TOOTH-Typing on Your TeetH: Tongue-Teeth Localization for Human-Computer Interface

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ACM MobiSys 2018


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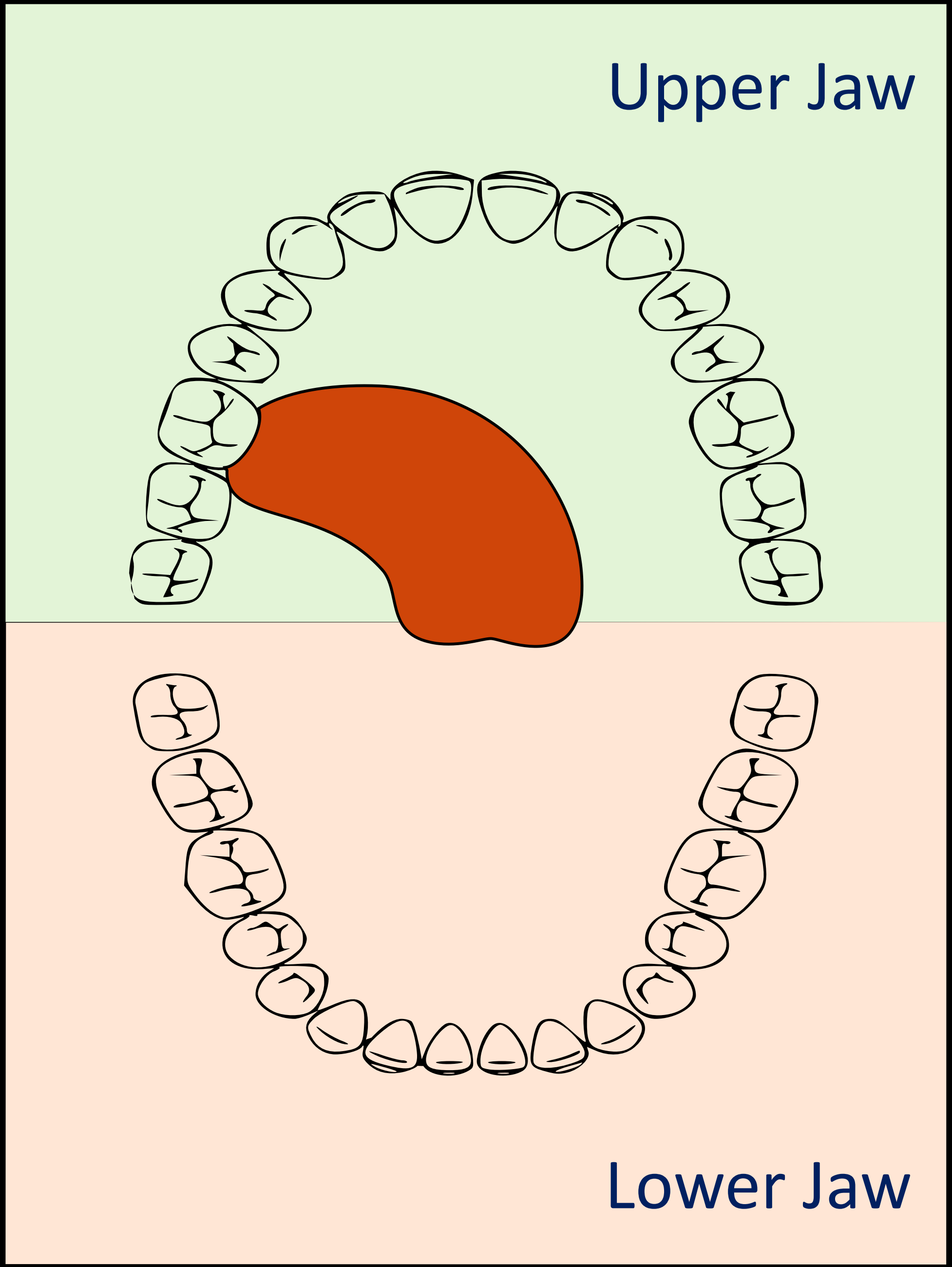
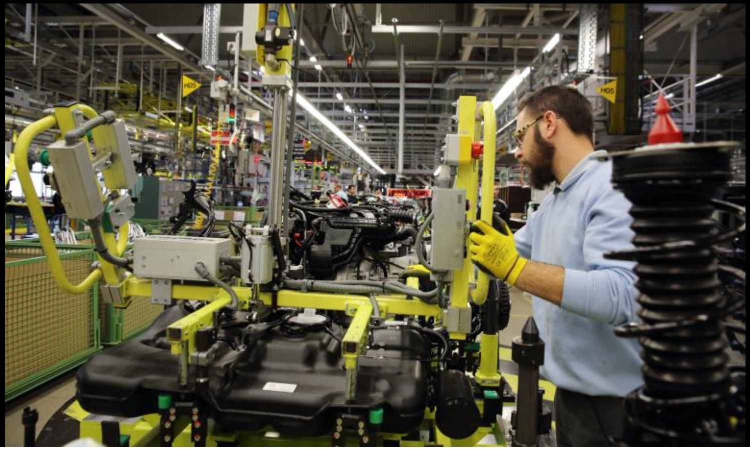

Upper Jaw
Lower Jaw

It is challenging for ALS patients to interact with computing devices

Other Potential Usages



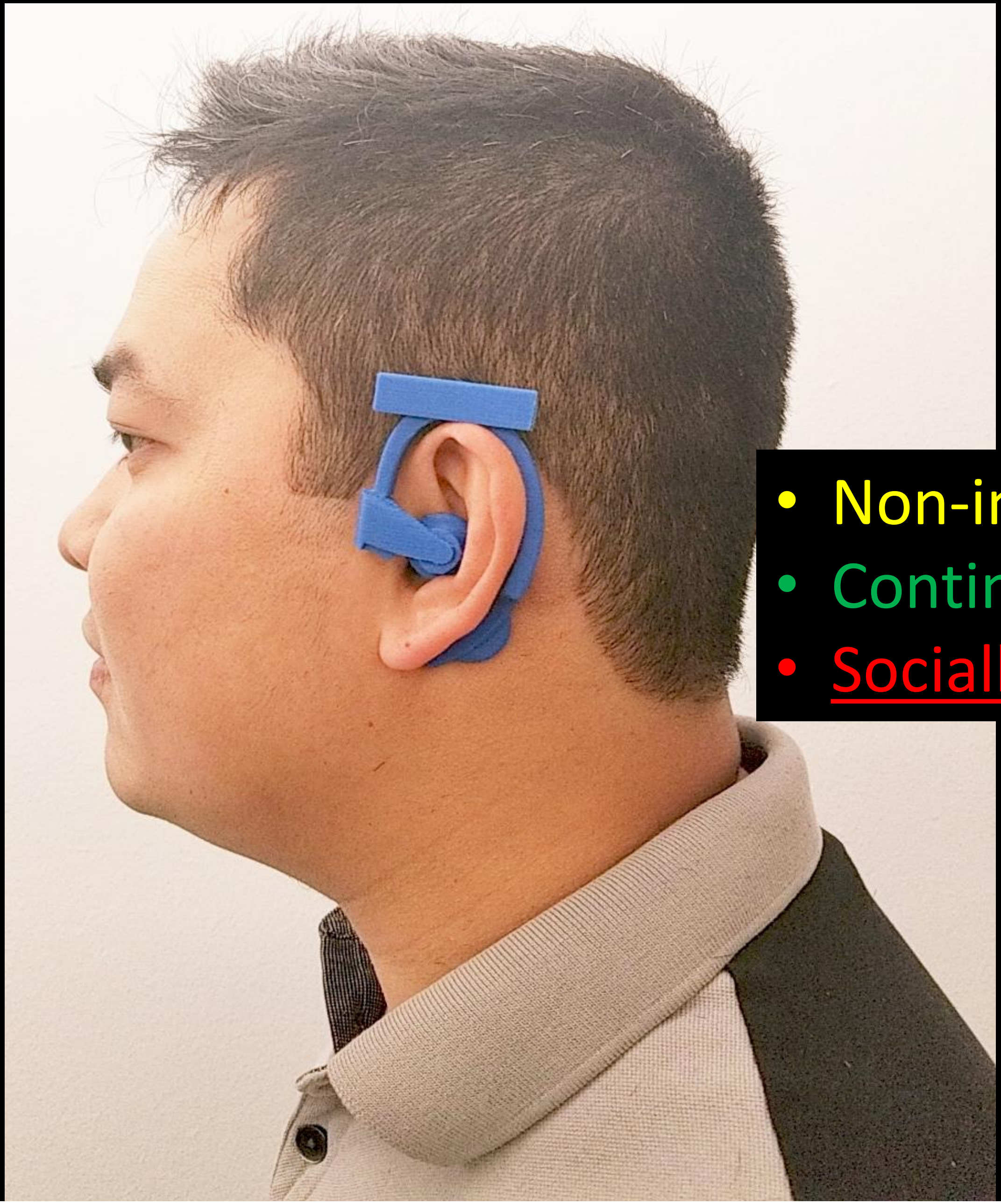
A HAND-FREE INTERFACE FOR **FACTORY WORKER**

TURNING **MUSIC SHEETS** FOR **MUSICIANS**

HIDEN **TEXT ENTRY** INTERFACE

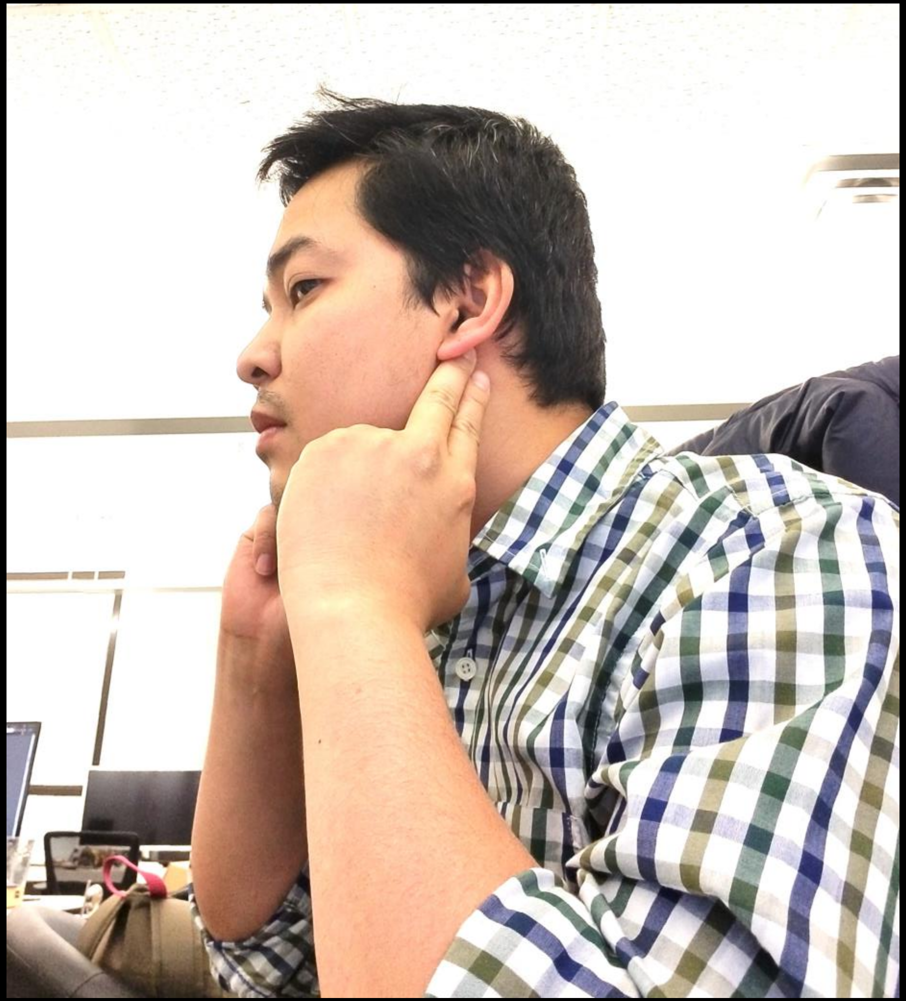
CONTROLLING **PHONE** WHILE **DRIVING**

USED IN **TACTICAL SCENARIOS**



- Non-invasive,
- Continuous & long-term use,
- Socially acceptable

TYTH – Typing on Your TeetH



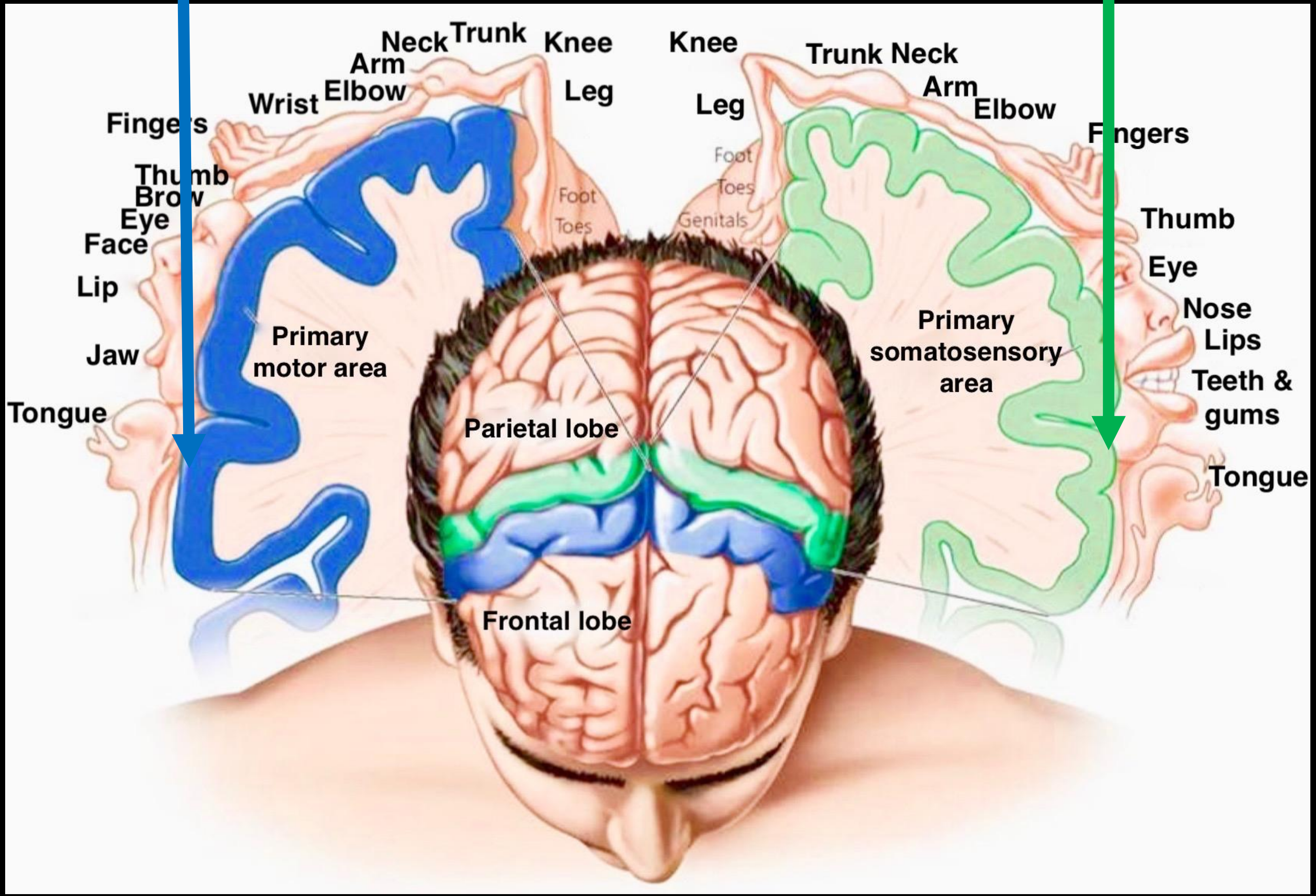
Experiment: Put your fingers at the back-of-the ear locations.
Then, press any teeth using your tongue

Anatomical and Neurological Analysis of Tongue-Teeth Interaction

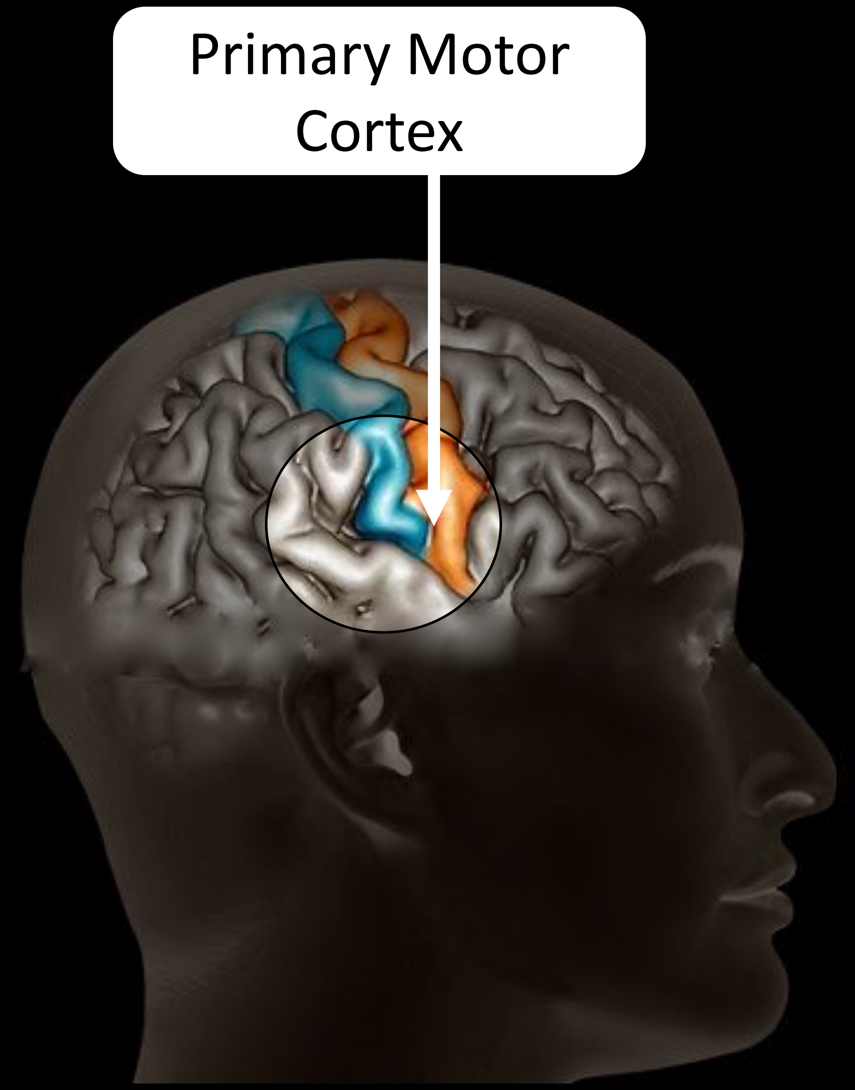
Primary Motor Cortex

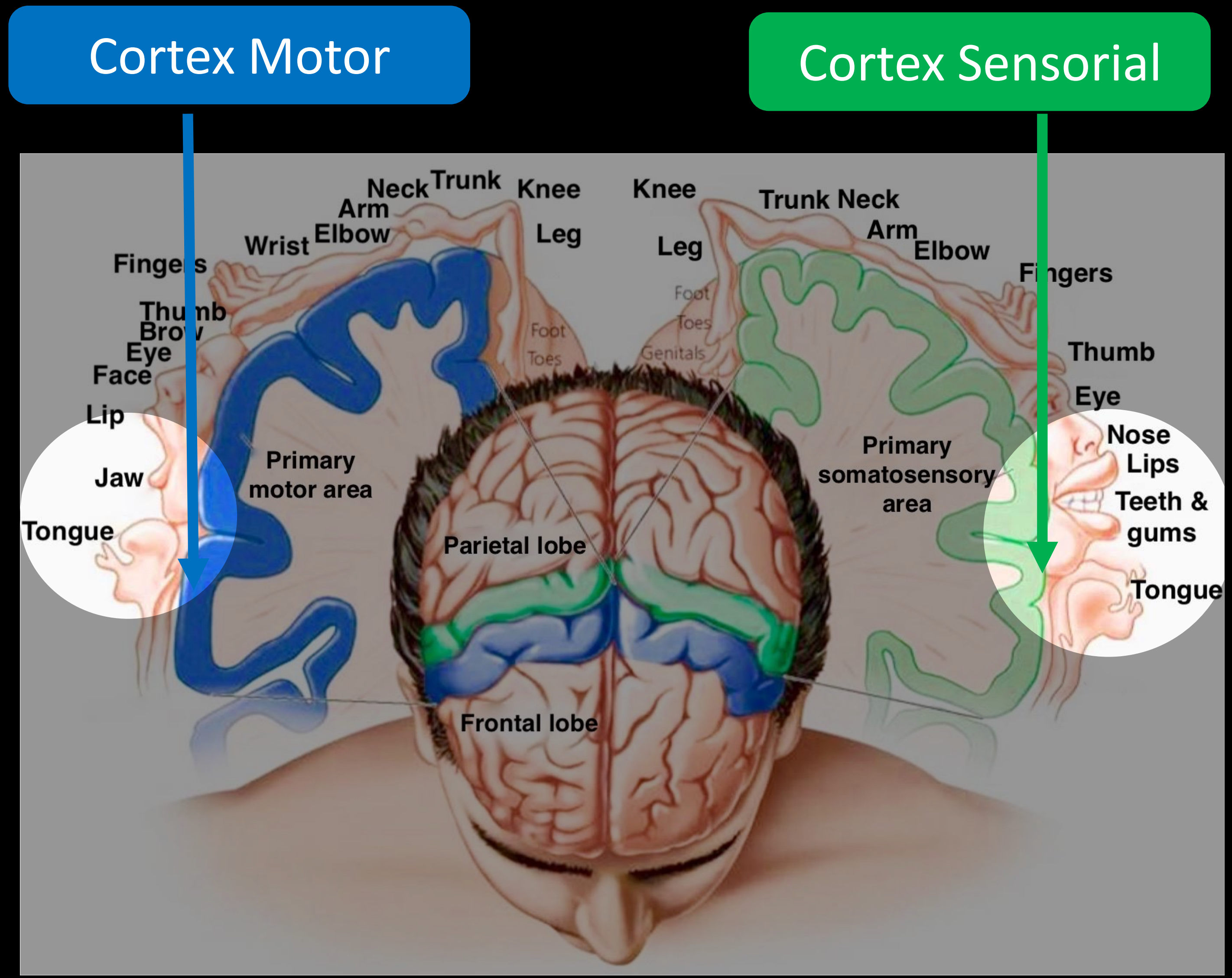
Cortex Motor

Cortex Sensorial

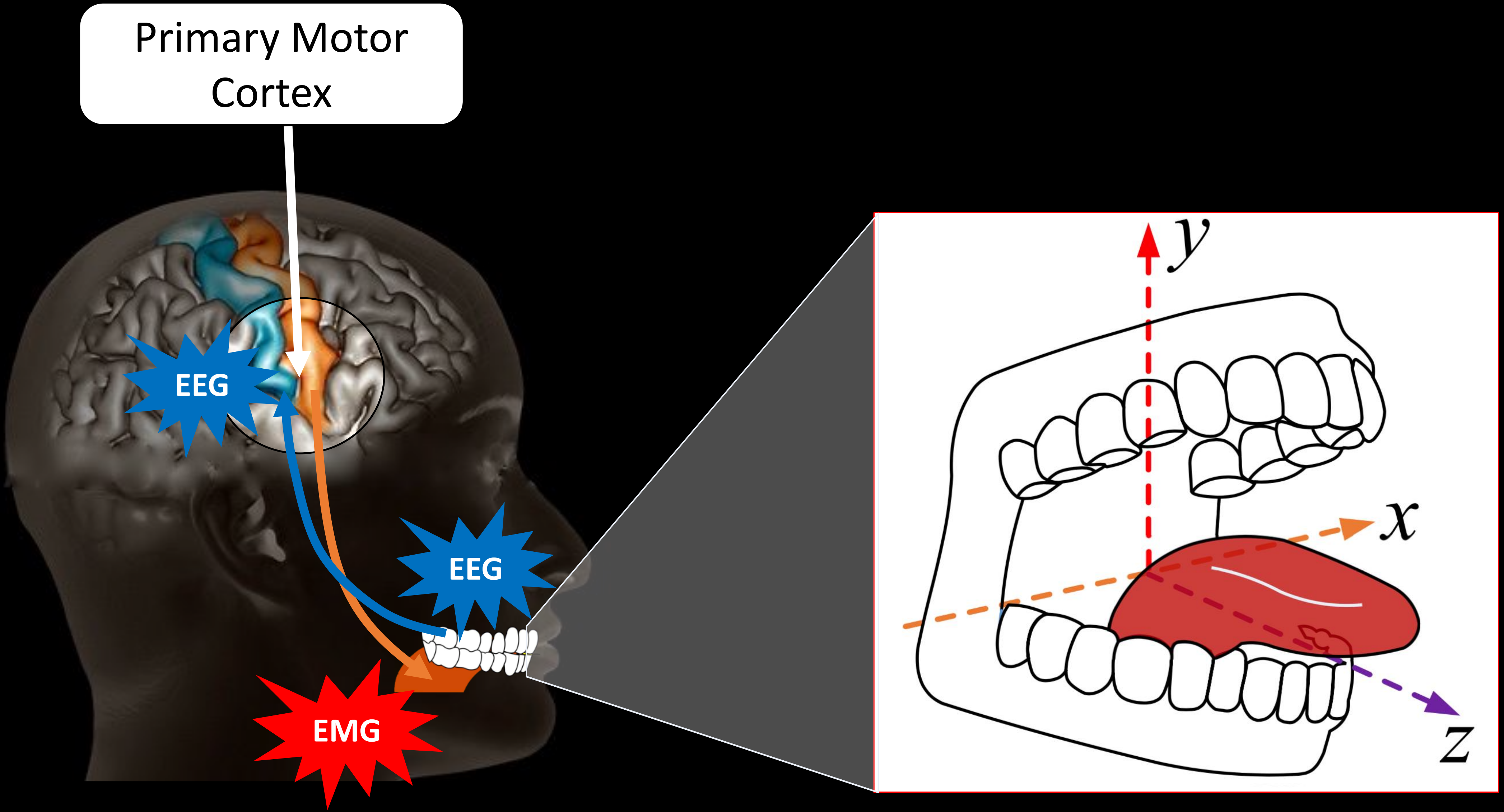


Brain sends commands out

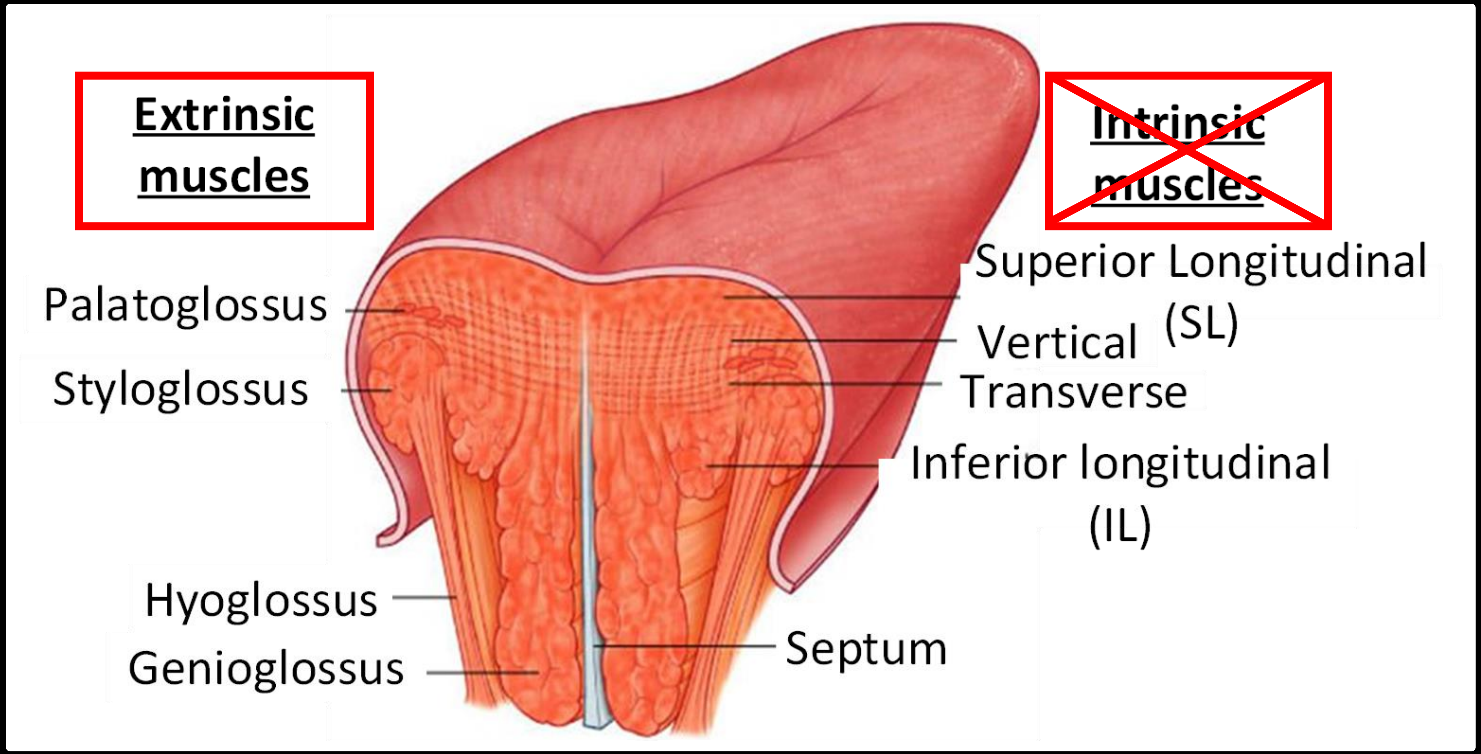


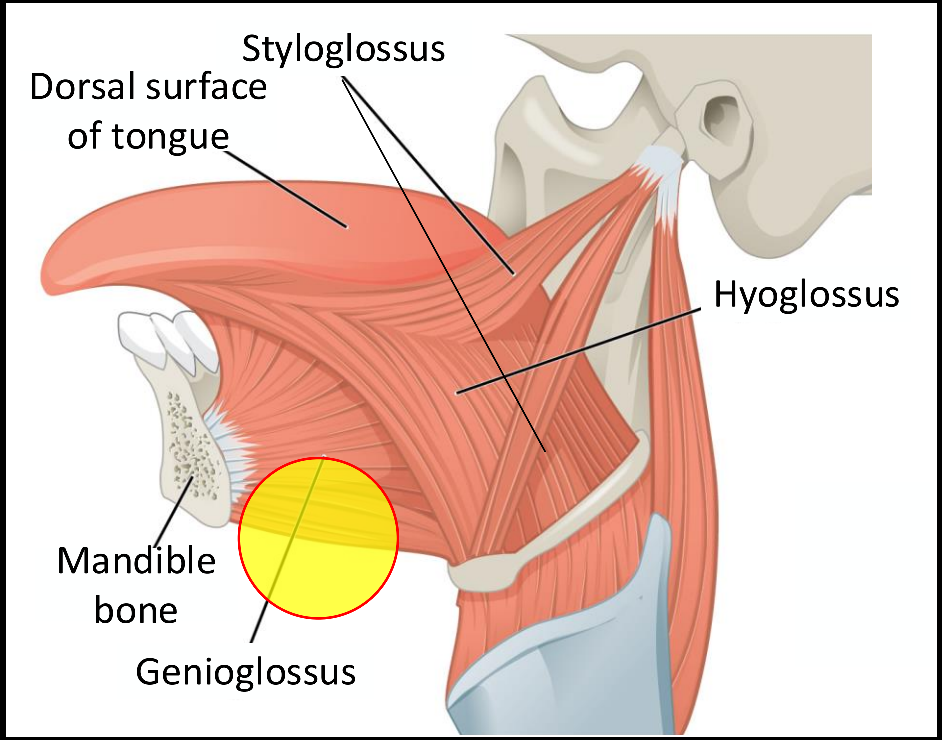


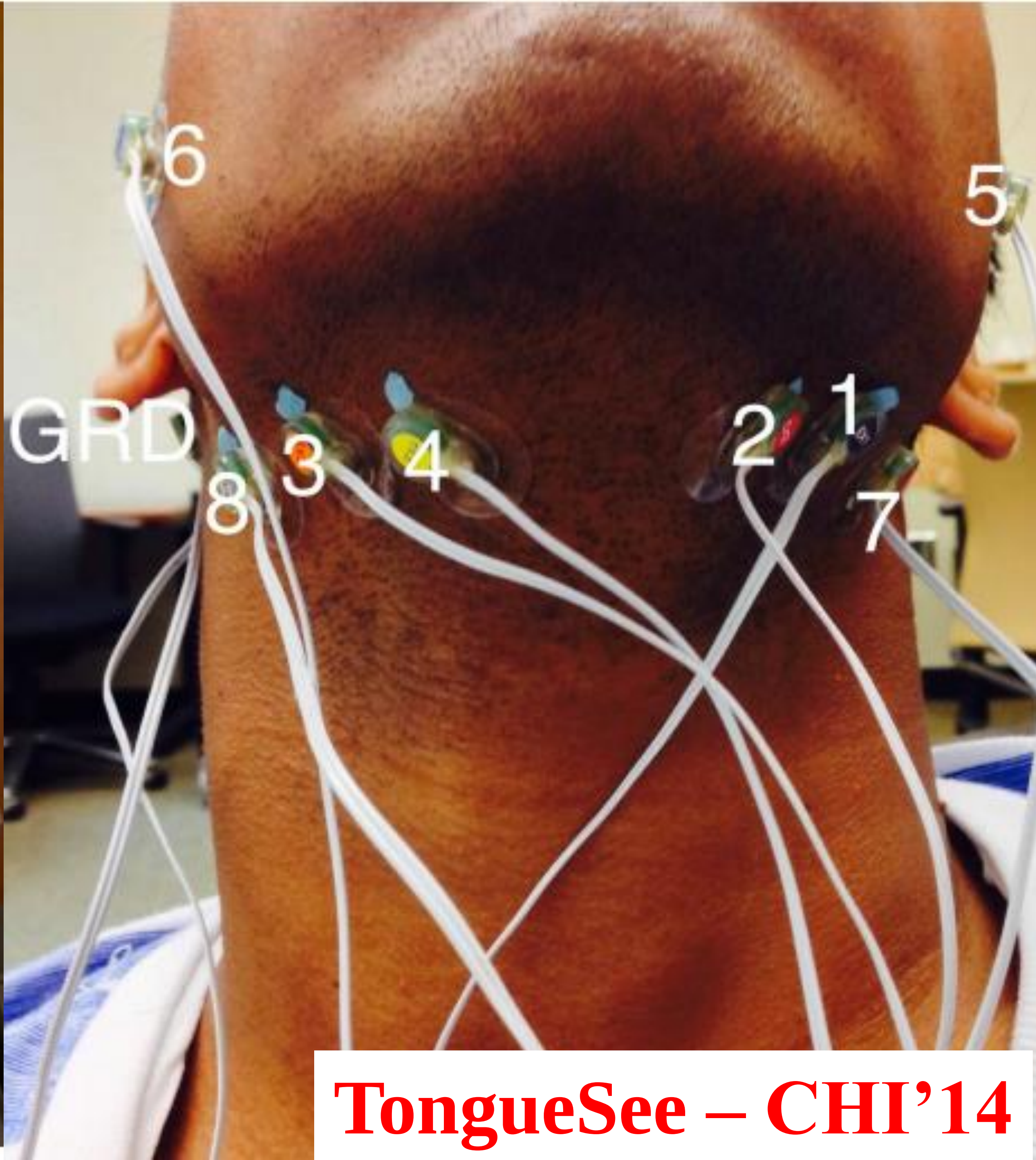
Anatomical Analysis of Tongue-Teeth Movement



Tongue is controlled by extrinsic and intrinsic muscles





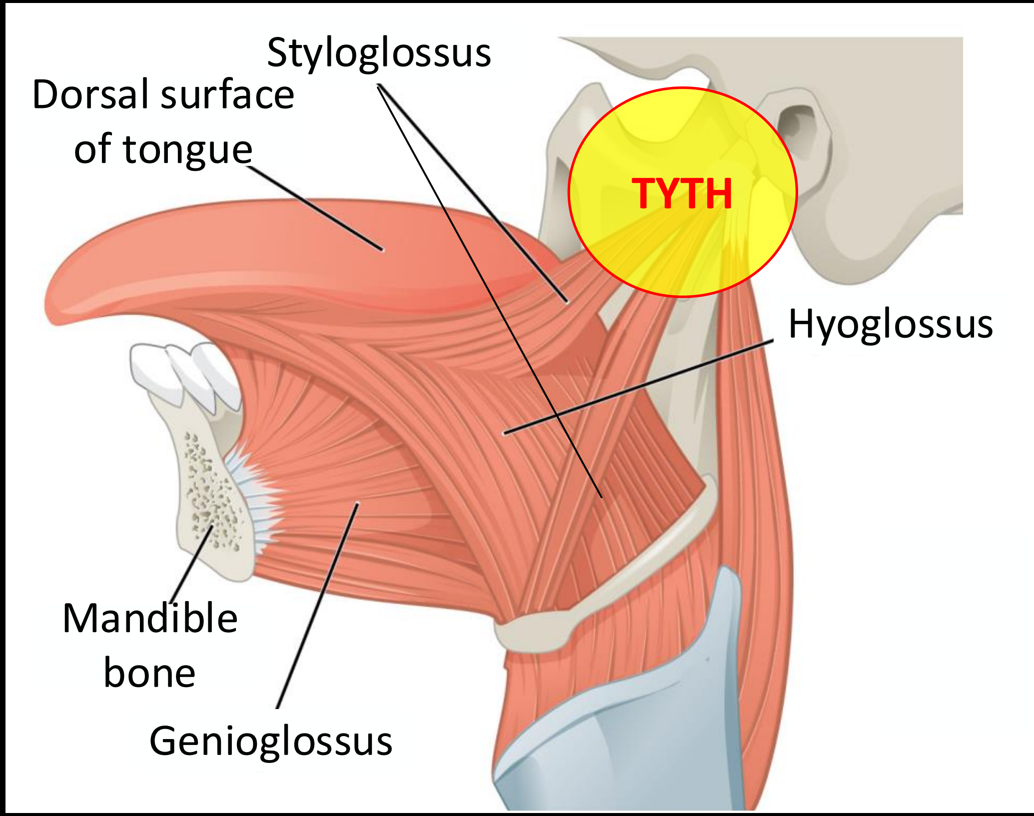


TongueSee – CHI'14

It is difficult to make the device socially acceptable

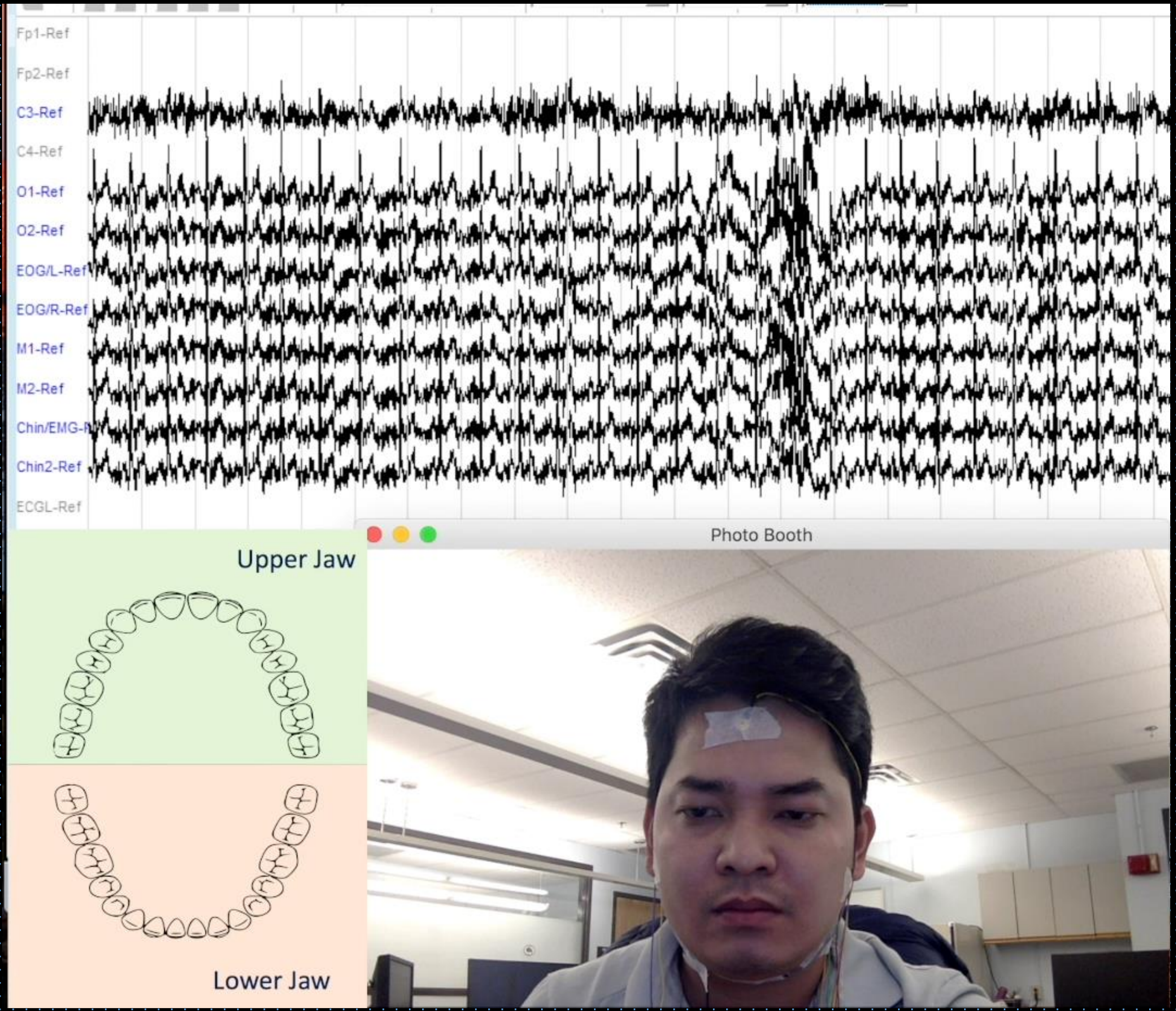
TongueSee – CHI’14

Tongue is controlled by extrinsic and intrinsic muscles



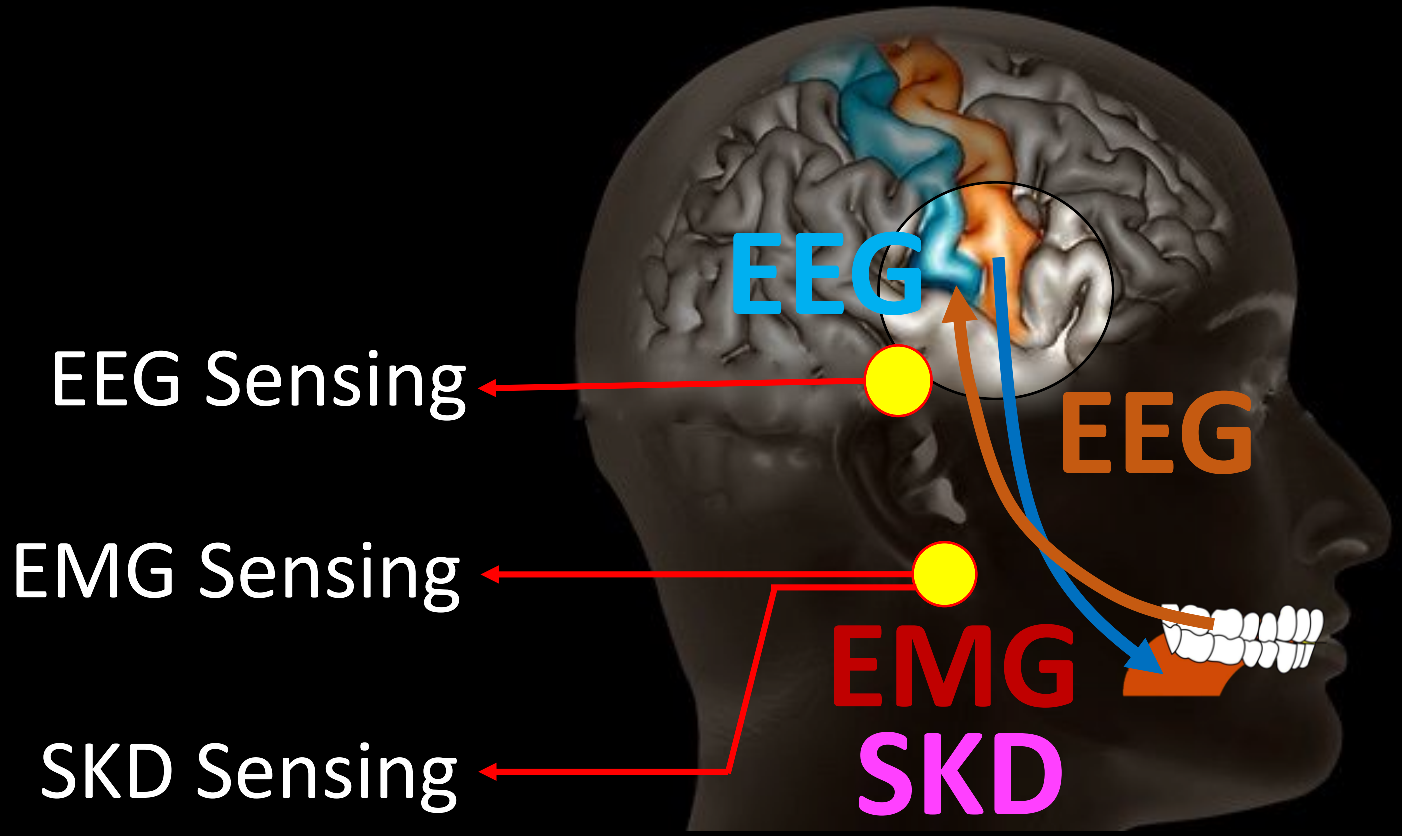
Can we capture the tongue movement signal from this location?

Experimental Validation

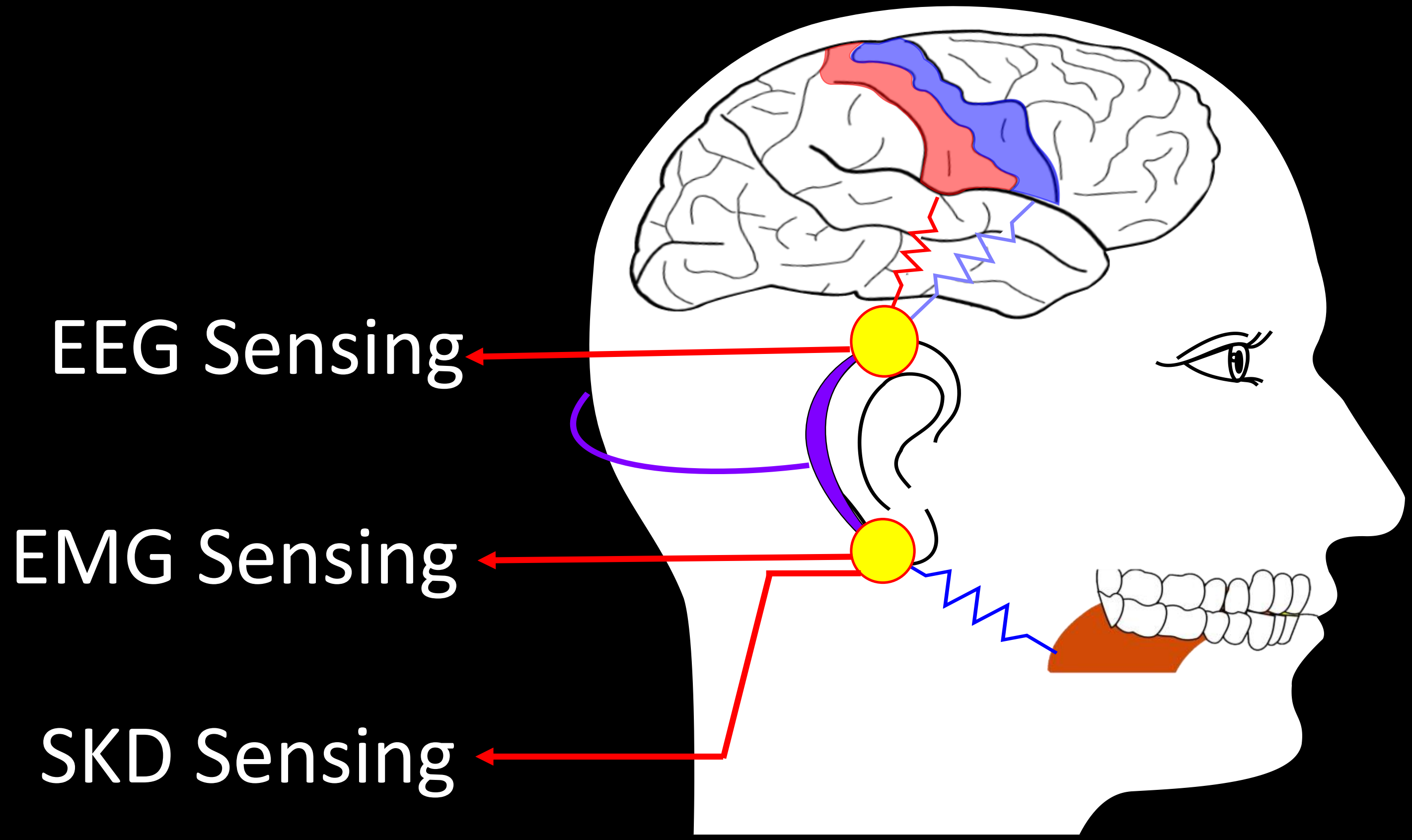


Hardware Design

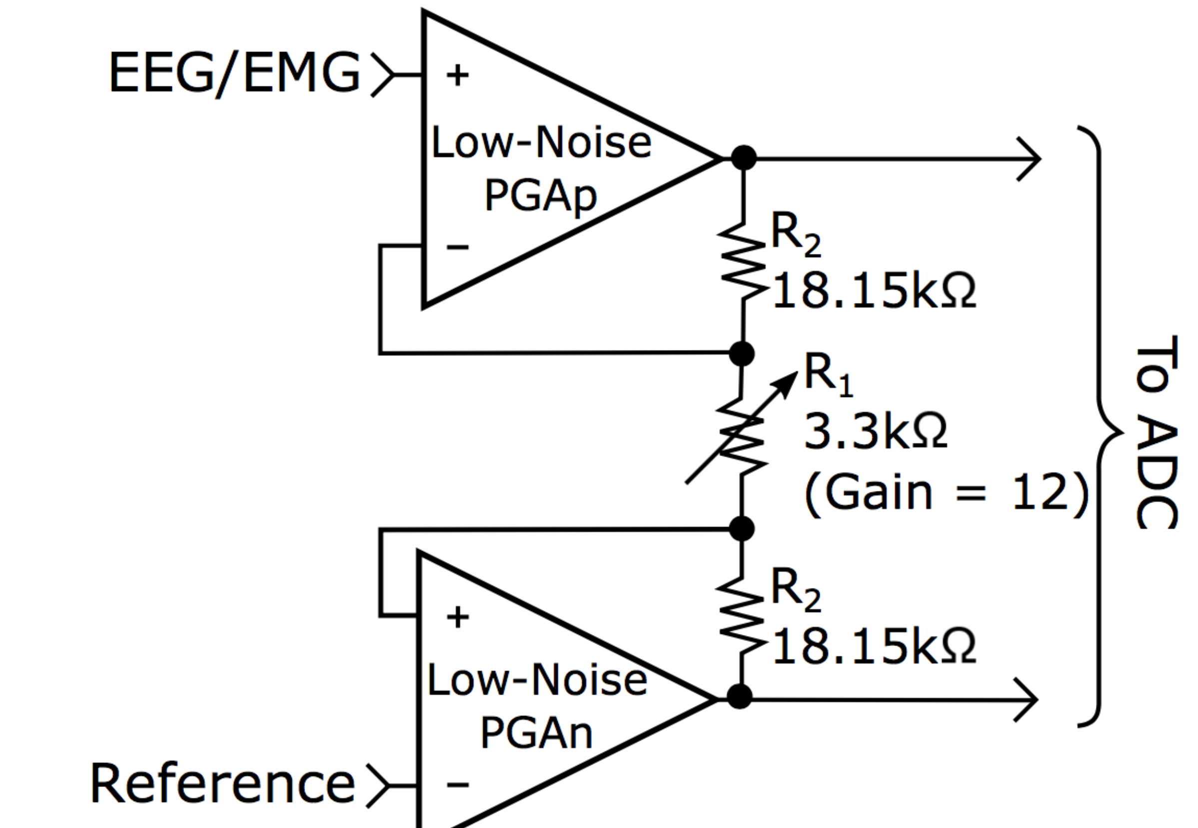
Sensing Techniques



Sensing Techniques



Sensing for EEG/EMG
COTS Bioelectrical Sensing Circuit



(a)

- **Programmable Gain**
- **Programmable Filters**
- **Low-Noise, 8 ADC Channel**
- **16kSample/s**
- **uV sensitivity**

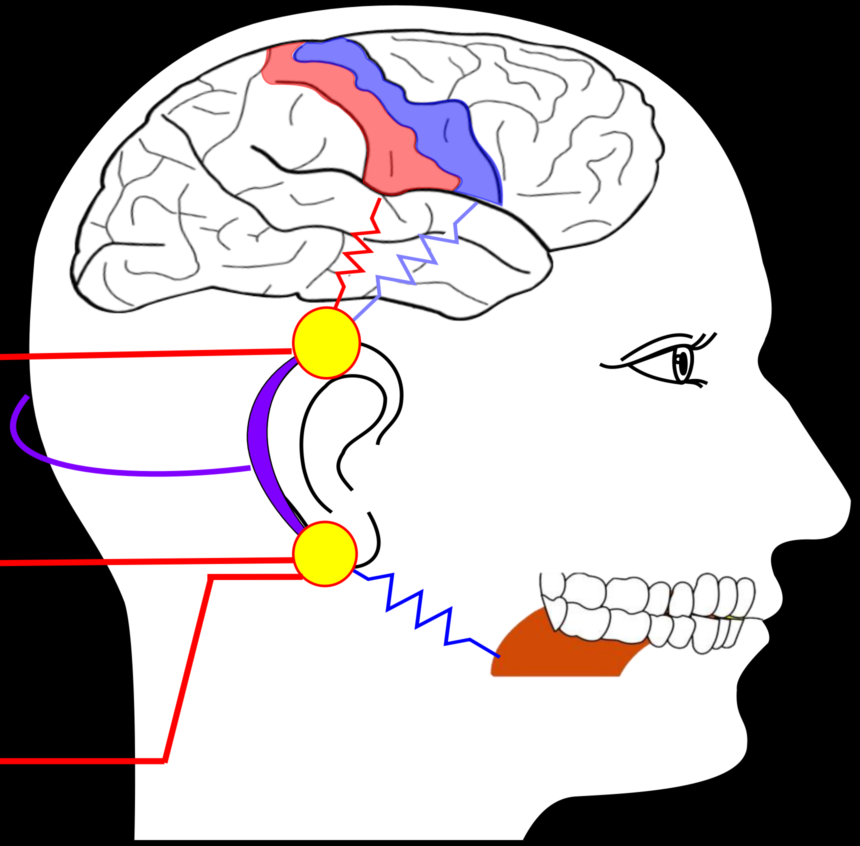
Sensing Techniques

EEG Sensing

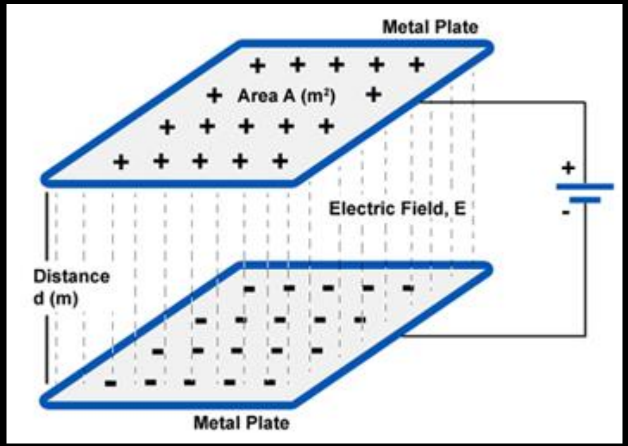
EMG Sensing

SKD Sensing

low amplitude
low frequency signal



Skin Surface Deformation Sensing Technique



Capacitive sensing approach

Permitivity

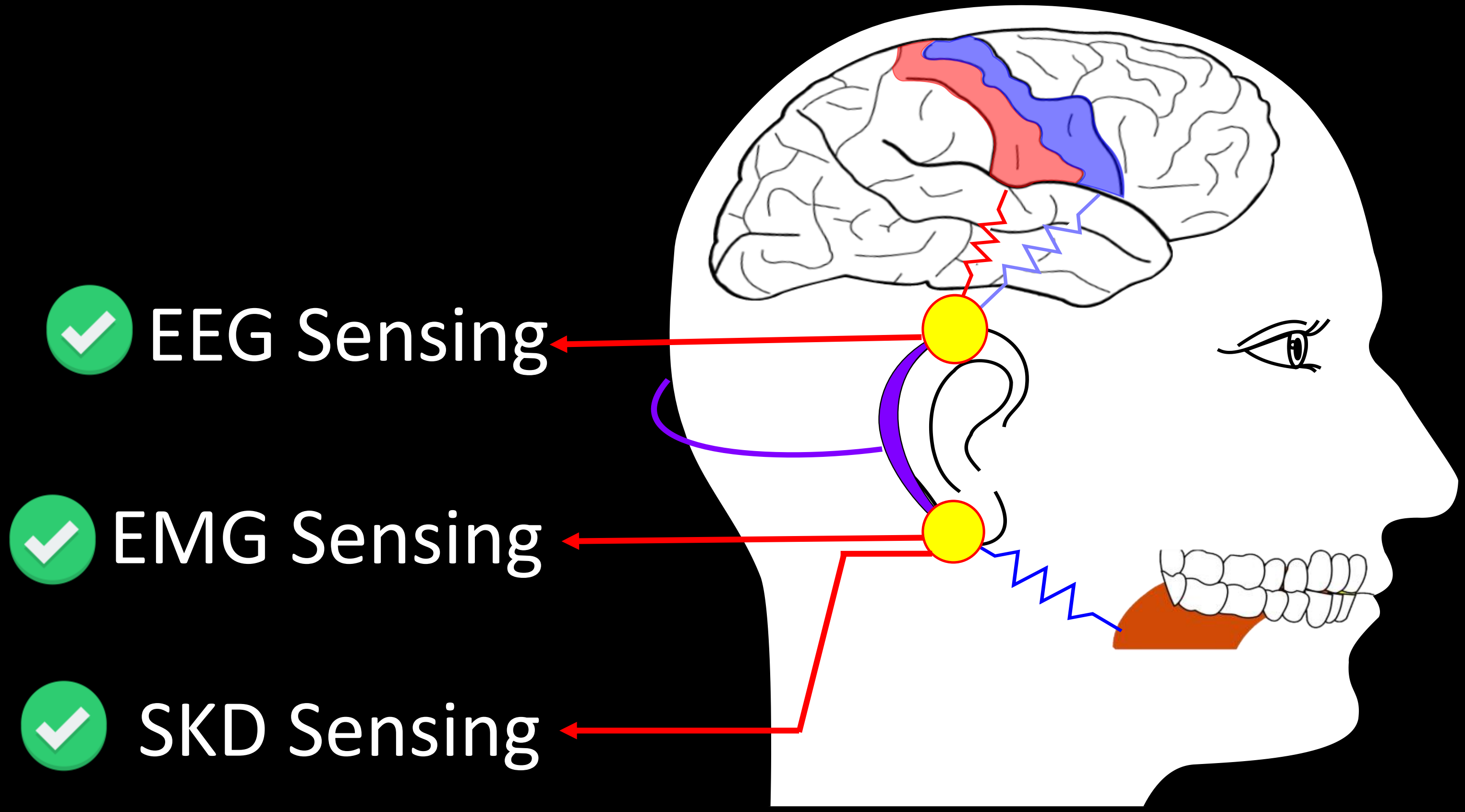
Area size

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

Capacitance

Distance b/w 2 plates

Sensing Techniques



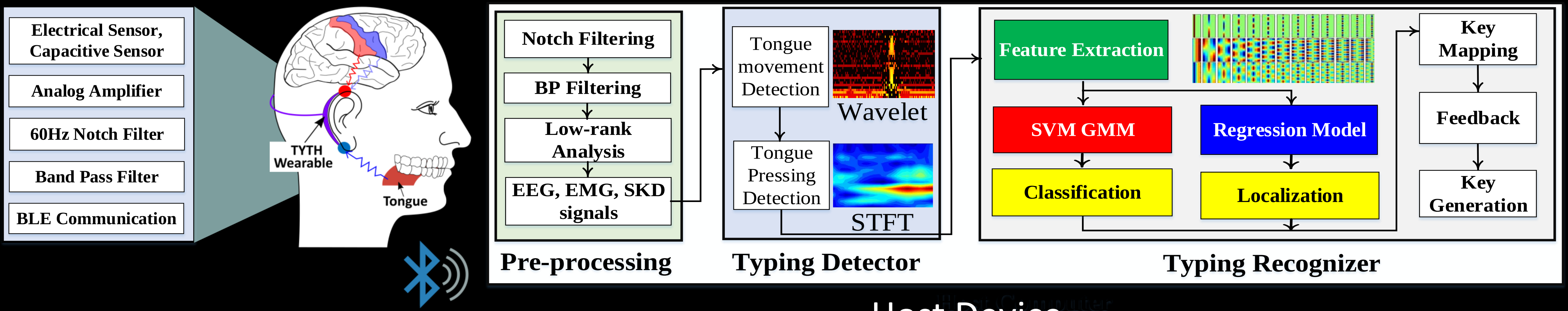
Challenge: These signals are extremely weak (mV/uV)

•Software Components to:

- De-noising the signal
- Extracting EEG, EMG from bio-electrical sensing data
- Detecting when the tongue is typing/pressing
- Classifying where the tongue is taping on
- Recognizing untrained areas

Challenge: These signals are extremely weak (mV/uV)

System Overview



Host Device

Low-Rank Analysis

Number of Gabor atoms in a dictionary

$$f(x) = \sum_{i=1}^{N_D} \delta_i g_i$$

atoms

coefficient

- Every bio-signal $f(x)$ can be represented as:
- Or,

$$f(x) = f(x_{\text{main structure}}) + f(x_{\text{detail structure}})$$
$$\Leftrightarrow f(x) = f(x_{\text{EEG signal}}) + f(x_{\text{EMG signal}}) + f(x_{\text{noise}})$$

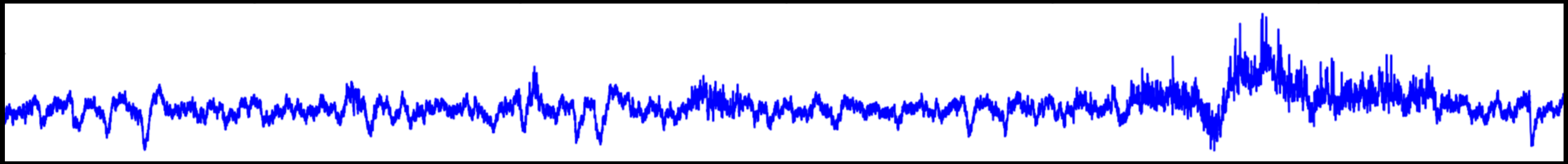
- Hence,

$$\Leftrightarrow f(x) = \sum_{\theta_1}^{\theta_M} \delta_{\theta_i} g_{\theta_i} + \sum_{\theta_{M+1}}^{\theta_N} \delta_{\theta_i} g_{\theta_i} + \sum_{\theta_{N+1}}^{\theta_{N_D}} \delta_{\theta_i} g_{\theta_i}$$

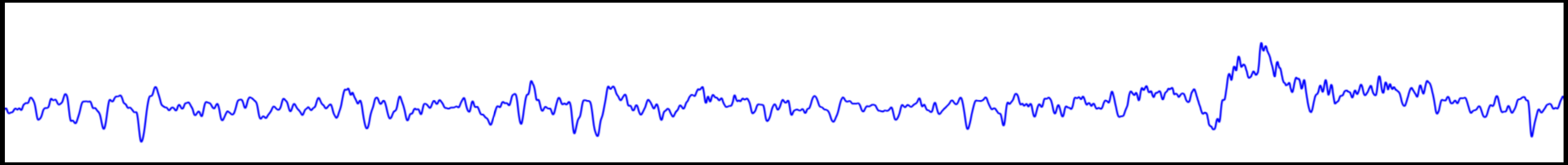
Please refer our paper for more details

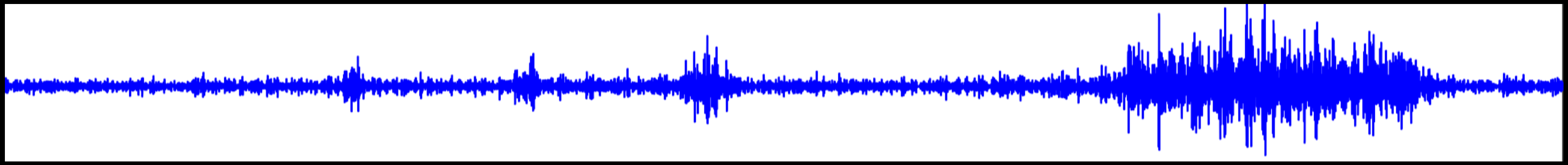
Low-Rank Analysis

$f(x)$



$$f(x_{\text{main structure}}) \begin{cases} f(x_{\text{EEG}}) \\ f(x_{\text{EMG}}) \end{cases}$$





$f(x_{\text{detail structure}}) \longrightarrow f(x_{\text{noise}})$

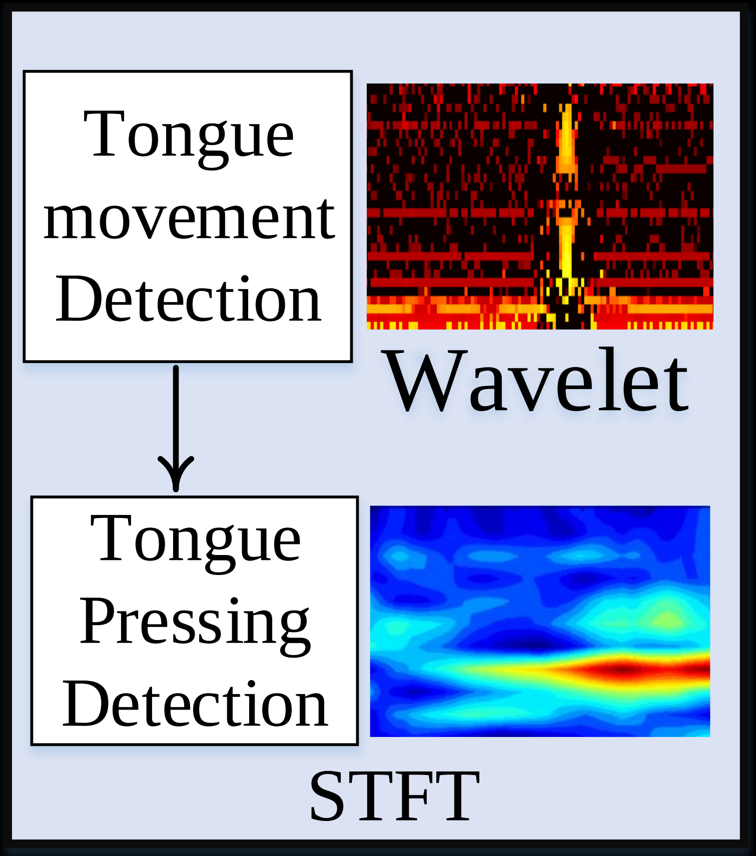
Pressing Detection

- How do we detect when a user is tapping?

$$W(s,p) = \int_{-\infty}^{+\infty} \tilde{r_f}(t)\overline{w_{s,p}}(t)dt = \frac{1}{\sqrt{s}} \int_{-\infty}^{+\infty} \tilde{r_f}(t)\overline{w_{s,p}}\left(\frac{t-p}{s}\right)dt$$

- How do we detect when a user is pressing the teeth?

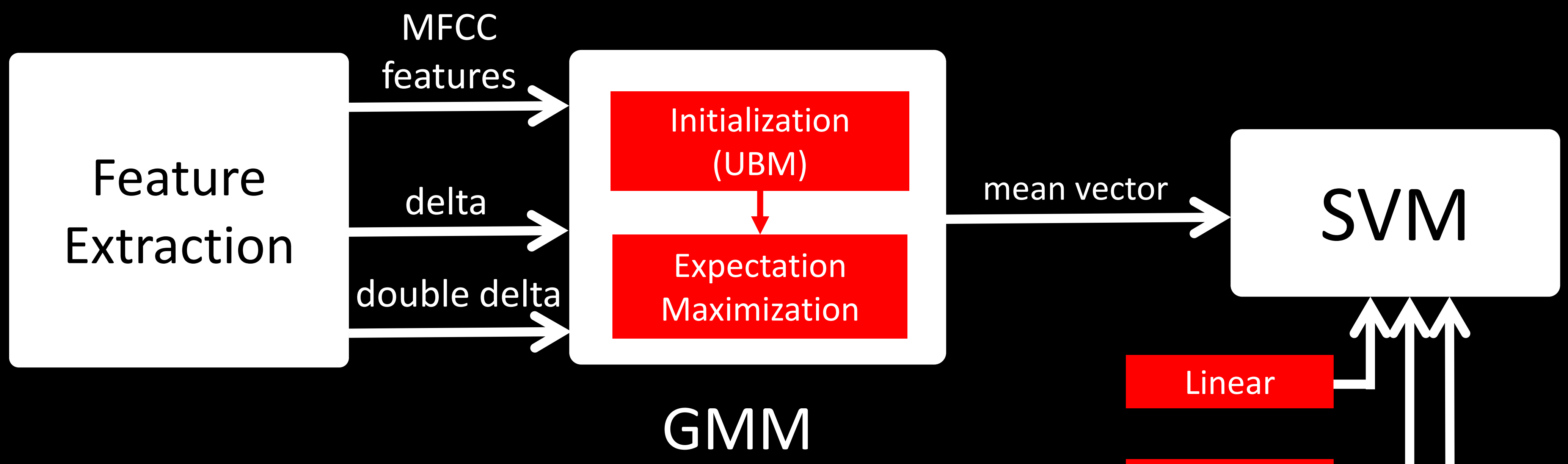
$$f_{brain} = \max_{[f_{min} \rightarrow f_{max}]} \left(\left| \sum_{k=1}^{N} x(t) e^{-j2\pi f t k} \right|^2 \right)$$



Detecting the <u>Tongue Movement</u> by identifying the discontinuity of the signal.

Detecting the <u>Tongue Pressing</u> based on the presence of the brain signal

Typing Area Classification: SVM - GMM



Building a classification model to detect the trained typing areas

Typing Area Localization

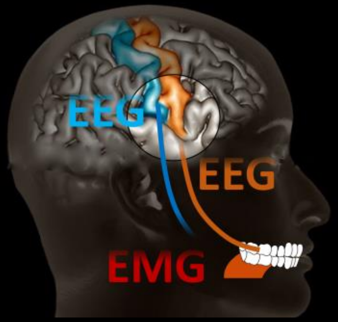
42 dimensions GMM output $\xrightarrow{\text{PCA}}$ 3D space coordination

During typing, typing location might not be exactly where it is trained. We build a

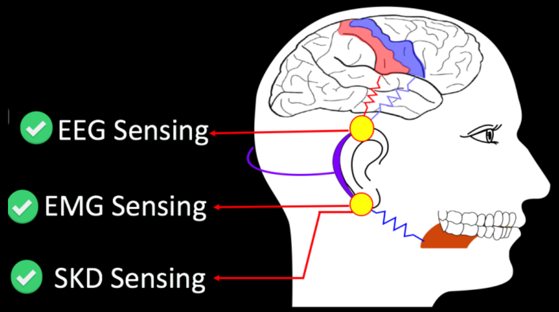
Please refer our paper for more details

Summary

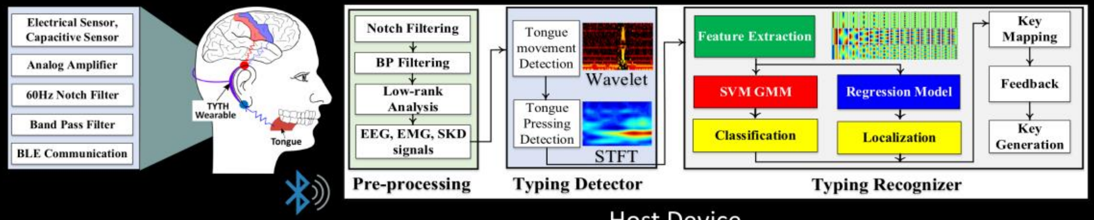
Anatomical and Neurological Analysis



Hardware Sensing Design

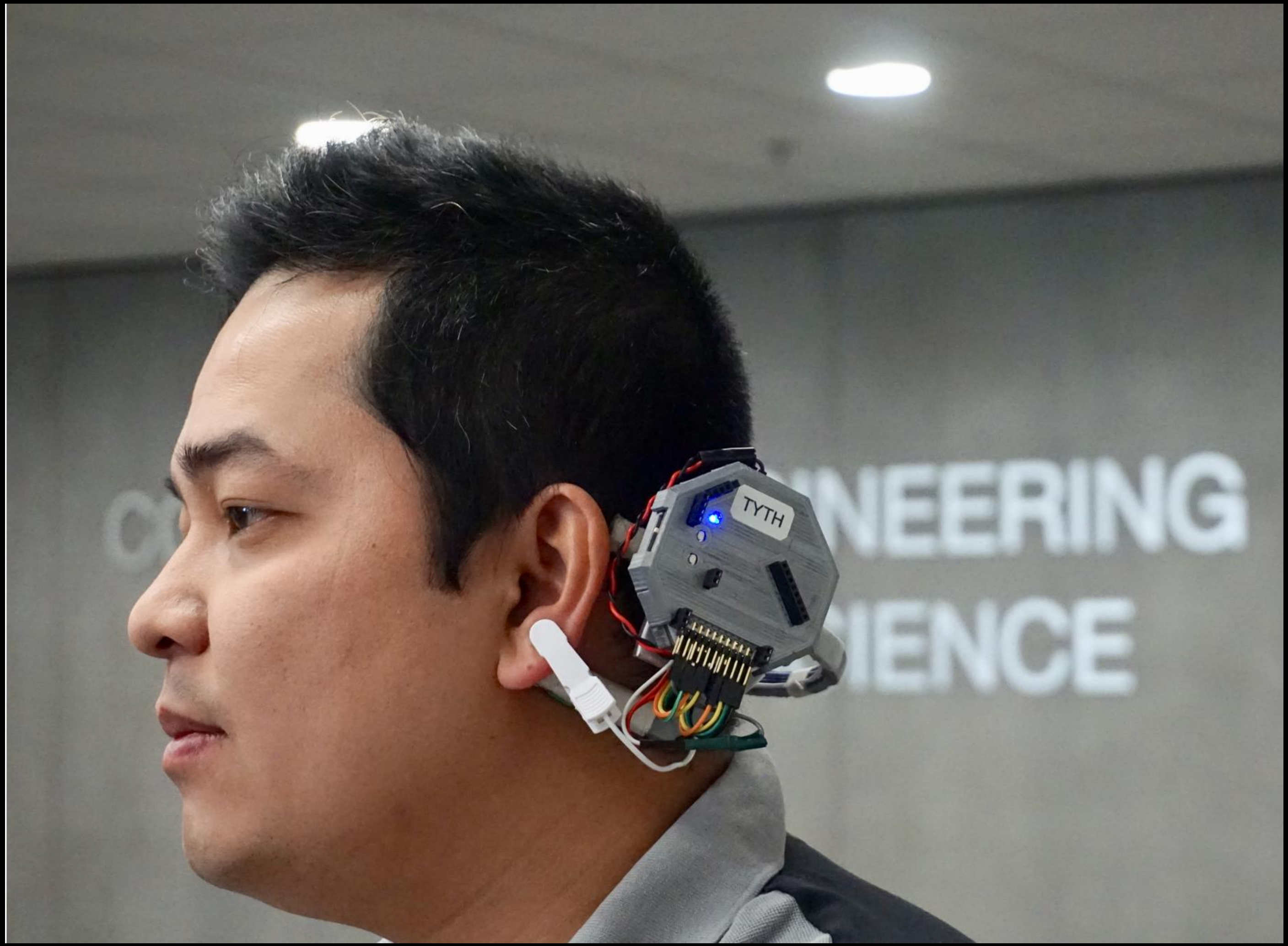


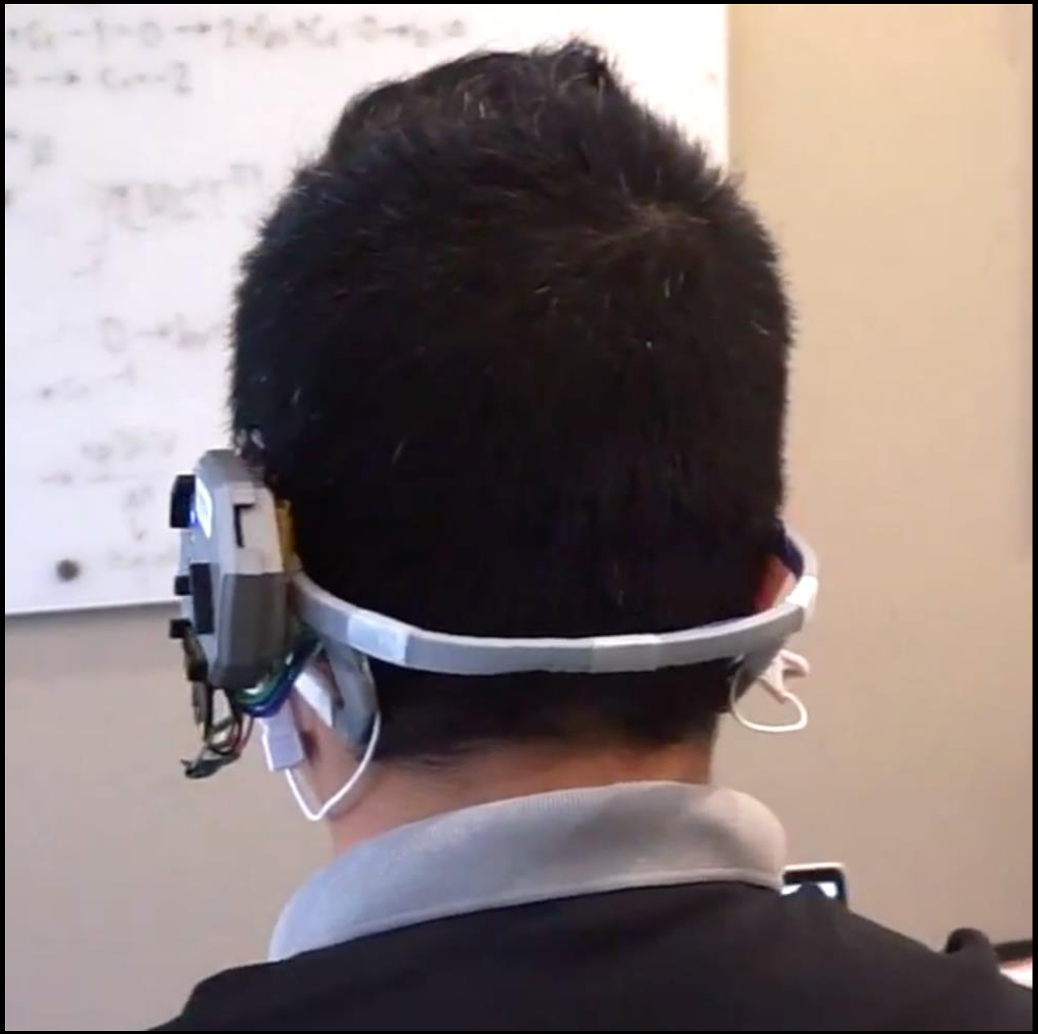
Software Components



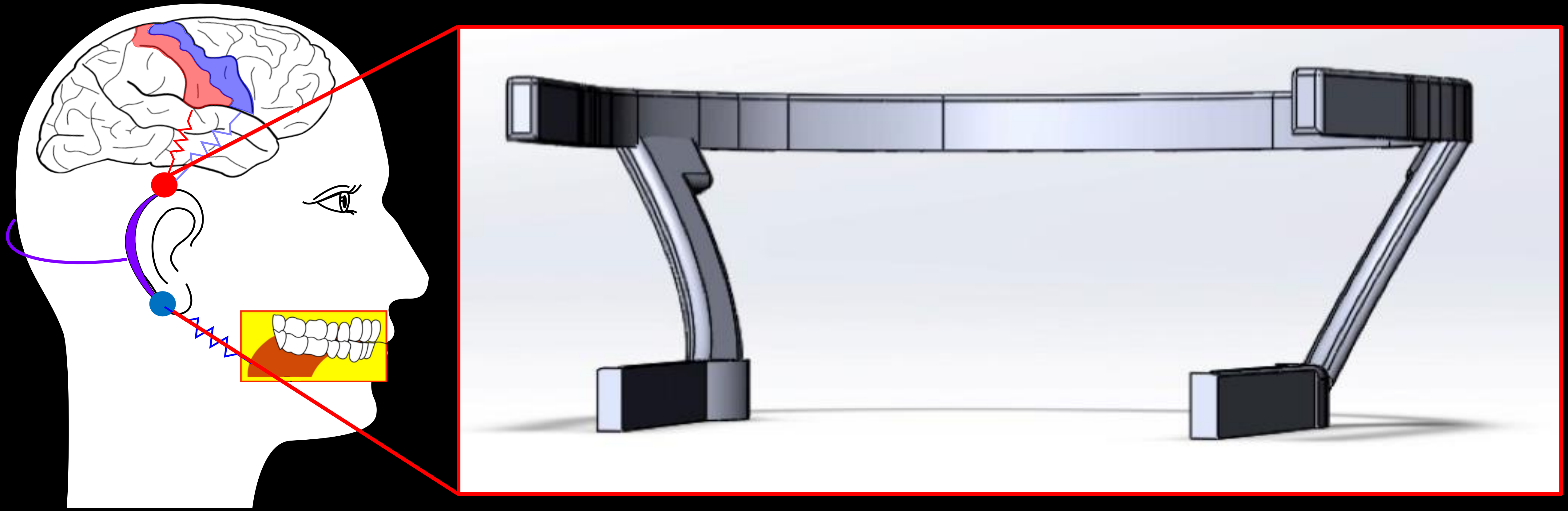
Let’s put things together

TYTH’s Prototype

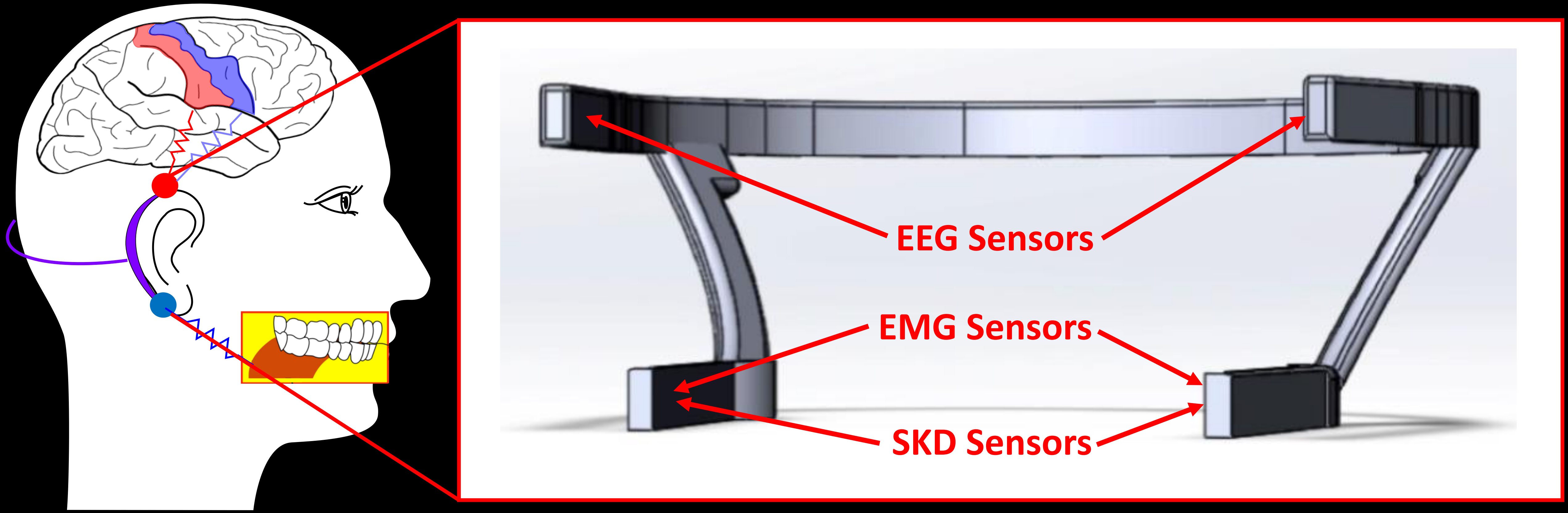




TYTH's Prototype



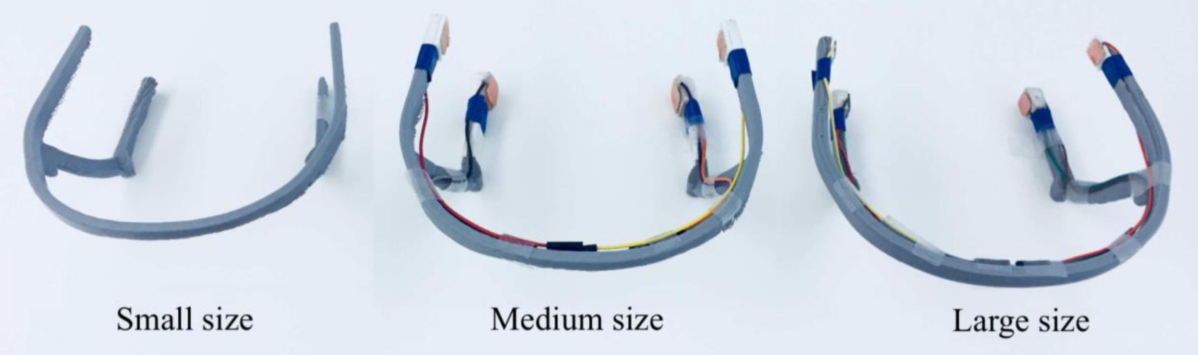
TYTH's Prototype

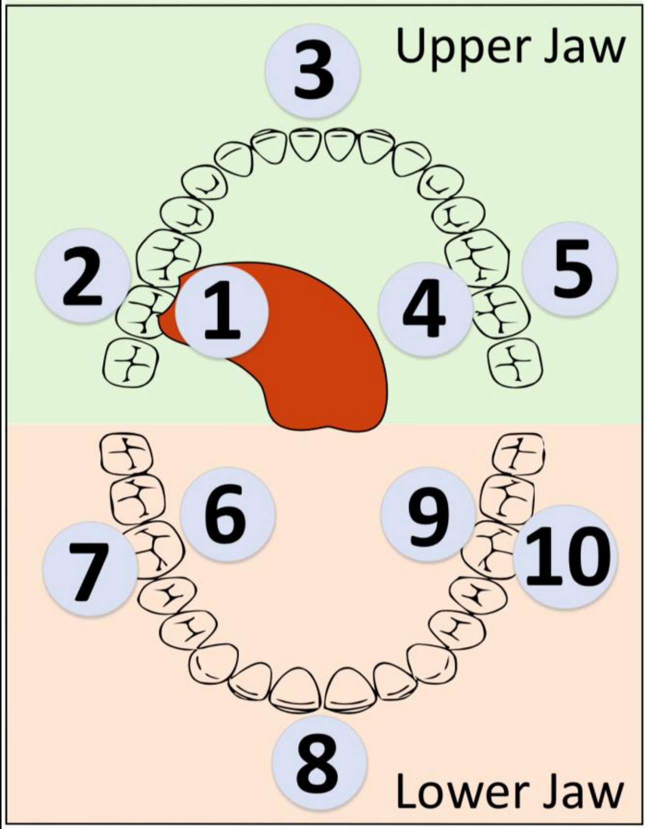


TYTH's Prototype

Performance Evaluation

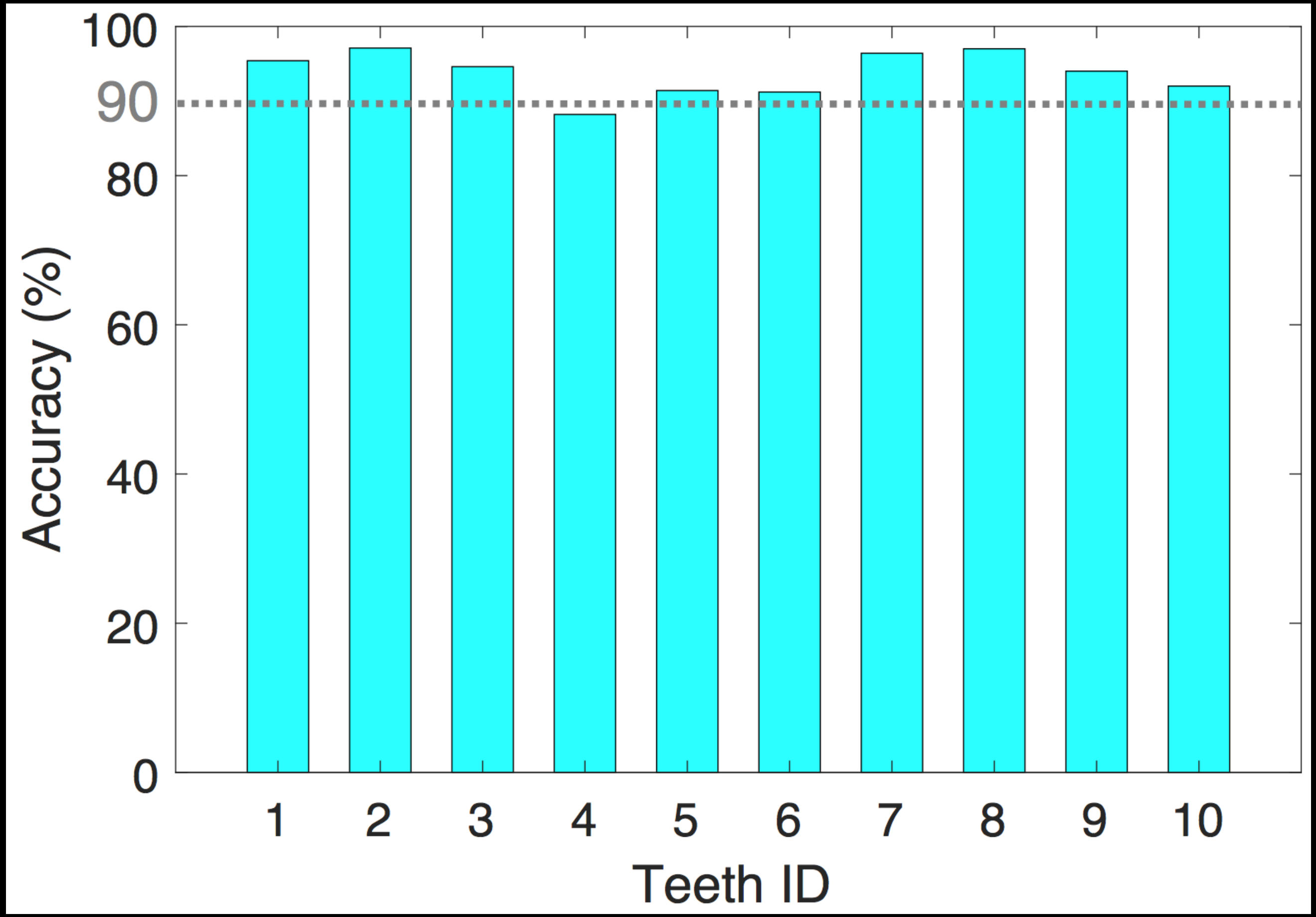
Participant Demographics	
Age (years)	18 - 35 years old
Gender Ratio	Male: 11, Female: 4
Head size use	Small: 3, Medium: 8, Large: 4





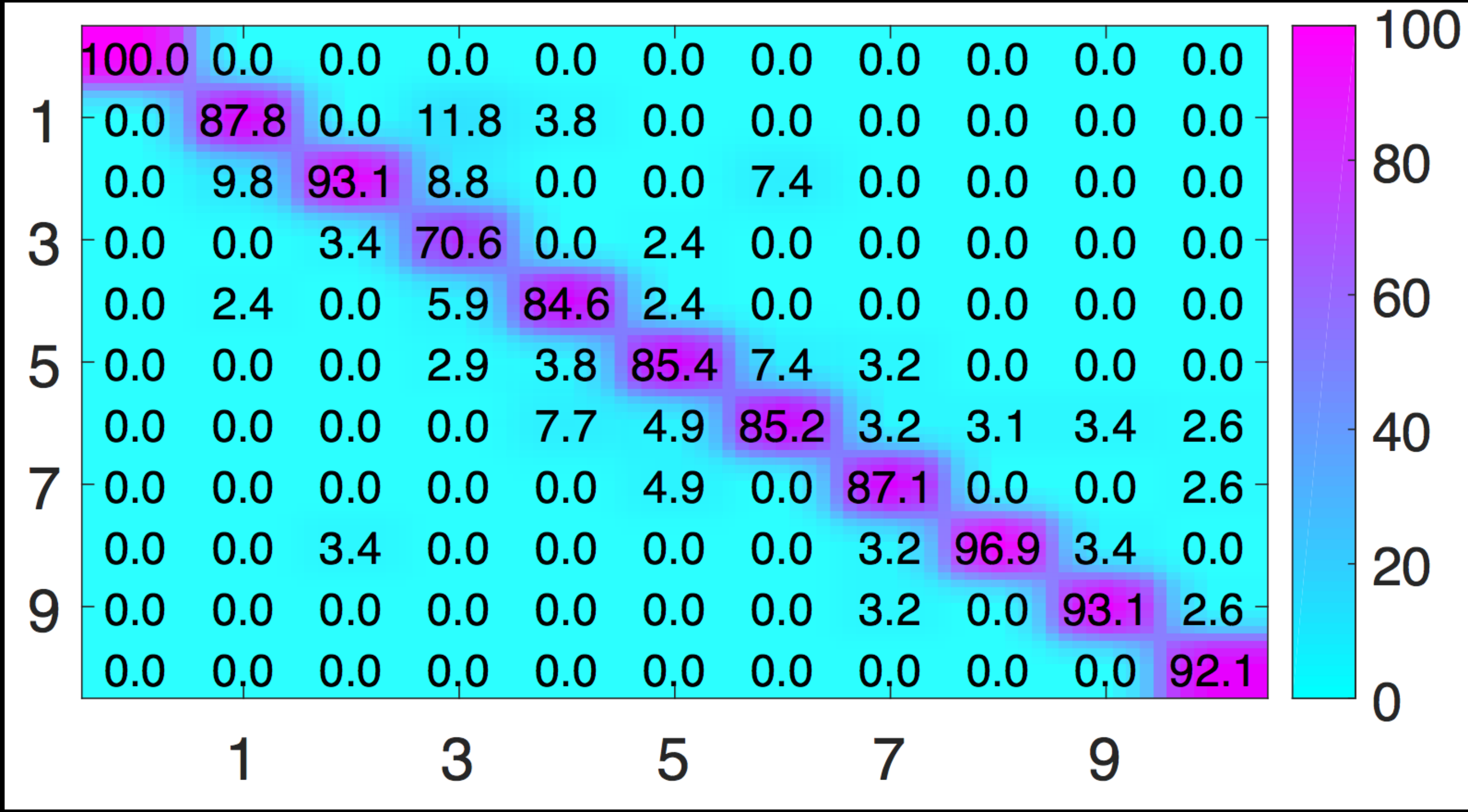
Teeth areas for evaluation

Typing Detection



Recognition Performance

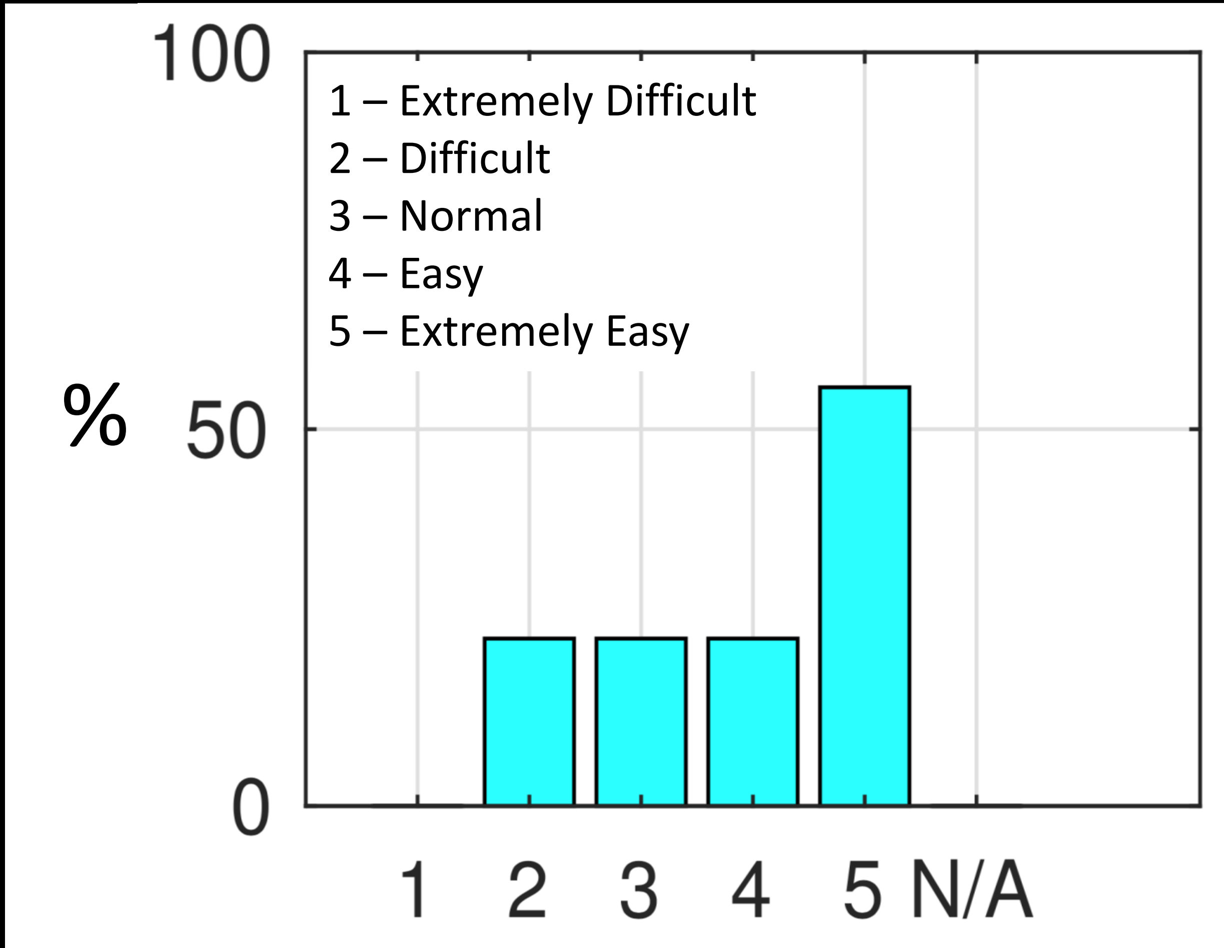
Classified Area



Ground Truth

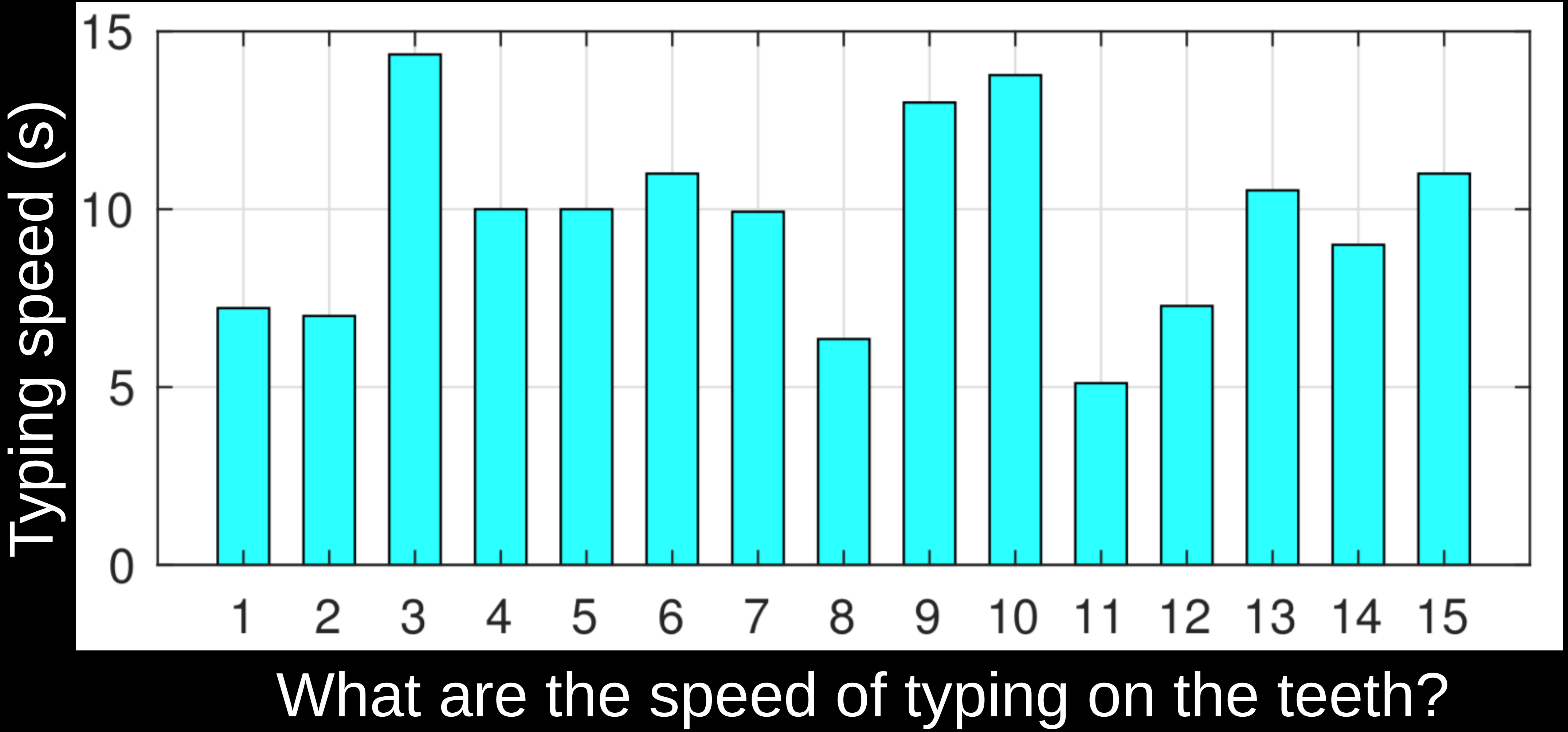
Average Accuracy: 88.61%

User Study

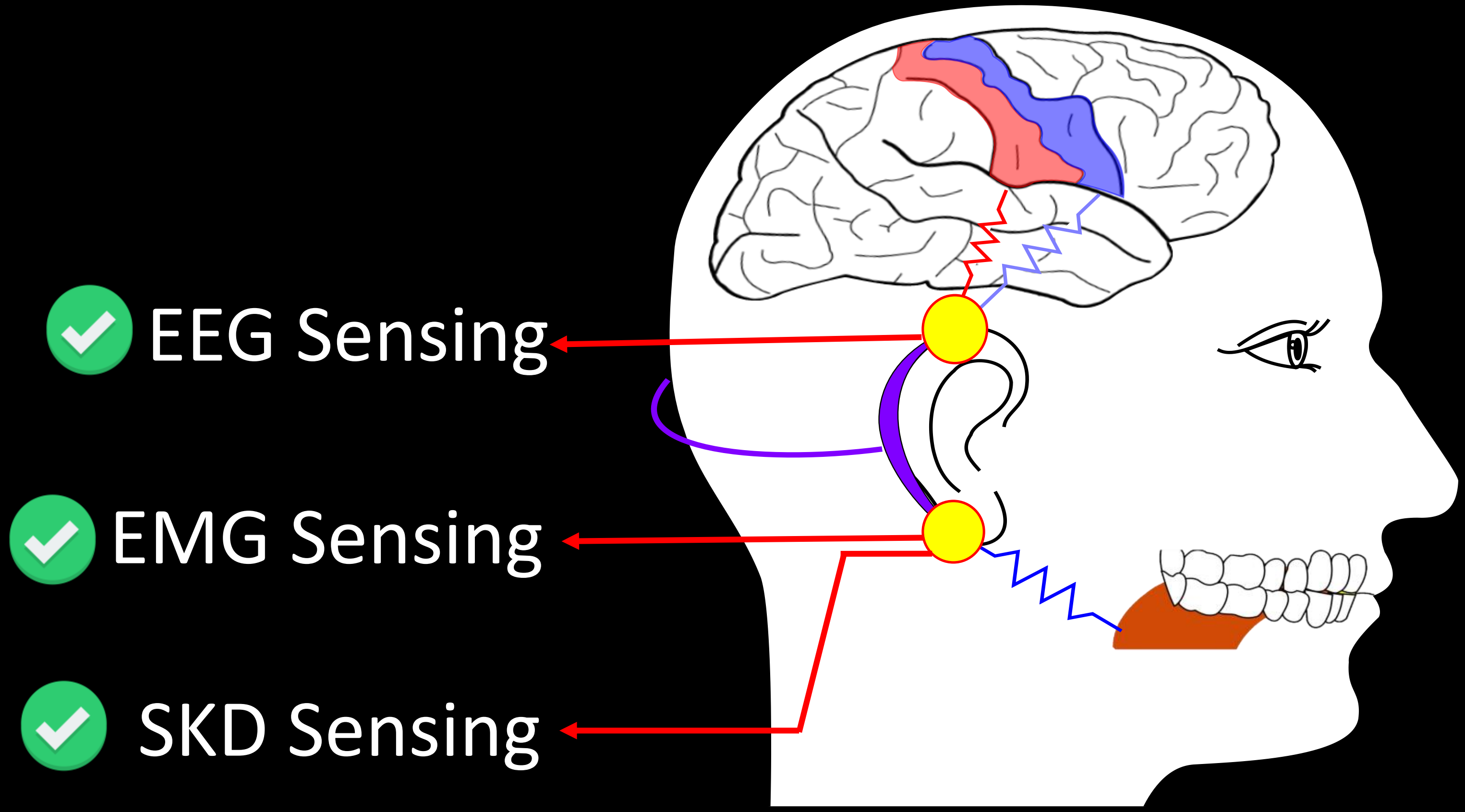


Ease to use TYTH

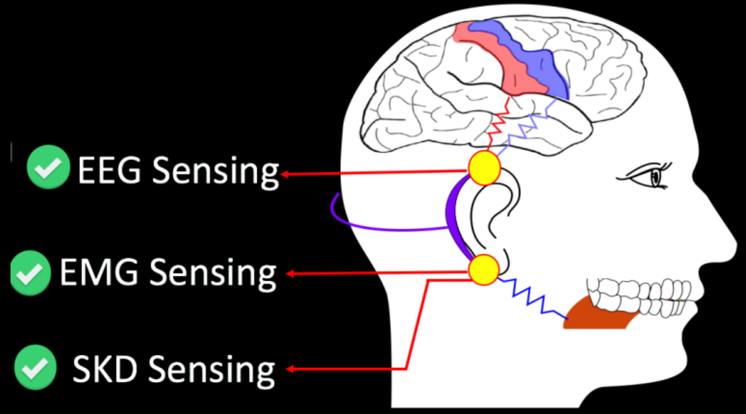
User Study


Typing speed (s)
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
What are the speed of typing on the teeth?

TYTH’s Sensing Techniques



Conclusions



- We introduce TYTH-Typing on Your TeetH,
  - A **Non-invasive**,
  - **Continuous** and **Long-term use**
  - and **Socially Acceptable**

  wearable device for Tongue-Teeth Localization Applications.

- The key contributions include:
  - An analysis of brain, muscle, and skin deformation from behind the ears
  - An algorithm to extract the EEG, EMG signals
  - A novel method to sense a new type of signal, termed SKD signal
  - A ear-mounted wearable prototype
  - An evaluation of the system on 15 subjects

In progress

- Miniaturization
- Remove the impact of talking and body movement artifacts
- Improve the form factor for better contact quality

Danke schön !!!

TYTH-Typing on Your TeetH: Tongue-Teeth Localization for Human-Computer Interface

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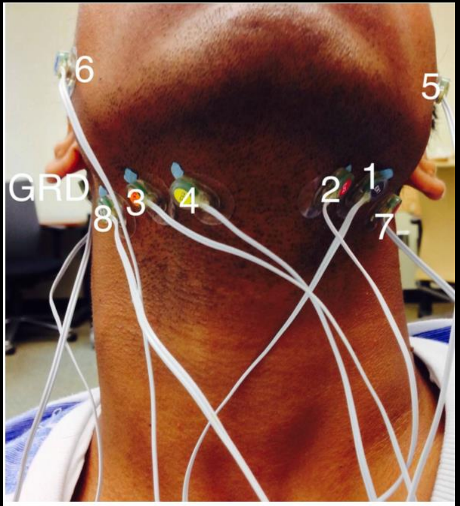
Thank you

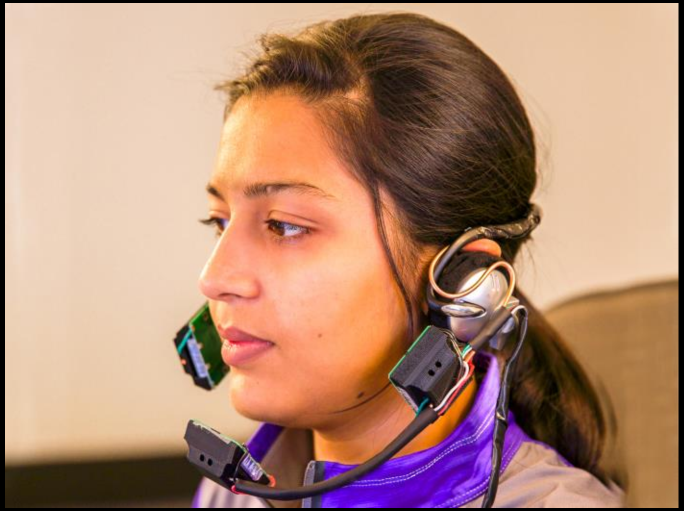
Related Works



TongueSee – CHI’14

TongueWise –EMBC’10

SITA - UIST '12



Tongue-in-Cheek – CHI’15