Why a lowered larynx is good for human speech production

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Speech

• Concentrate on physical aspects
  – speech as physical behaviour

• Speech organs and vocal tract have an evolutionary history
  – can look at physical traces in the fossil record
  – can look at comparative data from other primates etc.
This talk

• Focus on lowered larynx
  – found in humans but not (to same extent) in other primates

• Take issue with recent views on motivation for larynx lowering
  – size exaggeration hypothesis (Fitch)
  – point vowels (Lieberman)

• summarise range of possible benefits of low larynx
  – refine some old ideas
  – propose some new ones
Lowered larynx

Negus (1949: 196)
Lowered larynx

Fitch (2000: 209)
Lowered larynx

• Not *uniquely* human
  – Lowered for vocalisation in other animals
    • disengages from nasal cavity
    • louder vocalisations
    • not clear if all primates do (e.g. Owren et al. 1997)

• But humans have *permanent* lowering
  – have to raise larynx to swallow
  – we have a *pharynx*
What does this get us?

  • larynx lowering increases vocal tract length
    – reduces frequency of resonances
    – makes animal sound bigger
      • Size exaggeration hypothesis

• Larynx lowers from birth
• In human males, additional larynx lowering at puberty
  – males have disproportionately large pharynxes
  – supports size exaggeration hypothesis
    • sexual dimorphism

• No doubt longer VT means lower resonances
Increase vocal tract length

Data from Fitch & Giedd (1999).
Increase vocal tract length

Data from Fitch & Giedd (1999).
Lowered larynx

• Fitch (2000: 39)
  – “the initial impetus for the descent of the larynx in early hominids may have had nothing to do with speech, but instead functioned to exaggerate body size.”
  
  – permanent lowering – easier for vocalisation
  – pharynx enabled larger range of vowel sounds
However...

• Fitch often *confuses* mechanism of selection (bigger animal survives to reproduce more successfully) with *motivation* to lower larynx

• Too teleological:
  – implication that animals know what effect their actions will have
  – same goes for saying *louder* voices

• Don’t wish to assume lack of understanding of cause and effect but *simpler* not to assume this…
Respiratory function

Speech requires **airflow**

Usually pulmonic egressive outward from lungs

Lungs inflated and compressed

- elastic return forces
  - external intercostals
  - diaphragm
  - internal intercostals
  - abdominal muscles
Vocal fold vibration

- Subglottal pressure forces vocal folds apart
  - to maintain voicing 3 cm H2O
  - to initiate voicing 8 cm H2O
    - mechanical coupling
    - upper and lower portions

- closure phase
  - elastic return forces within folds
  - Bernoulli effect

- Cycle starts again
Vocal fold vibration

- Vocal folds in larynx
  - require *trans-glottal pressure drop* to vibrate
  - subglottal pressure *higher* than supraglottal pressure
    - 3 cm H$_2$O to *maintain* voicing
    - may need 8 cm H$_2$O to *initiate* voicing
      (figures variable)
  - so to achieve this we compress the lungs
Respiratory function

- trachea – c. 16 cm long (males)
- as long as vocal tract
- dead space...
Lower larynx – shorter trachea

• More direct reason to lower larynx
  – shortens *trachea* by 3-4 cm
  – *reduce* lung compression needed to achieve phonation pressure
    • cf. giraffes don’t vocalise

• result:
  – easier phonation but also…
    • louder calls
    • longer vocal tract > lower resonances
      – size exaggeration > selection
Other evidence

Negus (1949)
Other evidence

• Small glottis relative to trachea
  – vocal folds provide resistance to airflow
  – increases airflow volume velocity (Catford 1977)
    • increases Bernoulli effect
      – reduces pressure between vocal folds
      – promotes closure & continued vibration
        » (also vocal fold shape?)

• Respiratory factors crucial
Furthermore...

Owren et al. (1997)
Snout shortening

• Humans have a short snout
  – mandible *reduced* in length
  – dentition – *smaller* teeth
  – but vocal tract is about *same length* in adult *male humans* and
    *adult female baboons*

• Baboon grunts (Owren et al. 1997)
  – female baboon (VT length c. 16.3 cm)
    • F1: 448 Hz, F2: 1430 Hz, F3: 2677 Hz
  – adult male human (based on 16.1 cm in Fitch & Giedd 1999)
    • F1: 543 Hz, F2: 1628 Hz, F3: 2714 Hz
Snout shortening

• How does this fit in with size exaggeration hypothesis?
  – If VT length so important, why shorten snout?

• Also suggests larynx did not fall, it was pushed (Negus 1949)

• Possibly…
  – snout shortening (use of fire?) acted with tracheal shortening
  – tongue length maintained for mastication or vocalisation
    • speech already crucial?
Summary

• Larynx lowering not to make vocal tract longer
  – it isn’t (cf. female baboons)

• make trachea shorter
  – improve respiratory function
  – small glottis also suggests role for respiratory function

• results in louder speech and lower resonances
  – sexual dimorphism in males (also F0)
The role of the pharynx

• Pharynx supposedly gets us more vowels
  – lowered larynx crucial for point/Quantal vowels i, a, u
    • point vowels crucial for speech (e.g. Lieberman & Crelin 1971)

• Not so...
  1) some languages have 2 vowel or vertical vowel system
    • Kabardian, Marshallese
  2) some languages lack a point vowel (usually u – 84.5% UPSID)
    • Navaho, English
  3) u requires lips as well as tongue
    • more complex than just based on larynx position
      – low larynx could also be used for [u] production
Low vowels – the low down

• Confusion reigns about which low vowel
• Boë et al. (2007) in single paragraph (albeit including quotations):
  – [a], [æ], [ɑ]

• These are not the same vowels
• UPSID frequencies are important too:
  • [a] – 5.7%
  • [æ] – 13.6%
  • [ɑ] – 7.9%

  – Best candidate for low point vowel is [e] – 90.5% (cf. 90.9% [i])
  • central vowel – needs no constriction!
  • only [ɑ] might need pharynx (7.9%)
Vowels and the pharynx

• Granat et al. (2007)
  – bend in vocal tract unimportant
• Not so important acoustically
  – sound goes round corners
    but cf. Sondhi (1986)
• But what about *mechanically*?

• Don’t know much about human tongue
  – know even less about primates (especially extrinsic musculature)
The bent vocal tract
Vowels and the pharynx

• Lowered larynx gives the tongue a *pivot point*
  
  – rock *forward* for [i]
    • does exert pull on larynx via hyoid (in some subjects)
  – rock *backwards* for [ɑ] and other back vowels
    • gravity assisted
  – heave up and back for [u]
    • plus control of lips – is this more effort/variable?

• But arguably what we really need to know about are consonants
  – vowels are *relics* of prehuman vocalisation
The pharynx

• Useful for whole range of lingual consonants
  – tongue
    • muscular hydrostat
      (Kier & Smith 1985, Baker 2008)
    • bag filled with water (blood)
    • incompressible volume

• lingual volume must be accommodated somewhere
  – maybe it shifts into the pharynx
    • cf. acquisition of English /r/ by age 3 or so
Conclusions

• Larynx lowering has its origins in respiratory control
  – as widely seen in vocalisation

• Lower larynx and shorten trachea
  – shorten by as much as 4 cm
  – ‘delete’ dead space
  – makes lung compression more efficient
    • habitual lowering

  – other evidence for role of respiratory factors
    • glottal opening
Conclusions

• humans keep larynx low
  – importance of continuous vocalisation (Fitch 2000)
• may have been pushed back by snout shortening
  – not motivated by size exaggeration!
  – female baboons have same size vocal tracts as human males
  – if size matters, why not keep the snout?
  – teleology…
Conclusions

• vowel evidence shaky
  – point vowels not crucial
    • typological patterns
    • phonetic details of articulation
      – acoustic studies suggest pharynx not needed
        (Boë et al. 2002, 2007)

• pharynx may play a role though
  – indirectly: bent tongue *facilitates* the production of vowels
    • not making possible, but *easier/more efficient*
  – production of lingual consonants
    • accommodate displacements in lingual volume
Final word(s)

• Human speech production unique
  – harnessed existing structures
    • but changed them in the course of evolution…

• More data
  – on humans & other primates

• Gradual process
  – 2 million years (homo ergaster/erectus)
    • male-female cooperation?

• Wider view of speech production needed
  – look beyond vowel contrasts, consider mechanics