Cortical encoding of 3D tongue position and shape during feeding: Control principles and clinical implications

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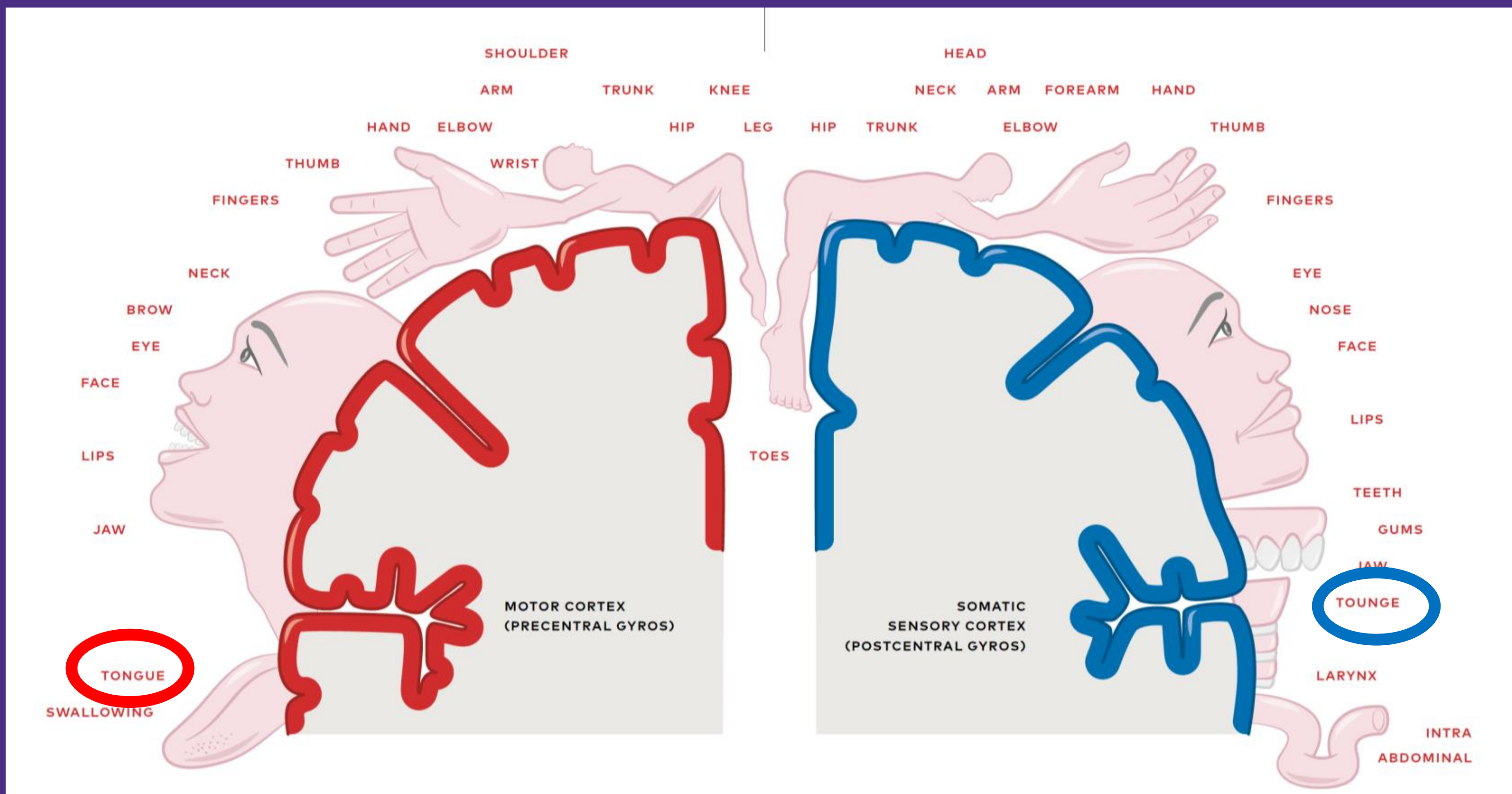
Cortical representation of face and tongue

MOTOR CORTEX　　SOMATOSENSORY CORTEX



Nicholas J., Johannessen A., van Nunen T. (2019)

The tongue plays a critical role in vital and complex oromotor behavior.

- Chewing
- Swallowing
- Breathing
- Speech

Disorders affecting lingual functions have devastating effects on the quality of life.

- Dysphagia
- Masticatory dysfunctions
- Sleep apnea
- Dysarthria
- Tongue cancer

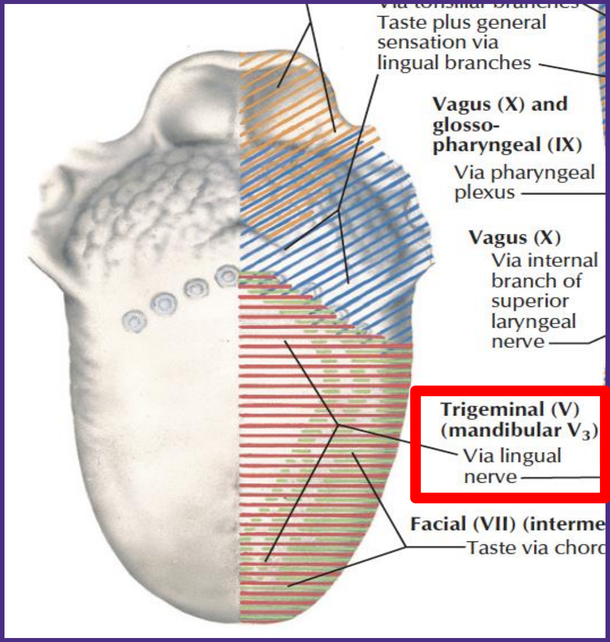
The tongue is one of the most densely innervated parts of the body.

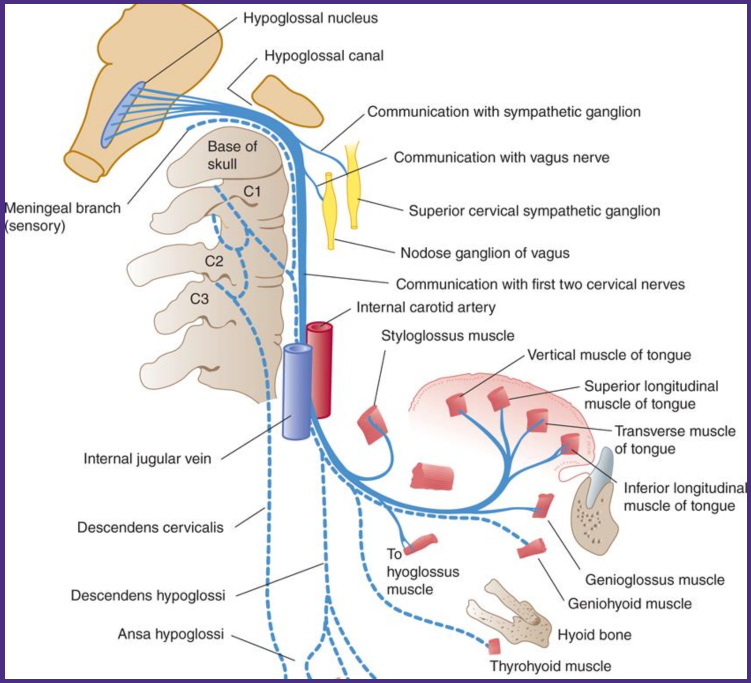
Tactile: Lingual n.

Contact with teeth, palate, food

Proprioception: Hypoglossal n.

Tongue Position and Shape





Illustrations from F. Netter

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Tactile and Proprioception

- to monitor food properties
- to regulate bite force
- to know when to swallow safely
- to perceive where the tongue is relative to teeth, palate

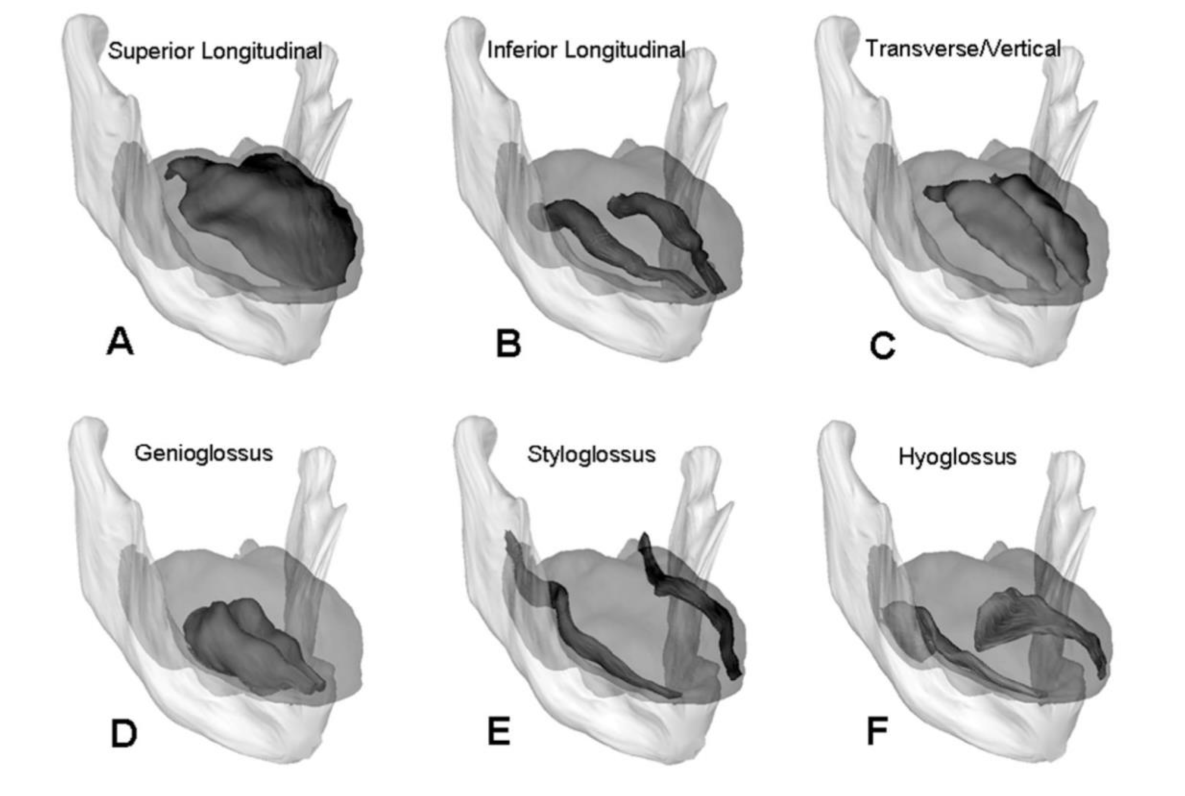
TONGUE MUSCLE GROUPS

Intrinsic Muscles

(Shape)

Extrinsic Muscles

(Position)



Sanders and Mu (2013)

The orofacial sensorimotor cortex is involved in the control of tongue movements.

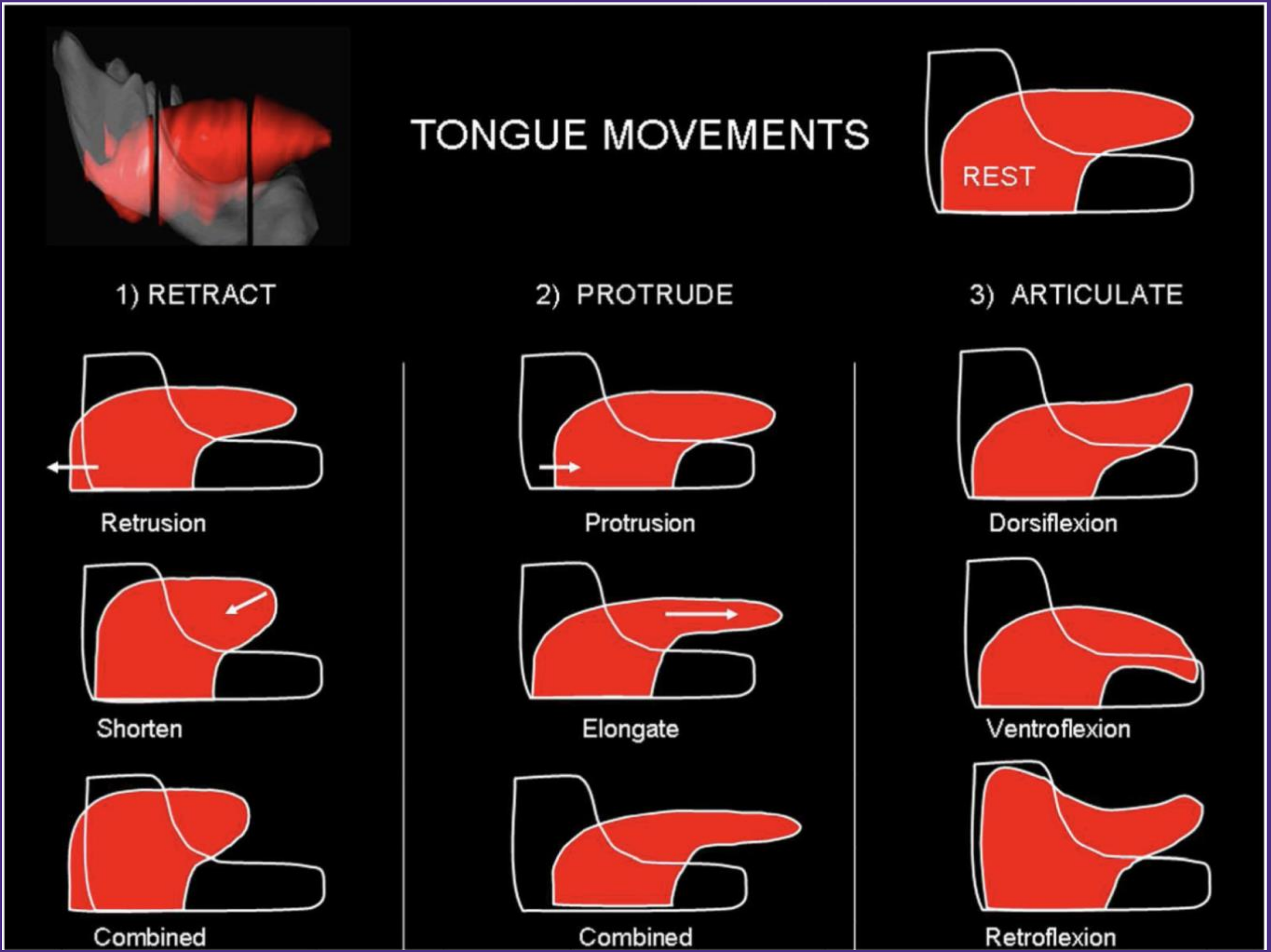
- **Neurons modulate their activity when generating tongue protrusive force and during natural feeding.**
  - Huang et al., 1989; Murray & Sessle, 1992; Lin et al., 1994; Yao et al., 2002; Hatanaka et al., 2005; Svensson et al., 2003, 2006; Arce-McShane et al, 2013, 2014, Liu et al., 2019; Laurence-Chasen et al., 2019, 2020, 2021; Tang et al., 2021

- **Neurons undergo learning-induced plasticity.**
  - Murray et al,Avivi-arber et al., 2010, 2011; Arce-McShane et al., 2016

- **Neurons form coherent networks within and across motor and somatosensory areas in a reciprocal manner.**
  - Arce-McShane et al., 2016; Balasubramanian et al., 2019; Sheridan, Laurence-Chasen & Arce-McShane, 2021

Are 3D tongue position and shape encoded by the orofacial sensorimotor cortex?

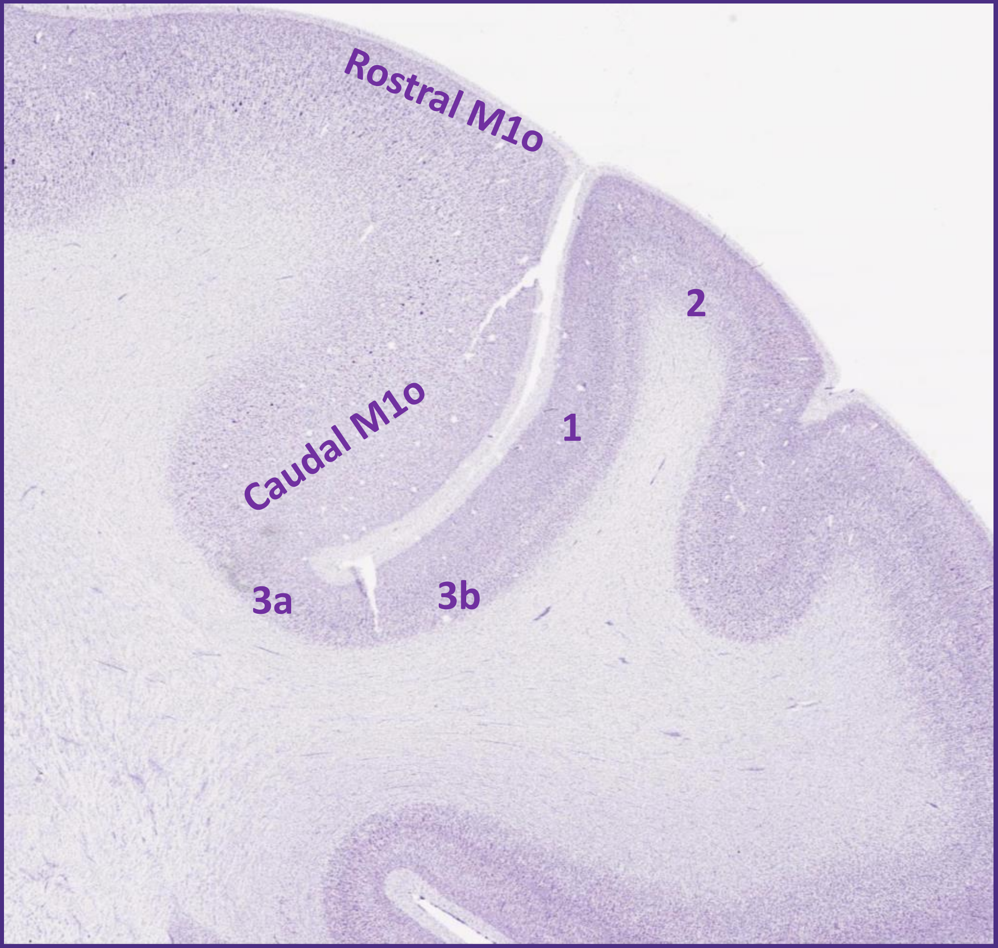
Tongue posture and shape are important features of lingual function.



Sanders and Mu (2013)

Methods

Orofacial sensorimotor cortex



Primary motor cortex (Rostral M1o, Caudal M1o)

Primary somatosensory (area 3a/3b, 1, 2)

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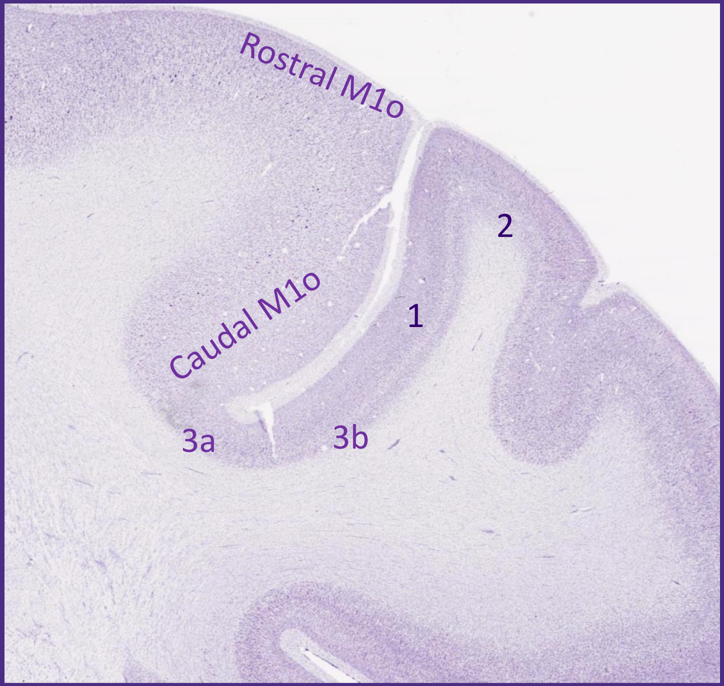
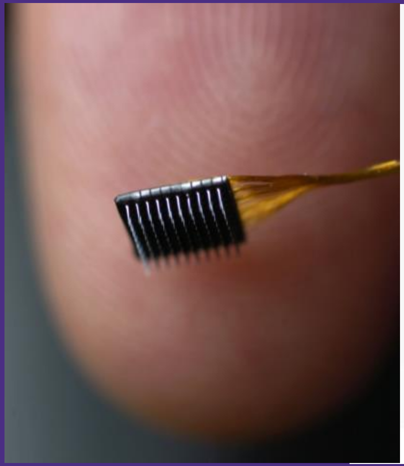
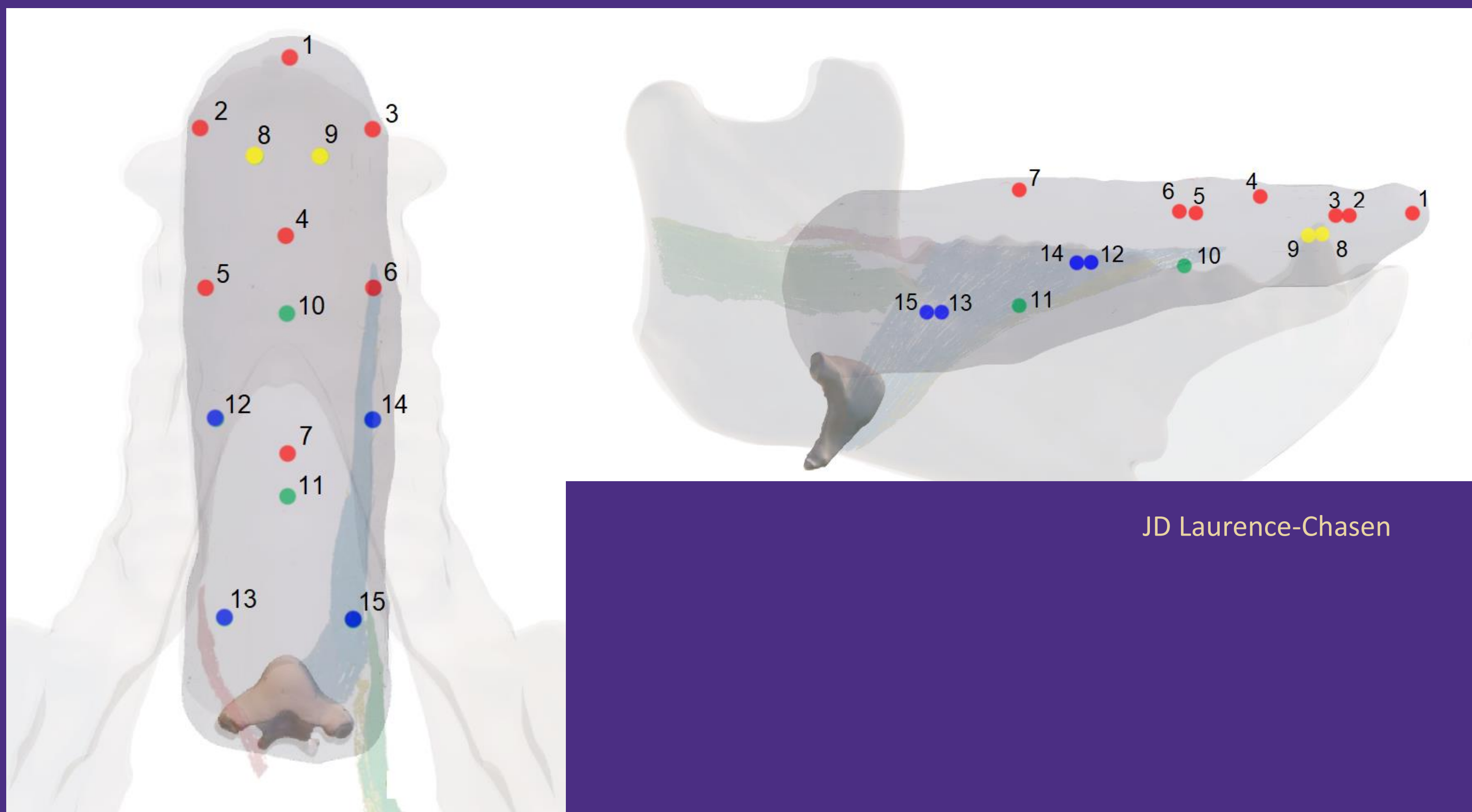
Neural recording from chronically implanted multiple micro-electrode arrays





Superficial and deep lingual markers



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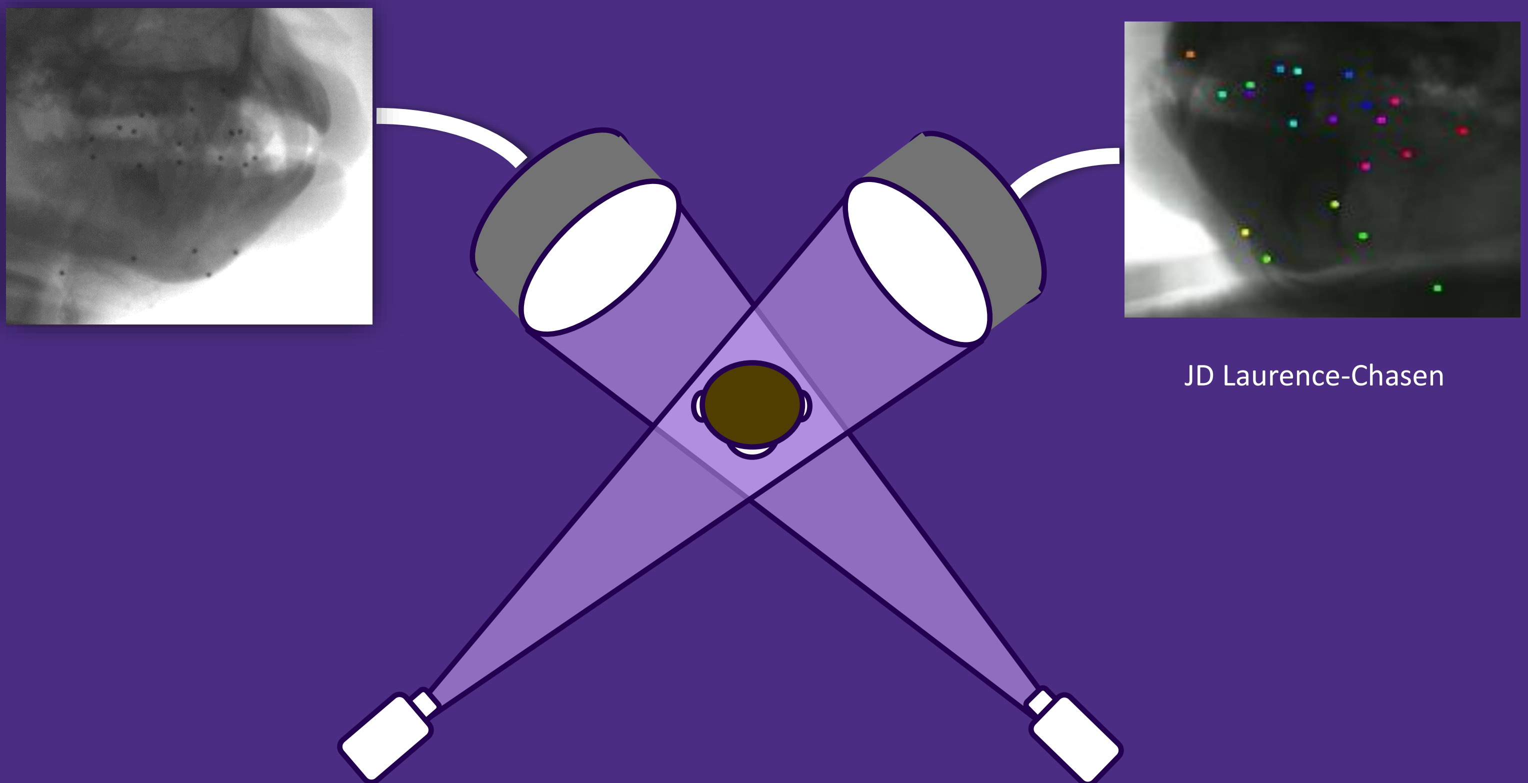
Tracking tongue and jaw movements using hi-resolution biplanar video-radiography



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X-ray Reconstruction of Moving Morphology (XROMM)

Brainerd et al., 2010

Automated tracking of 3D tongue and mandible kinematics

Journal of Experimental Biology

METHODS & TECHNIQUES

Integrating XMALab and DeepLabCut for high-throughput XROMM

J.D. Laurence-Chasen, Armita R. Manafzadeh, Nicholas G. Hatsopoulos, Callum F. Ross, Fritzie I. Arce-McShane

Journal of Experimental Biology 2020 223: jeb226720 doi: 10.1242/jeb.226720 Published 4 September 2020

nature neuroscience

TECHNICAL REPORT

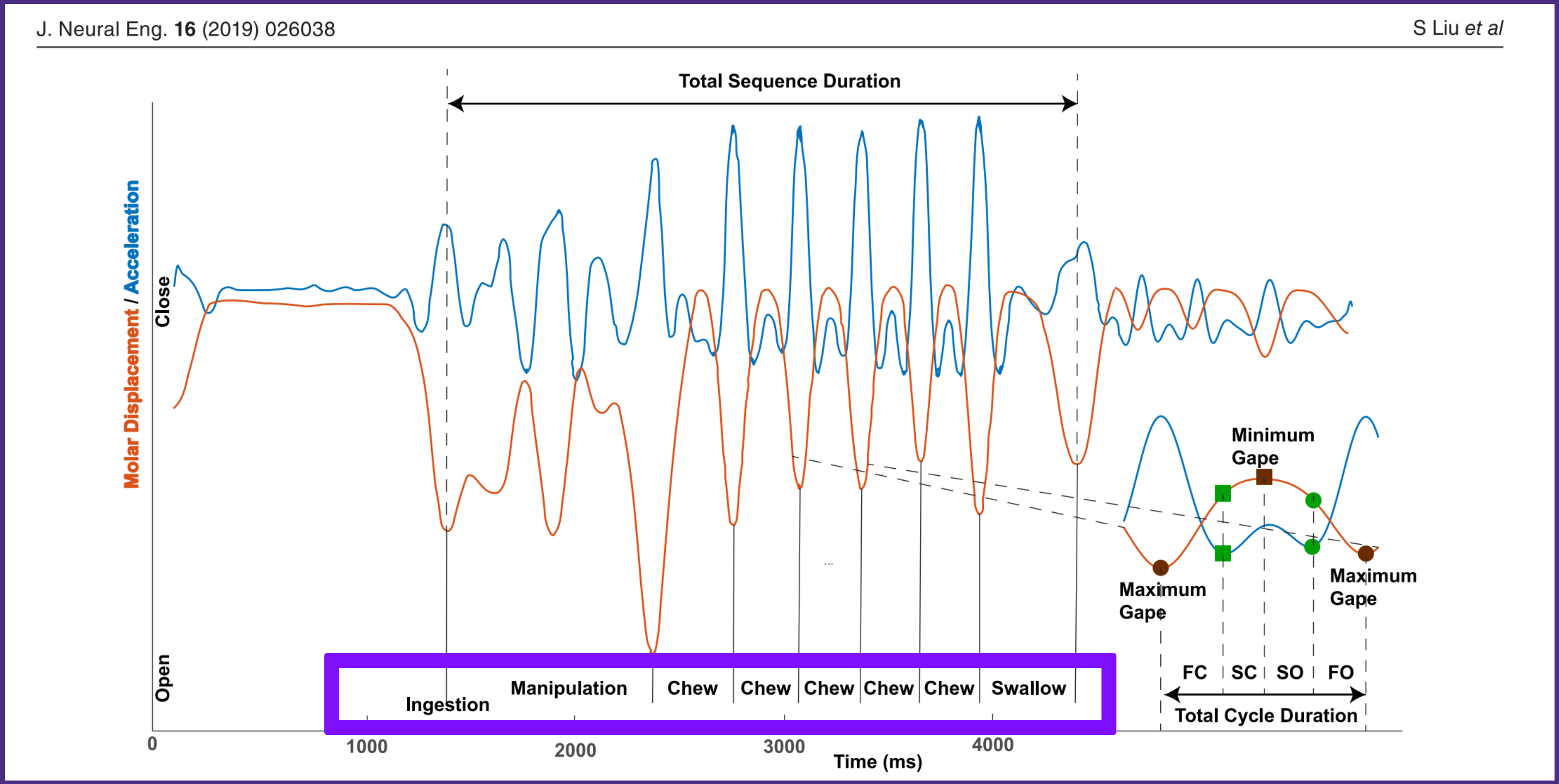
https://doi.org/10.1038/s41593-018-0209-y

DeepLabCut: markerless pose estimation of user-defined body parts with deep learning

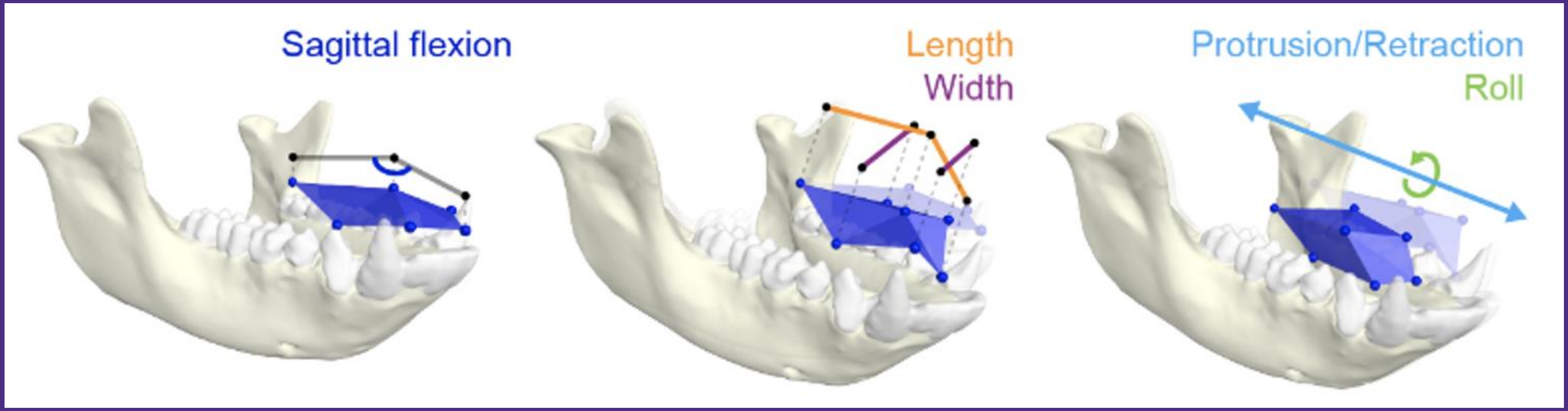
Alexander Mathis[1,2], Pranav Mamidanna[1], Kevin M. Cury[3], Taiga Abe[3], Venkatesh N. Murthy[2], Mackenzie Weygandt Mathis[1,4,8]* and Matthias Bethge[1,5,6,7,8]

Behavioral paradigm: Natural feeding

Feeding sequence



Tongue Kinematic Variables



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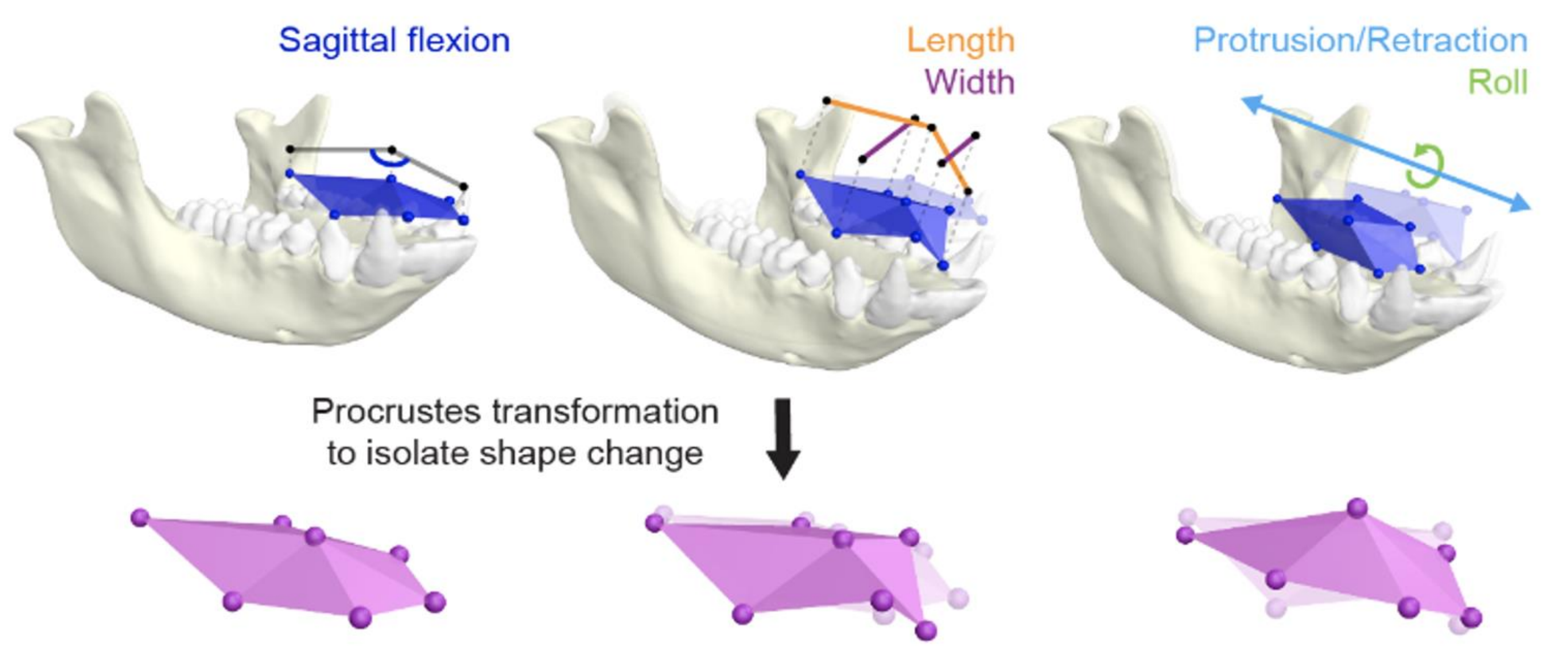
Isolating Tongue Shape

Generalized Procrustes Analysis



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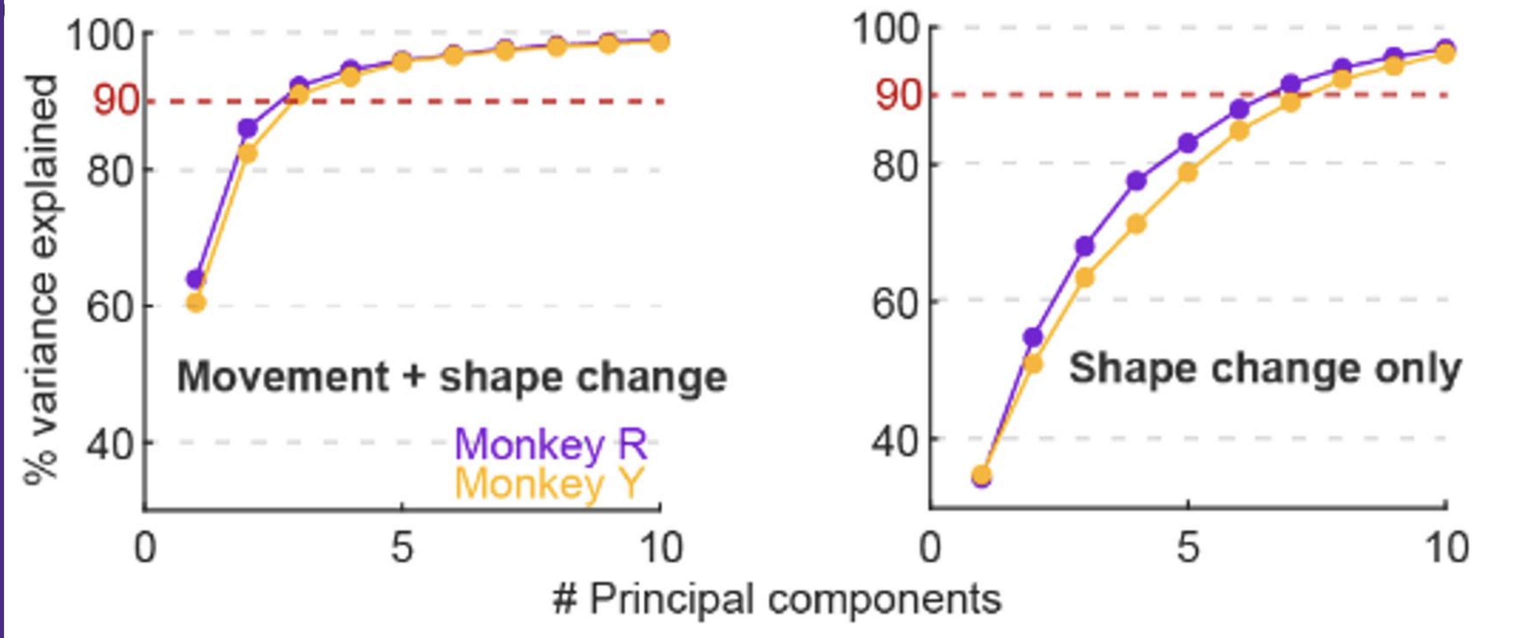
Higher dimensional control signal is required to reproduce tongue shape



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Decoding Analysis

- **Long- short-term memory (LSTM) network**

  Hochreiter & Schmidhuber, 1997; Glaser et al., 2020

  - 7-fold cross-validation strategy to avoid overfitting
    - Test fold: 4 trials
    - Train fold: 24 trials

  - Decoding accuracy measured using fraction of variance accounted for (R^2)

Results

Results

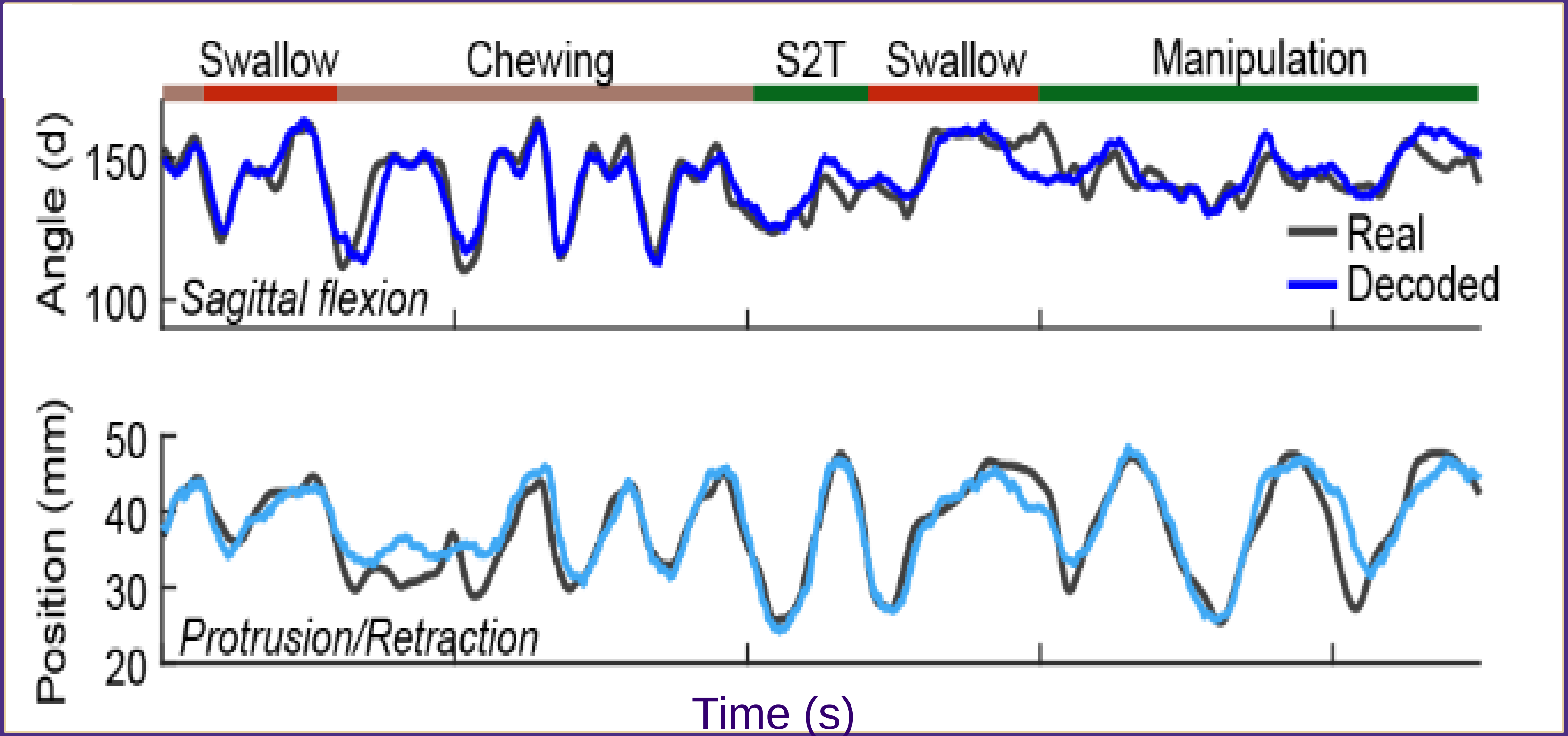
Dr. JD Laurence-Chasen

1. Decoding movement + shape

2. Decoding shape only

3. Decoding performance: M1 vs S1

1. Decoding tongue position and shape from motor cortex (M1)



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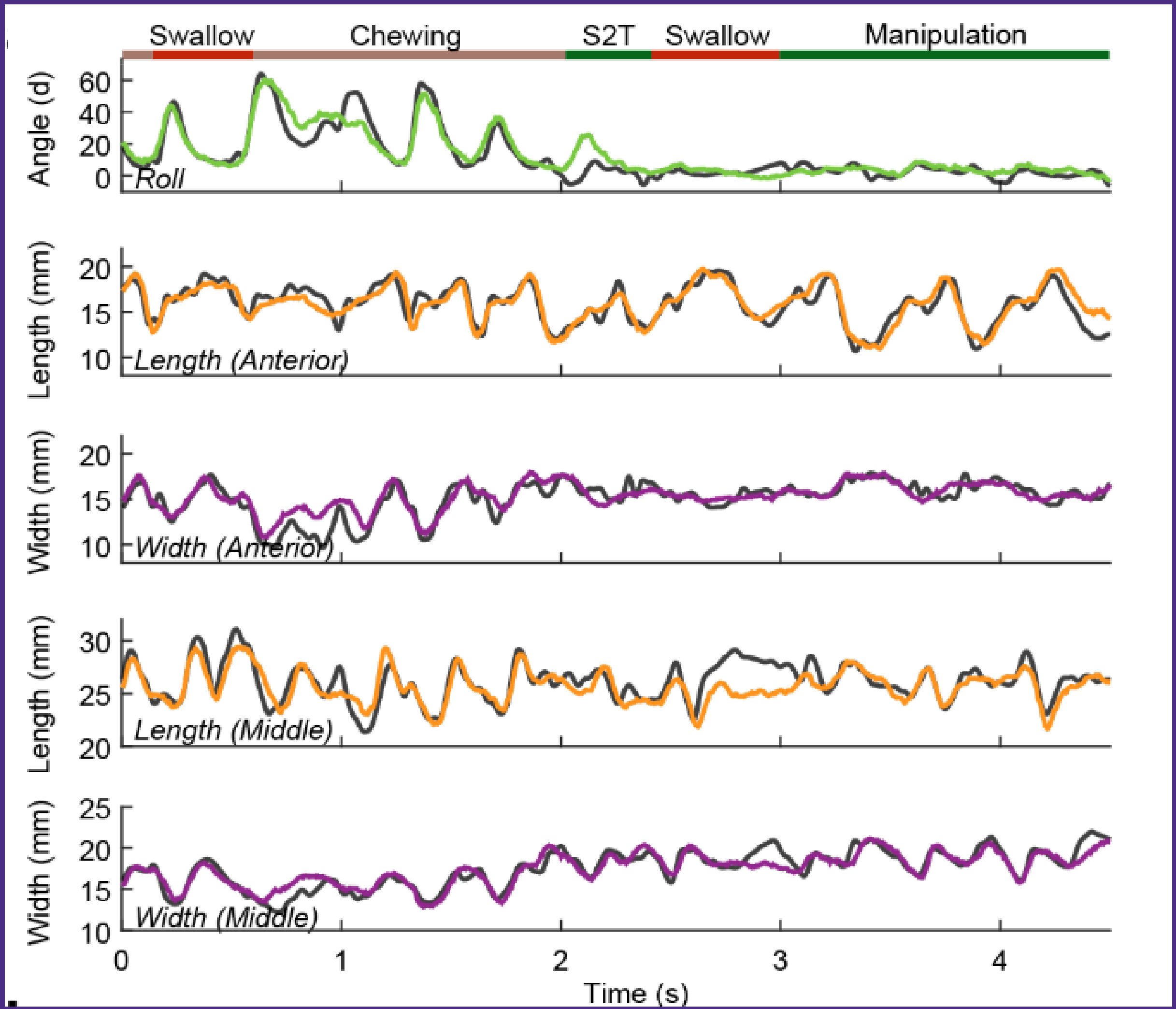

Roll

Anterior Length

Anterior Width

Middle Length

Middle Width

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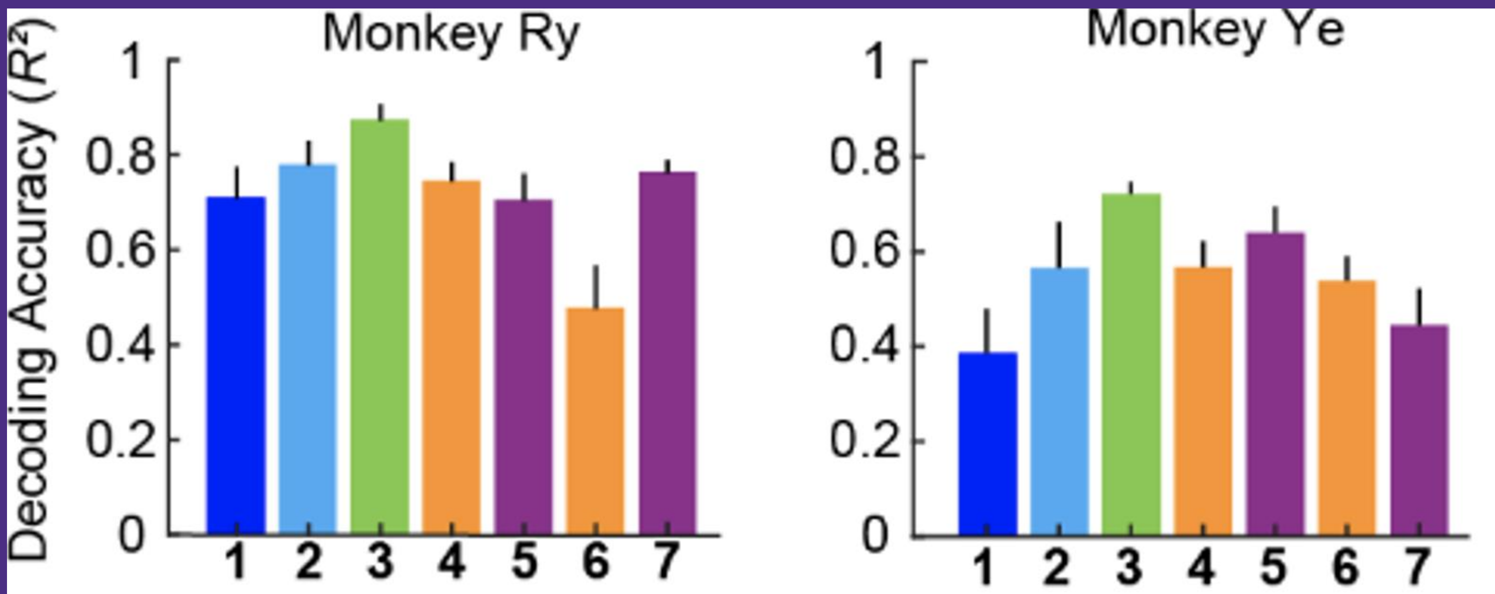
High decoding accuracy by M1 neurons



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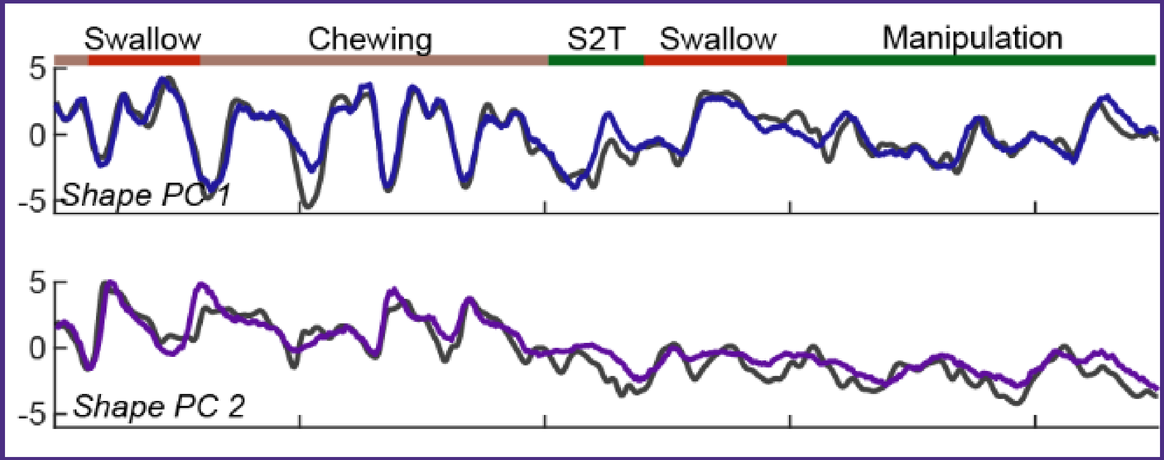
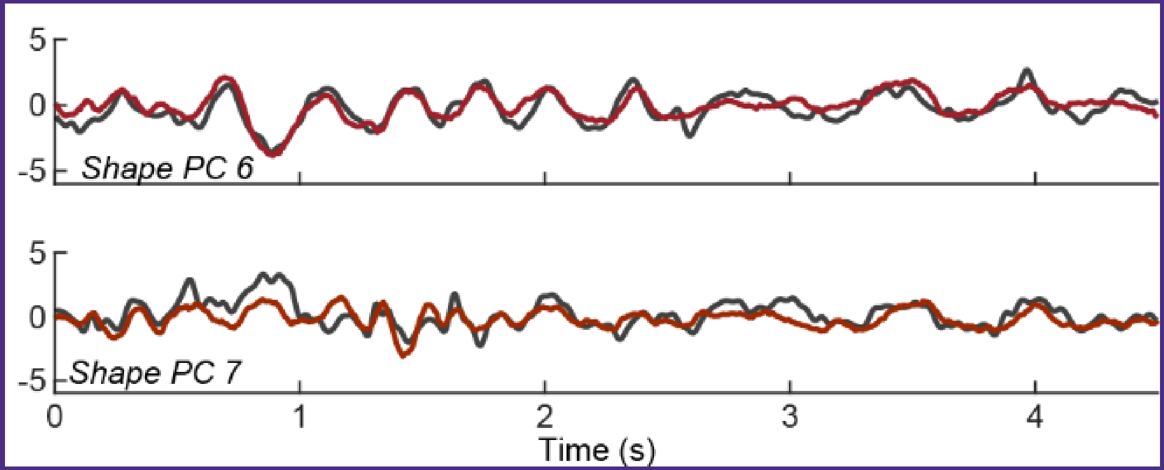
1 Sagittal Flexion
2 Protrusion/Retraction
3 Roll
4 Length (Anterior)
5 Width (Anterior)
6 Length (Middle)
7 Width (Middle)

2. Decoding tongue shape only



Shape PC 1

Shape PC 2



Shape PC 6

Shape PC 7

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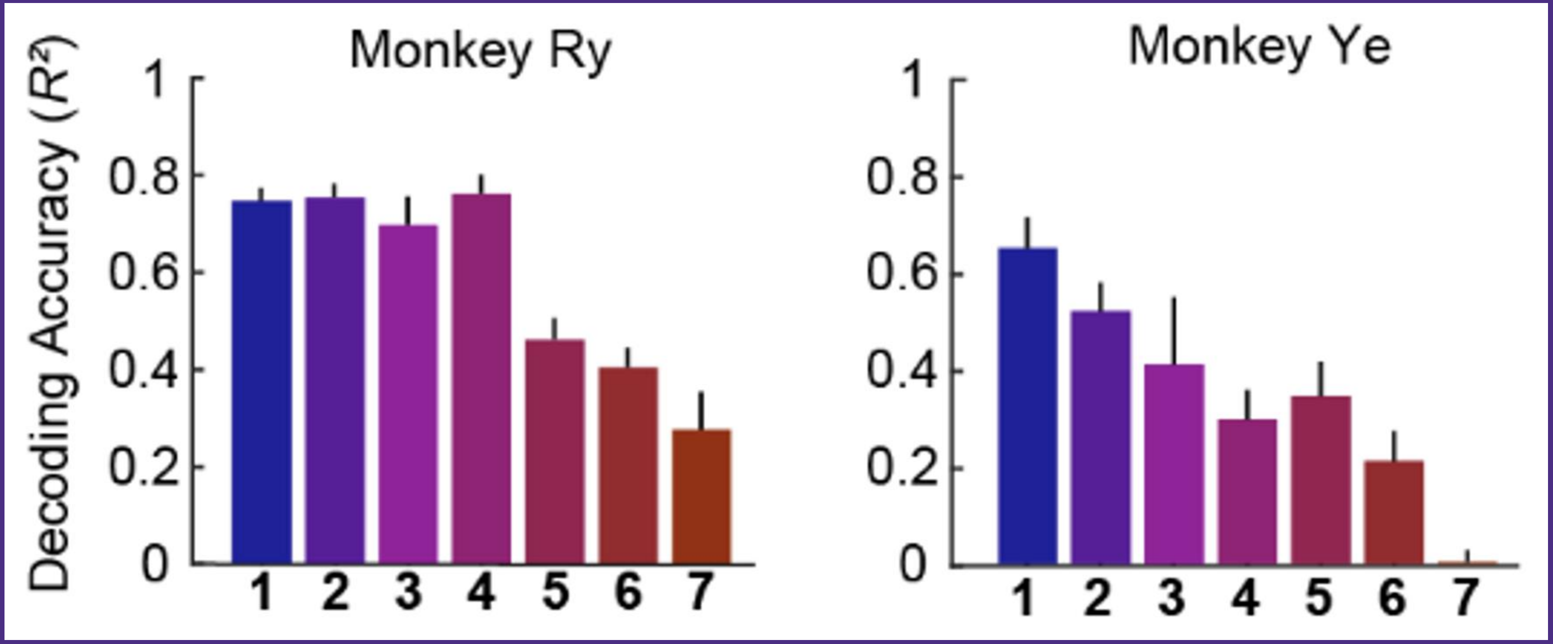
Comparable decoding for tongue shape



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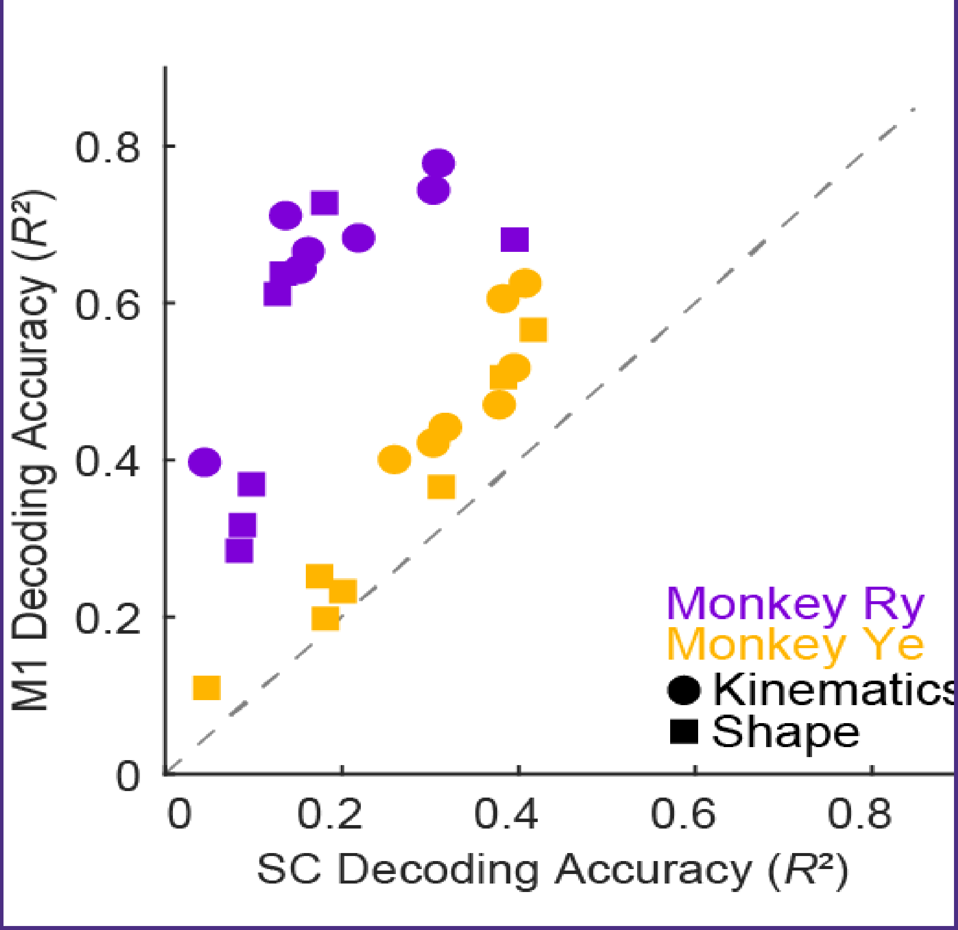
3. Decoding performance: M1 vs S1

Higher decoding accuracy in M1



Summary

Summary and Conclusions

Orofacial sensorimotor cortex is involved in lingual control during feeding.

1. **Both 3D tongue position and shape can be decoded reliably from orofacial sensorimotor cortex.**

2. **Decoding using M1 neurons yielded better performance than S1 neurons.**

Clinical Implications

- Development of evaluation and treatment of orofacial sensorimotor dysfunctions (dysphagia, dysarthria, tremors) and neural prosthesis to restore lingual function
- Groundwork for studies on oral somatosensation, pain mechanisms, and sensorimotor integration
  - treatment of sensory impairments associated with dental implants, trigeminal neuralgia, temporomandibular disorders, orofacial pain

SURF Posters

- **Eli Cosovan, *Encoding of Tongue Direction During Natural Feeding***
- **Kevin Huang, *Tongue Kinematics in Healthy Aging vs. Loss of Sensation***
- **Wolfgang McLelland, *Sensory Loss Affects Functional Connectivity in Orofacial Sensorimotor Cortex***

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