Restoring Communication with Speech Neuroengineering

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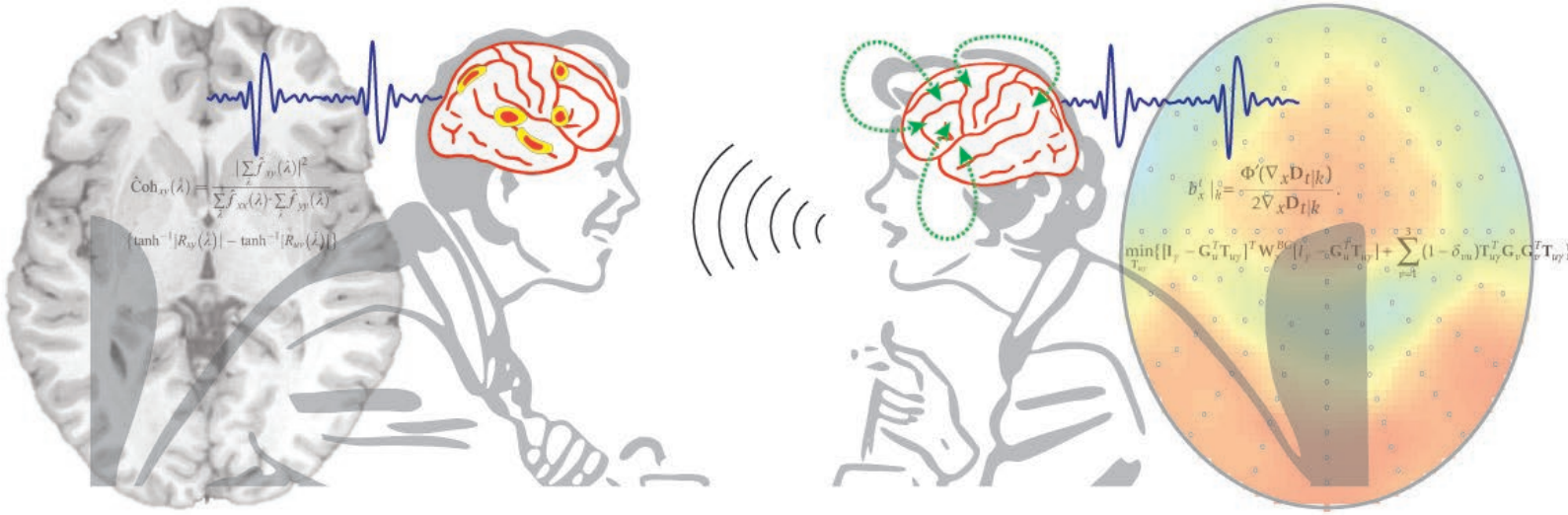

9/9/2025
NFOSD
TAD Talk

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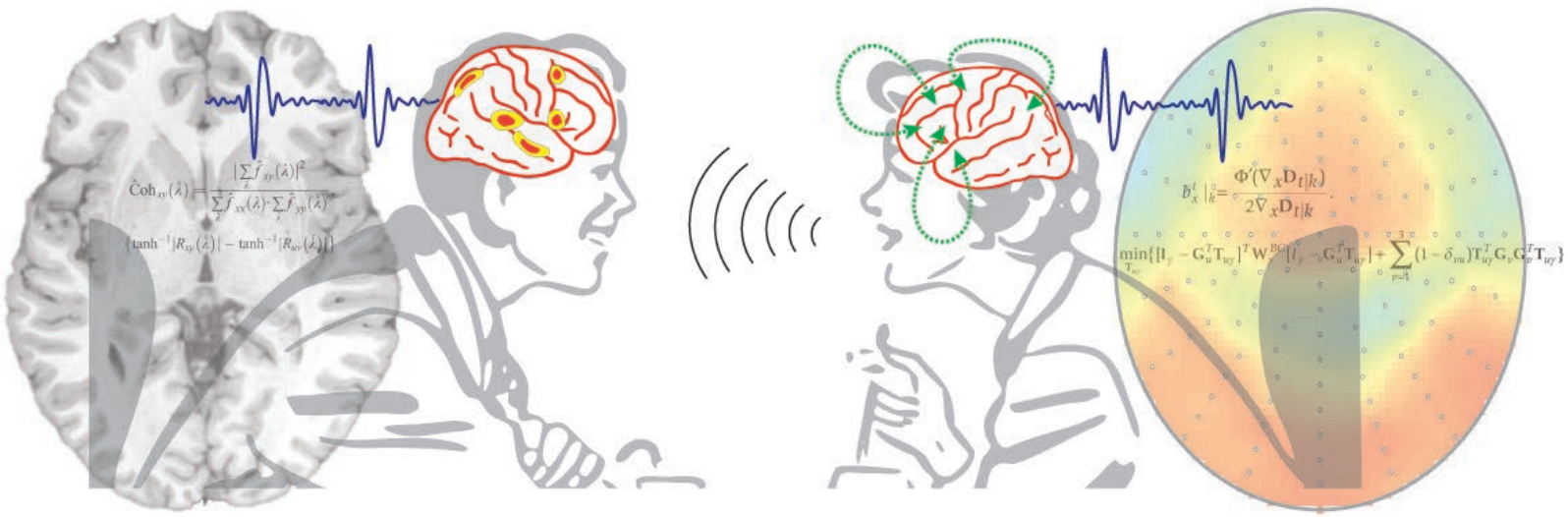
https://millerlab.faculty.ucdavis.edu/

Disclosures

- Work supported by research grants and gifts from public sponsors, industry (Meta, Accenture, Google, Starkey Technologies), philanthropy (Child Family Fund)
- Patent for brain-based listening diagnostic (U.S. #10,729,387, Regents of the Univ. of CA); patents pending for “silent speech” EMG decoding, automatic speech evaluation for BCI
- No contracts, consulting, ownership, or other financial interests to report

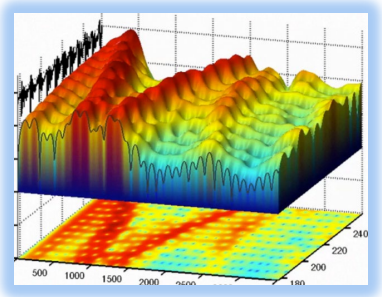
Goal

1. **Understand** neural mechanisms of perception and action in communication
2. Improve **diagnosis** of impairments
3. Design **solutions** that work in real environments



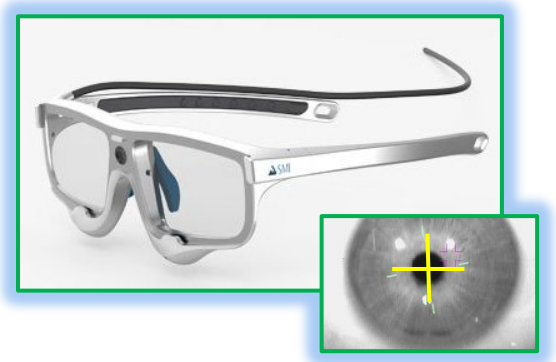
Approaches

EEG,
EMG



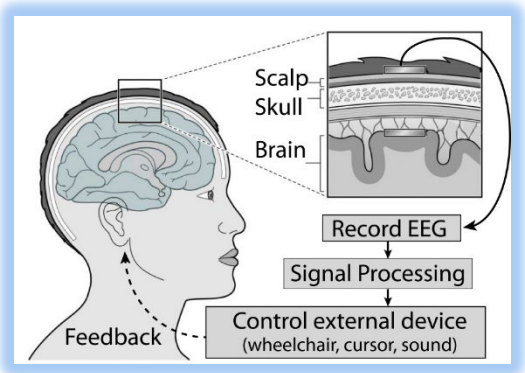
Speech
analysis /
synthesis

Eye tracking,
pupillometry
AR/MR

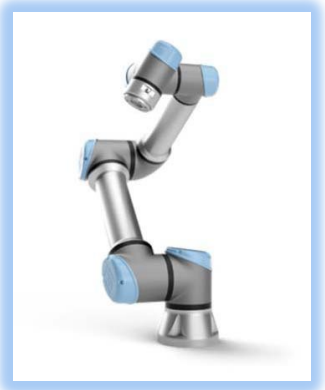


Cochlear
implants,
assistive
listening
devices

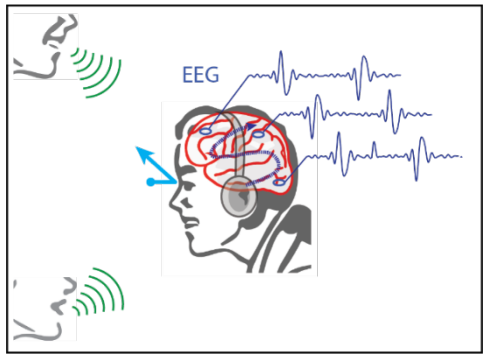
Brain/Body-
Computer
Interfaces



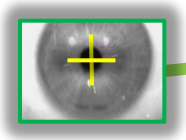
Human-
Machine /
Robotics

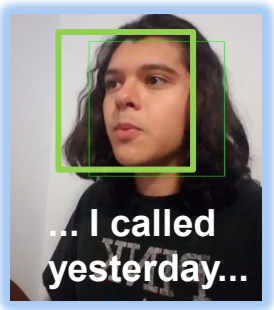


Projects



Brain-based (EEG)
Listening Diagnostic



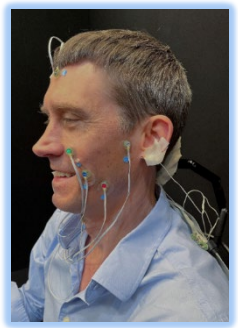


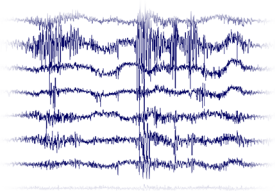
Assistive Listening:
Gaze-beamforming and AR

UCDAVIS

BCI Speech Assessment:
"AI Listener"

Restoring
"Silent Speech"





Inclusive Wrist
EMG Decoding

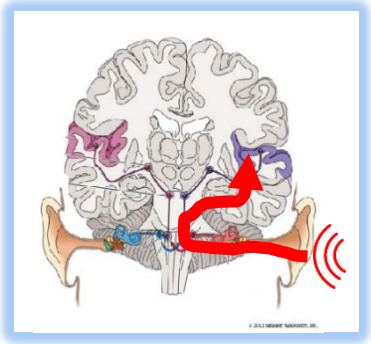
Brain-based Listening Diagnostic

(Dr. Hilary Brodie, Dr. Doron Sagiv)

Kelsey Mankel (U. Memphis)

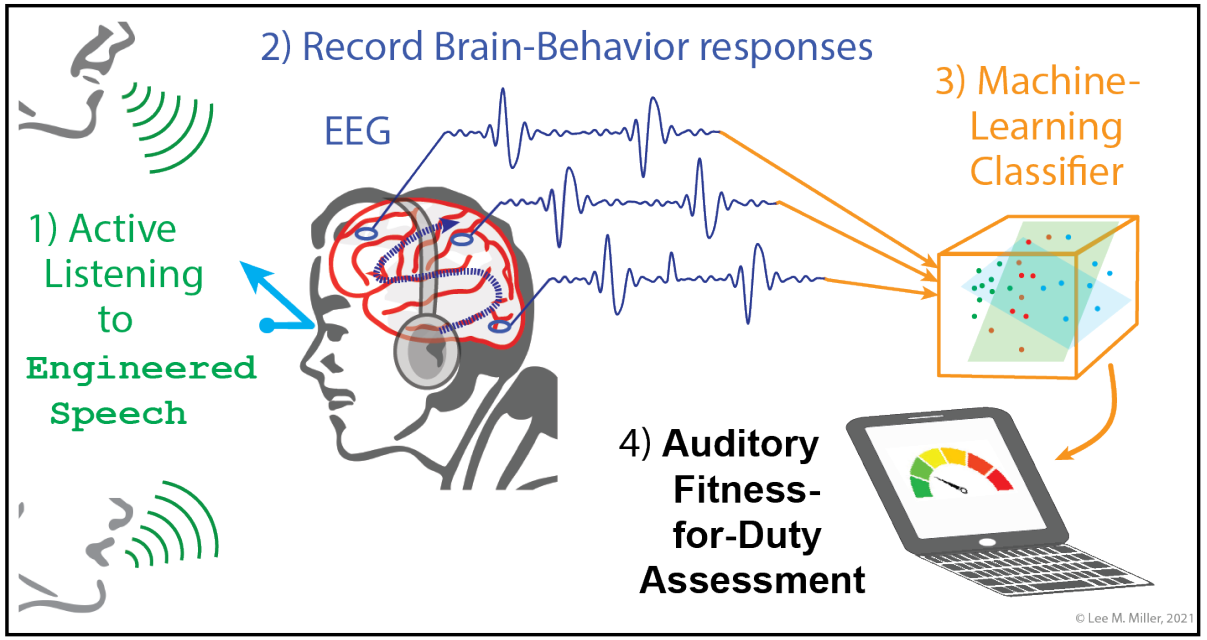
Dan Comstock

- many listeners with ***and without*** hearing loss struggle to understand speech ("hidden hearing loss")
- listening success in life relies on how *individual's brain interprets the ear*



- Current methods:
  - can't relate neural, perceptual, cognitive mechanisms
  - not ecologically valid
  - take a long time (no clinical use)

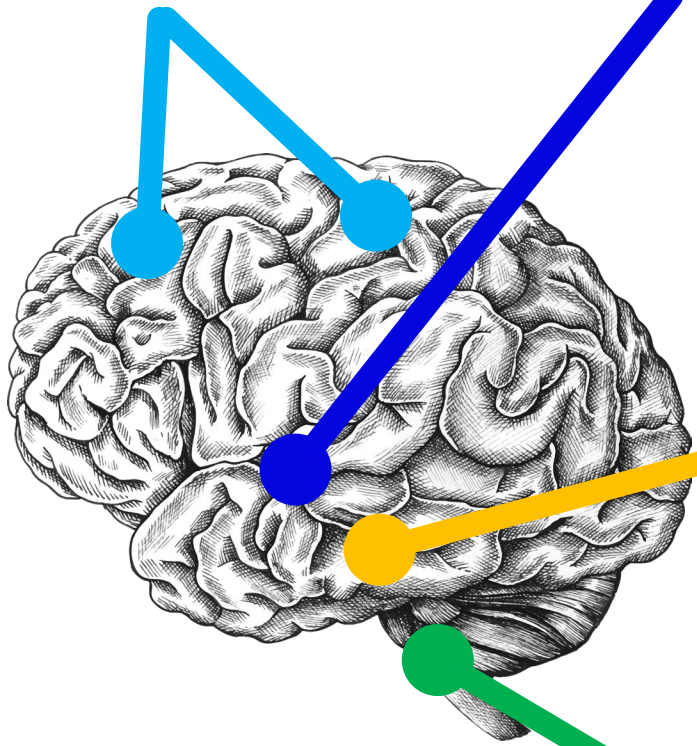
Solution: Rapid, neurobehavioral (EEG) classifier/ profiler for speech perception ability



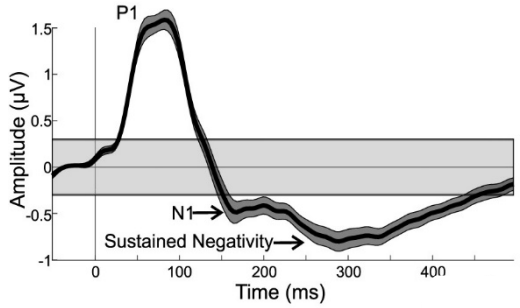
Acoustically engineered Chirp-Speech (Cheech) evokes neural responses:

- along the **entire auditory-language-attention pathway**
- using **continuous speech**
- in **realistic, challenging listening task**
- in **5-10 min**

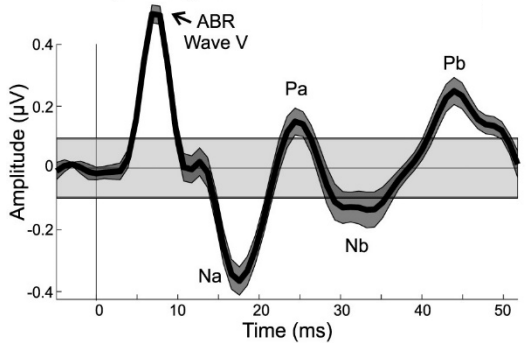
Cognition, Mental States



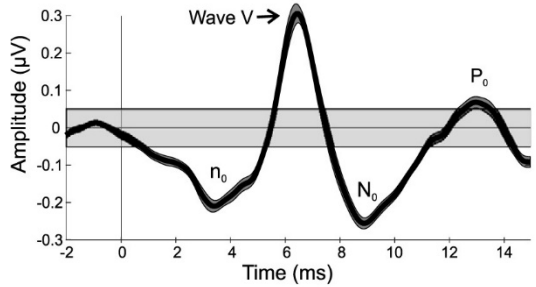
Speech encoding and Comprehension



Feature extraction (e.g. spatial location)

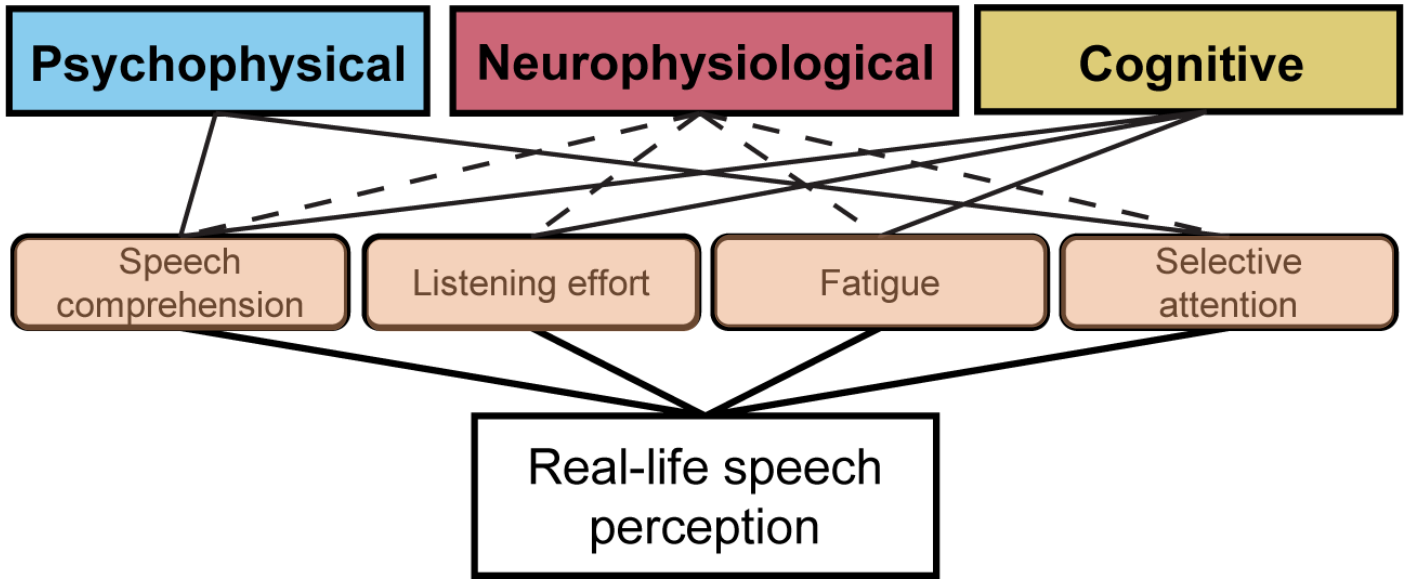


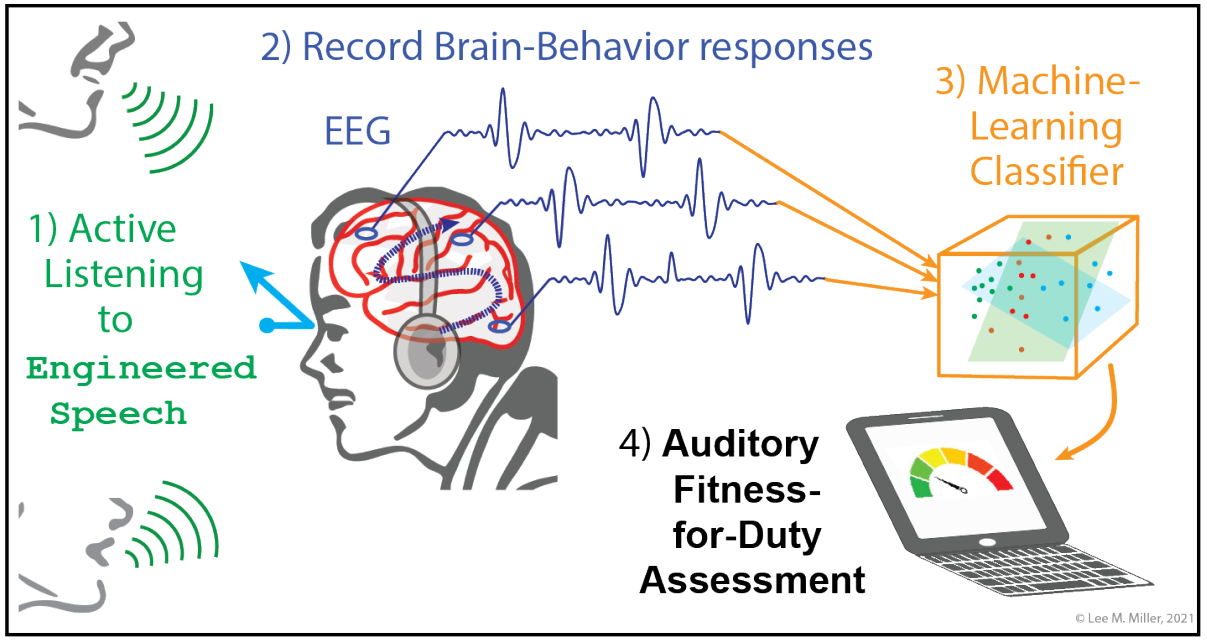
Sound detection and fidelity



Backer et al, 2019, *J Neurophys*

Putting it together

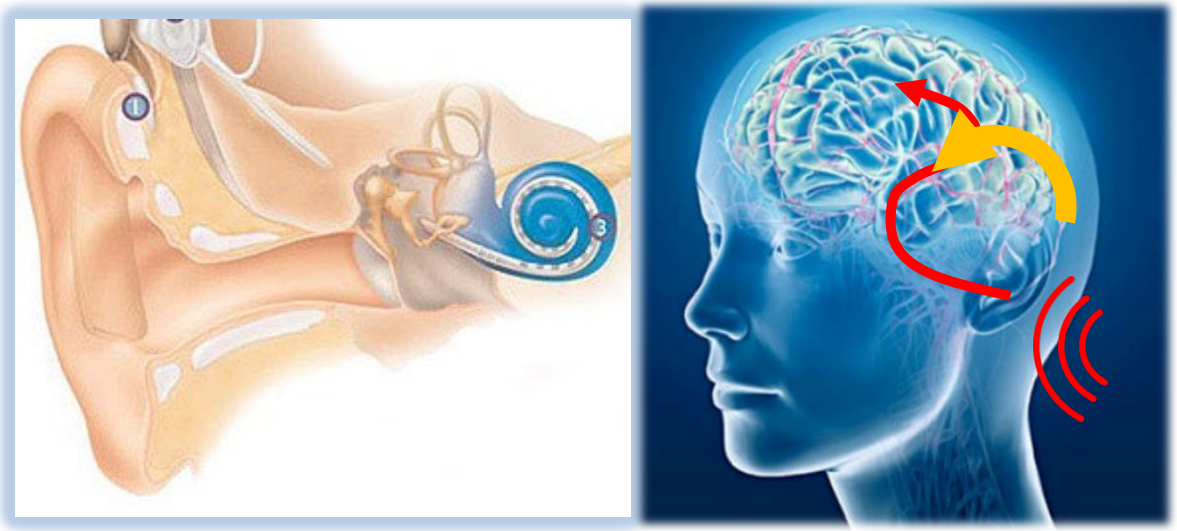




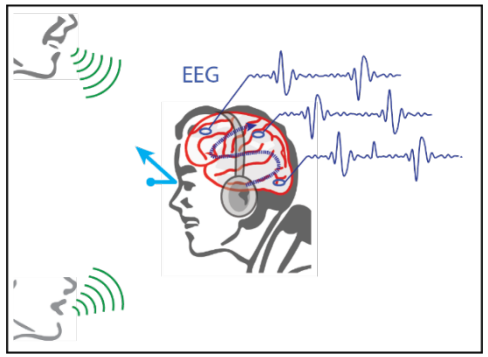
Cochlear Implants and Brain Plasticity

(Prof. David Corina, Dr. Doron Sagiv)

- CI's are most successful neuroprosthesis in history (1,000,000 worldwide)
- *Challenge*: young visual system can "take over" auditory system; old auditory system can "forget" speech
- *Goal*: Using chirp-speech to relate multi-leveled neural plasticity (EEG) to sensory-language exposure and speech-language outcomes
    - Help guide personalized treatment



Projects



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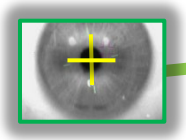
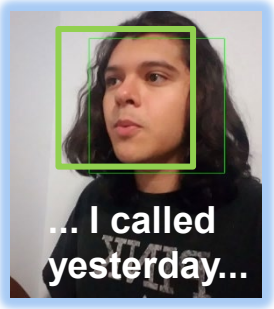




Assistive Listening:
Gaze-beamforming and AR

UCDAVIS

Assistive Listening: Gaze-directed Beamforming

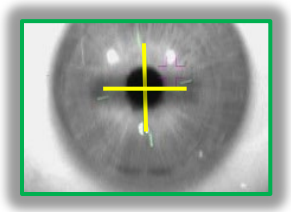
- speech-in-noise is hard, especially for older adults (and hearing aids often fail!)

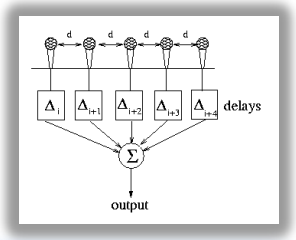
→ Use eye gaze and other biosignals to ***hear best wherever you're looking***

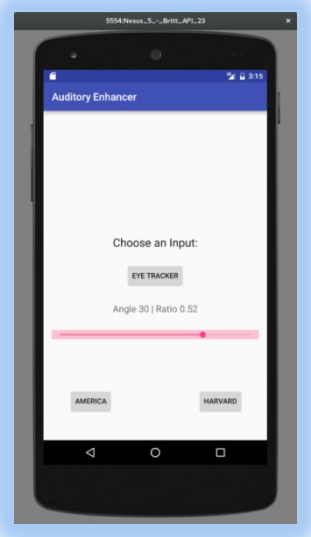
→ Further improve intelligibility with AR

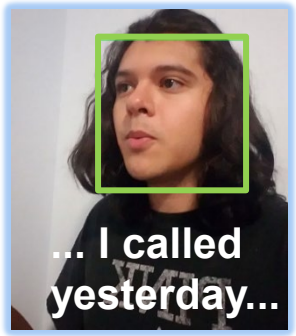
Naturally leverages the brain's:

- attentional focus
- listening effort
- speech encoding

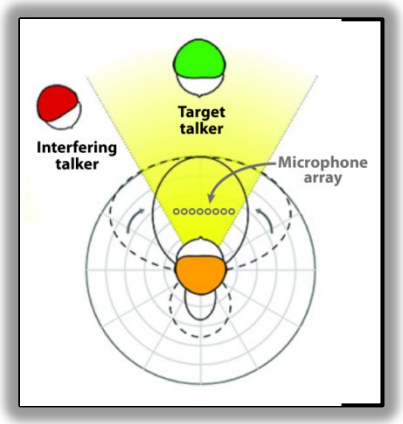








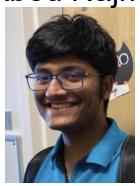
Beamforming

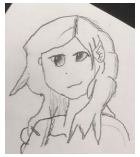


Mana Narayanan

Karim Abou Najm

Keenan Kalra


Aman Ganapathy


Ashley Bilbrey

Sarah Yuniar

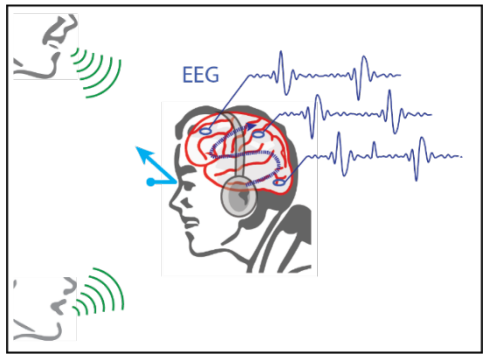
Assistive Listening: Gaze-directed Beamforming

Applications of Gaze-directed beamforming and AR

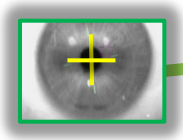
- assistive listening for individuals with hearing loss
- assistive listening for the “situationally impaired” (large meetings, conferences, restaurants)
- leveraging space, attention, cognition in naturalistic tele-presence and remote collaboration

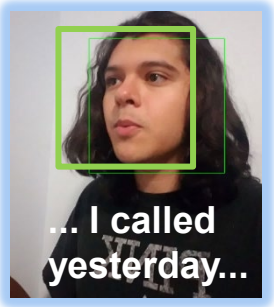
images: cnet.com, agentmajeur.com, npr.org

Projects



Brain-based (EEG)
Listening Diagnostic





Assistive Listening:
Gaze-beamforming and AR

UCDAVIS

Inclusive Wrist
EMG Decoding

Inclusive, Adaptive Wrist EMG Decoding

Harsha Gowda

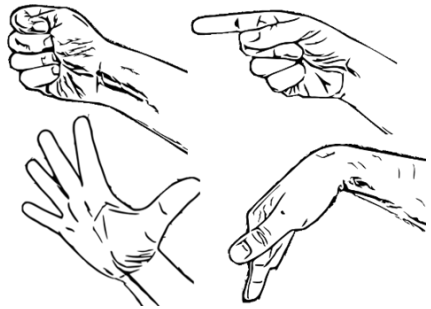
- Supported by Meta's Ethical Neurotechnology program
- We communicate not only through speech but also with our *hands* (typing, swiping, gesturing)
- Wrist EMG may be the most impactful human-computer interface since the mouse
- Doesn't work well for most people! (older, high BMI, dry skin)

  → Goal: develop decoder that adapts to any individual's arm (skin, muscle), and over time

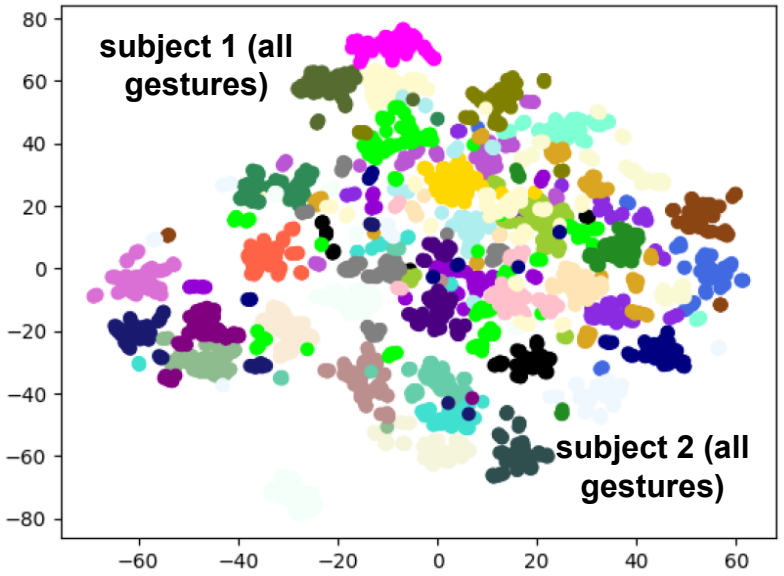
Image: Meta

Inclusive, Adaptive Wrist EMG Decoding

- align different subjects in a high-dimensional space that normalizes *relationships* among EMG sensors (fancy math!)
- use real-time neural state (EEG) signals to guide decoding *adaptively*
- similar challenges, approach to restoring speech…

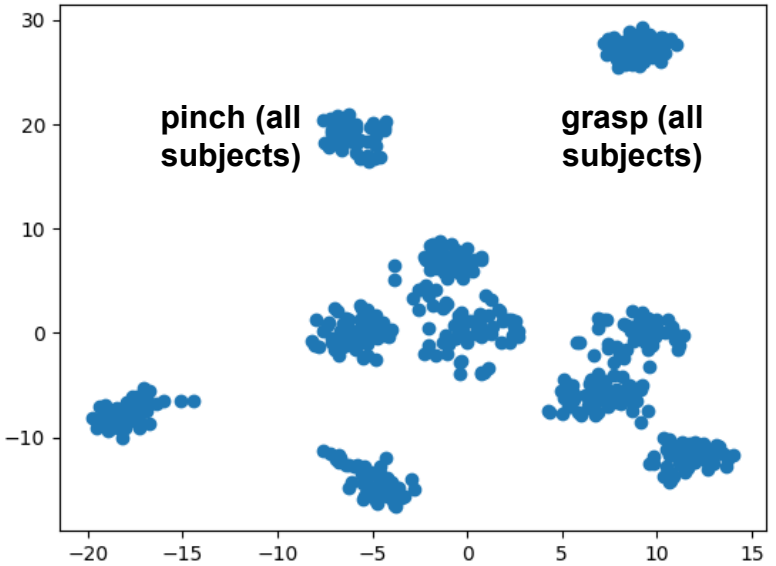


Subjects are all different from one another



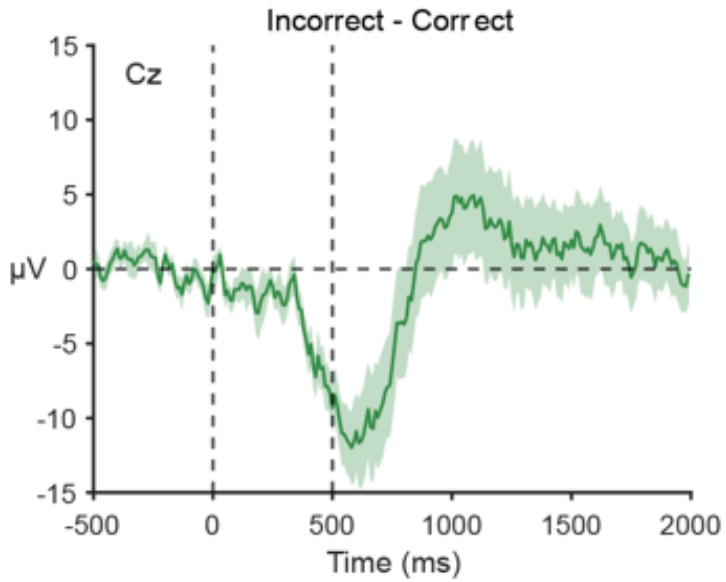
→ no way to distinguish gestures across individuals

After realignment, gestures are distinct



One classifier works on anyone

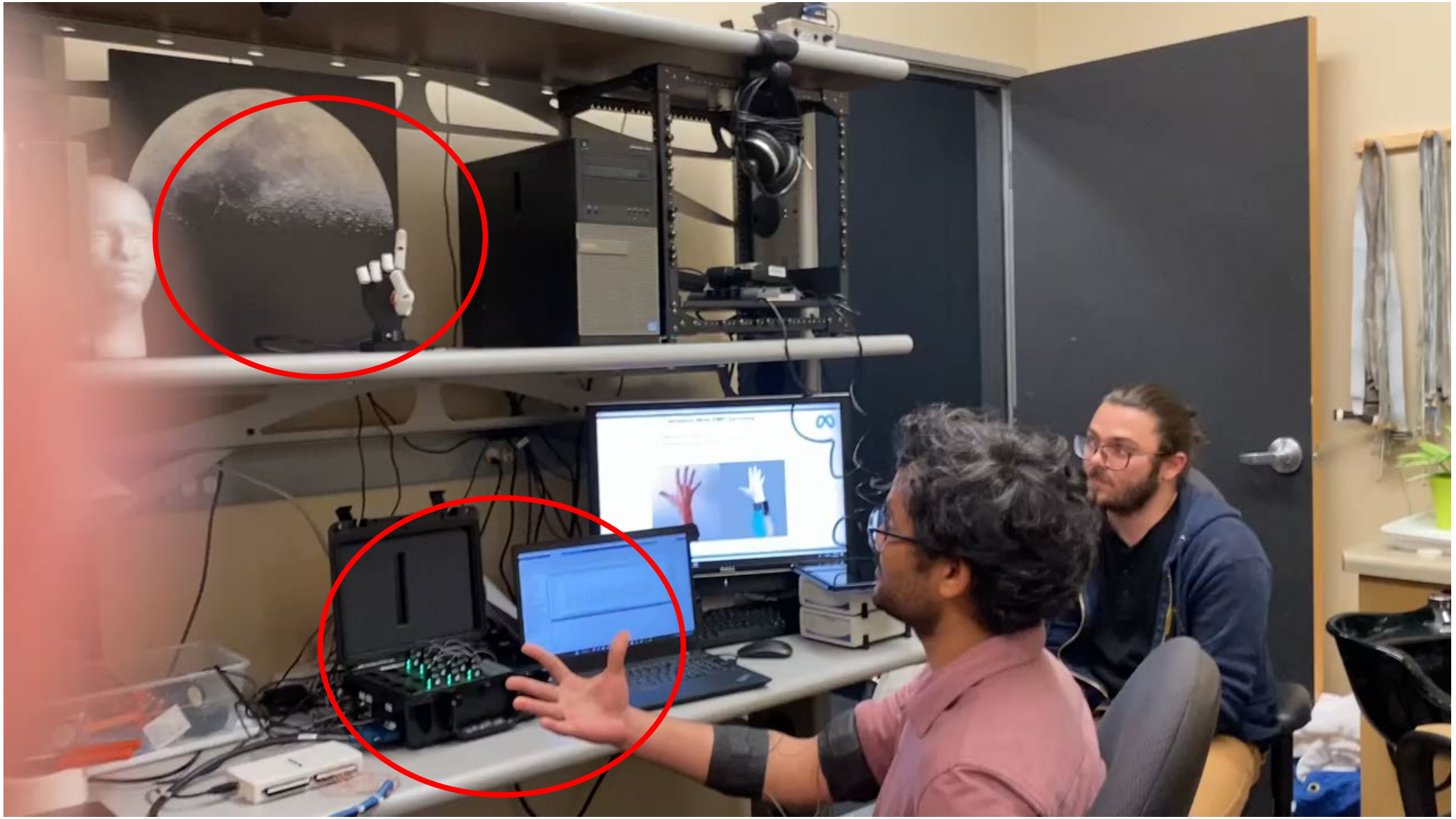
EEG Error-Related Potential



Classifier can adapt

Gowda HT & Miller LM (2024)
J. Neural Eng.

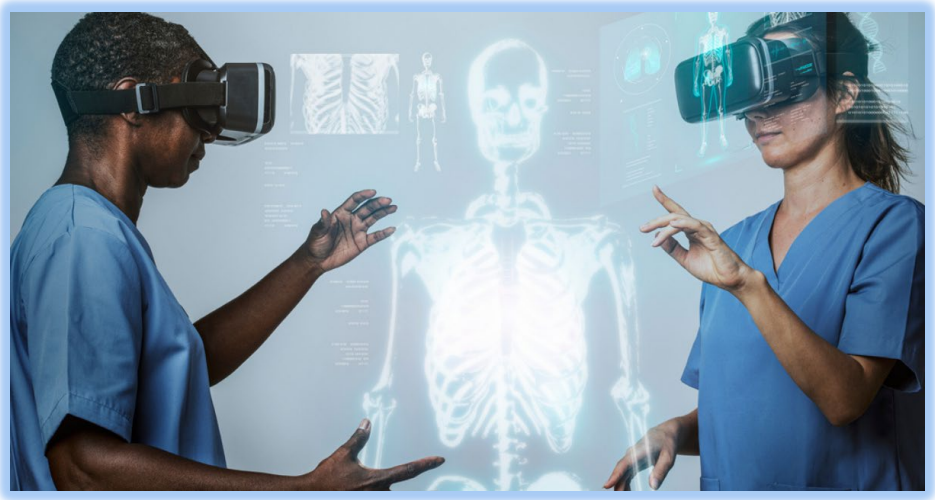
Inclusive, Adaptive Wrist EMG Decoding



Speech Neuroengineering and Cybernetics Laboratory, University of California Davis. leemiller@ucdavis.edu

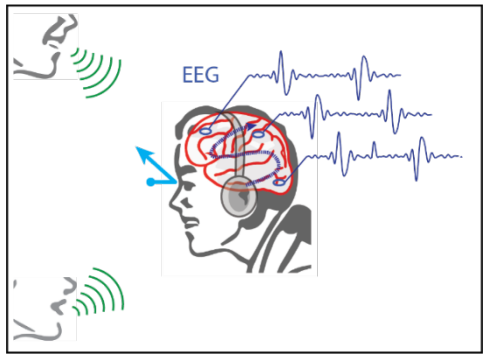
Use Cases for Adaptive Biosignal Decoding

- more responsive, capable assistive devices and prosthetics
- fair and broad access to consumer technology
- more immersive and responsive AR and VR



images: industryweek.com; bdtechtalks.com, uhospitals.org

Projects



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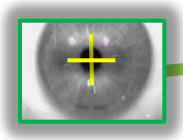

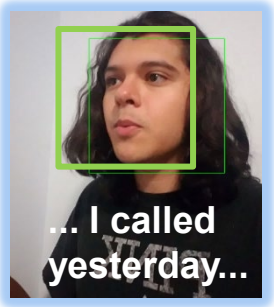

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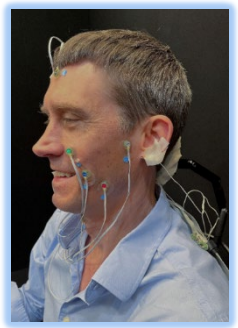
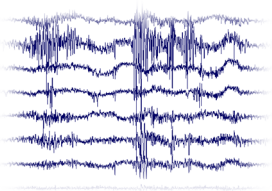




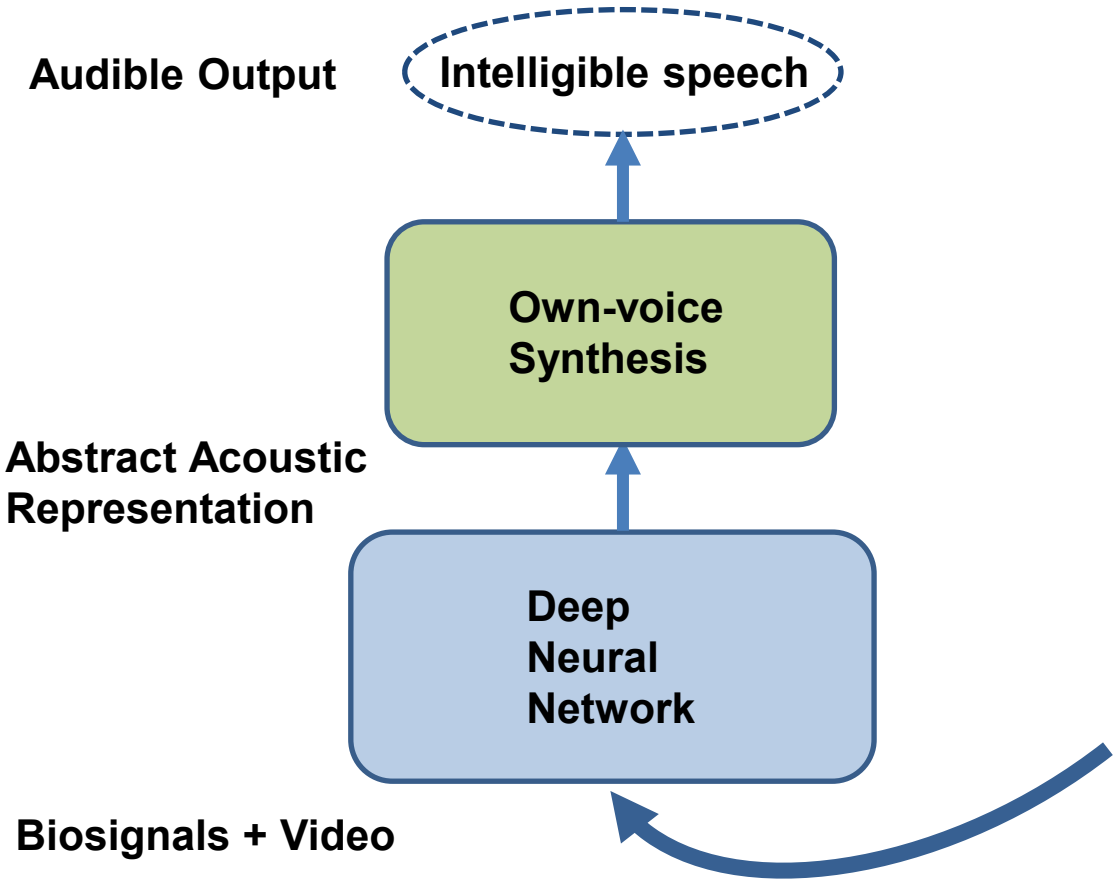
"Silent Speech" Biosignal Decoder

(Peter Belafsky, Sergey Stavisky, David Brandman)

- 100 million worldwide have lost ability to produce natural, comprehensible speech
- *Challenge*: Medical approaches to restore speech inadequate
  - profound emotional impact: increased risk of anxiety, depression, suicide

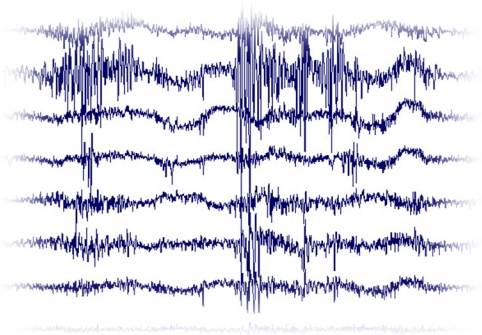
→ *Goal*: Combine EMG and other biosignals to restore near-real-time, *own-voice* speech production

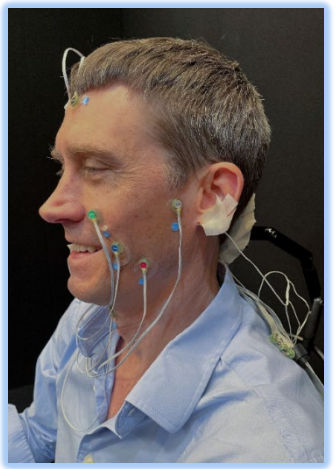
Harsha Gowda



Visual speech

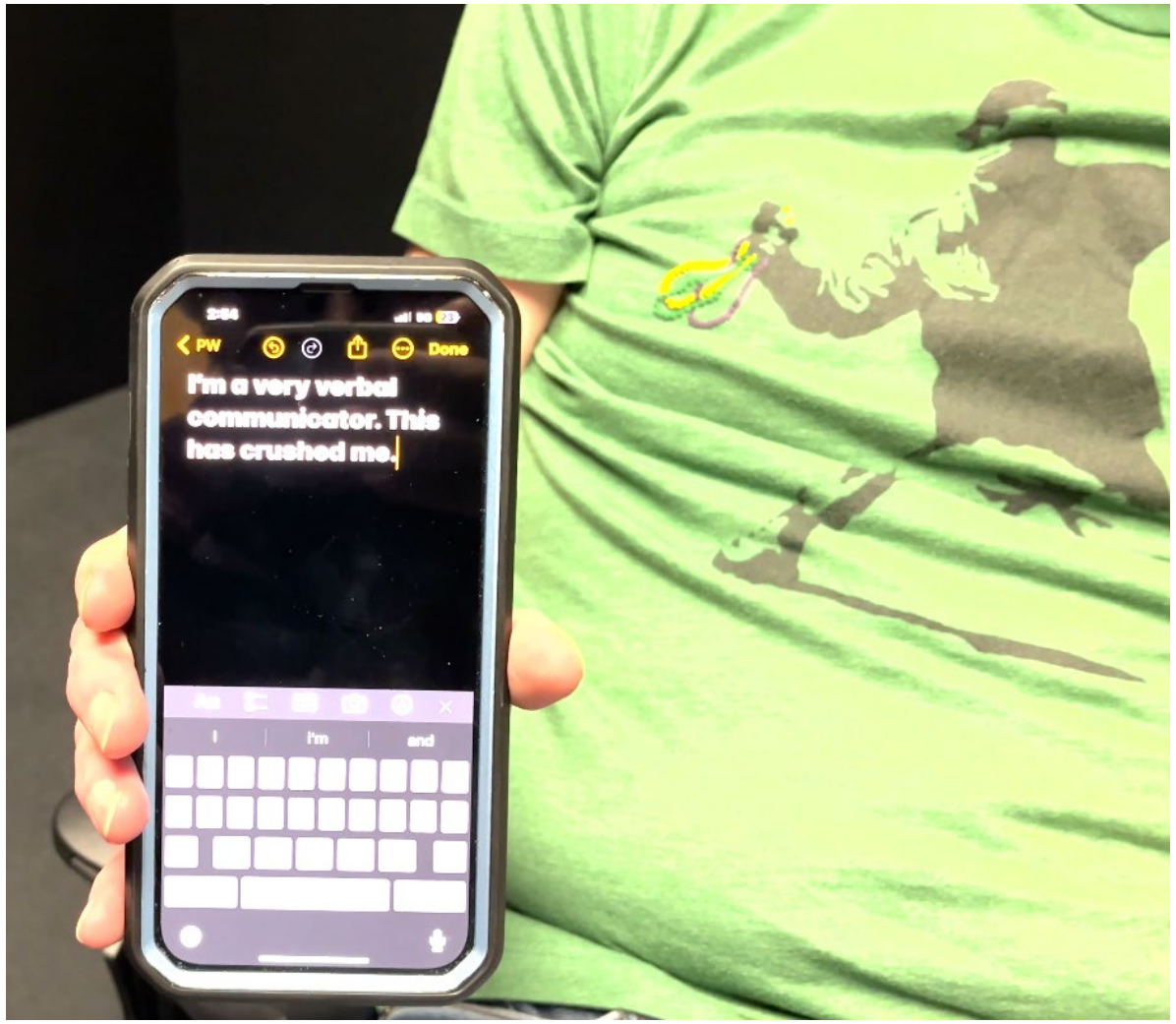
Neuromuscular activity (EMG, EEG)





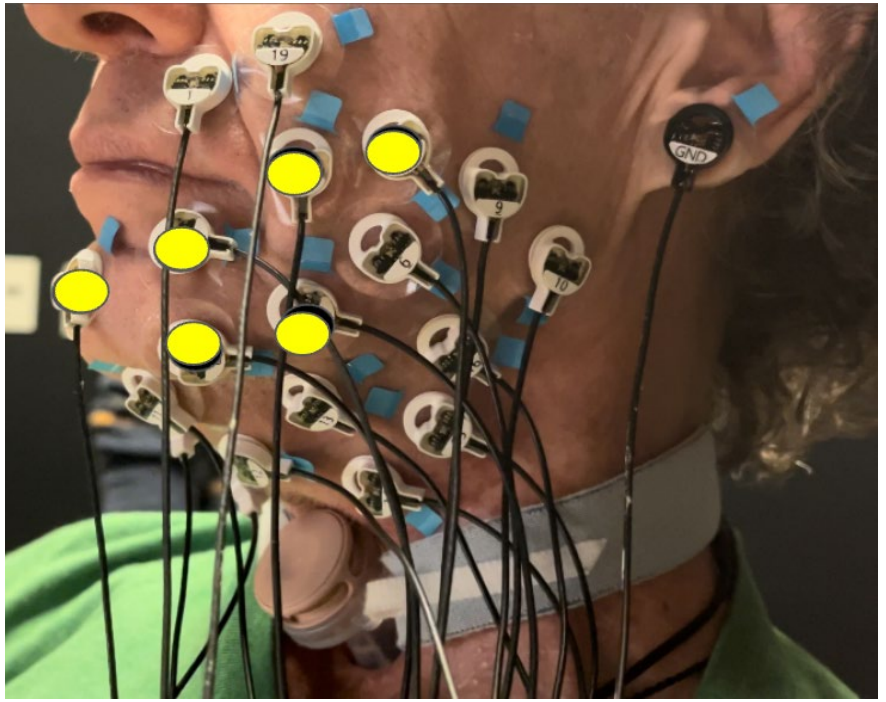
(silent) "*Do you like amusement parks?*"

Post- Total Laryngectomy Speech Restoration



Typical post-laryngectomy (cancer) patient:

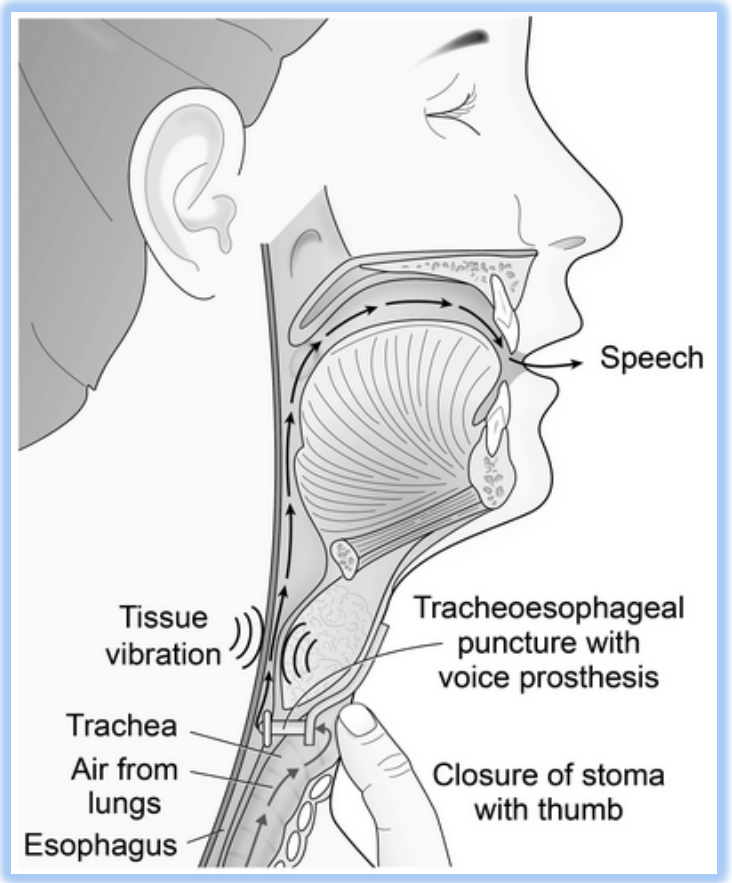
- TEP complications, pneumonia, radiation toxicity
- totally unable to speak



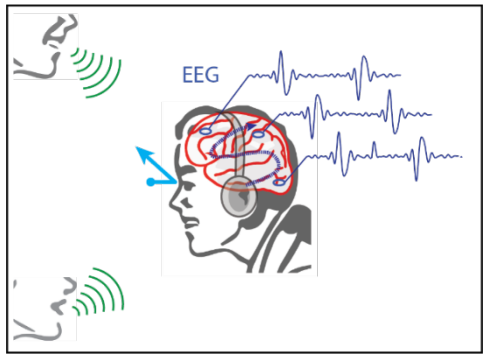
Applications of Silent Speech

- **Health:**
  - head-neck cancer
  - neuromuscular disorder (Parkinson's disease, ALS, CP)
  - stroke
  - TBI

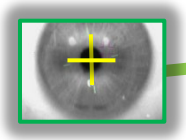
- **Consumer:**
  - any situations where audible speaking is difficult or prohibited

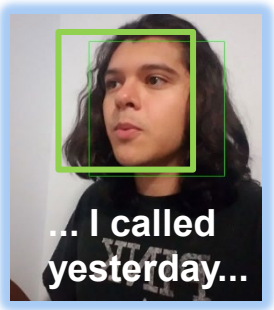


Projects



Brain-based (EEG)
Listening Diagnostic



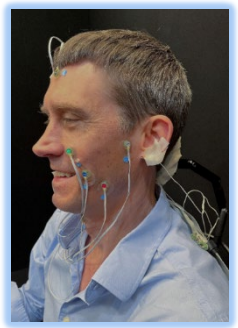


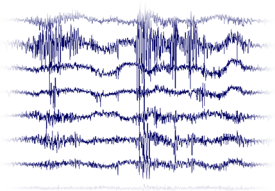
Assistive Listening:
Gaze-beamforming and AR

UCDAVIS

BCI Speech Assessment:
"AI Listener"

Restoring
"Silent Speech"





Inclusive Wrist
EMG Decoding

Voice Cloning and Synthesis

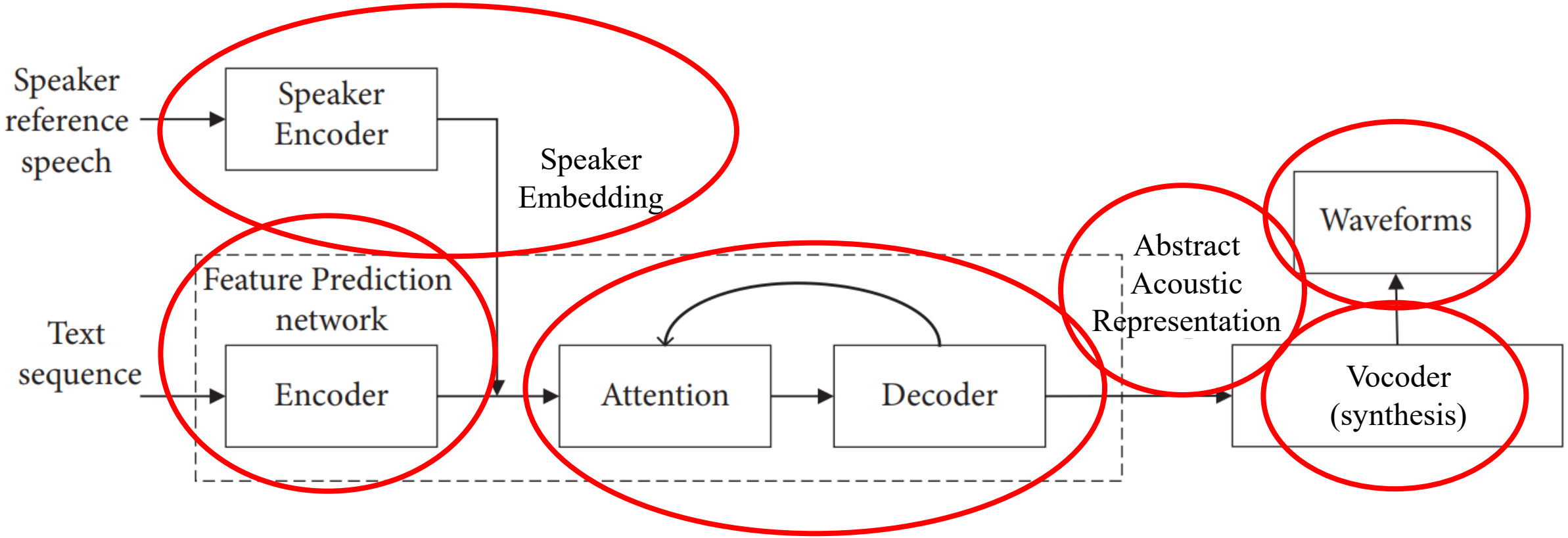


Image: A Voice Cloning Method Based on the Improved HiFi-GAN Model (2022), Qiu et al.

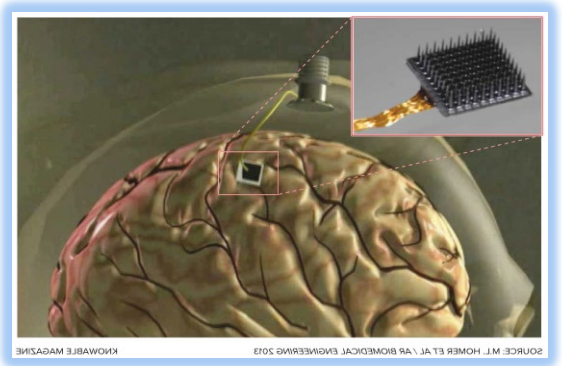
“AI Listener” for Speech Brain-Computer-Interfaces (BCI)

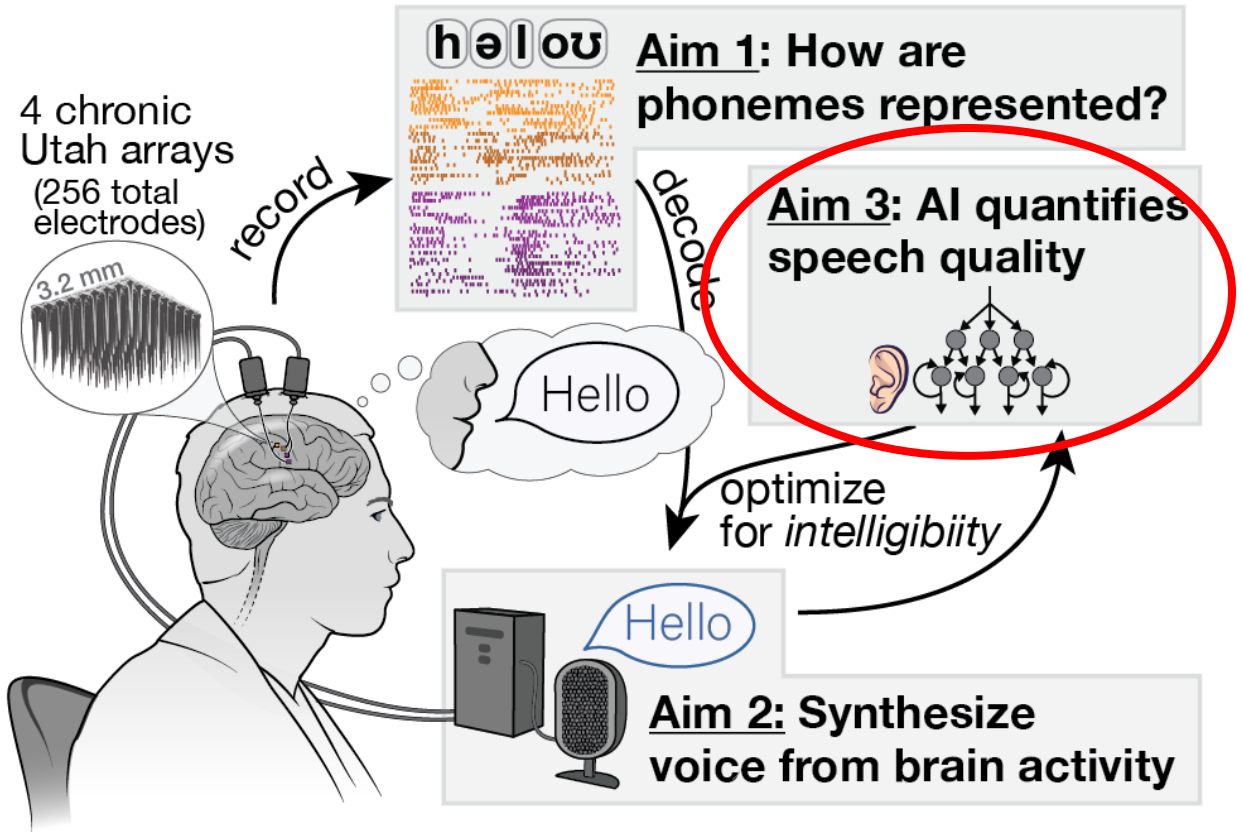
(Sergey Stavisky, David Brandman, Dana Farias)

Aparna Srinivasan

Harsha Gowda

- Individuals who can no longer communicate or even move (ALS, brainstem stroke) would gain incomparable benefit from speaking simply *by thinking of speaking*
- Goal: a clinically interpretable “AI listener” metric for synthesized speech quality
- Apply this continually to improve decoding performance and speech output





Varshney et al., 2023

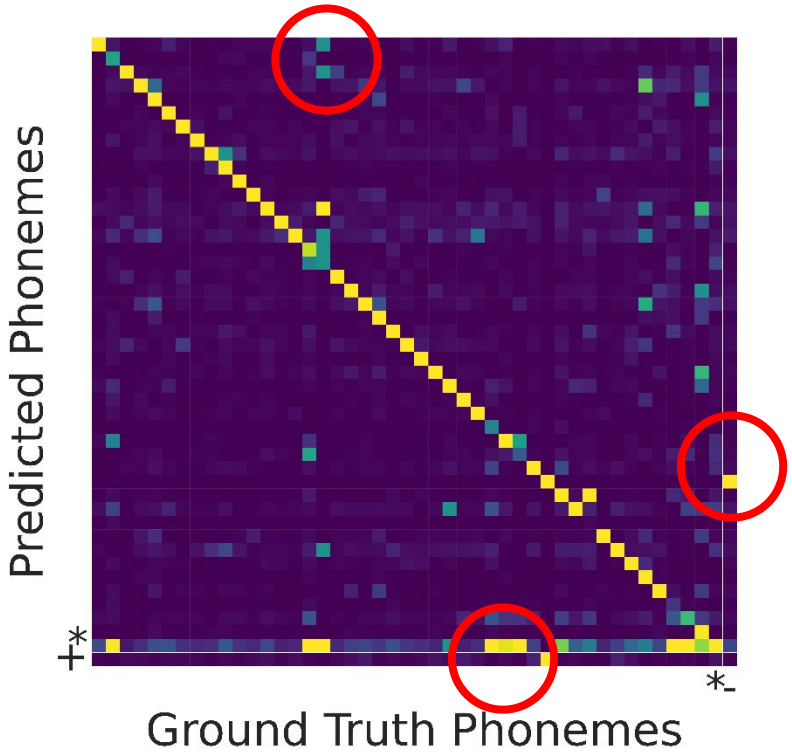
images: istockphoto.com

Machine-Human Validation

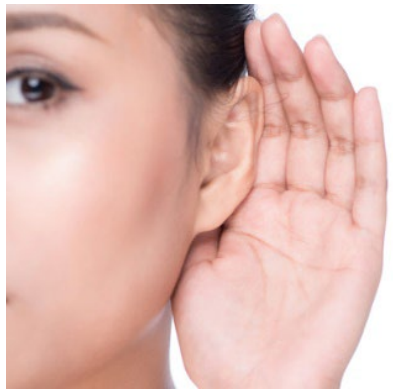
1) Building a Deep Neural Network “AI Listener”
2) Collecting, evaluating dysarthric and BCI voice with varied intelligibility
3) Human intelligibility scoring (trained SLPs) to validate metric

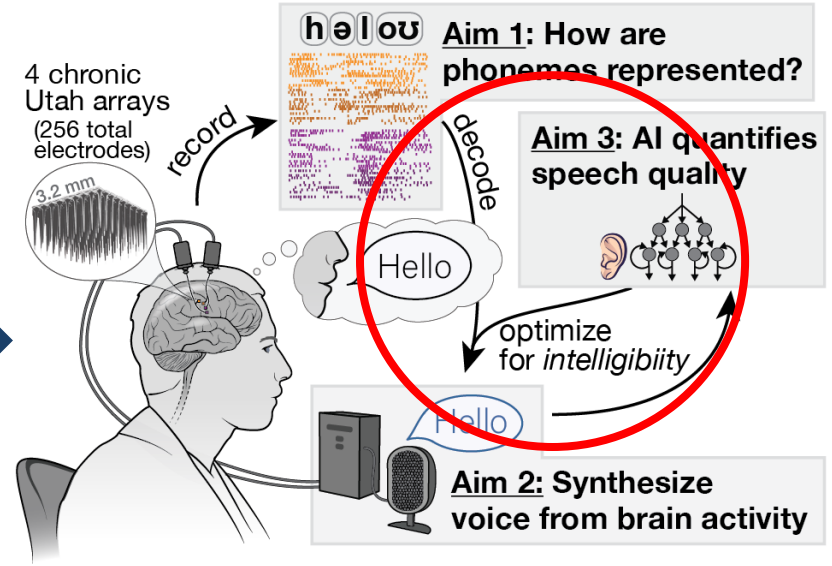
Automatic Speech Assessment

BCI / Dysarthric Speech



?





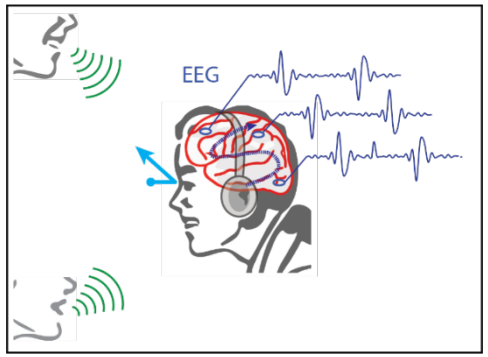
https://patient.uwhealth.org/healthfacts/774

Use Cases of an “AI Listener”

- Optimize intelligibility in Speech BCIs, Silent speech
- Voice-speech ***biometric with high specificity*** for diagnostic and predictive health
- Large-corpus digital analysis / scholarship (law, entertainment)
  - open-source software Voxit (https://github.com/MillerLab-UCDavis/Voxit)

MacArthur et al, *Los Angeles Review of Books* 2022

Projects



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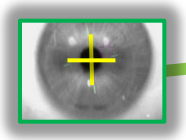

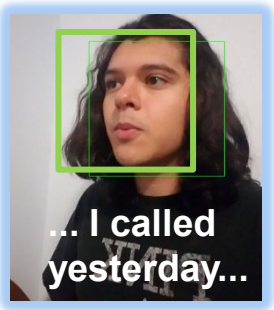

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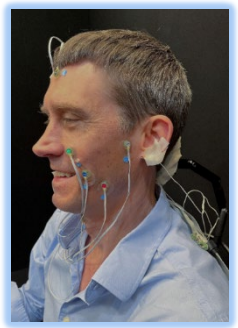

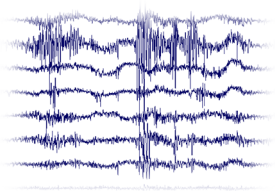

Inclusive Wrist
EMG Decoding

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Keenan Kalra
and many more!

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CITRIS

Department of Defense

accenture

UC Davis School of Medicine

Child Family Fund
Nasa
Intel
UC Davis Office of Research
UC Davis Academic Senate
College of Biological Sciences
NSF: National Science Foundation
National Endowment for the Humanities
Social Science and Humanities Research Council (Canada)

THANK YOU

Want to help? Please Give!

- 4 of these 5 projects relied on philanthropy
- support students and trainees
- provide critical supplies and equipment
- outreach to patients and caregivers
- email me: *leemiller@ucdavis.edu*