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

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
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)
Neural recording from chronically implanted multiple micro-electrode arrays
Superficial and deep lingual markers
Tracking tongue and jaw movements using high-resolution biplanar video-radiography

X-ray Reconstruction of Moving Morphology (XROMM)
Brainerd et al., 2010

JD Laurence-Chasen
Automated tracking of 3D tongue and mandible kinematics

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

DeepLabCut: markerless pose estimation of user-defined body parts with deep learning
Alexander Mathis, Pranav Mamidanna, Kevin M. Cury, Taiga Abe, Venkatesh N. Murthy, Mackenzie Weygandt Mathis, and Matthias Bethge
Behavioral paradigm: Natural feeding

Feeding sequence

J. Neural Eng. 16 (2019) 026038

S Liu et al

Total Sequence Duration

Ingestion
Manipulation
Chew
Chew
Chew
Chew
Swallow

Total Cycle Duration

Open
Close
Tongue Kinematic Variables

- Sagittal flexion
- Length Width
- Protrusion/Retraction Roll

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Isolating Tongue Shape

Generalized Procrustes Analysis

Procrustes transformation to isolate shape change

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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

1. Decoding movement + shape

2. Decoding shape only

3. Decoding performance: M1 vs S1
1. Decoding tongue position and shape from motor cortex (M1)
Roll
Anterior Length
Anterior Width
Middle Length
Middle Width

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High decoding accuracy by M1 neurons

[Bar charts showing decoding accuracy for different movements in monkeys Ry and Ye.]

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
Comparable decoding for tongue shape
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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