Speaking tongues are always braced

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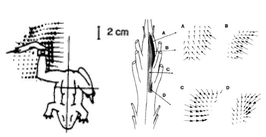
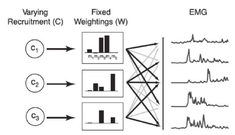
Interdisciplinary Speech Research Laboratory

Introduction: Neuromuscular modules in speech

- Bodies have too many degrees of dreedom (DOF) to cognitively control (Bernstein 1967)
  - Need to reduce DOFs = central problem in motor control
- Neurophysiology reveals fixed neuromuscular modules (functional groupings of muscles) reduce DOF



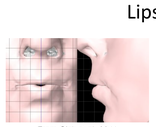
Bizzi et al's. (1991) "spinalized frogs"



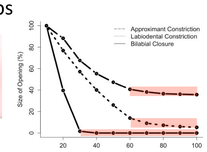
Safavynia & Ting's (2012) "spatially fixed muscle synergies" (SFMSs)

- Gick et al. (2011, in press) describe sphincter-like "devices" in speech having these properties

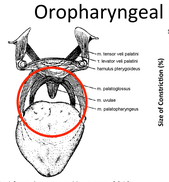
Lips



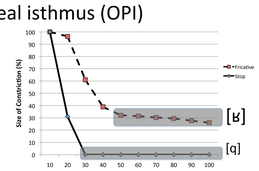
From Gick et al. 2011



Oropharyngeal isthmus (OPI)

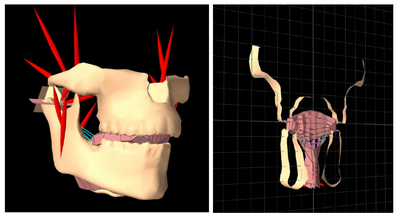


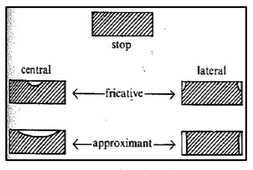
Adapted from Анатомия Человека 2010



- What about the tongue?
  - Supposed to be "free", like a trunk or tentacle (Kier & Smith 1985, Smith & Kier 1989)

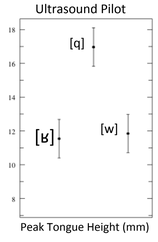
Bracing: Tongue as mechanical hemisphincter?





From Catford (1977)

- Gick et al. (in press)
  - OPI constrictions: tongue appears fixed for /w/ & /R/, ballistic for /q/? ➔



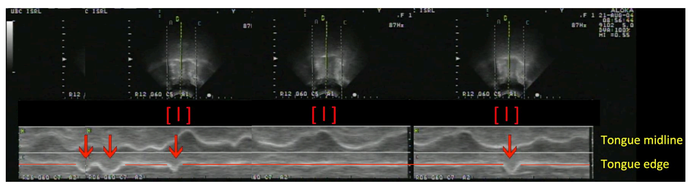
- Honikman (1964): Tongue "tethered" or "anchored"
- Stone, M. (1990): "assumption that consonants are braced tongue behaviors, and vowels are unbraced (2208)."
  - Mechanics?: facilitate "rotation of the tongue about a lateral point" (2215)
- Lateral closure creates the aeroacoustic "tube" for speech – always "braced" when we need this!
  - Honda et al. (2010) and citations (Honda 2004, Stevens, etc.): "side cavities" (observed w/MRI) created by tongue bracing
- Many previous studies have looked at bracing, but none during running speech
  - Narayanan et al. (1997) found more variation in bracing for in-context vs. sustained speech sounds
- McLeod, Roberts, and Sita (2006): conjecture that adults may brace against "the teeth rather than the palate during consonant production" (384)

Hypothesis: Tongues are *always* braced *somewhere* for biomechanics (reduces DOF)

Methods & Results: EPG/ultrasound study

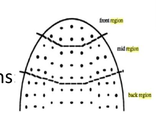
We used M-mode ultrasound imaging to pilot this study…

- Found *constant* lateral contact during running speech *except during /l/*



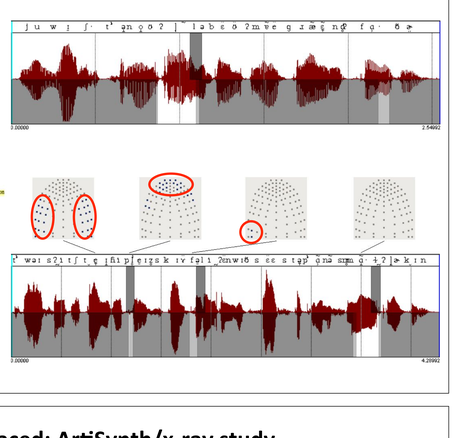
Mary had a little lamb, its fleece was white as snow. Everywhere that… Mary went, the lamb was sure to go.

- A follow-up EPG study revealed more detail…
- Kay EPG database study:
  - electrodes on molars!
  - 1 male, 1 female speaker
  - Several long spoken passages
  - Used Zsiga's (1995) EPG regions



- Results:

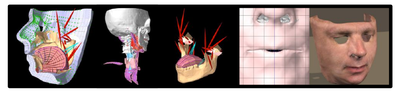
All sounds braced at all times, except:
Bilateral bracing lost:
- [l]: 24.5% (n=110)
- [a]: 40.5% (n=20-30)
  - less in diphthongs ([aʊ]:10%; [aɪ]: 4.5%)
- [ʌ]: 2.8% (n=36)



What happens when not braced: ArtiSynth/x-ray study (pharyngeal/palatopharyngeal bracing)

1) All instances of onset /l/ were braced anteriorly throughout (see EPG figure above)!

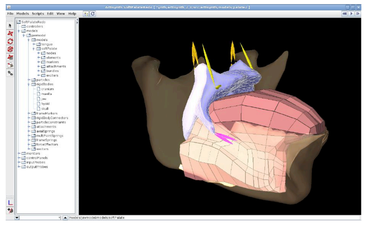
2) For ~25% of dark /l/ & low vowels, bracing appeared to "slide" behind rearmost electrodes
   ? Is bracing lost, or just too far back to measure?
   Hard to image off-midline structures…

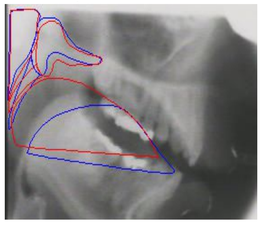


- Simulations used models in the ArtiSynth simulation toolkit (www.artisynth.org)
  - e.g., Fels, Gick, Jaeger, Vogt & Wilson (2003), etc.
  - 3D finite-element method (FEM) model with realistic collision detection & tissue compression
  - Used jaw-tongue-hyoid model described by, e.g., Stavness et al. (2011, 2012)
  - coupled with palate model as described in Gick et al. (in press)

Results: Tongue retracts to brace against maxilla, lateral pharyngeal walls, & palatopharyngeal arch

- Visible in x-rays of retracted variant of French uvular fricative (described in Gick et al. 2013)





Discussion

- Our results show that the tongue is effectively braced *at all times* during running speech in English
- Bracing is almost always against the rear molars, except:
  - Consistently lost for onset /l/, where anterior bracing is maintained
  - Occasionally lost for dark /l/ & low vowels, where posterior bracing is maintained against maxilla & lateral pharyngeal walls/arch
  - Also: Each speaker consistently favors one side (L or R)
- Q: Why "bracing" and not just "contact"
  - consistent/predictable
  - constrains DOF!!
  - usually necessary for aeroacoustics (the "tube")
  - otherwise hard to explain consistent behavior of onset /l/

CONCLUSION:
Tongues are always braced
- at least for English
- also against tongue floor, mandible, lower teeth, etc.

Implication:
- Tongues are mechanically very different from existing models
- Use surrounding skeletal structure like a flexible "exoskeleton"
- Not like trunks, tentacles, etc.; more like lips

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