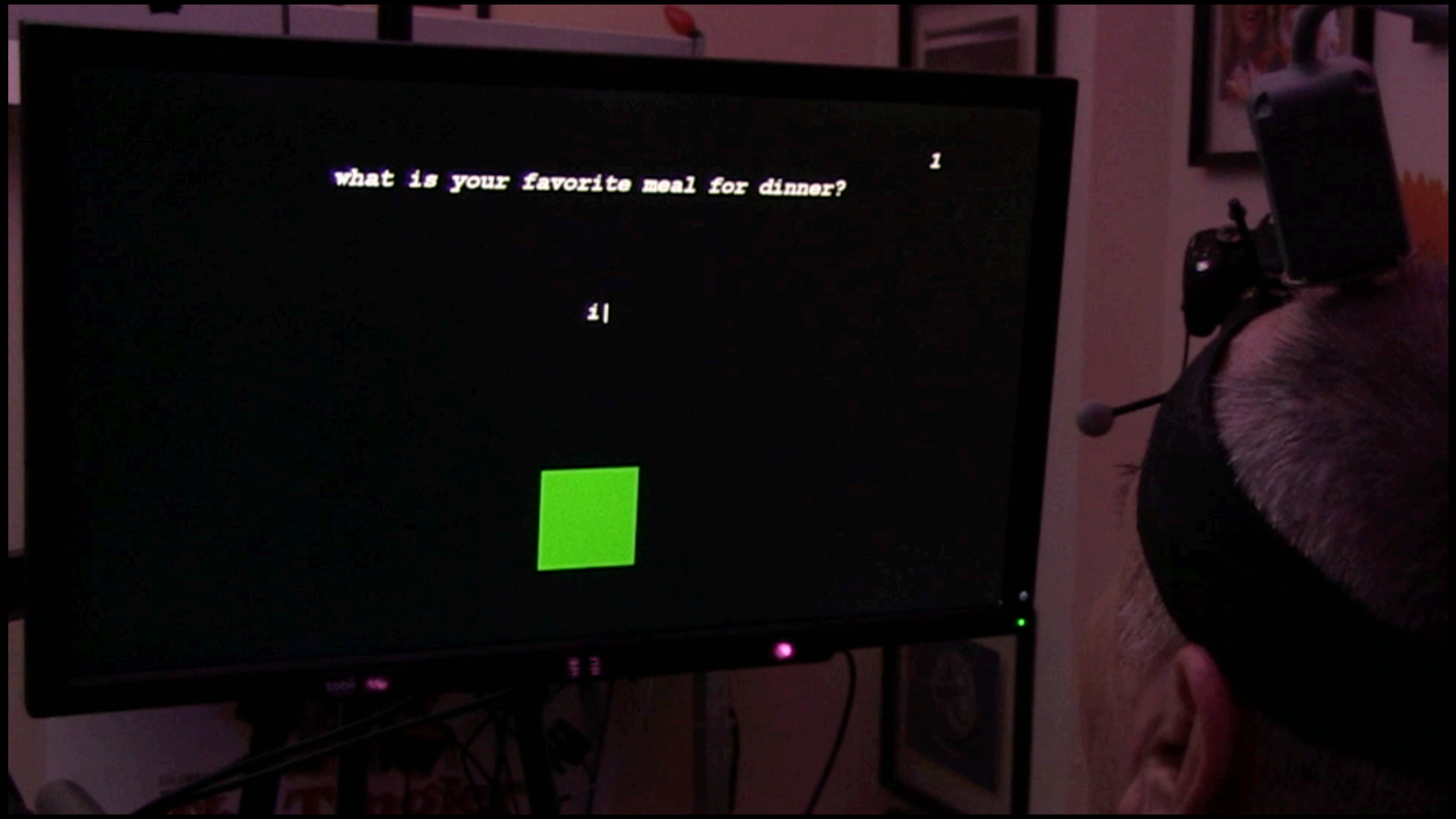
Handwriting iBCI System Diagram




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

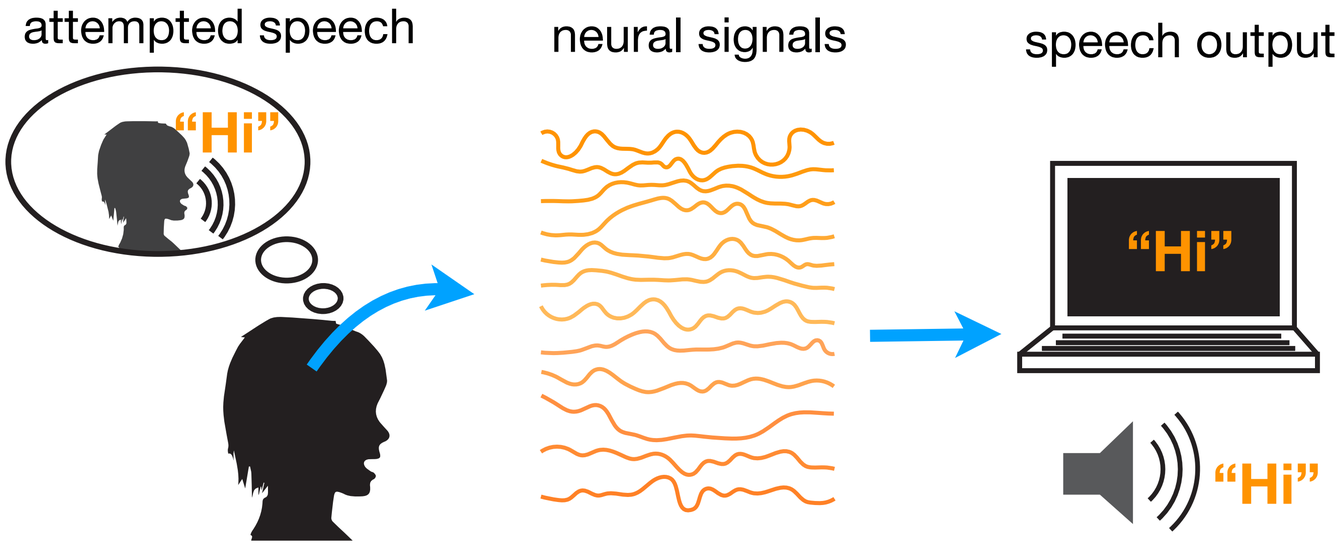

1
what is your favorite meal for dinner?
i

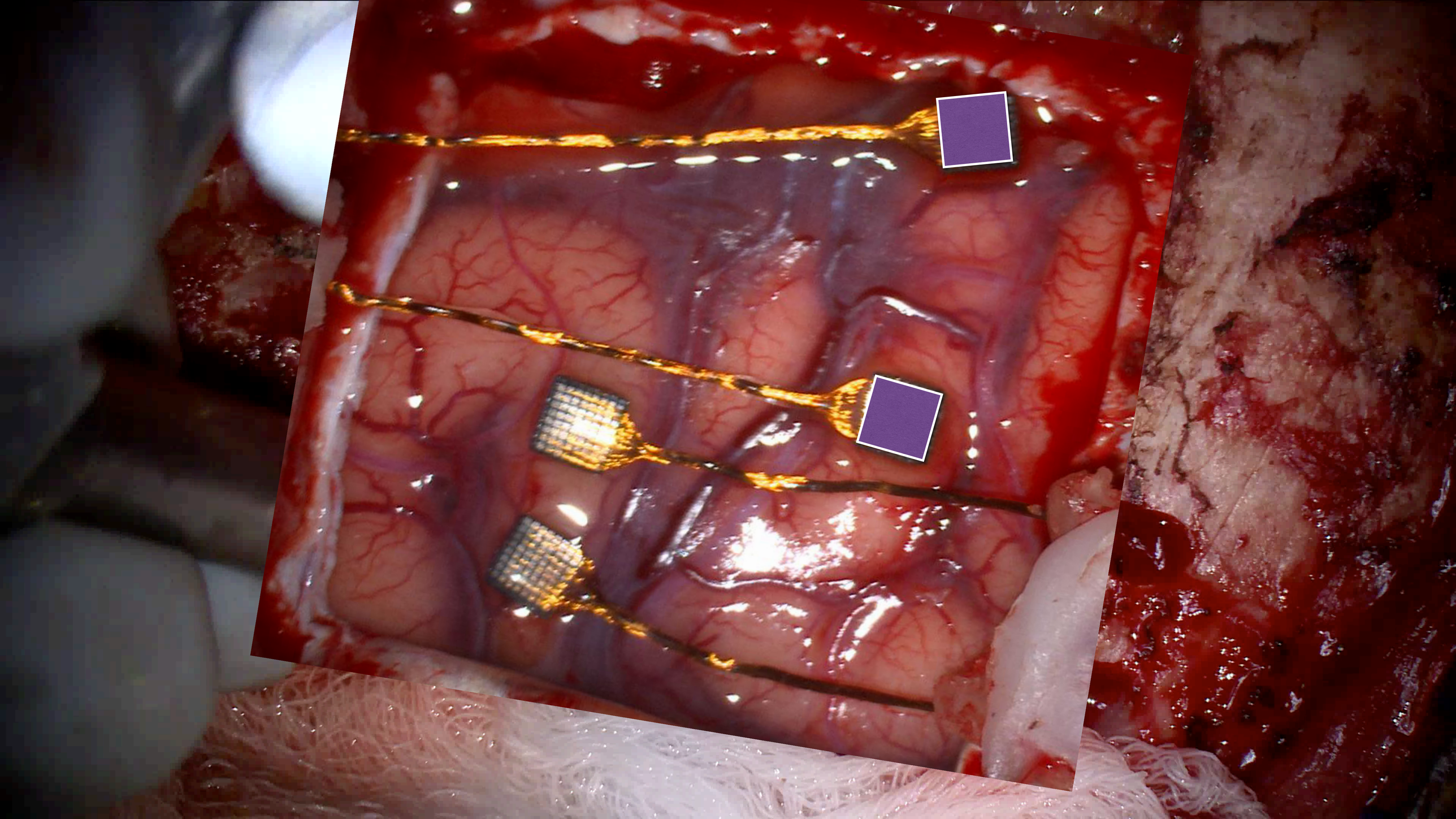
Studying the Neural Bases of Speech in People

1. Fundamental neuroscience of an exquisite motor control problem.

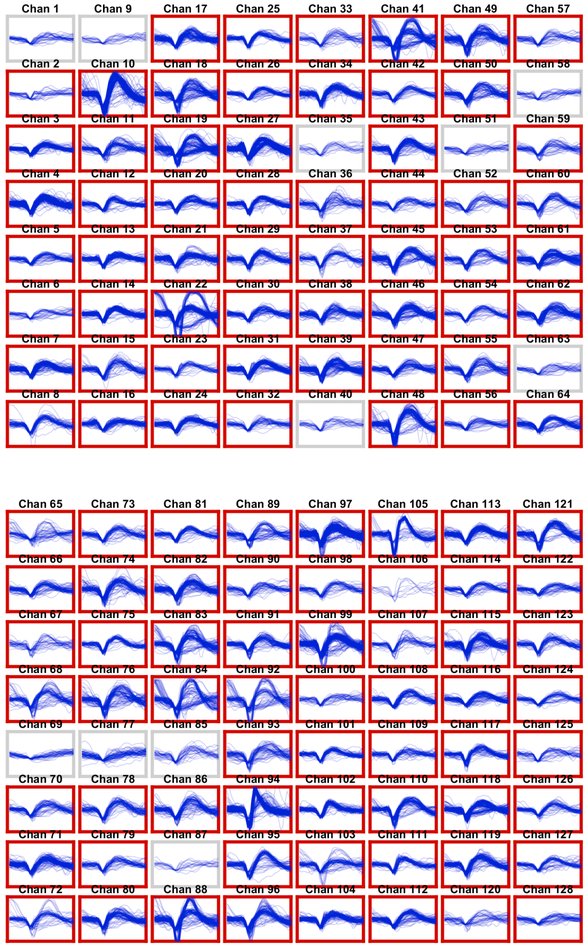
Uecker et al. (2010) *NMR in Biomed.*

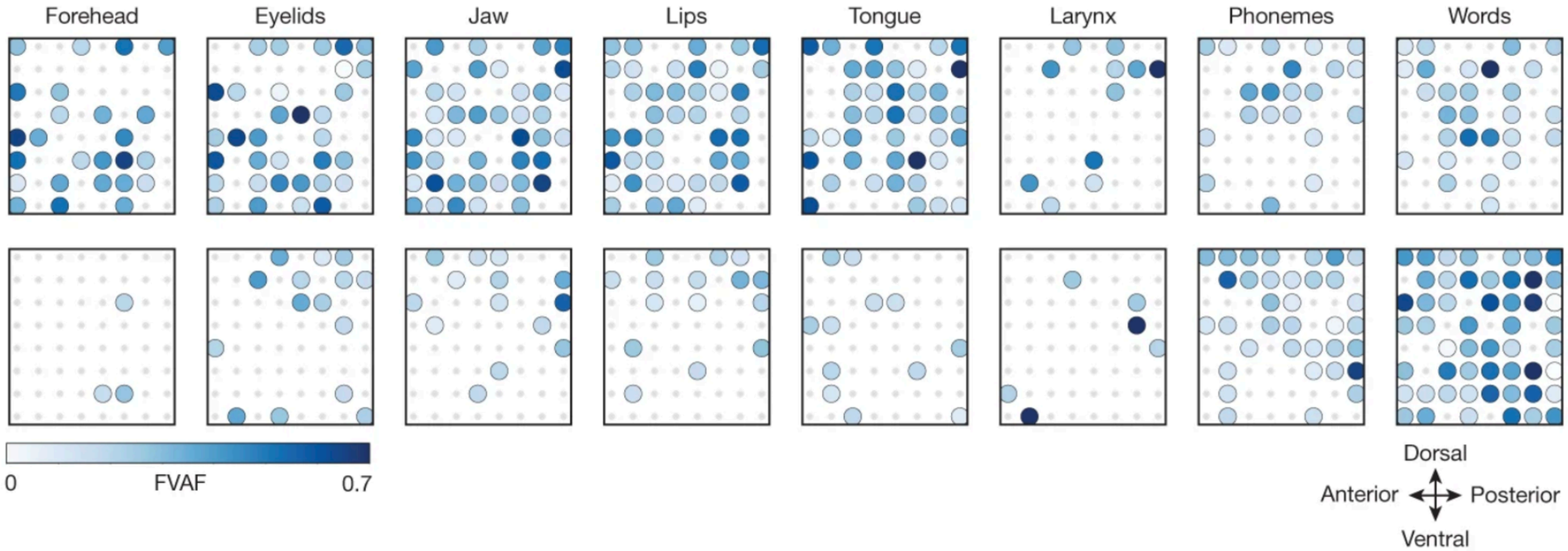
2. Translational need for speech BMIs for patients who cannot speak.

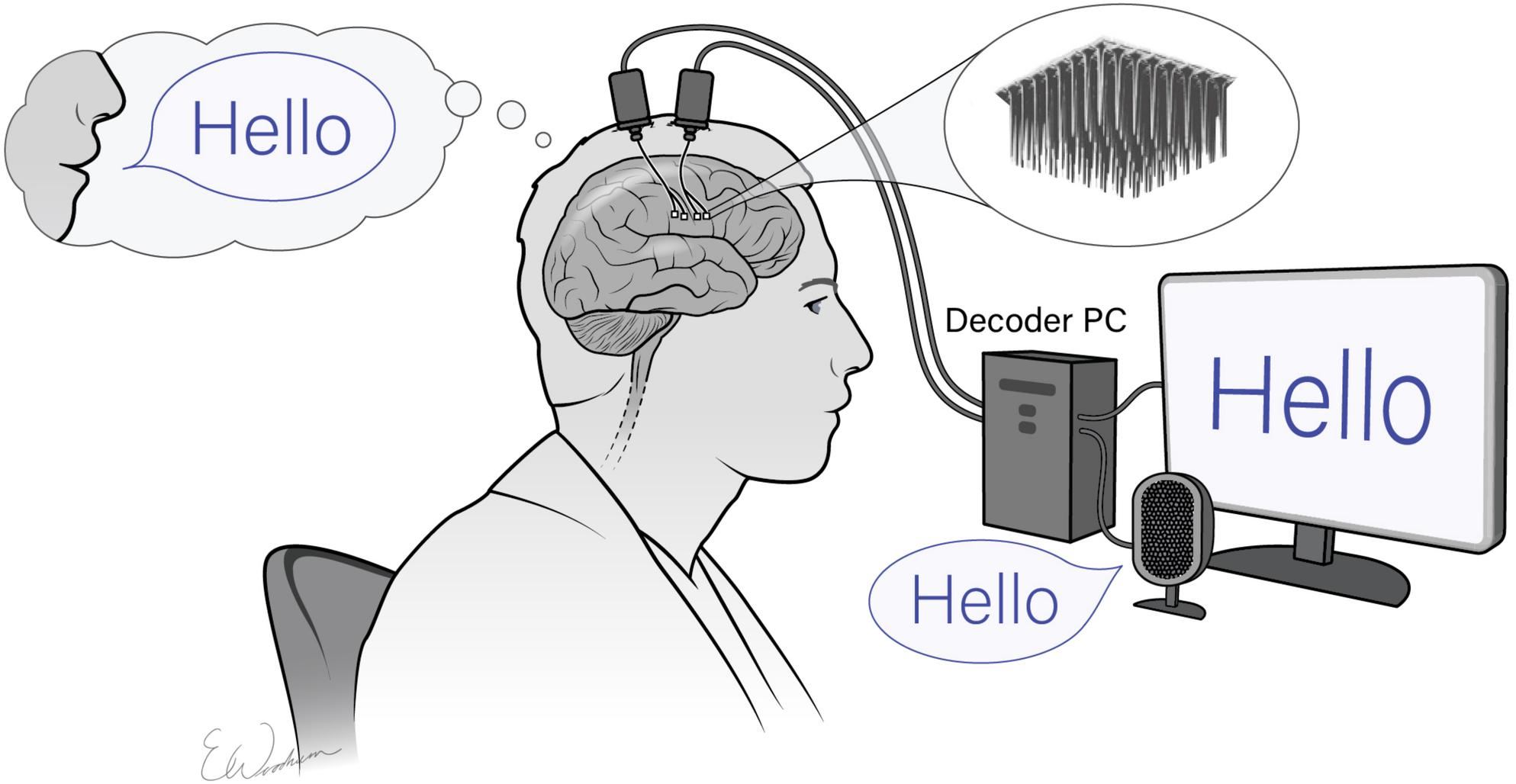




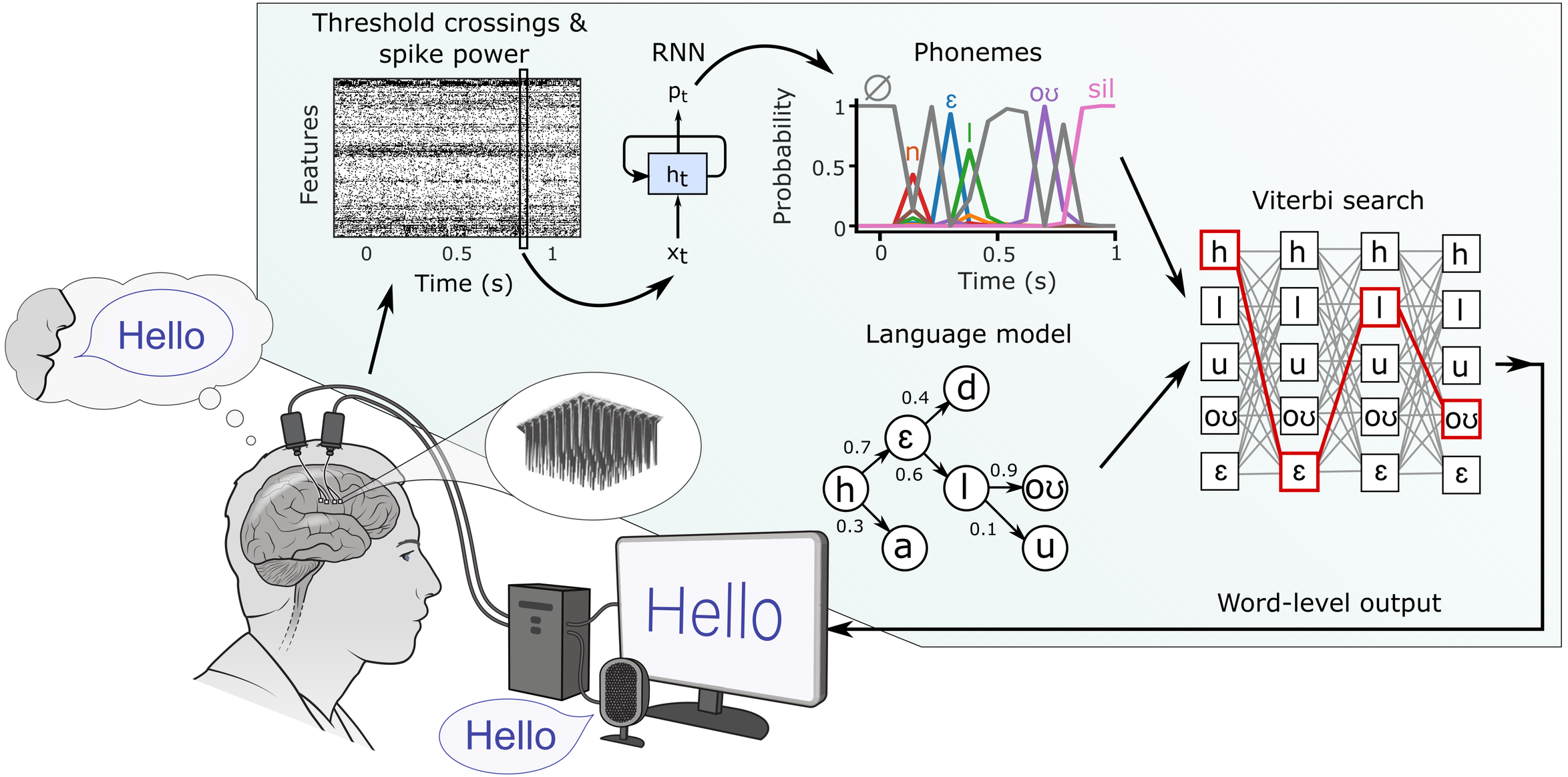
Orofacial and Speech Tuning



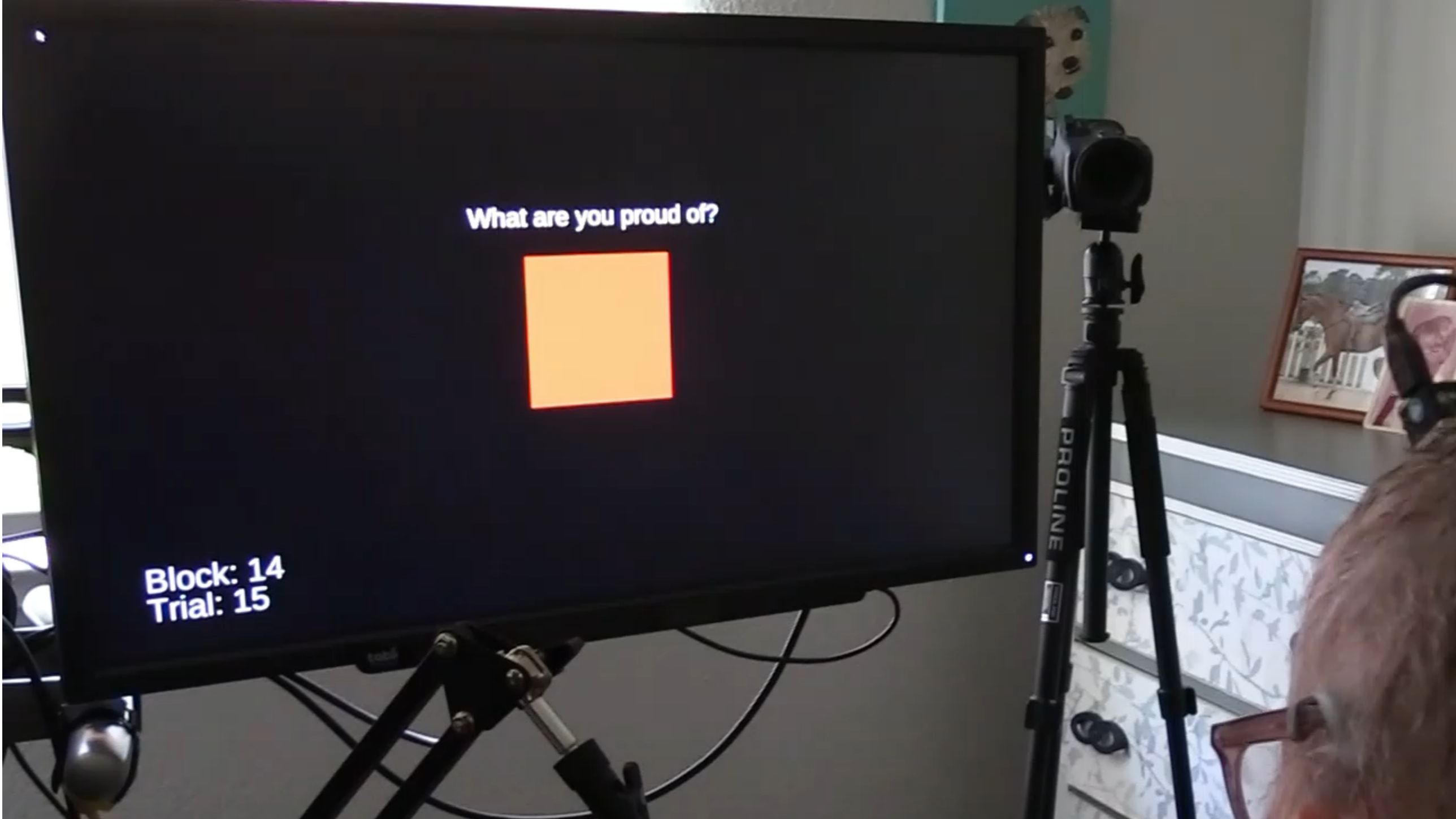



Hello
Decoder PC
Hello
Hello

Decoding Methods

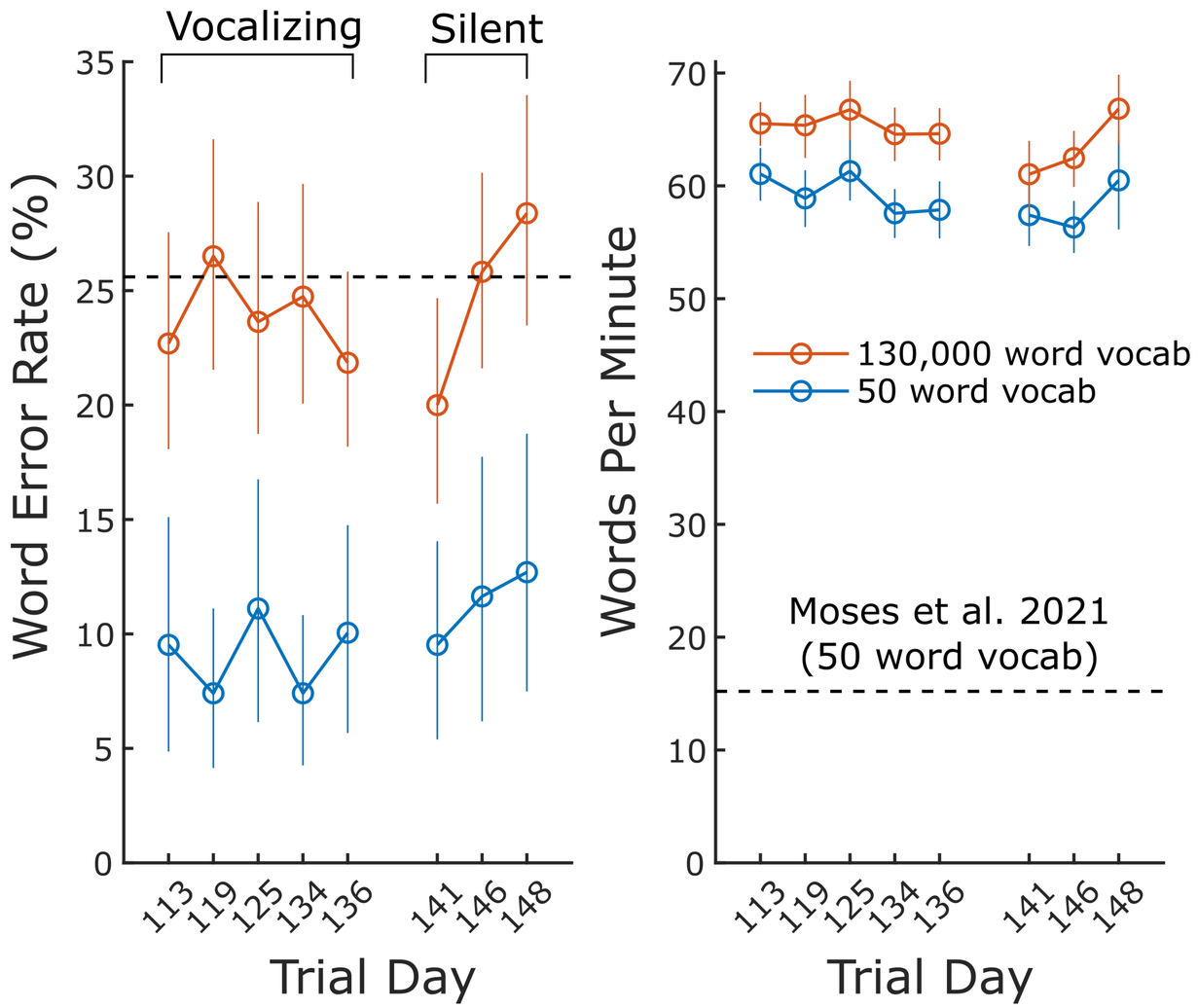



I don't want to call her a baby sitter.
Block: 17
Trial: 32
Canon

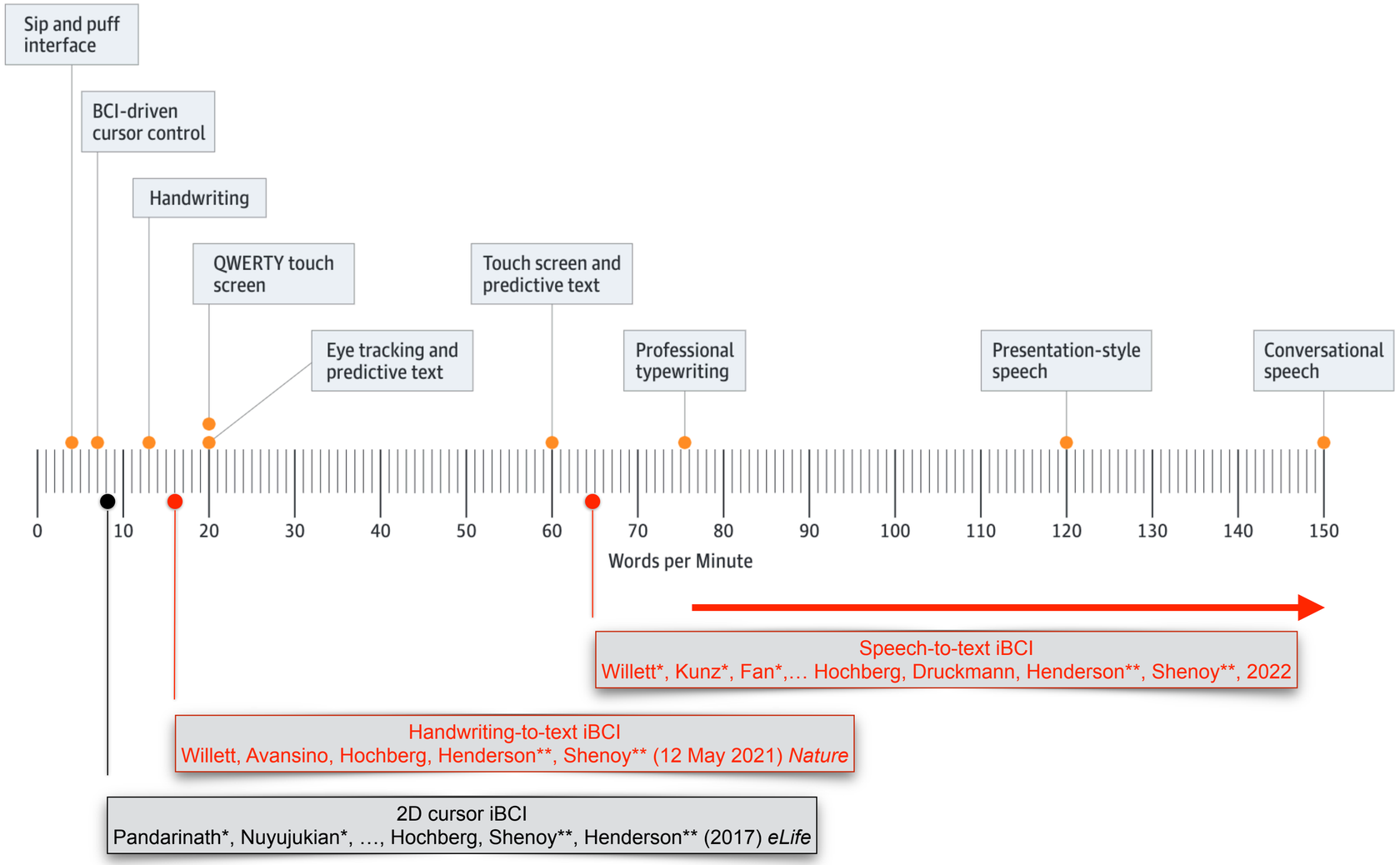

What are you proud of?
Block: 14
Trial: 15
PROLINE


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

A New Record for Speech Decoding

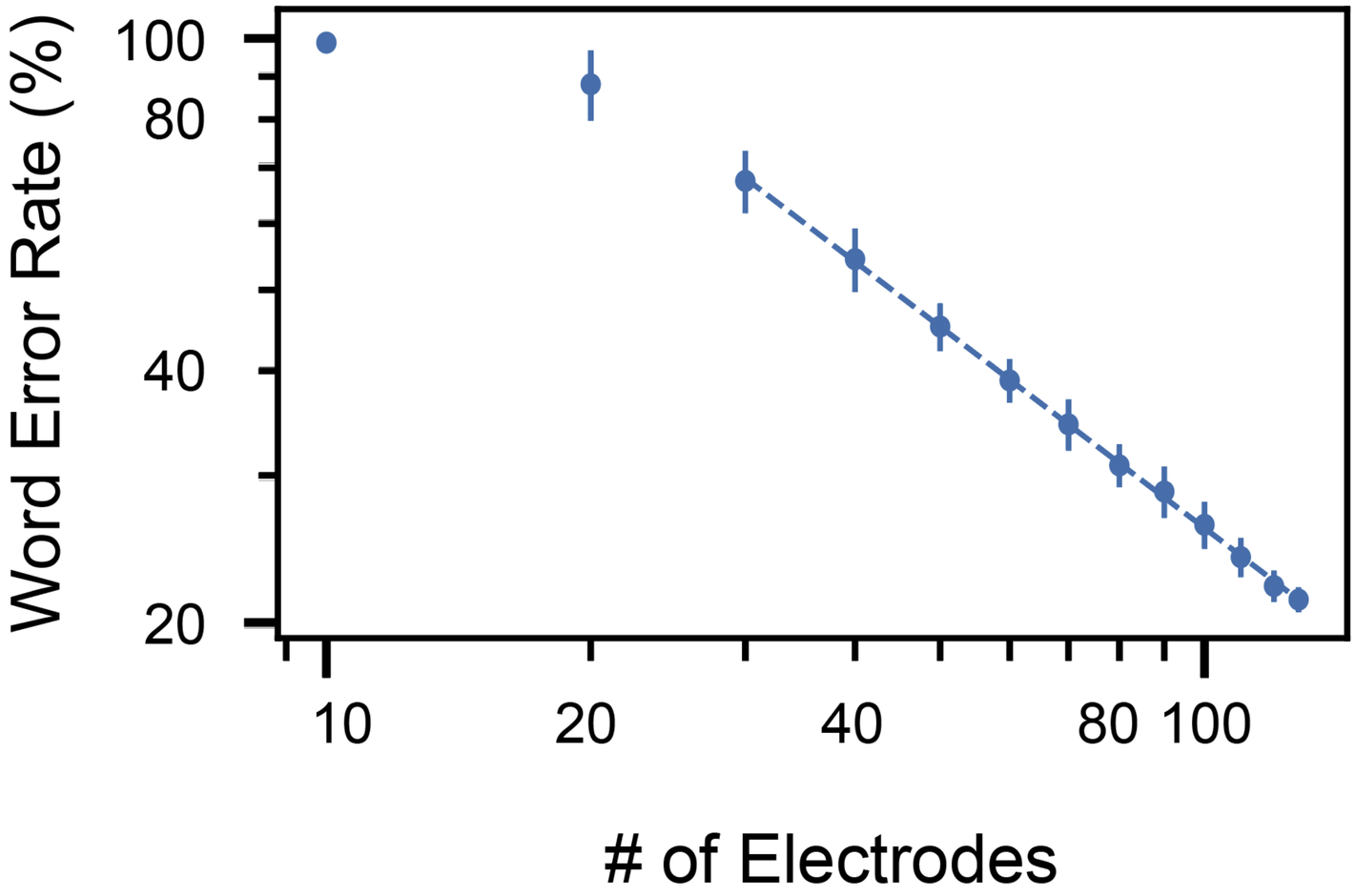


Increasing the performance of iBCIs with rapid and dexterous behaviors (including speech)



Chang & Anumanchipalli (2019) *JAMA*

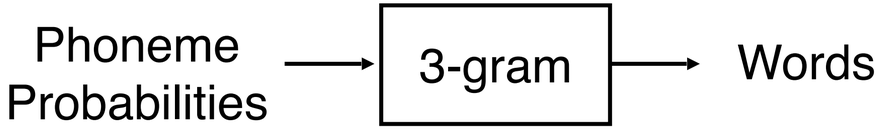
Performance Increases with More Electrodes



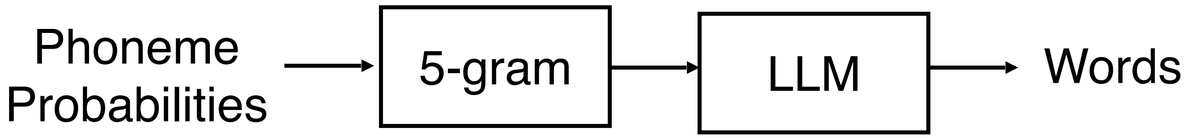
Willett FR*, Kunz E*, Fan C* et al. A high-performance speech neuroprosthesis. *Nature*. 2023.

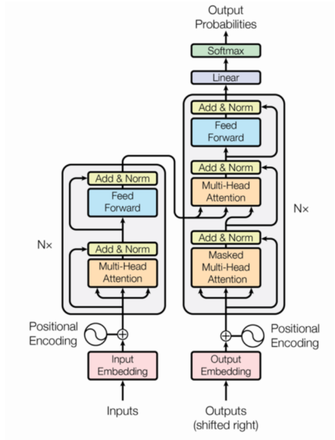
Language Model Improvements Still Possible

Original architecture



Improved architecture





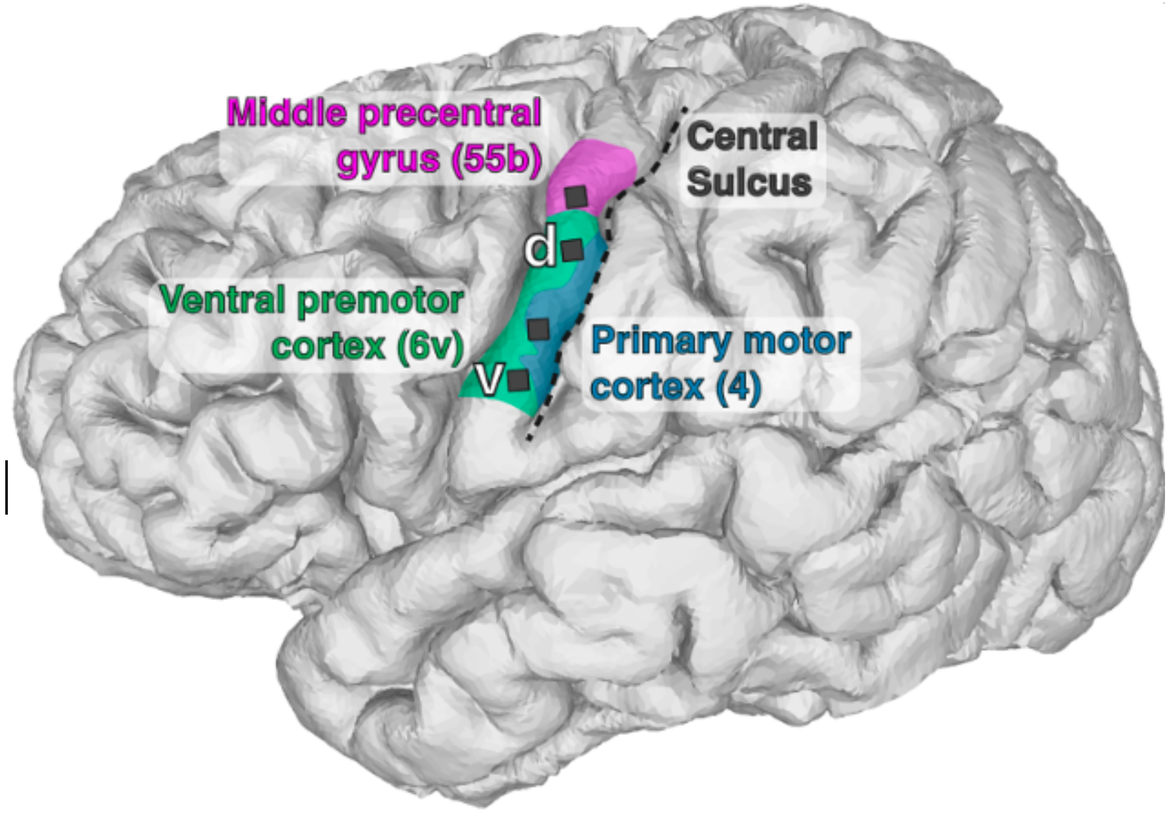
Offline word error rates improved from **23.8%** to **17.4%**

Willett FR*, Kunz E*, Fan C* et al. A high-performance speech neuroprosthesis. *Nature*. 2023.

New Results from UC Davis Team

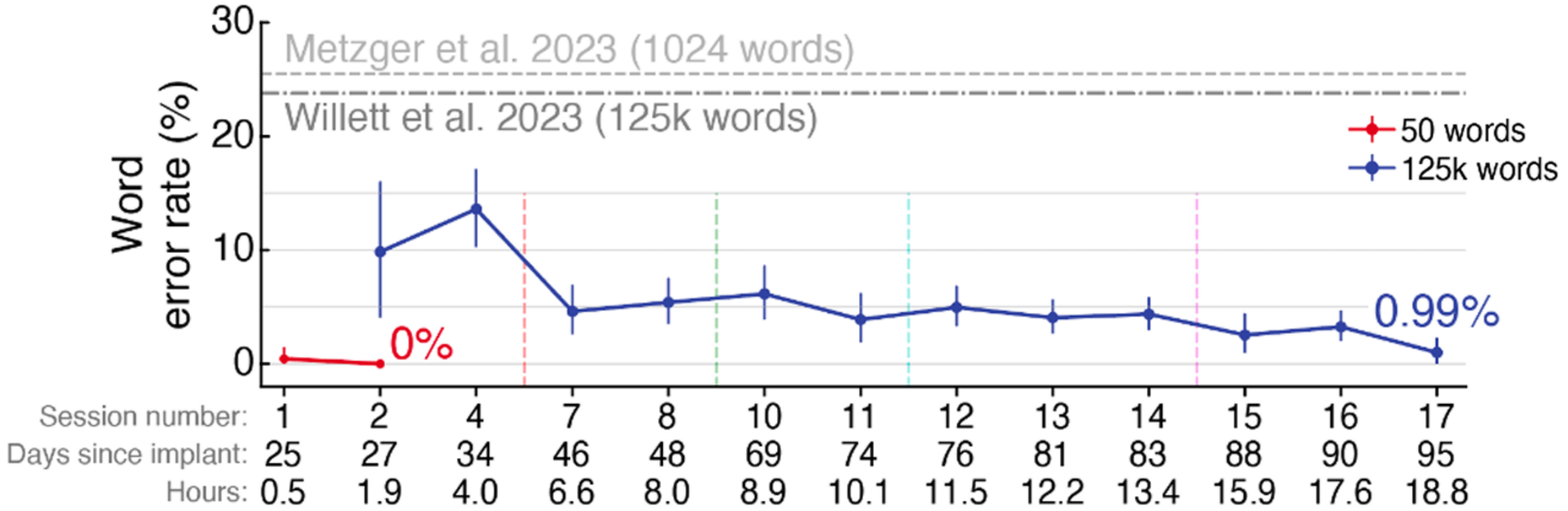
1) Doubled electrode count

2) Improved real-time language model



Card N, …, Brandman D**, Stavisky SD**. An accurate and rapidly calibrating speech neuroprosthesis. *medRxiv*. 2023.

New Results from UC Davis Team

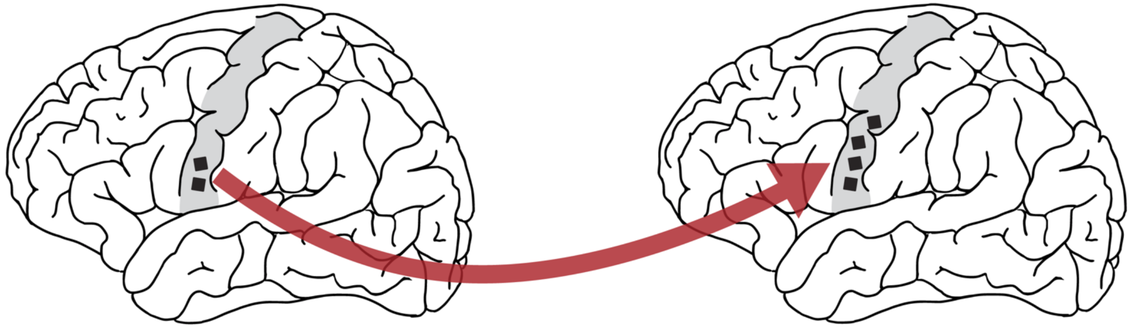


Card N, …, Brandman D**, Stavisky SD**. An accurate and rapidly calibrating speech neuroprosthesis. *NEJM*. 2024.

Toward Full Clinical Implementation

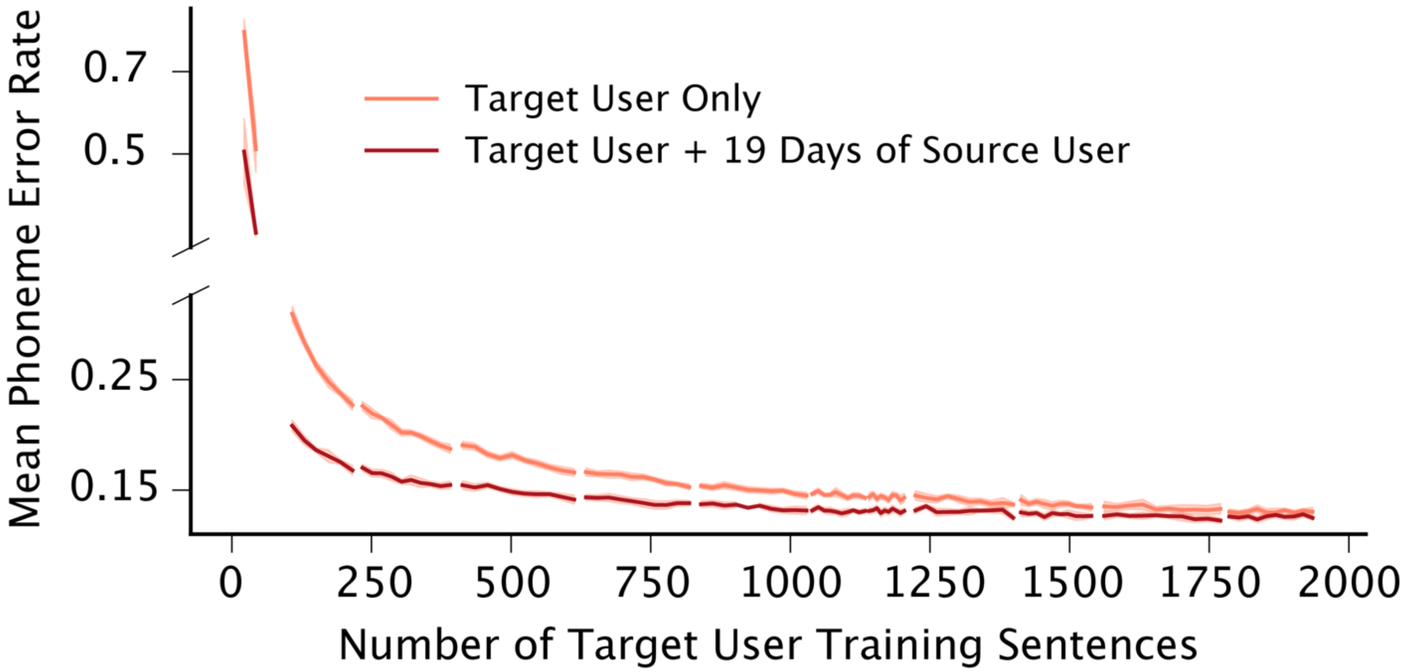
- Improving ease of use
  - Elimination of patient cable and pedestal
  - Fully-implantable wireless system
- Engineering Improvements
  - Calibration & Stability
  - Array Targeting
  - Accuracy

Minimizing Calibration Time via Transfer Leanring



Source User

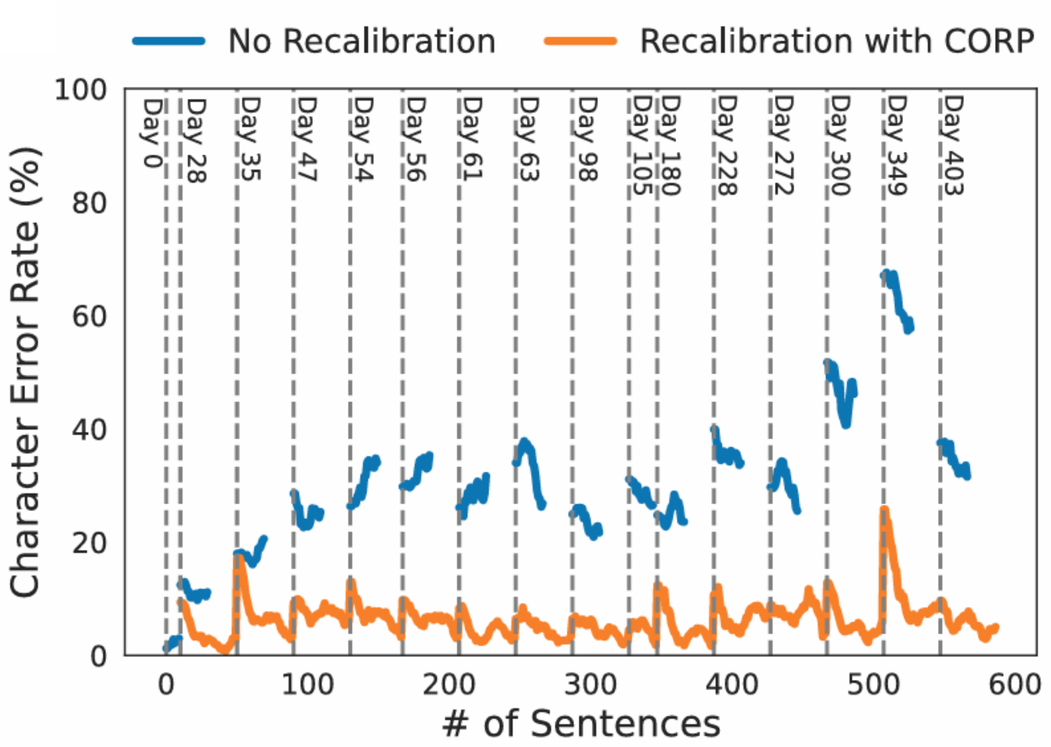
Target User

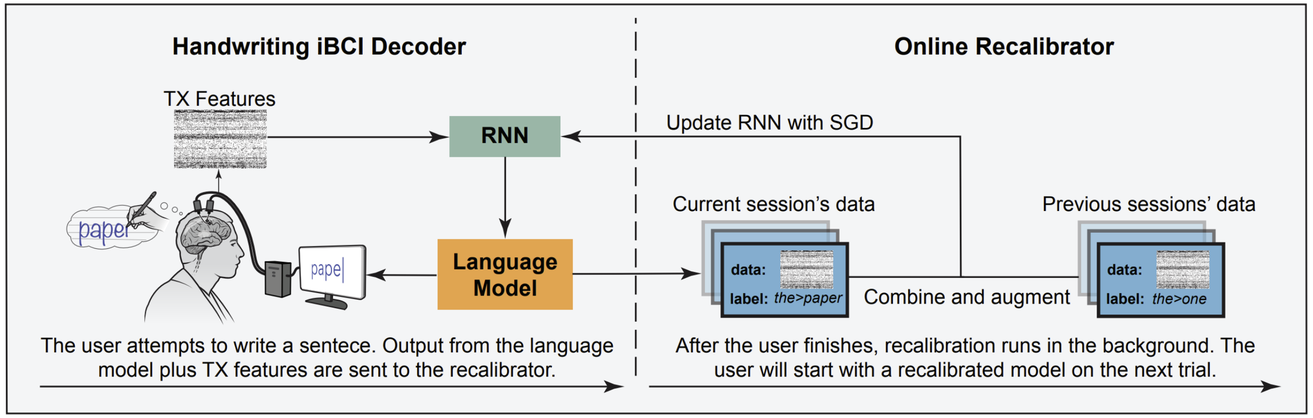


Alisa Levin

Stabilization via Continual Self-Training

Signals change **slowly enough** and decoding is **accurate enough** to enable self-recalibration: retraining on error-corrected outputs.

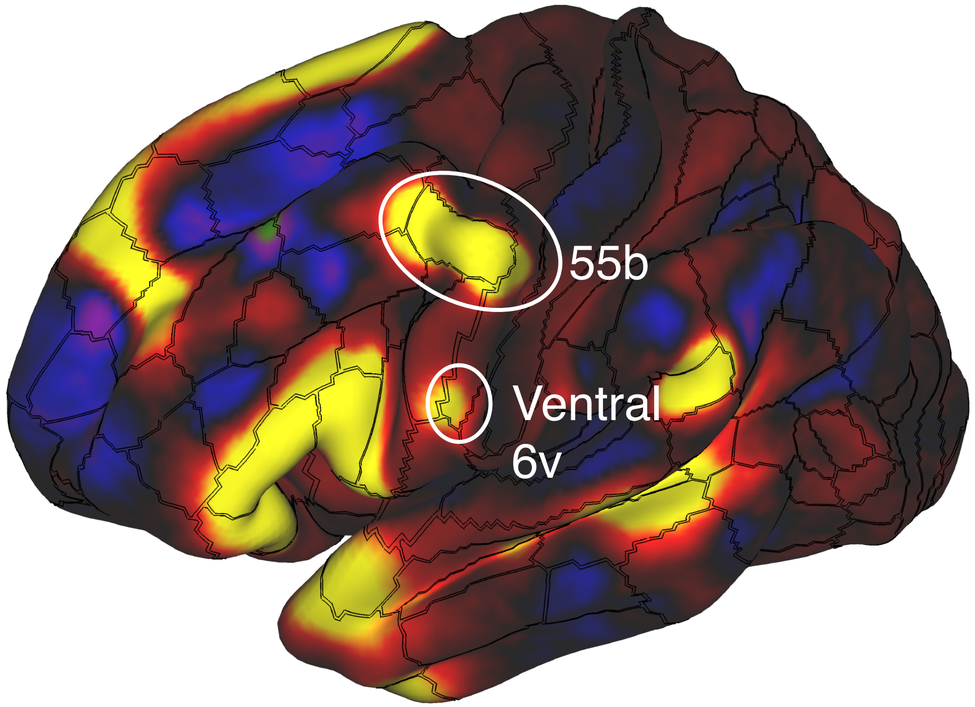




Fan, C. et al. Plug-and-Play Stability for Intracortical Brain-Computer Interfaces: A One-Year Demonstration of Seamless Brain-to-Text Communication. *NeurIPS* 2023.

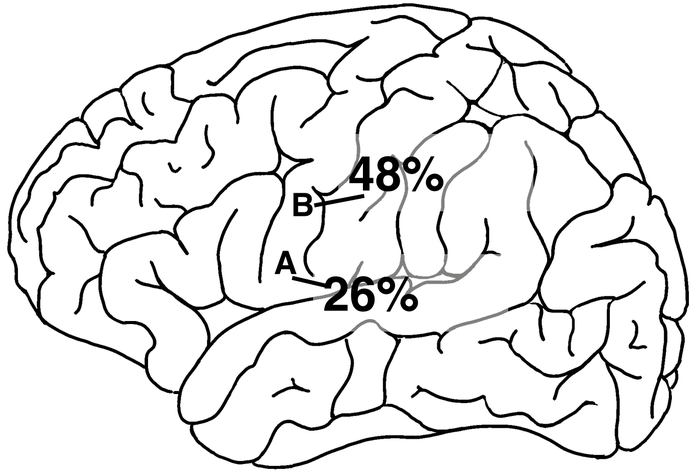
Chaofei Fan

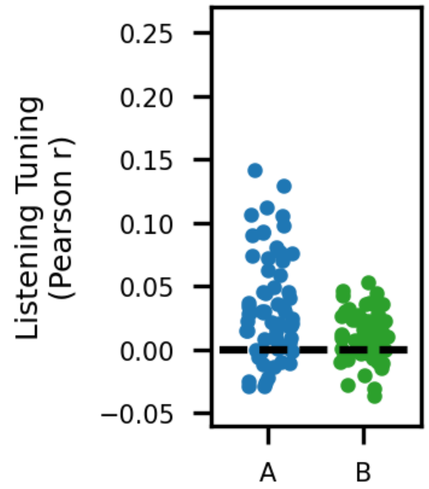
Speech Area Targeting: Two Speech Areas in Motor Cortex?



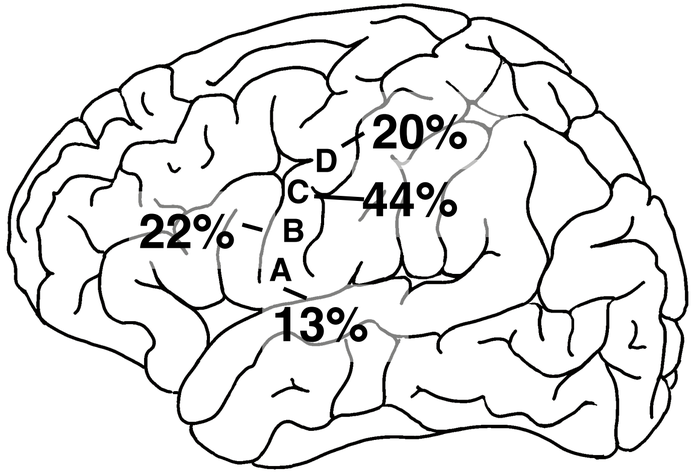
Glasser MF et al. A multi-modal parcellation of human cerebral cortex. *Nature*. 2016.

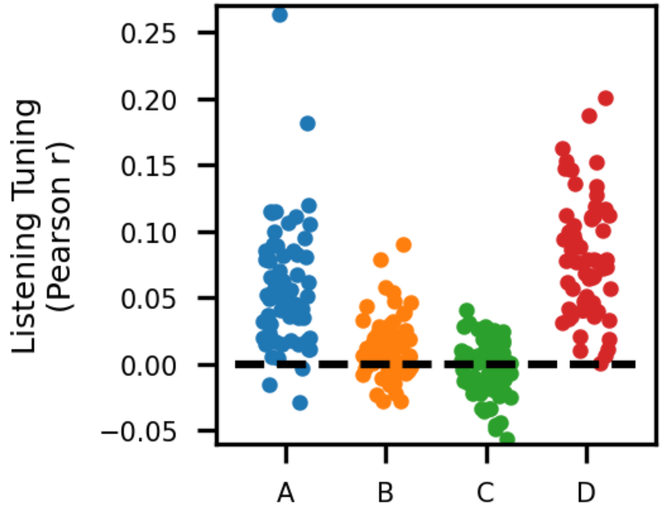
Stanford Participant





Davis Participant





Human Connectome Project Targeting

MRI

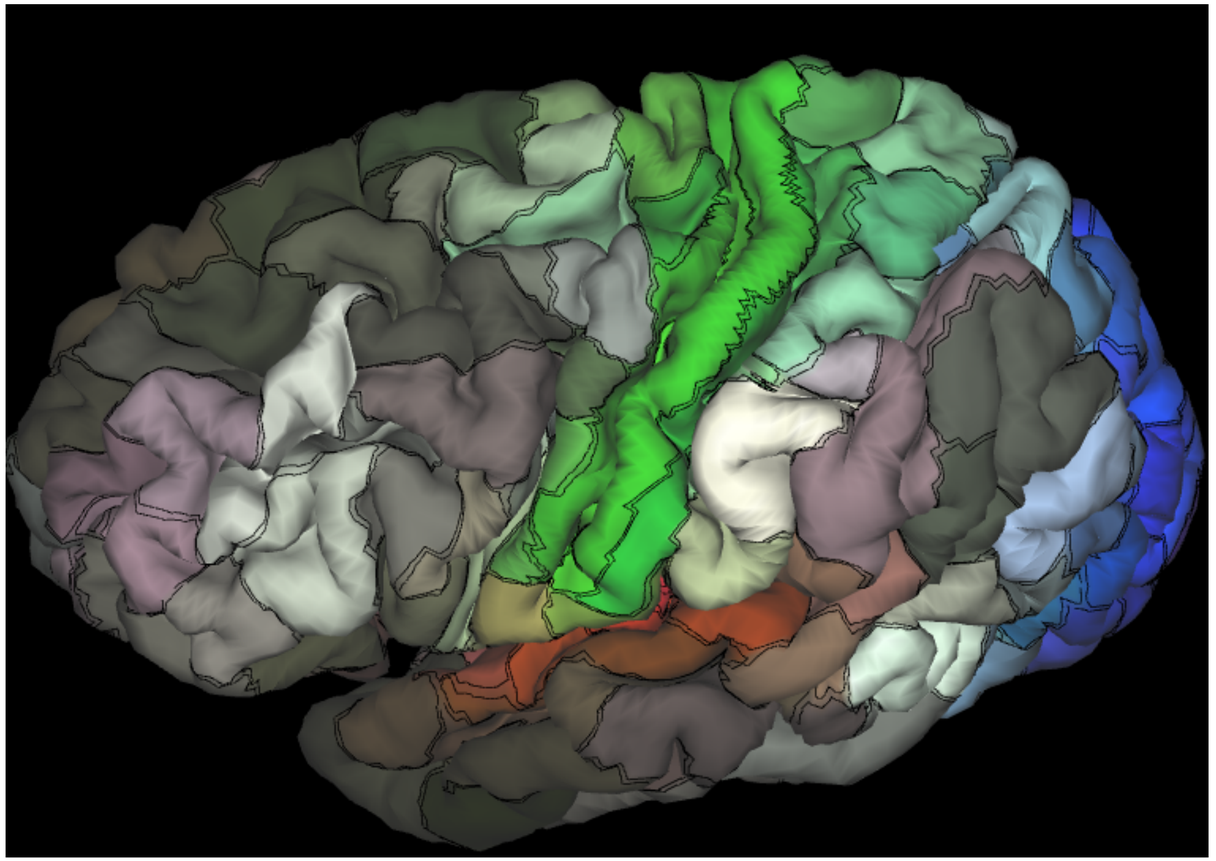
Cortical Thickness

Myelination

Folding

fMRI

Resting State Networks



Glasser MF et al. A multi-modal parcellation of human cerebral cortex. *Nature*. 2016.

Future Directions in Science

- Exploring representations in the brain
  - Where is language and speech motor production represented?
  - What else is represented in these areas?
  - Could similar principles be applied to develop neurprostheses for other types of communication disorders (aphasias from stroke, nonverbal autism?…)

Conclusions

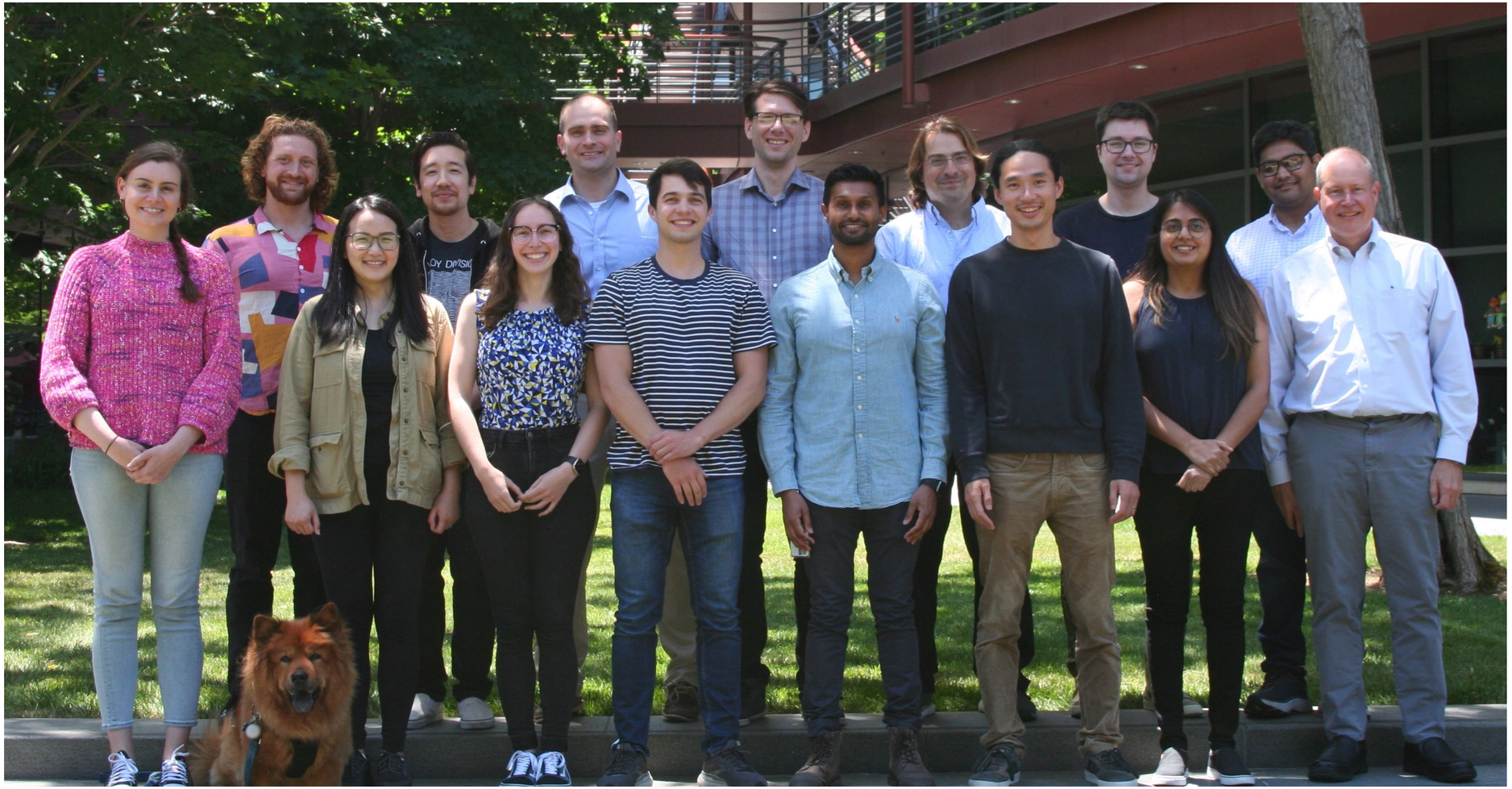
- Brain-computer interfaces are moving closer than ever to clinical reality
- BCI research enables insights in fundamental human neuroscience
- We will soon have systems that can provide real assistance to people with communication disorders and paralysis
- The future is very exciting!

Krishna Shenoy

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

hhmi
Howard Hughes Medical Institute

Participants
T5, T6, T12,
T15, T16, T17



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