Stanford University
Neural Prosthetics Translational Laboratory

# Implantable BCIs for Restoring Communication

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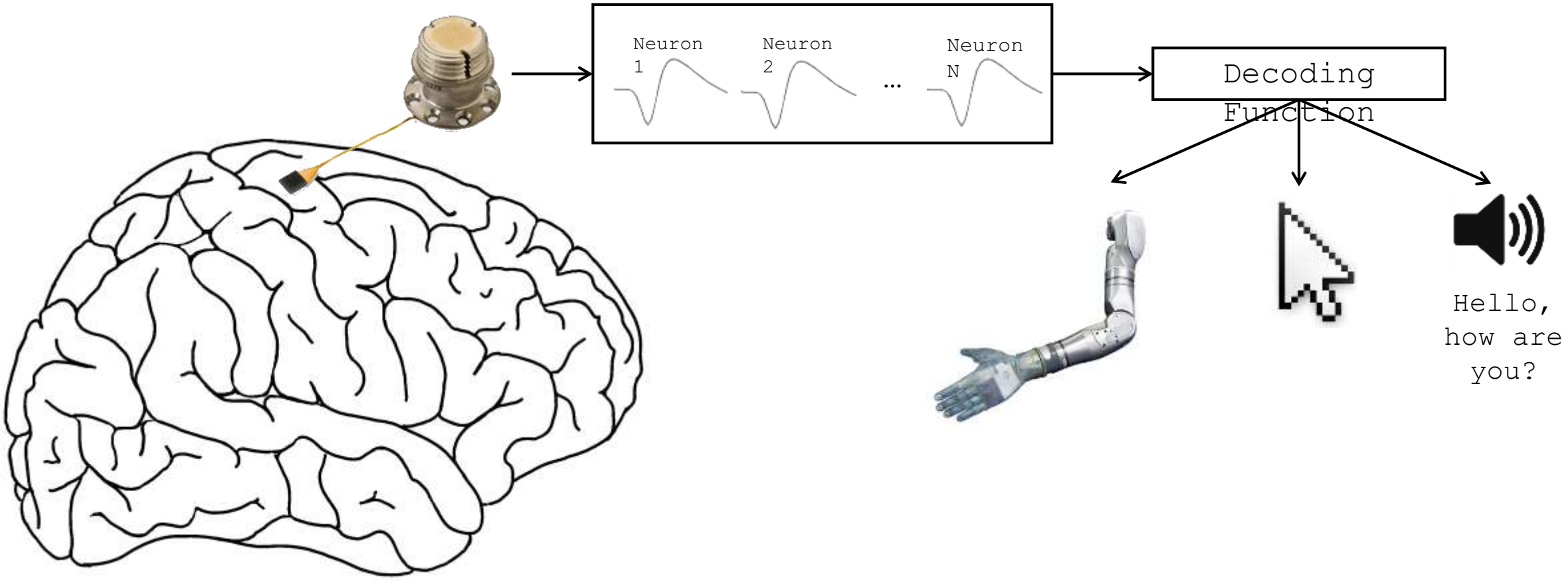
# The Clinical Need

# The Clinical Need

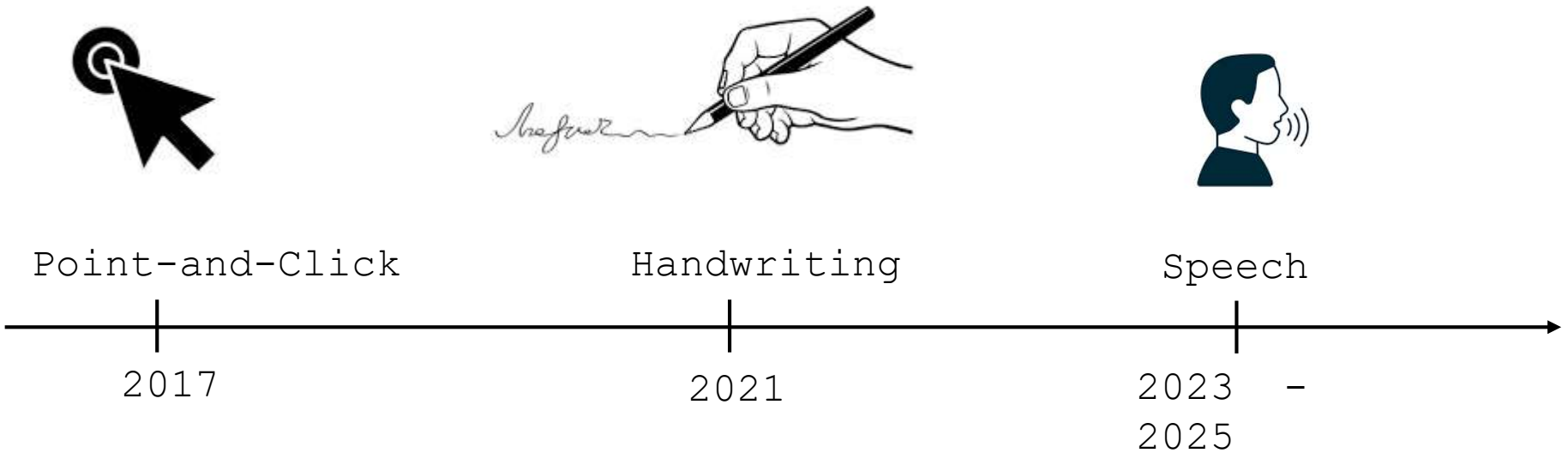
my communication system disqualifies repartee: the keenest rapier grows dull and falls flat when it takes several minutes to thrust it home. … It deprives conversation of its sparkle, all those gems you bat back and forth like a ball.

-Jean-Dominique Bauby

# Brain-Computer Interfaces



# 8 Years of BCI Progress

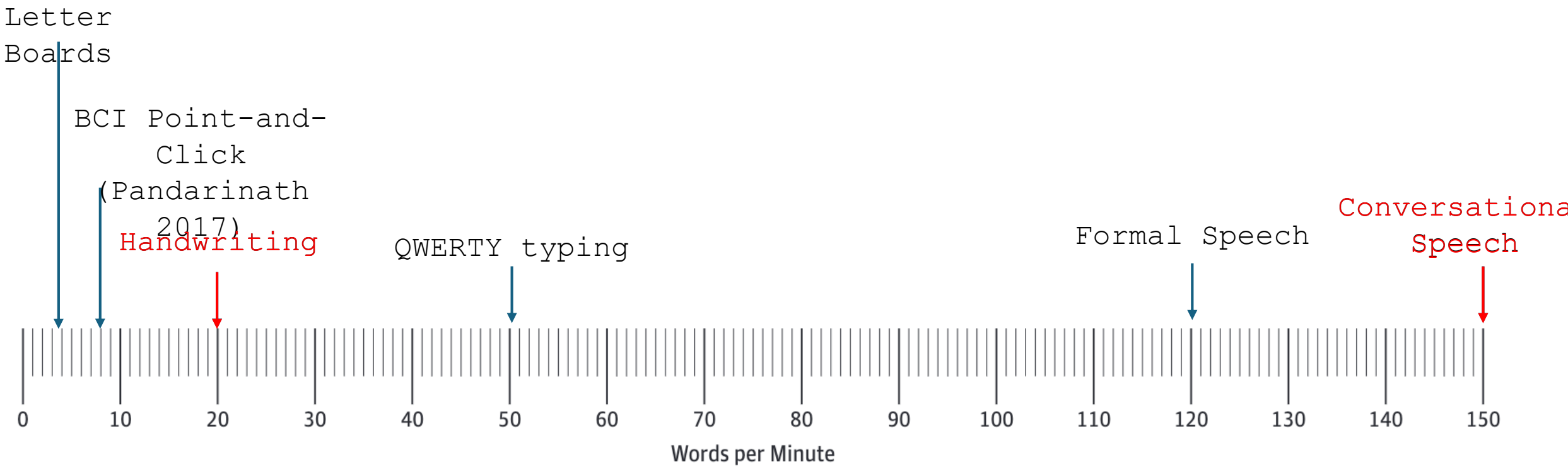


# The Beginning: Point-and-Click Typing

BCIs for point-and-click typing have achieved typing rates of **8 words per minute**

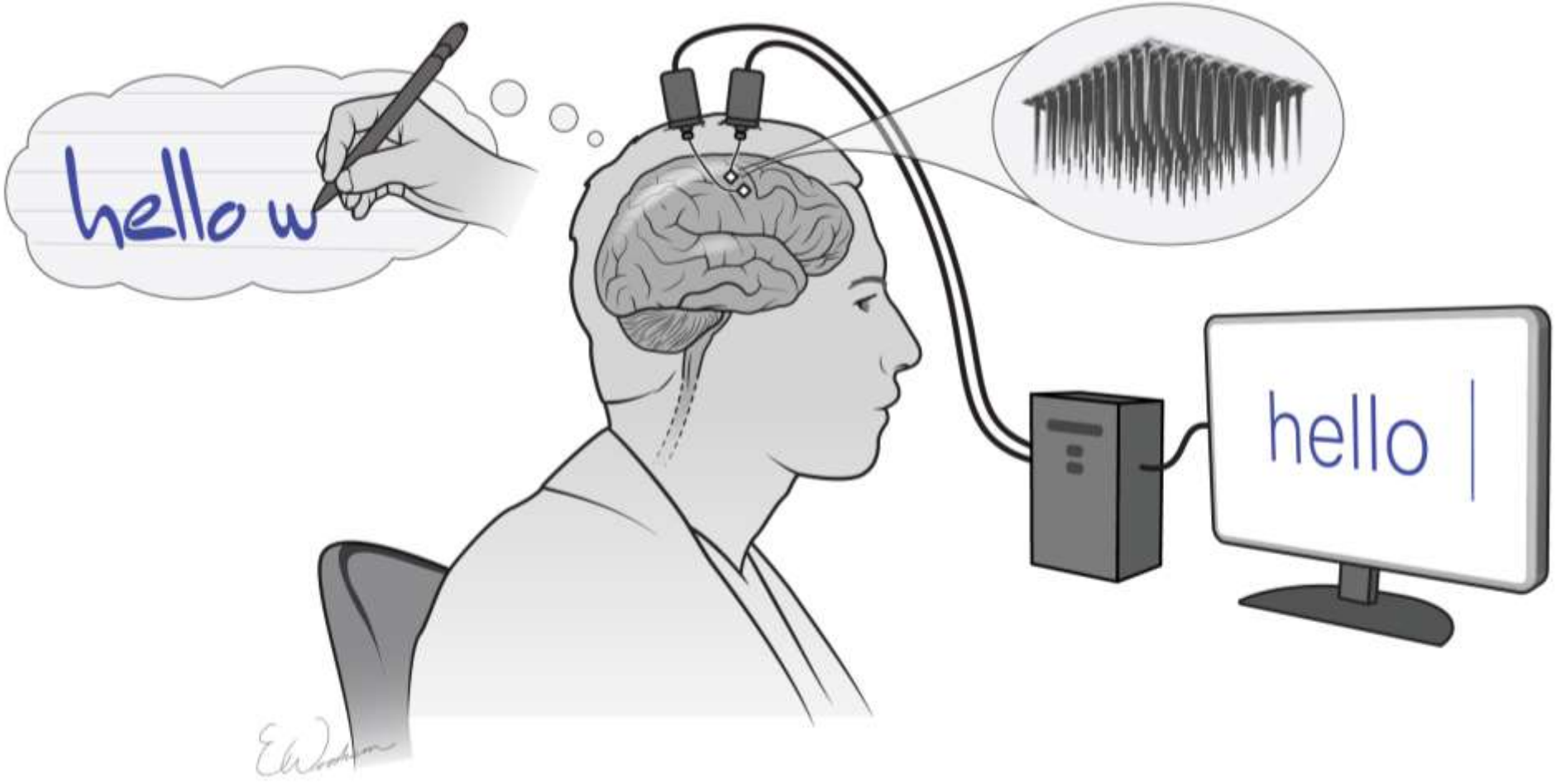
Pandarinath et al. 2017

# Words per minute in context




Can BCIs based on faster behaviors like **handwriting** and **speech** improve communication rates?

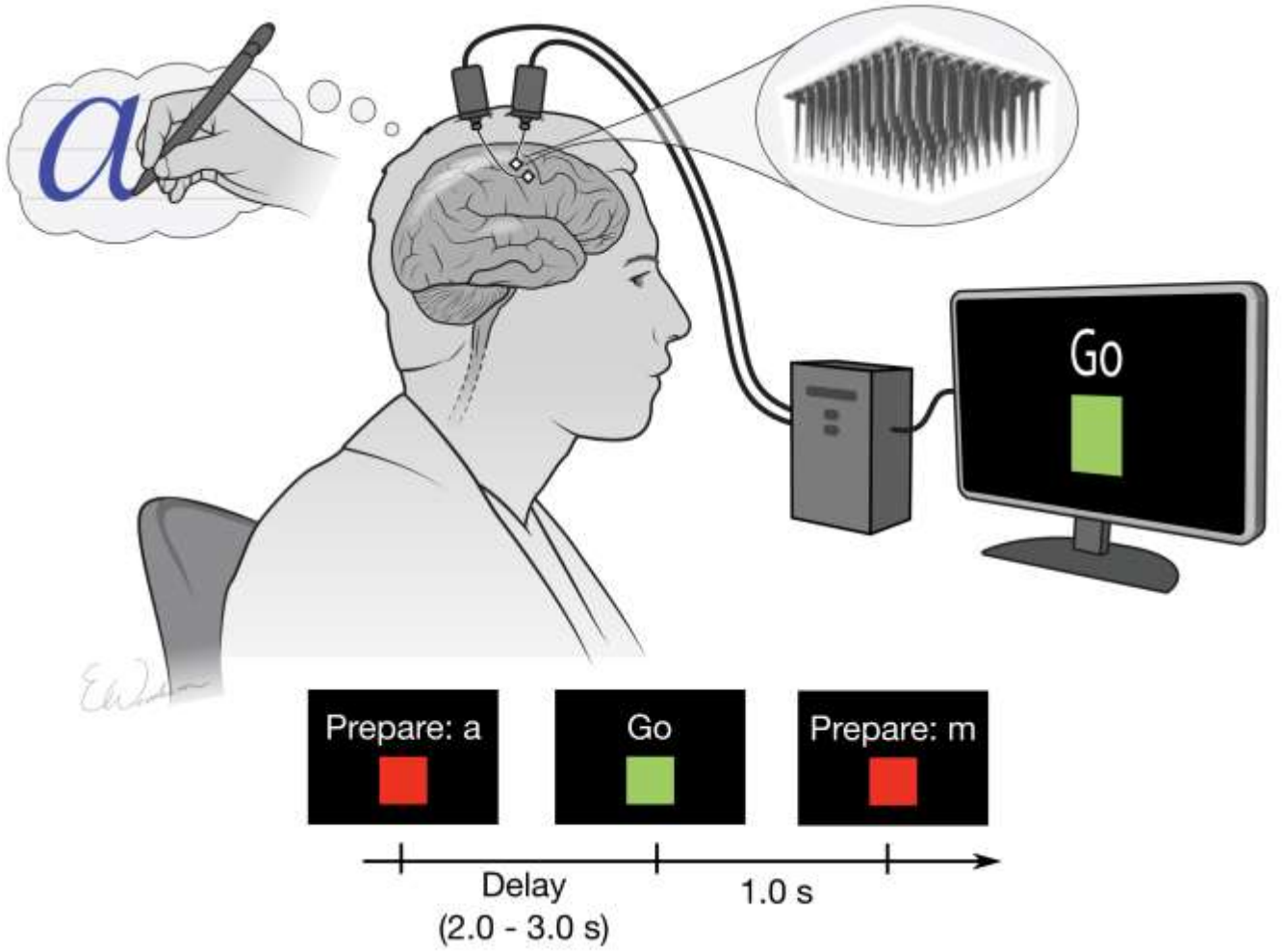
# A Handwriting BCI




Willett et al. High-performance bra
to-text communication via handwriti
*Nature* 2021

# Neural Representation of Handwriting

Does the neural representation for a highly dexterous skill, like handwriting, remain intact years after paralysis?



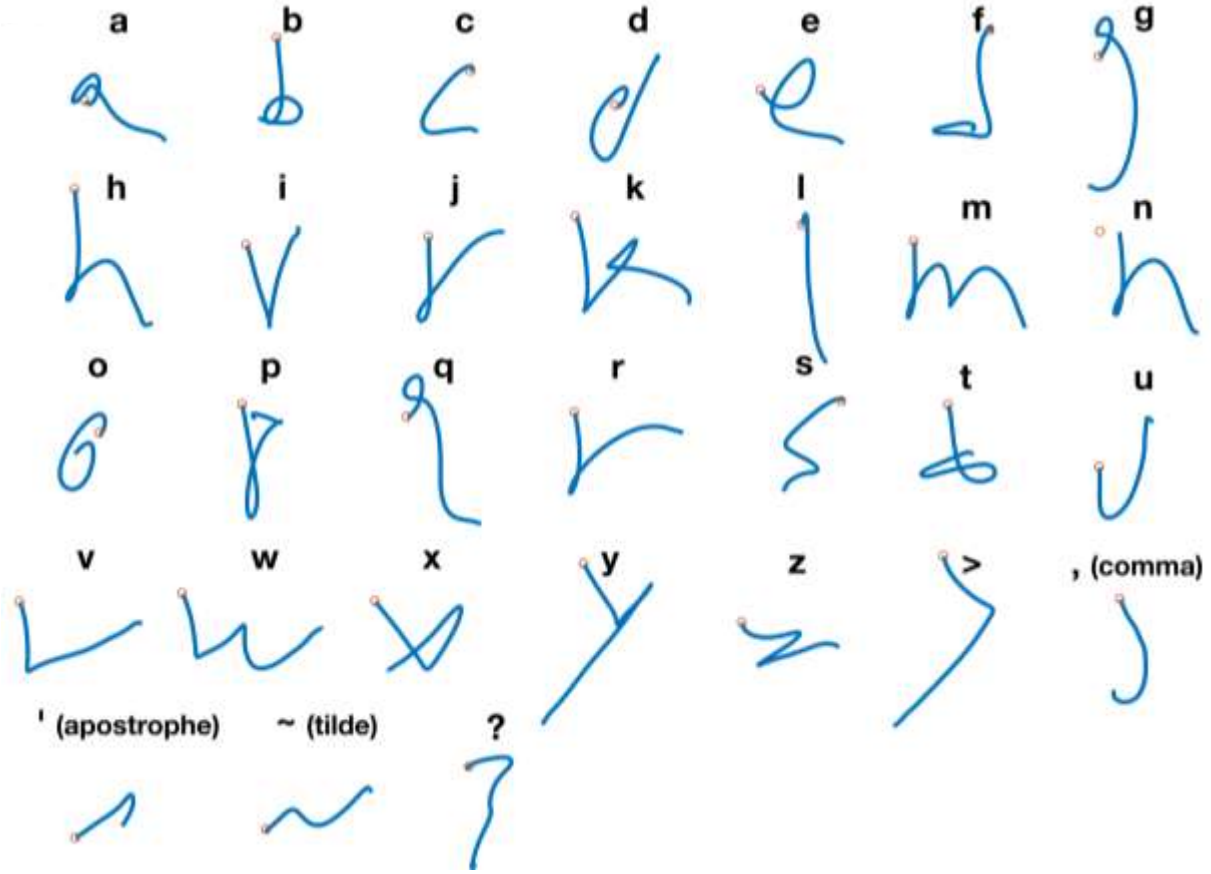

Willett et al. High-performance brain-to-text communication via handwriting. *Nature* 2021

# Neural Representation of Handwriting

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

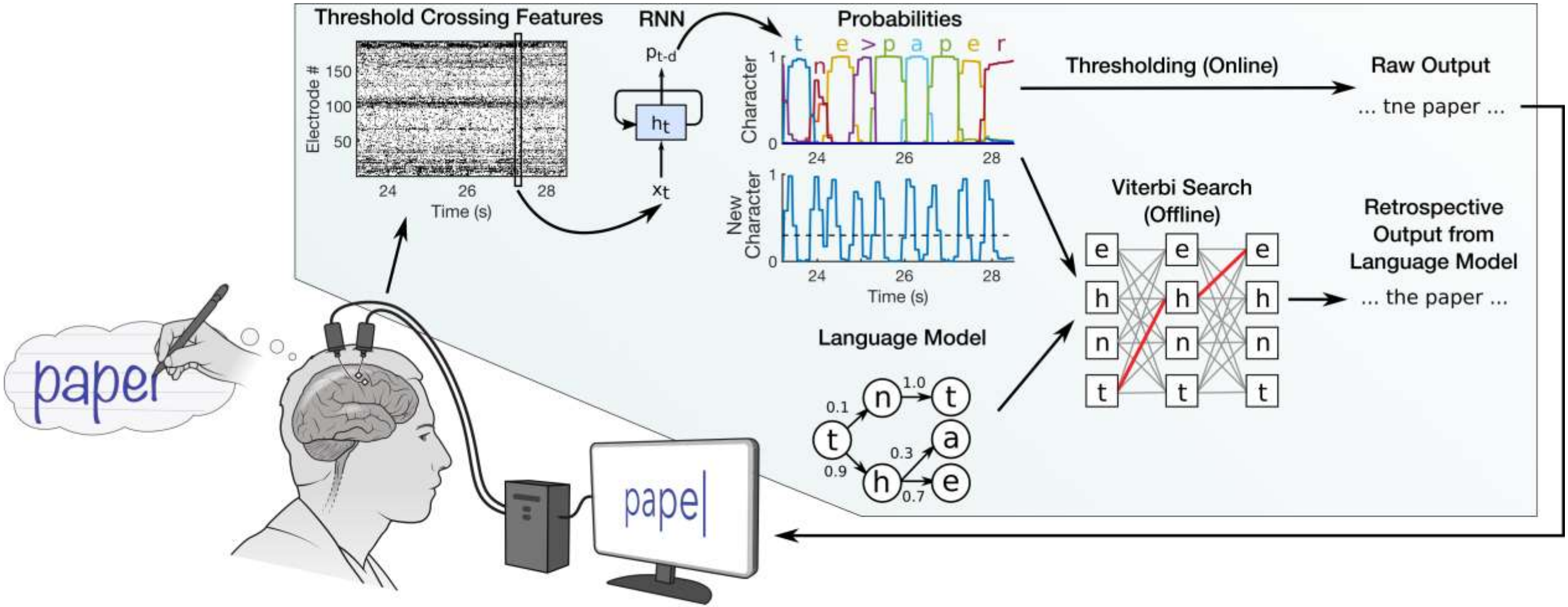
$$v_t = Df_t$$

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




Willett et al. High-performance brain-to-text communication via handwriting. *Nature* 2021

# System Diagram




Willett et al. High-performance brai
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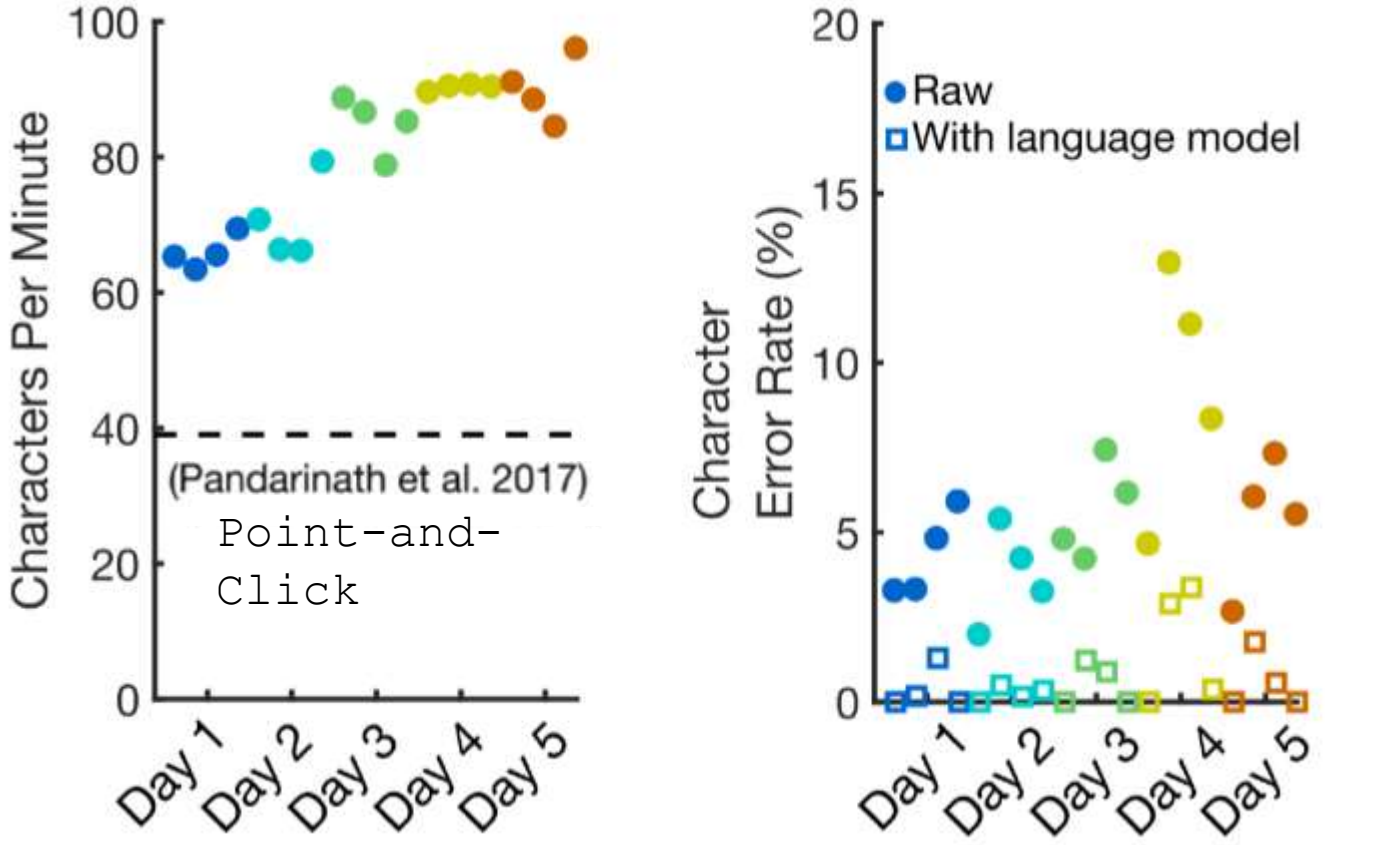
*Nature* 2021

# Real-Time Operation

Willett et al. High-performance brain-to-text communication via

# Copy Typing Performance




Willett et al. High-performance br
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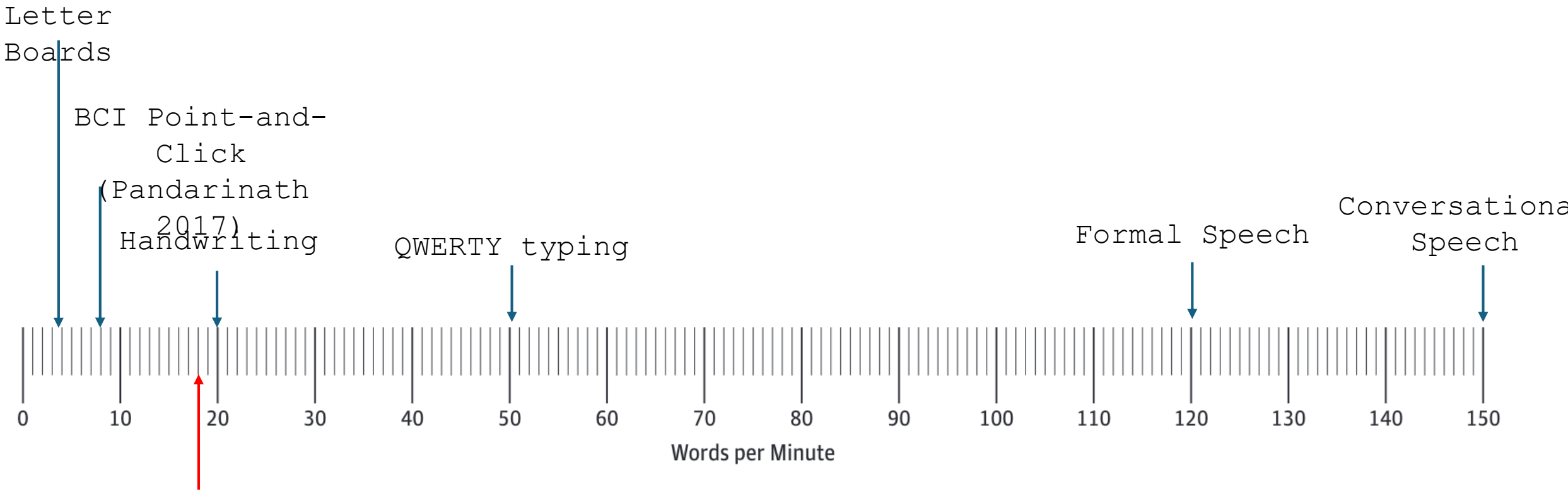
# Words per minute in context

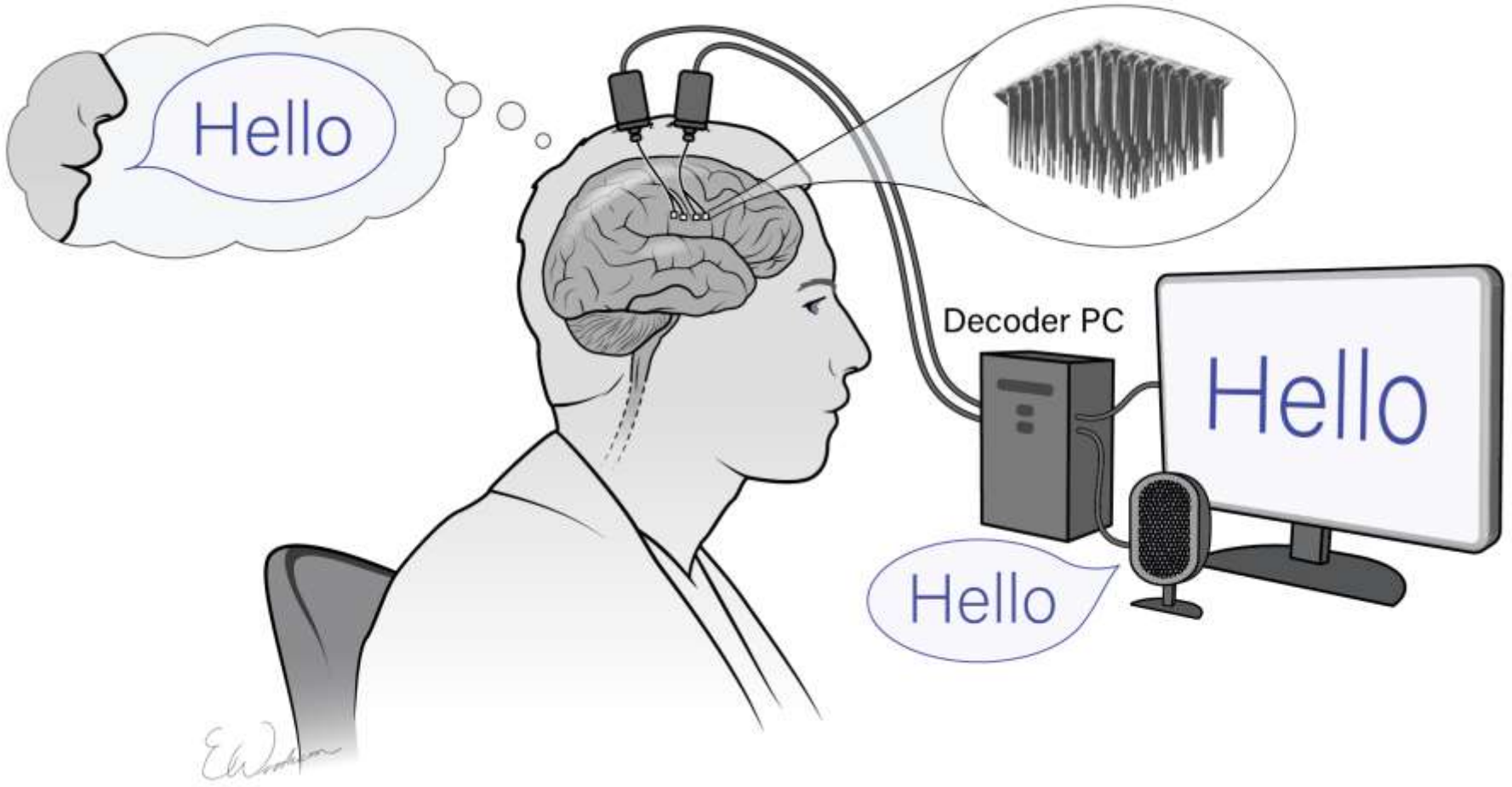



Willett et al. High-performance brain-to-text communication via handwriting. *Nature* 2021

What about speech?

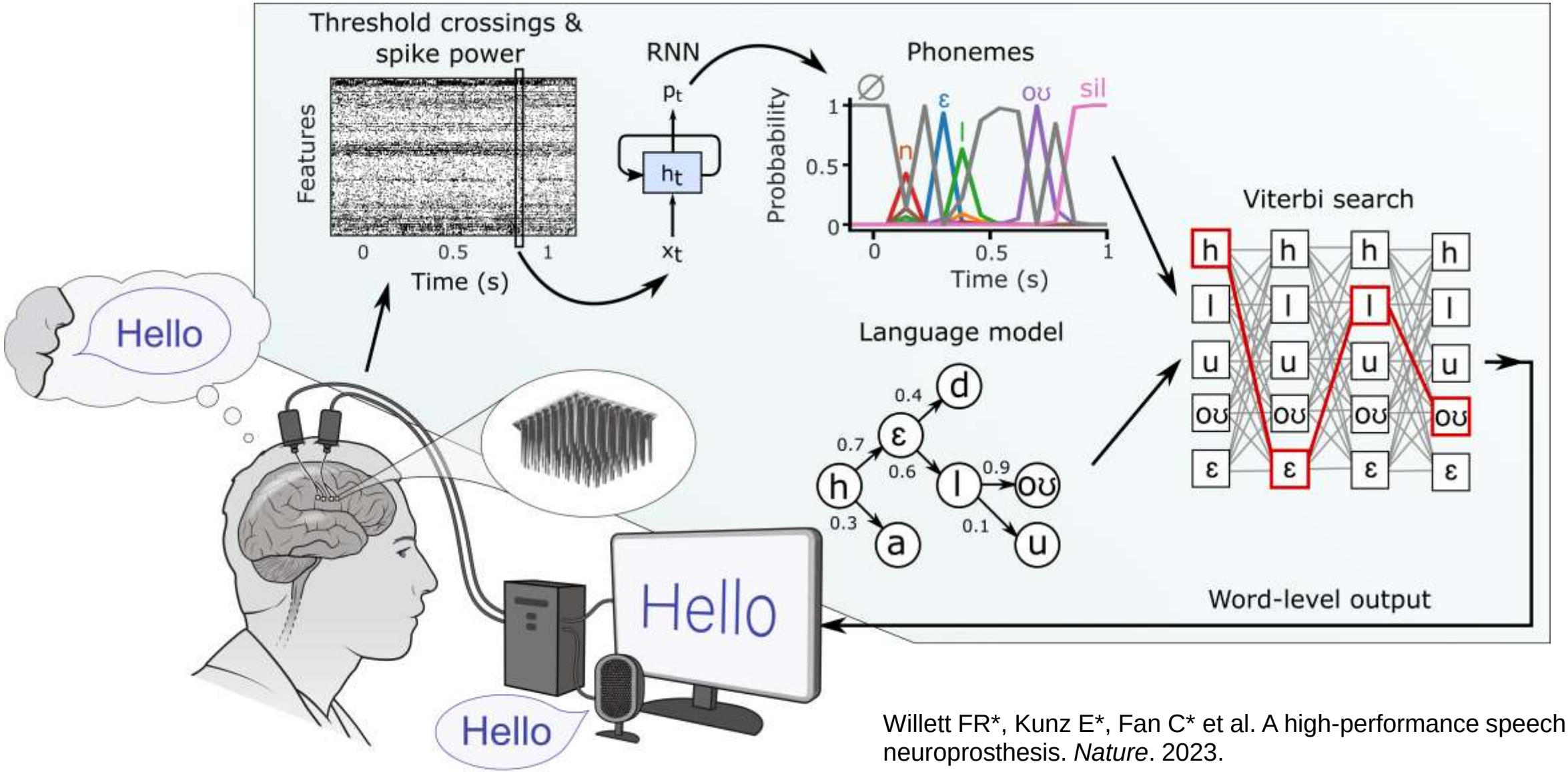
Wilson et al. 2020, Moses et al.2021

# A Speech BCI




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

# Decoding Methods

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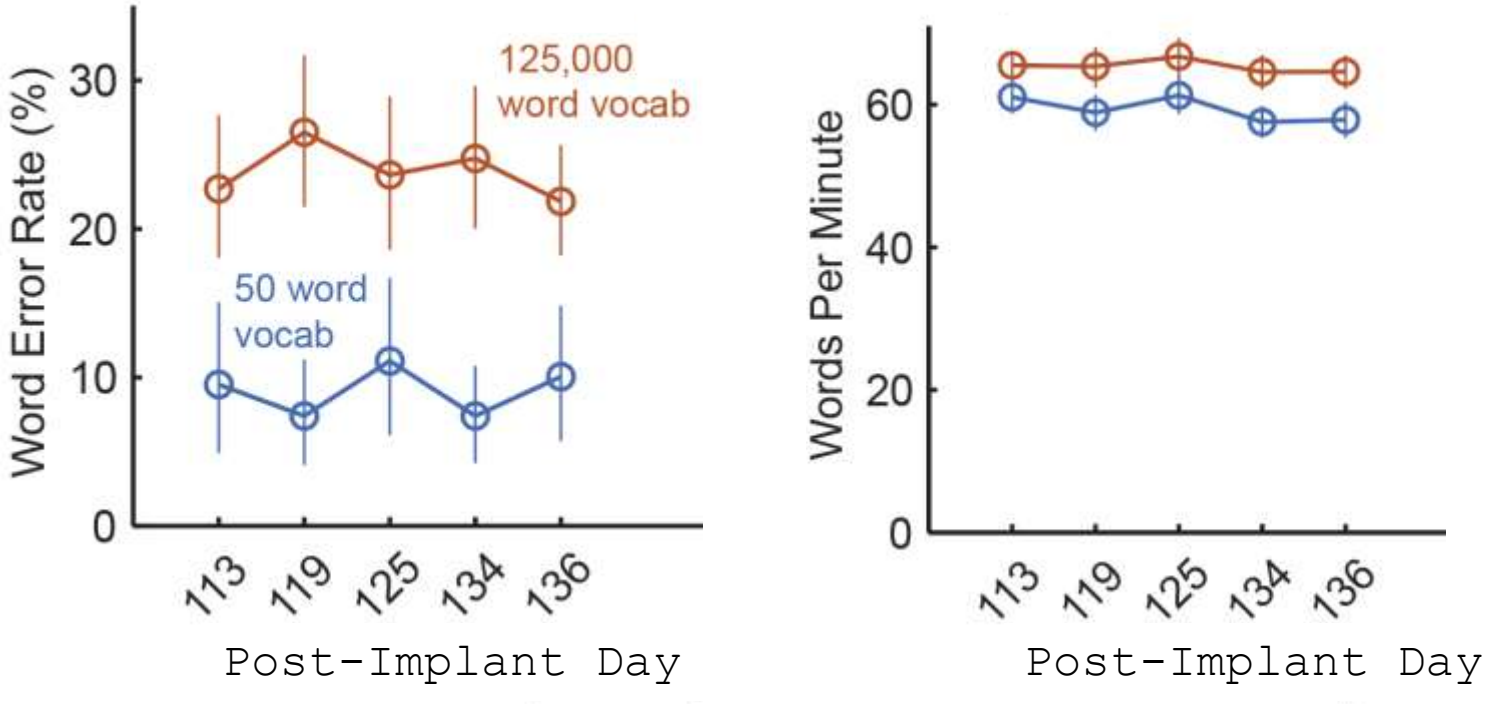
Willett FR*, Kunz E*, Fan C* et al. A high-performance speech neuroprosthesis. *Nature*. 2023.

# High-Performance Decoding

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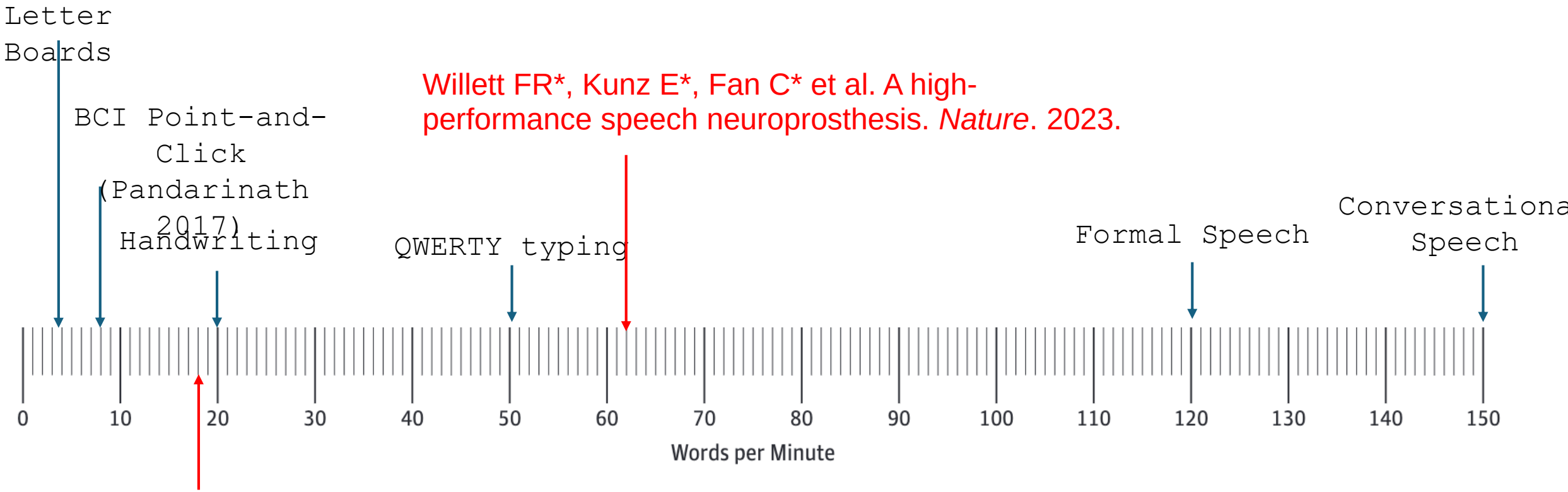
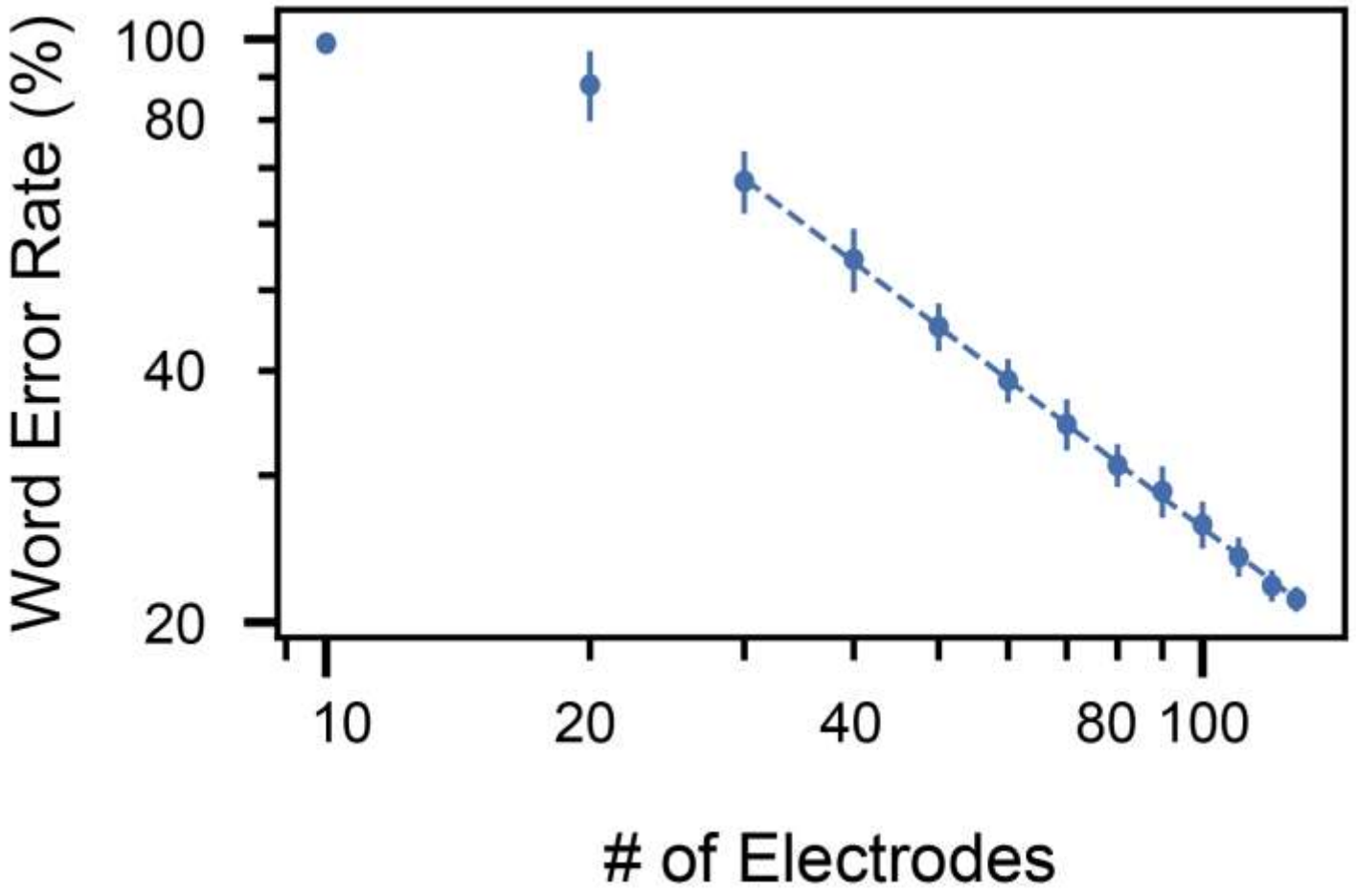
# Words per minute in context




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

Willett et al. High-performance brain-to-text communication via handwriting. *Nature* 2021

# Performance Increases with More Electrodes

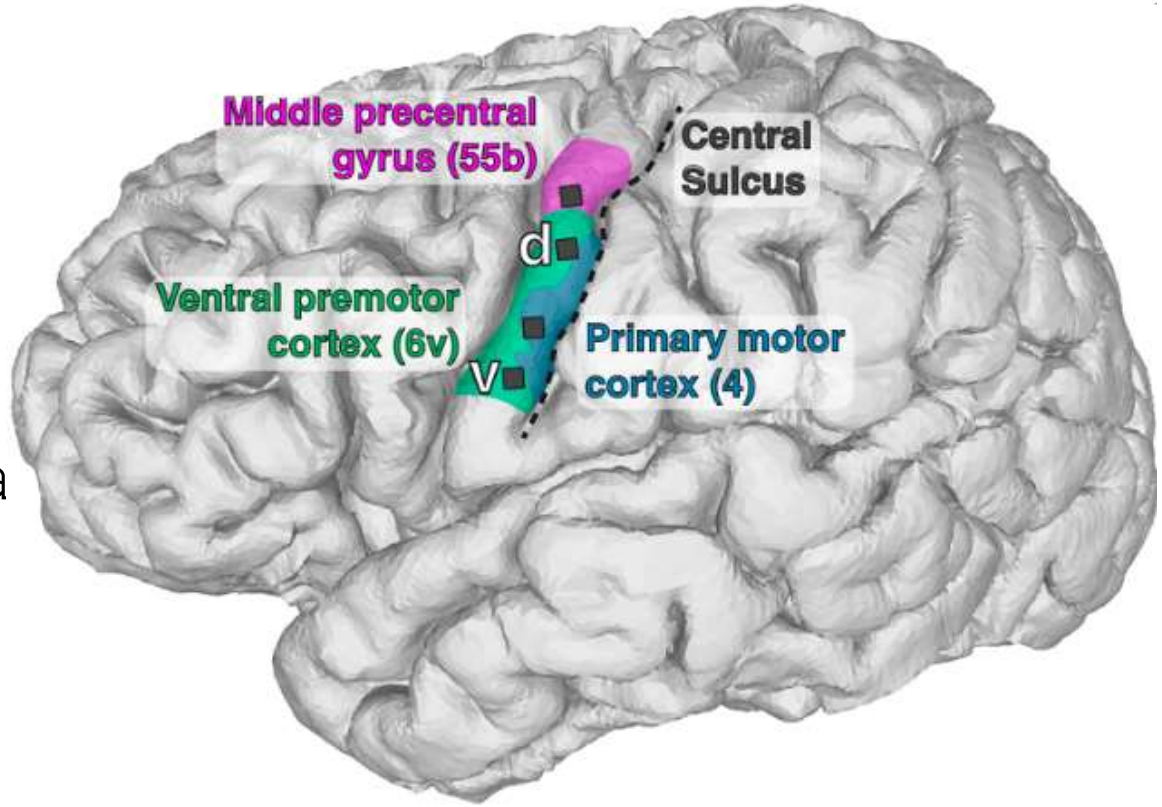



Willett FR*, Kunz E*, Fan C* et al. A high-performance speech neuroprosthesis. *Nature*. 2023.

# Latest Results from UC Davis Collaborators

1) Doubled electrode count

2) Improved real-time langua




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

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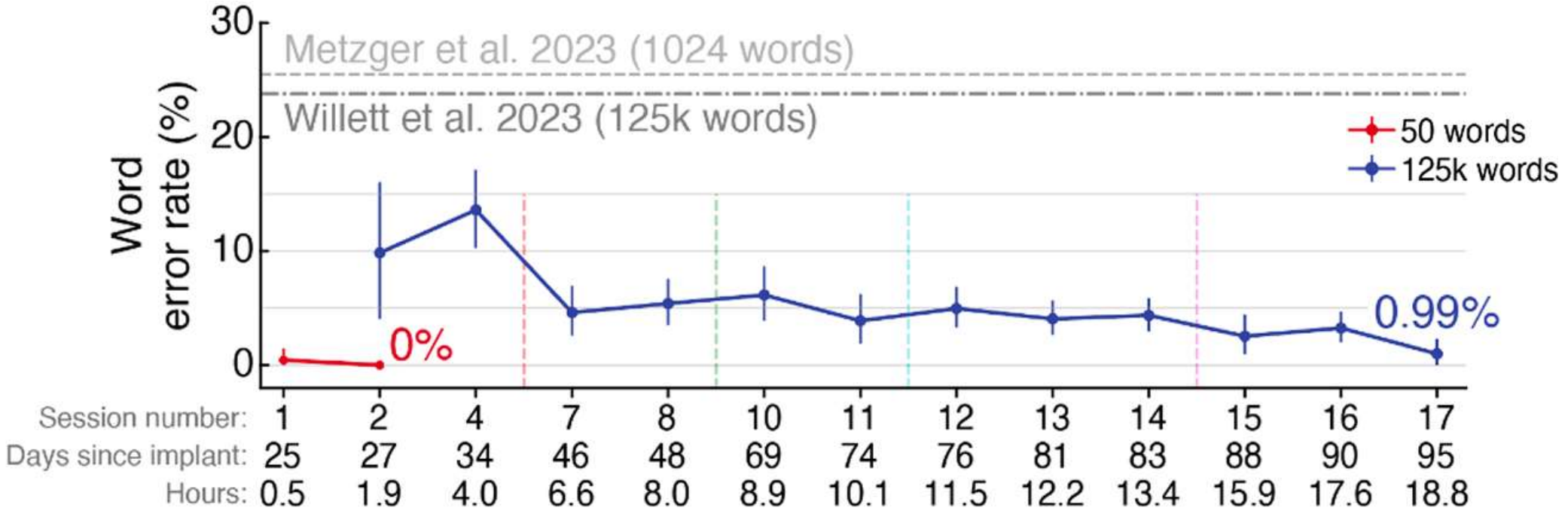


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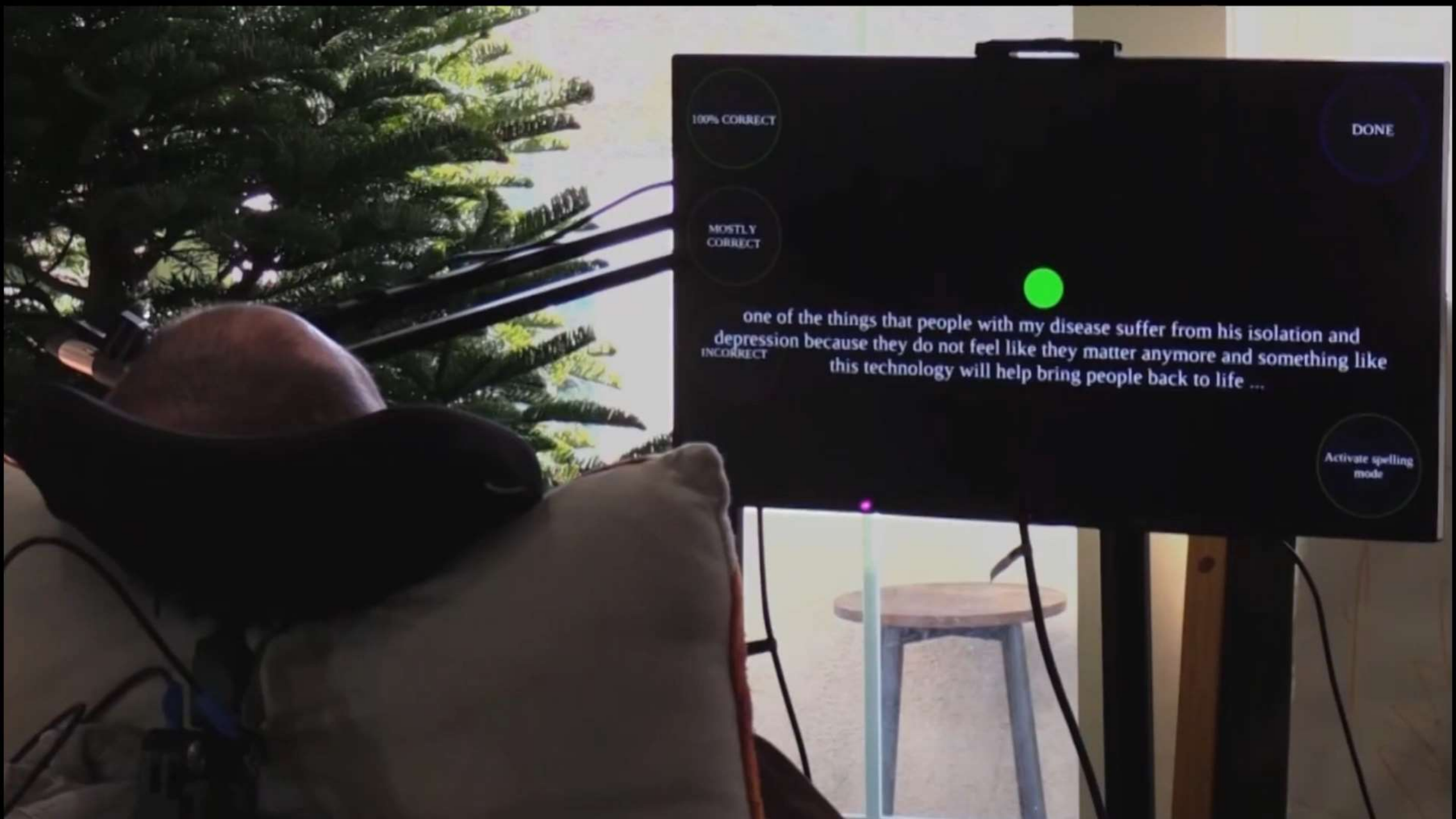
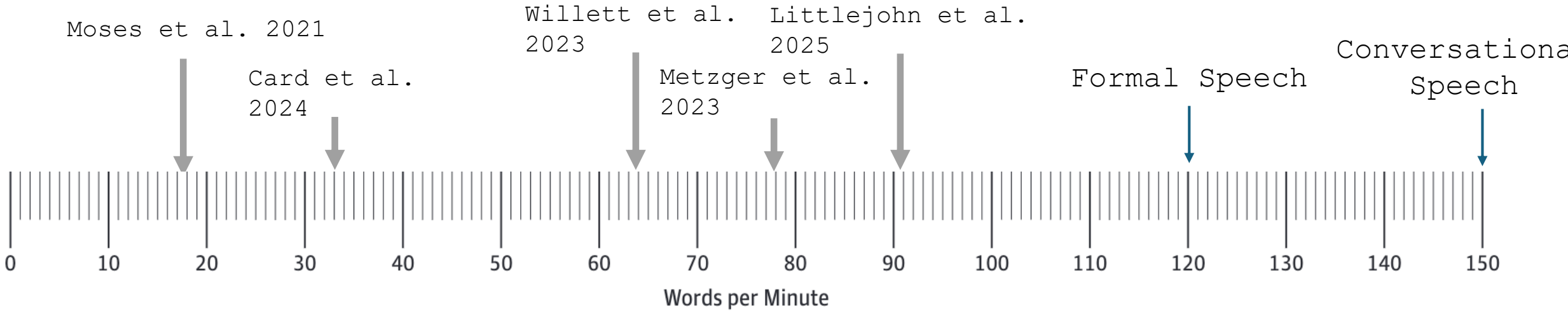
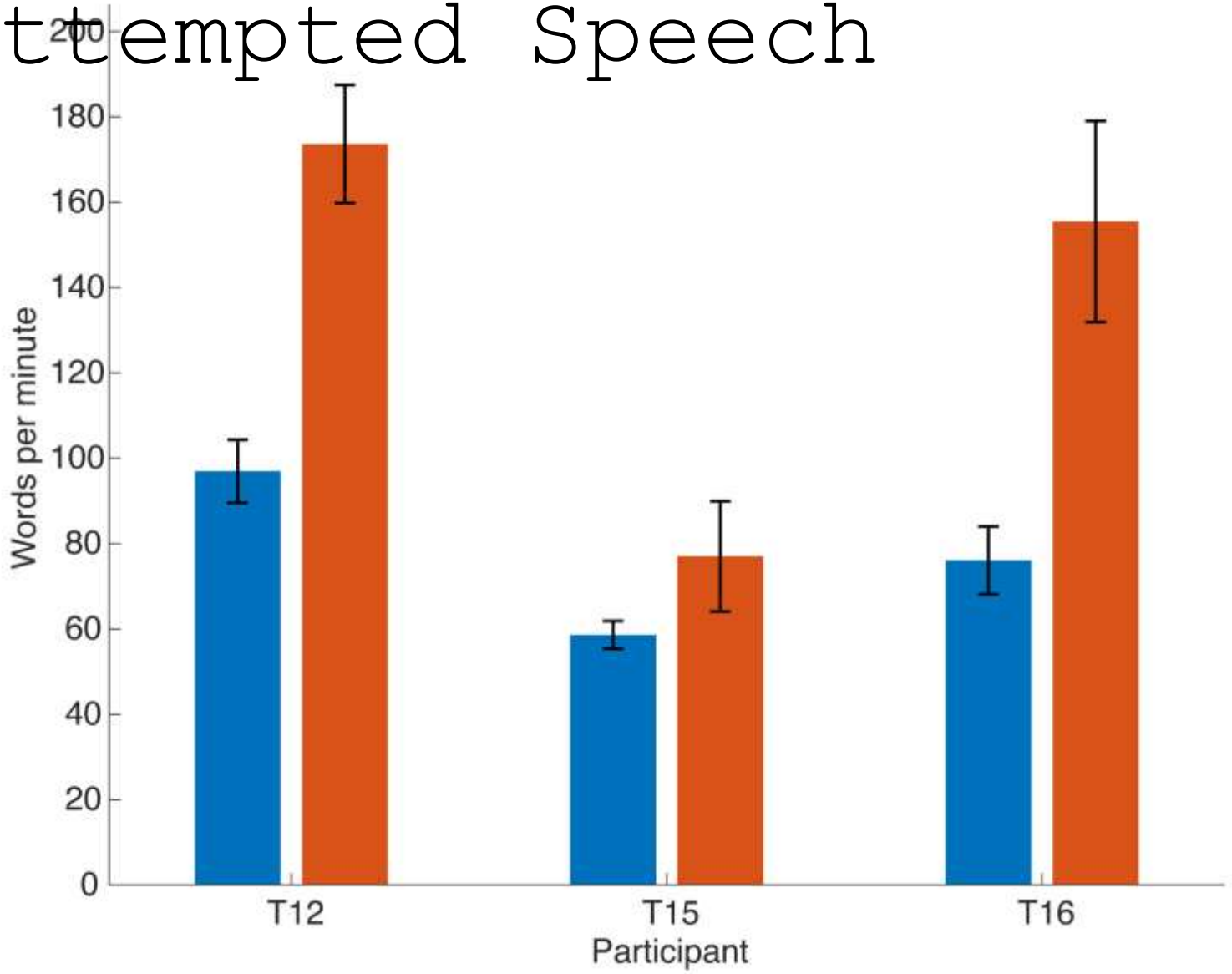

100% CORRECT
DONE
MOSTLY CORRECT
one of the things that people with my disease suffer from his isolation and depression because they do not feel like they matter anymore and something like this technology will help bring people back to life ...
INCORRECT
Activate spelling mode

# How can we reach conversational speeds?




**Hypothesis:** Imagined speech can improve speaking rates in people with paralysis

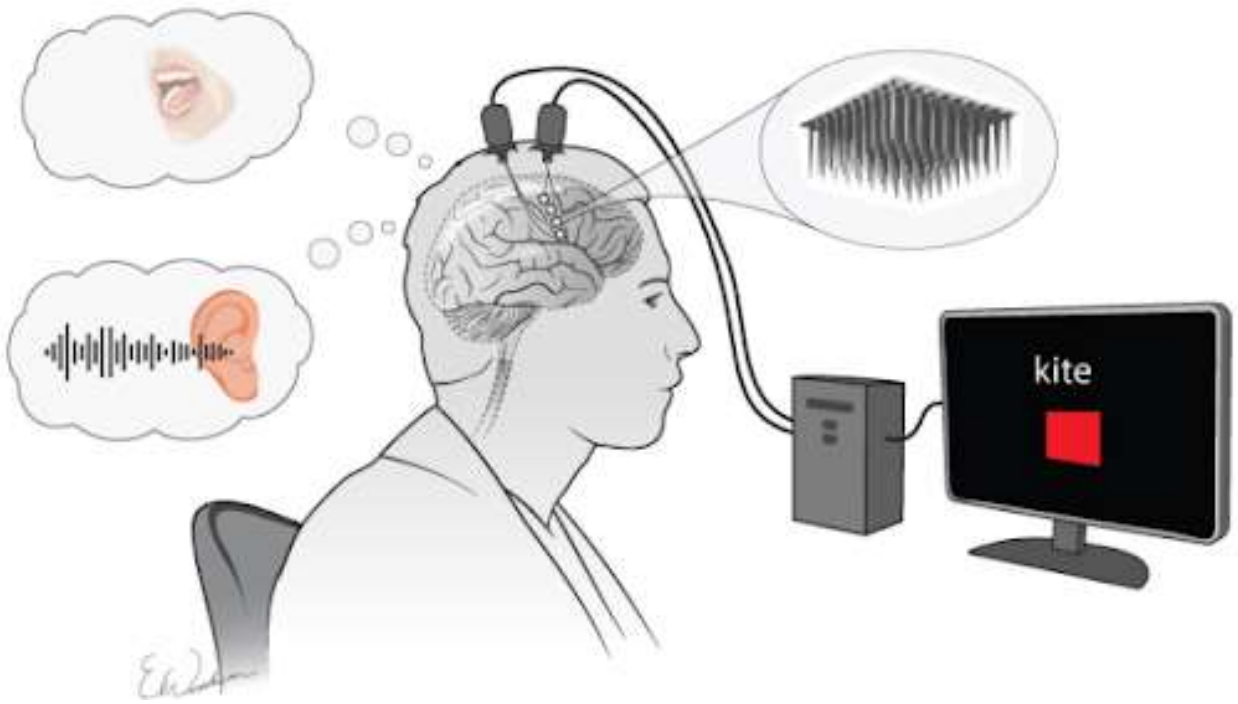
# Imagined Speech is Faster than Attempted Speech




"[Attempted speaking] is like you're stuck in quicksand and you have a weighted blanket or two on top of you."

– T15

# 7 Words Experiment

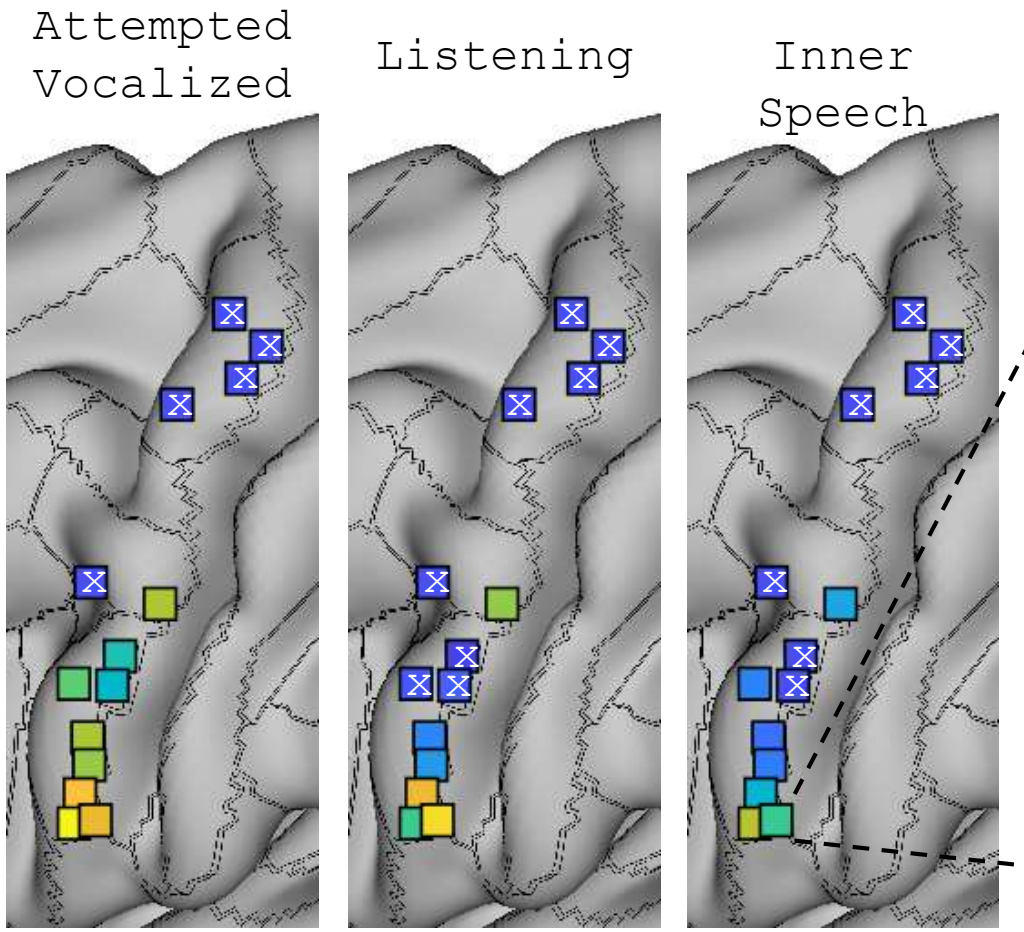


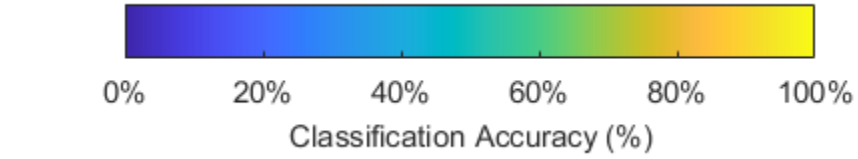

**Conditions:**
Attempted
Vocalized
Inner Speech
Listening

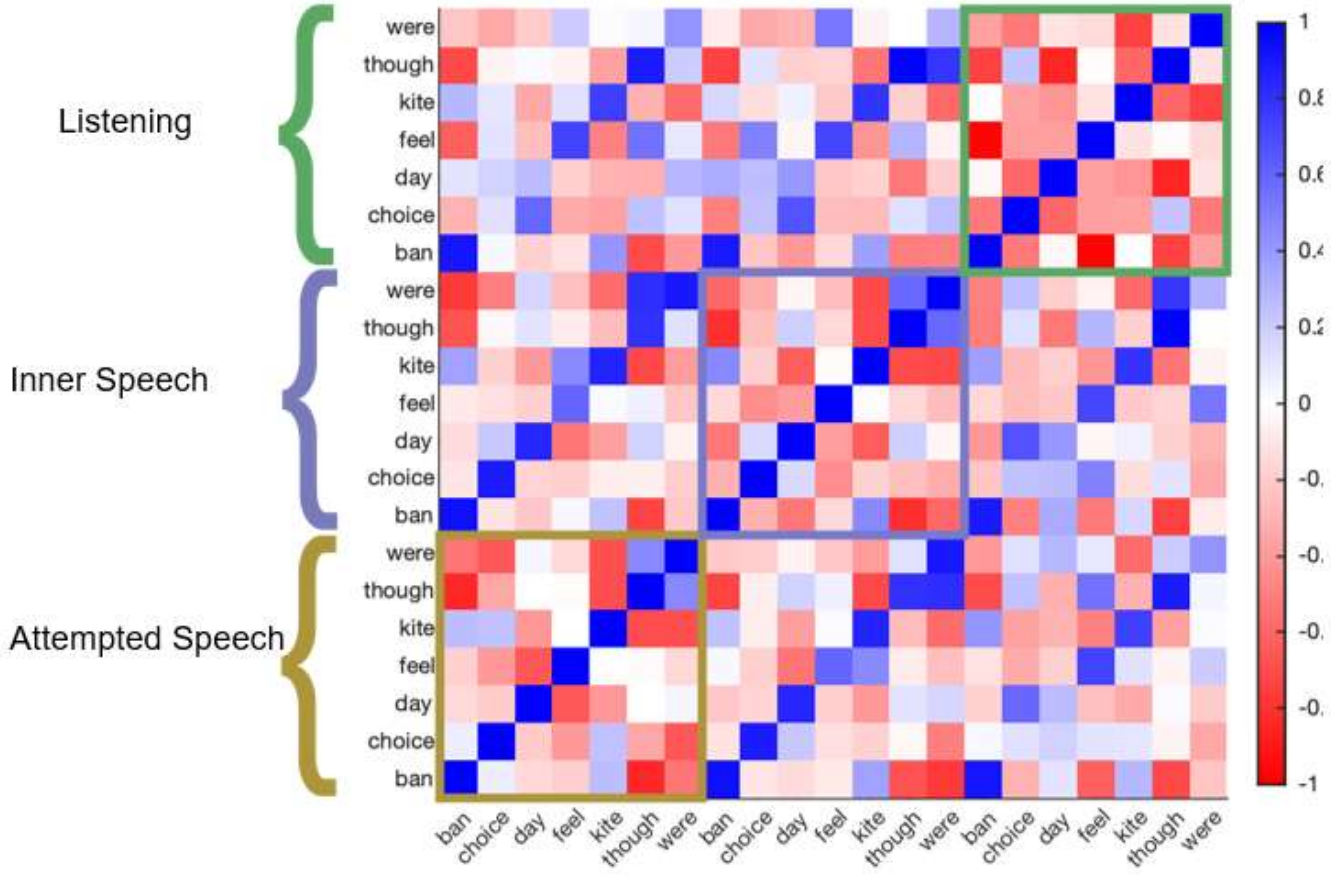
**Words:**
Ban
Choice
Day
Feel
Kite
Though
Were

Kunz*, Meschede-Krasa*, … Henderson, Willett. Inner speech in motor cortex and implications for speech neuroprostheses. *Cell*. 2025

# Shared representation across behaviors

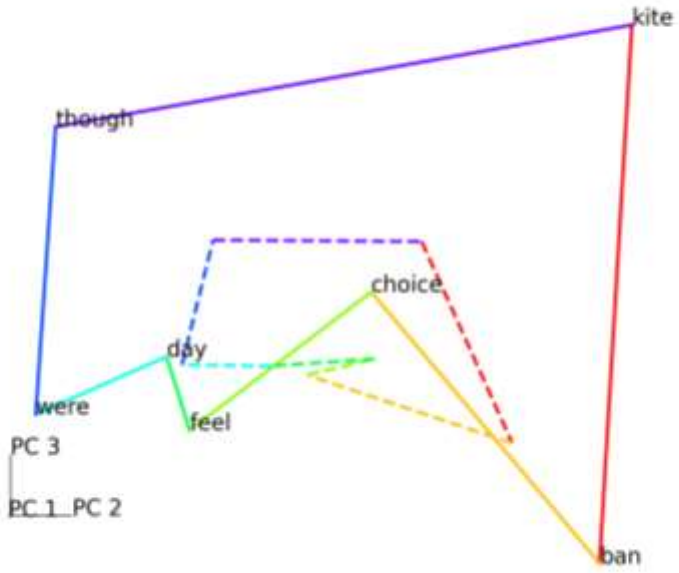


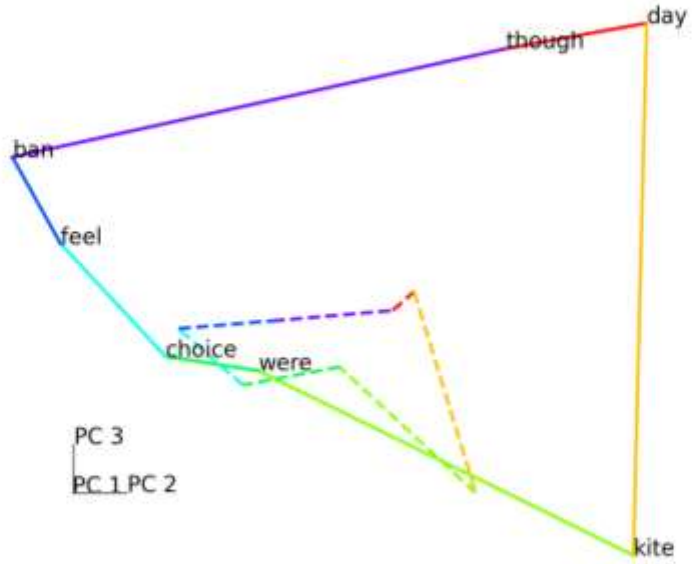




Kunz*, Meschede-Krasa*, … Henderson, Willett. Inner speech in motor cortex and implications for speech neuroprostheses. *Cell*, 2025

# Neural Geometry of Attempted vs. Inner Speech

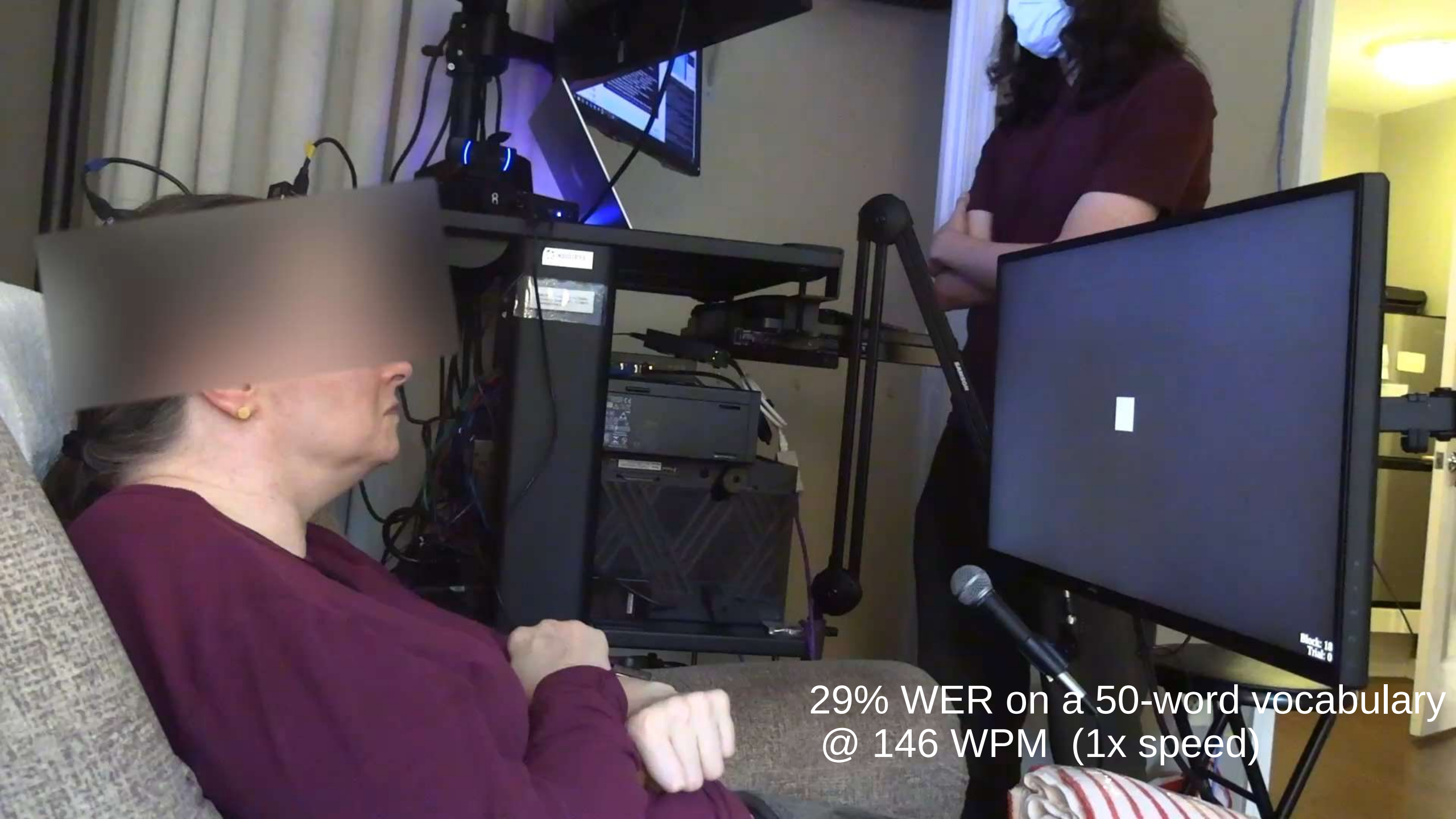



T12

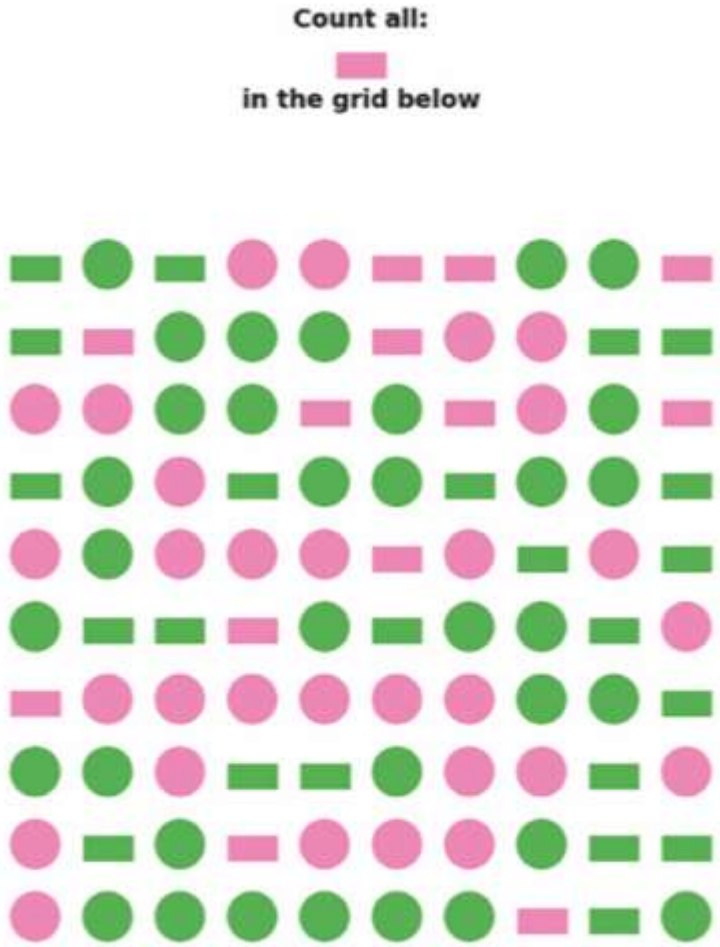


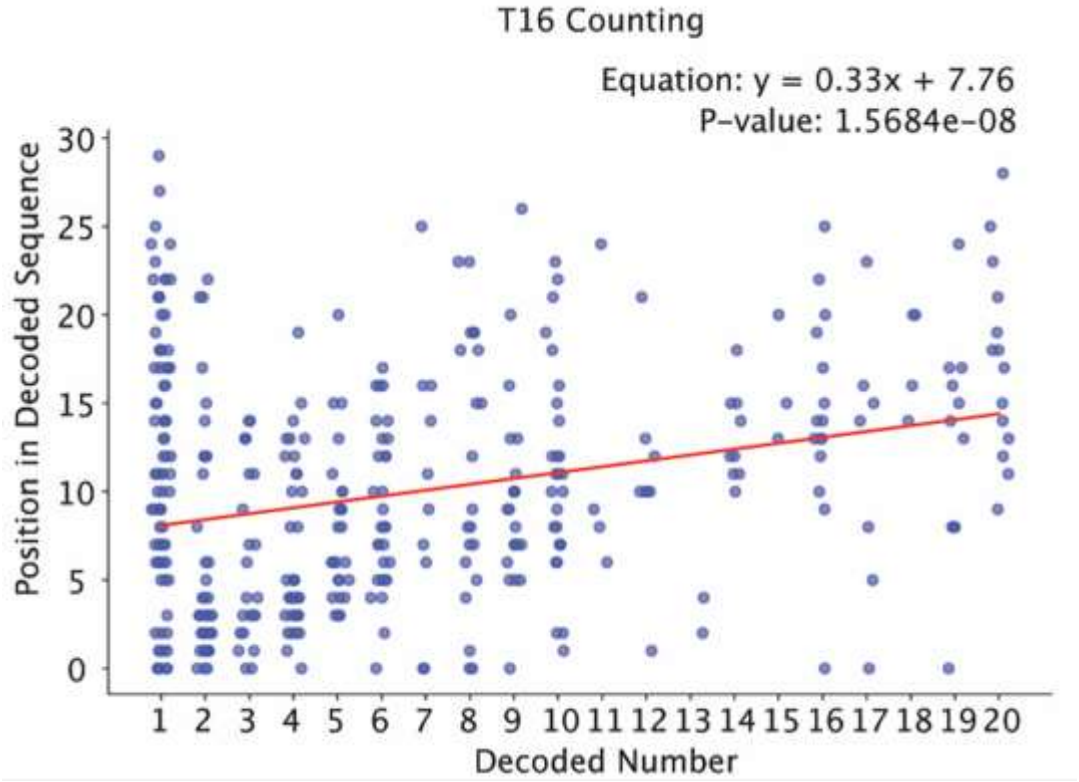

T17

Kunz*, Meschede-Krasa*, … Henderson, Willett. Inner speech in motor cortex and implications for speech neuroprostheses. *Cell*. 2025


29% WER on a 50-word vocabulary
@ 146 WPM (1x speed)

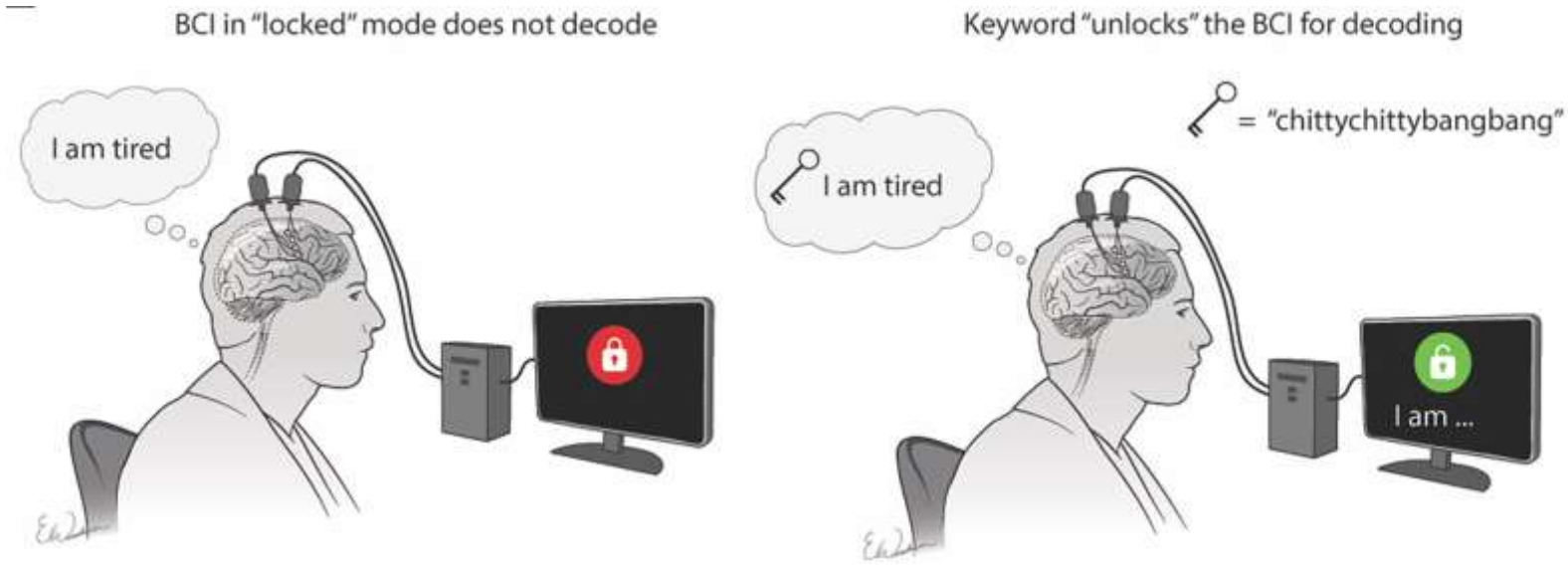
# Detection of Spontaneous Inner Speech




Kunz*, Meschede-Krasa*, … Henderson, Willett. Inner speech in motor cortex and implications for speech neuroprostheses. *Cell*. 2025

# Password Protection for Inner Speech Decoding




T12 Inner Speech BCI w/ Keyword Performance

| | |
|---|---|
| Keyword Detection Accuracy (%) | 98.75 (93.23, 99.97) |
| Word Error Rate (%) (50 word Vocab) | 42.45 (35.71, 49.41) |

Kunz*, Meschede-Krasa*, … Henderson, Willett. Inner speech in motor cortex and implications for speech neuroprostheses. *Cell*. 2025

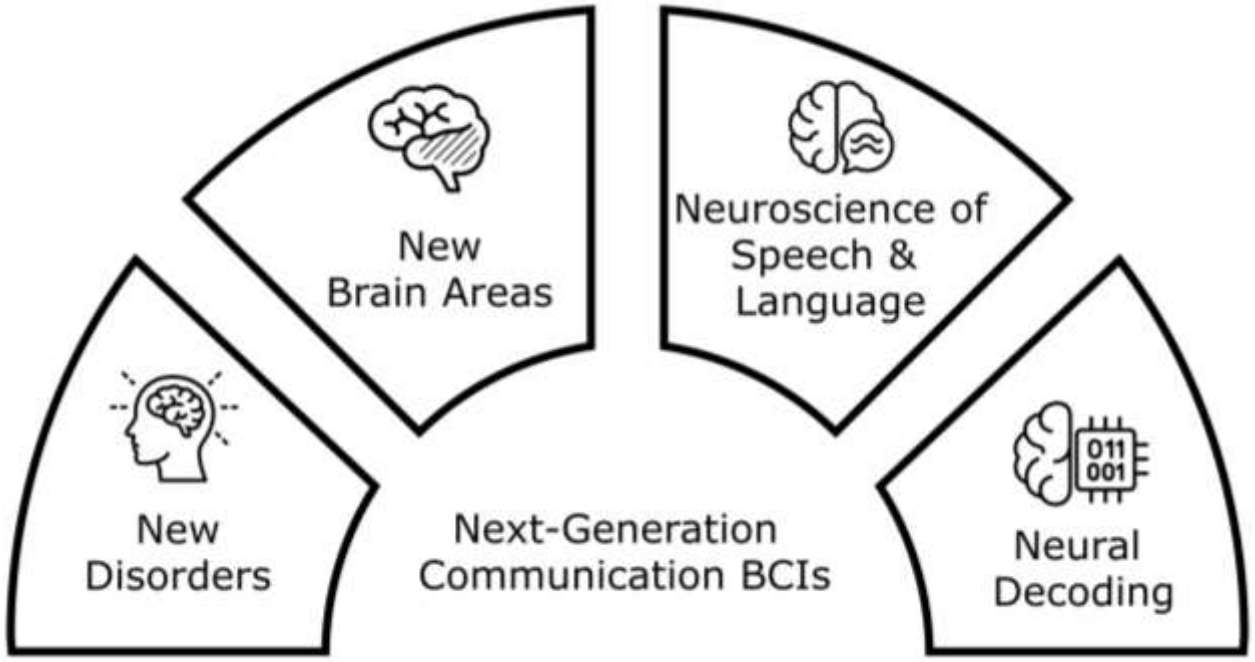
# What does the future hold?

# Translation is Underway

We can expect: Fully implanted, wireless, more electrodes, better longevity

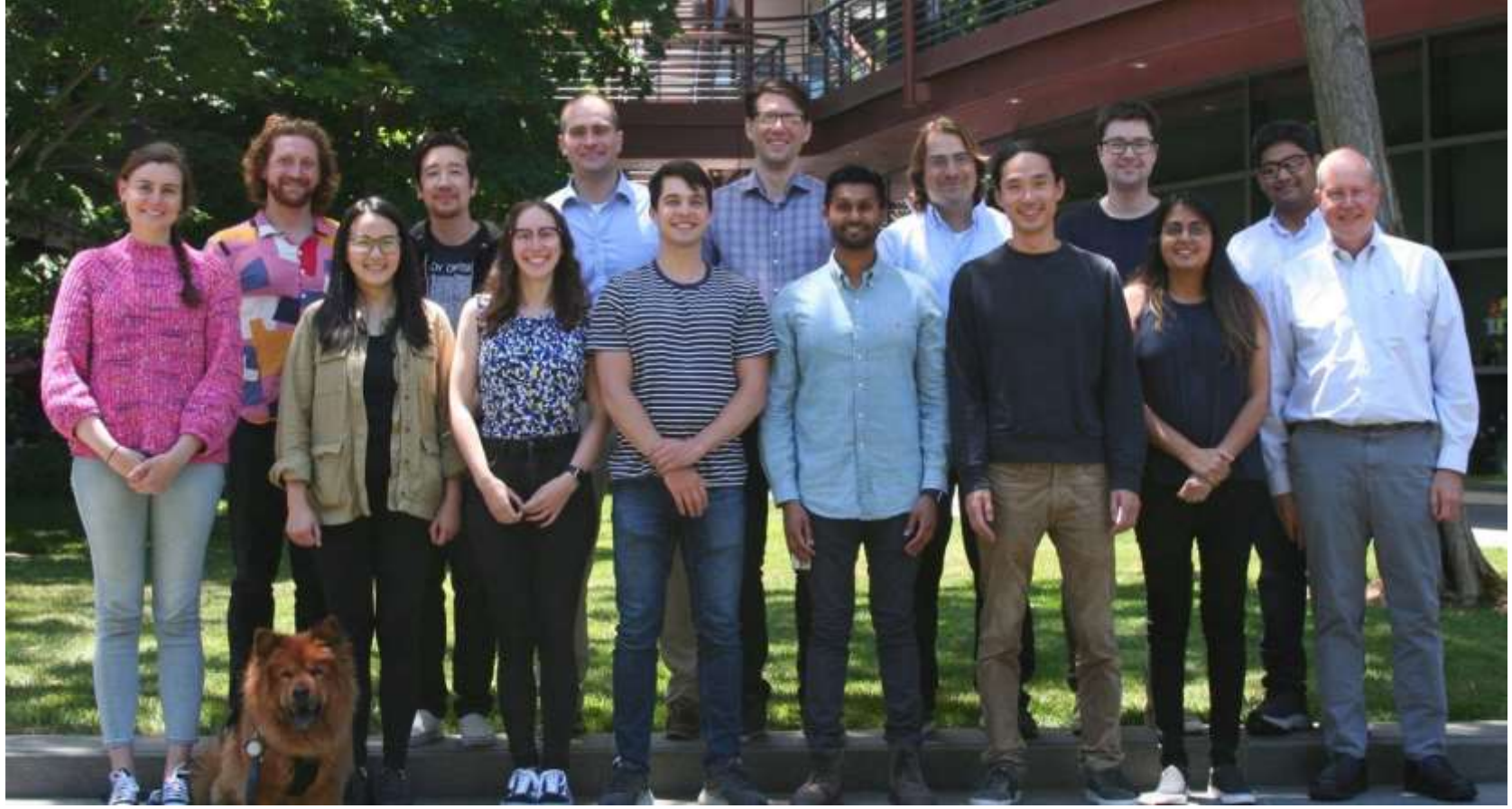
# Future of Communication BCIs

- New disorders beyond ALS & brainstem stroke
  - Cerebral palsy
  - Broca's aphasia caused by stroke
- New brain areas outside of motor cortex
- Understanding the neural representations of language
- Neural decoders that can work with higher-level representations



# Conclusion

- Communication BCIs for ALS and brainstem stroke have progressed from point-and-click to speech
- Inner speech may enable even faster and more comfortable communication
  - Care must be taken to ensure user agency, but this is a solvable engineering problem
- Decades of implantable BCI demonstrations have inspired promising commercial efforts for translation
- Future work will address new disorders with larger populations



# Stanford Neural Prosthetics Translational Lab (NPTL)

Thank you to the participants: T5, T12, T15, T16, and T17

Providence VA Medical Center

Massachusetts General Hospital

Brown University

Carney Institute for Brain Science

Emory University

Harvard Medical School

Stanford University

University of California, Davis