Constriction Degree and Sound Sources
Contrasting Oral Constriction Gestures

• Conditions for gestures to be informationally contrastive from one another?
  • shared across members of the community (parity)
  • not confusable with one another under a variety of speaking conditions.

• Anatomically distinct constricting organs meet criterion
  • lips
  • tongue tip
  • tongue dorsum

• Shared by all members of the community

• Decomposition of body into distinct organs is at least partially innate.

• These contrast in all languages.
Sensorimotor “homunculus”

Homunculus of Primary Somatosensory Cortex in Blue

Note that each hemisphere receives info from the opposite side of the body.
Coding in ventral sensorimotor cortex (vSMC) while speaking

- Electrocorticography (ECoG) application of a mesh of tiny electrodes directly on the surface of the brain of a patient who is being prepared for brain surgery.
- Allows recording from very small populations of neurons.
- Developed at UC San Francisco in Edward Chang’s lab
- Examine multiple sites in vSMC while patient is speaking.
- Test which descriptions of speech best predict patterns of activation in particular electrode locations.

460 read sentences (MOCHA-TIMIT)
5 participants
Pseudo-EMA kinematics
130 electrode sites (across participants)

Example from one site

**Inferred EMA**

“Stimulating discussions ...”

**Weights**

Weight pattern corresponds to coordinated articulator motion that produces and releases a coronal constriction.
Sites code distinct constricting effectors
Examples of Early Mimicry

Meltzoff and Moore, 1977
Sensorimotor Integration of oro-facial system

How are humans able to use sensory information to specify bodily movement?

• Human infants (even neonates) are capable of oro-facial mimicry.

• Facial mimicry is remarkable in that:
  • Infant cannot see its own face.
  • Infant cannot feel the models’ face.
  • Infant may not get the gesture entirely correct, but almost always chooses the right organ
Constriction Degree

- potential continuum

- how is it partitioned into discrete regions that are contrastive across speakers?
Quantal Theory of Speech (Stevens, 1968, 1989)

• map the relation between: dimensions of physical device and sound produced

• relation is non-linear
  • Regions of map where small change in dimensions do not effect sound
  • Regions of map where small change in dimensions cause jump in sound
Experiment with a straw

1. Blow gently into straw, so it makes only soft noise.

2. Start gradually narrowing just behind tip of straw.

3. At some point, sound will suddenly become loud and/or high pitched.

4. Loud sound will remain until straw is tightly pinched.
Results of experiment: map relating opening and sound

- **Stable regions**
  Small change in opening do not effect sound

- **Transition regions**
  Small change in opening shifts from one stable region to another.
Stevens' Quantal Theory

- Stable and transition regions generally characterize relations between dimensions of sound producing devices and the sounds they produce.

- This is true of the human vocal tract.

- The nonlinear nature of this map partitions a potential gestural continuum into distinct stable regions.

- Languages employ contrastive gestures that are produced in distinct stable regions of the map relating articulation and sound. Why?
Example: Constriction Degree
Interaction of Constriction Degree and Voicing

- New Experiment:
  1. Produce [v]
  2. Widen constriction until turbulence disappears.
  3. Now stop voicing
  4. Turbulence is back, why?
Turbulence

• Turbulent flow of a liquid (or gas) involves generation of random (or chaotic) patterns of molecular vibration.

• Depends on:
  • Channel size
    Narrower channels more readily cause turbulence.
  • Volume velocity (cm$^3$/sec) of airflow
    Higher airflow rates more readily cause turbulence.
- Dimensionless quantity that takes both channel size and volume velocity into account.

- A given channel area (CD, constriction degree) will have different Reynold's number (Re), depending on the volume velocity of the flow.

- Turbulent flow will result at a particular Re threshold (for speech conditions, Re=1700), and the intensity of the generated turbulence will increase linearly as Reynolds number increases above threshold.

From: Catford, 1977
Voicing reduces volume velocity

- Glottis is closed roughly half the time.

<table>
<thead>
<tr>
<th>CD</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD&lt;20 mm²</td>
<td>Re &gt; 1700</td>
</tr>
</tbody>
</table>
| 20<CD<100 mm² | Re > 1700 for voiceless flow  
              | Re < 1700 for voiced flow rates |
| CD>100 mm² | Re<1700   |
Instability of Voiced Fricatives

- Voiced fricatives are statistically rare in the languages of the world

- Aerodynamic requirements of turbulence and voicing are at cross purposes.

- What happens to them?

  - **devoicing** to preserve turbulence, voicing may be lost

  - **loss of turbulence** to preserve voicing, constriction degree may increase
Classification of CD
Catford

- stop: no flow
- fricative: turbulent flow
- approximant: turbulent flow if voiceless
- resonant: laminar flow
Lateral Fricatives

• Zulu
Trills

- aerodynamic phenomenon
- depends on:
  - airflow
  - constriction degree
  - articulator tension
- Constrictors that can trill:
  - lips labial
  - tongue tip coronal
  - soft palate uvular
- MRI examples (frame rate is not quite fast enough)
- gargling
Dutch

[Rot] ‘red’
Constriction Degree of trills

• intermediate between stop and fricative
• Articulators touch, but are not compressed
• Stability of trills
Summary of Constriction Degrees

Catford, 1977