High spatio-temporal resolution multi-slice real-time MRI of speech using golden angle spirals with constrained reconstruction, parallel imaging, and a novel upper airway coil

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Declaration of Financial Interests or Relationships

Speaker Name: Sajan Goud Lingala

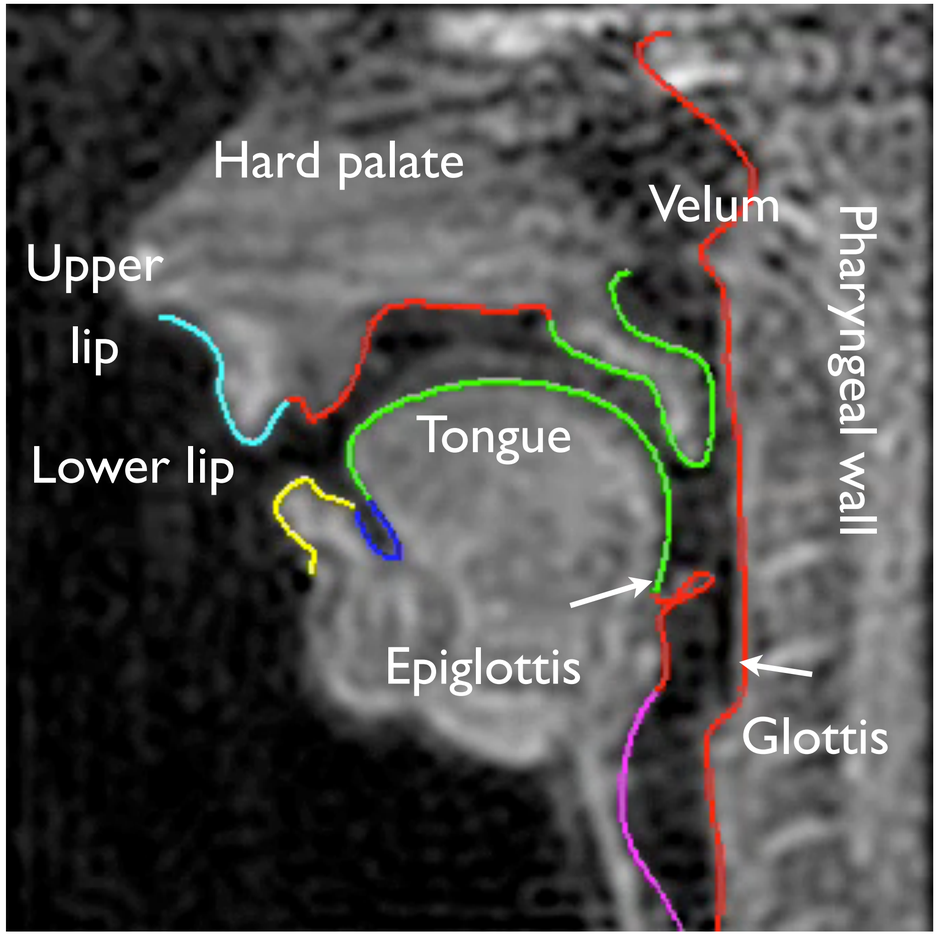
I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.

Real time (RT) imaging of speech

- Speech production
  - Complex coordination of several articulators
- RT imaging: several applications
- Speech science
  - Insights into language production
  - Emotional speech / Phonetics of singing
  - Modeling speech
  - ..
- Clinical practice
  - Movement disorders
  - Cleft palate
  - Apraxia
  - Tongue Cancer treatment, ..

Spiral RT-MRI

native time res. = 78 ms



E.Bresch et al, 2008 S.Narayanan et al, 2004

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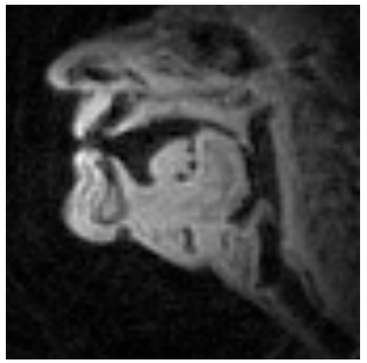
Post-Glossectomy



Spiral RT-MRI

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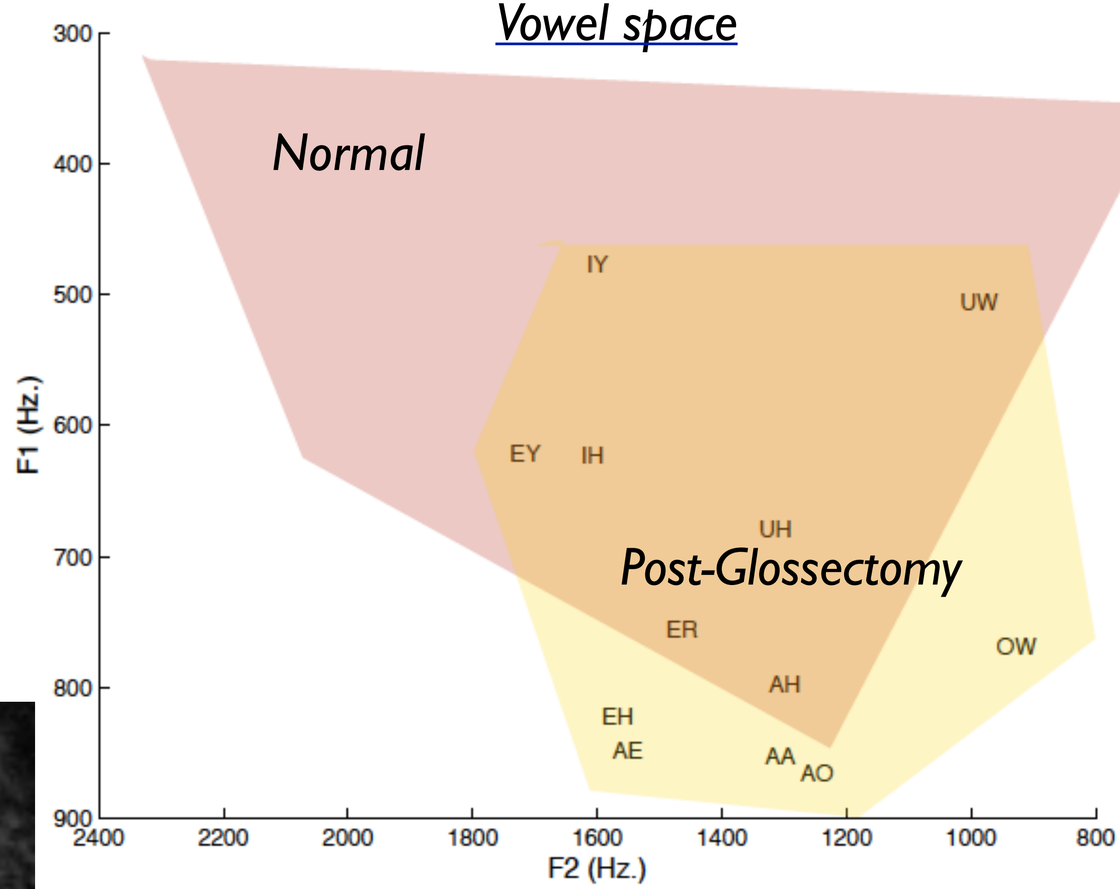
Vowel space



C.Hagedorn, 2014

MRI v/s other modalities

- Electromagnetic Articulography (EMA)
  - High temporal res.

    - (upto 1 ms/frame)

- RT-MRI
  - Non-invasive
  - Soft tissue contrast
  - Image deep structures
  - Arbitrary image planes

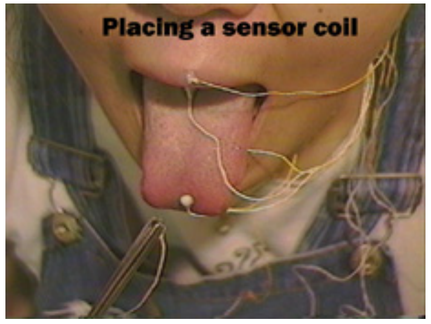
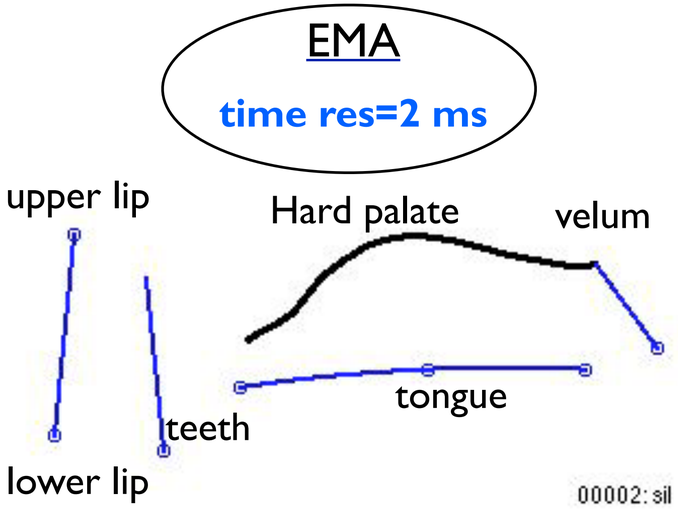
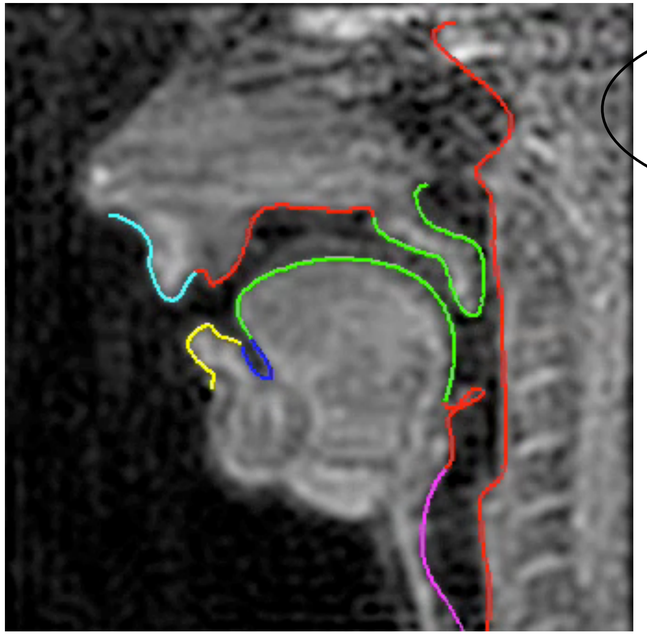


Image Courtesy: UCLA Phonetics Lab



A.Toutios et al, 11 A.Wrench et al, 00



Spiral RT-MRI

native time res. = 78 ms

E.Bresch et al, 08 S.Narayanan et al, 04

MRI v/s other modalities

- Electromagnetic Articulography (EMA)
  - High temporal res.
    - (upto 1 ms/frame)
  - Invasive
  - Cumbersome
  - Cannot visualize deep structures

- RT-MRI
  - Non-invasive
  - Soft tissue contrast
  - Image deep structures
  - Arbitrary image planes
  - Limited by speed !
    - Tradeoffs in
    - Spatial resolution
    - Temporal resolution
    - Slice coverage

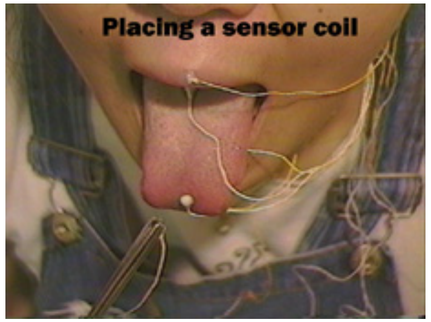
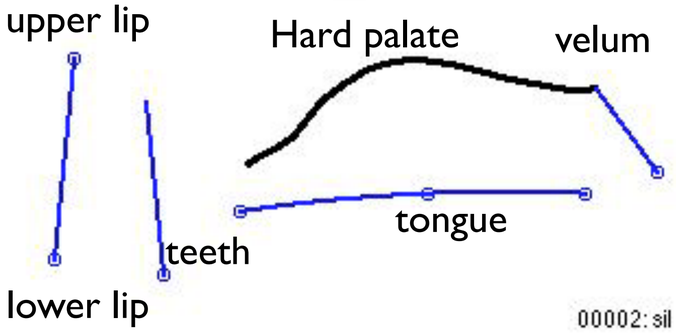


Image Courtesy: UCLA Phonetics Lab

EMA

time res=2 ms



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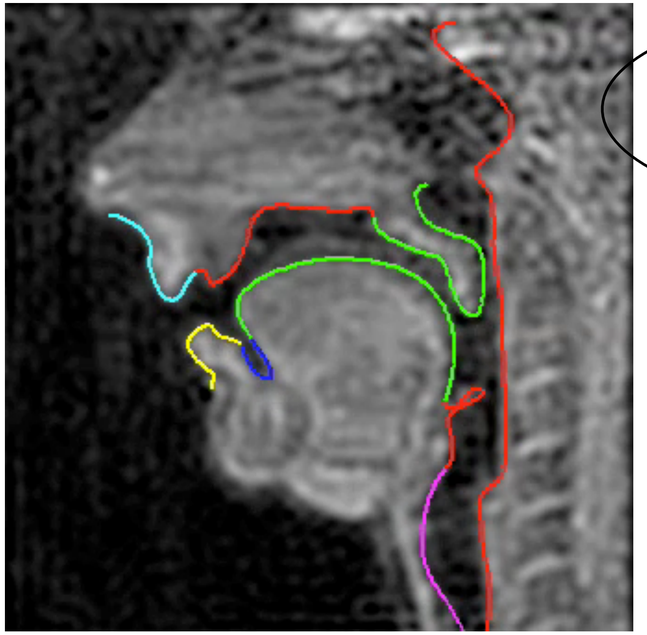

Spiral RT-MRI

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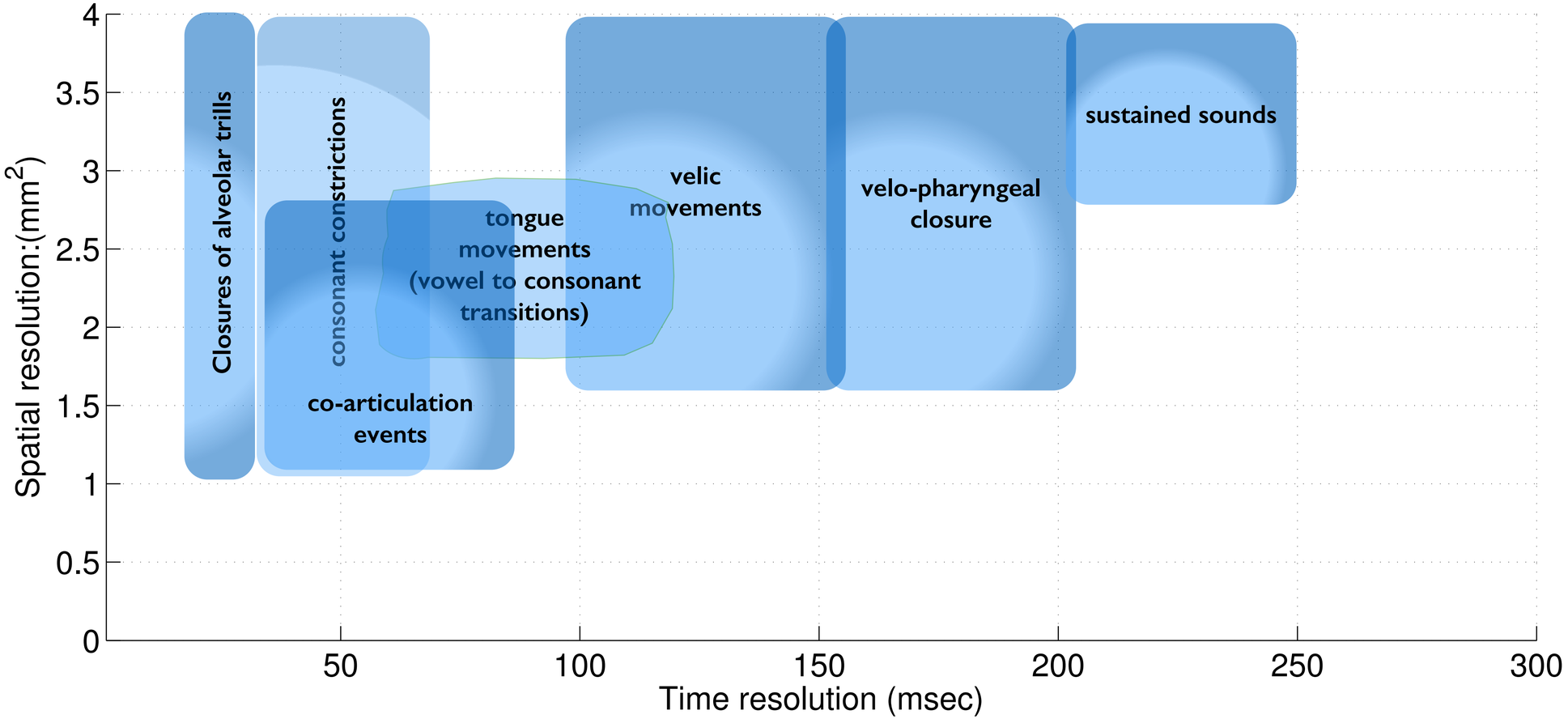
E.Bresch et al, 08 S.Narayanan et al, 04

Spatial v/s Temporal resolution

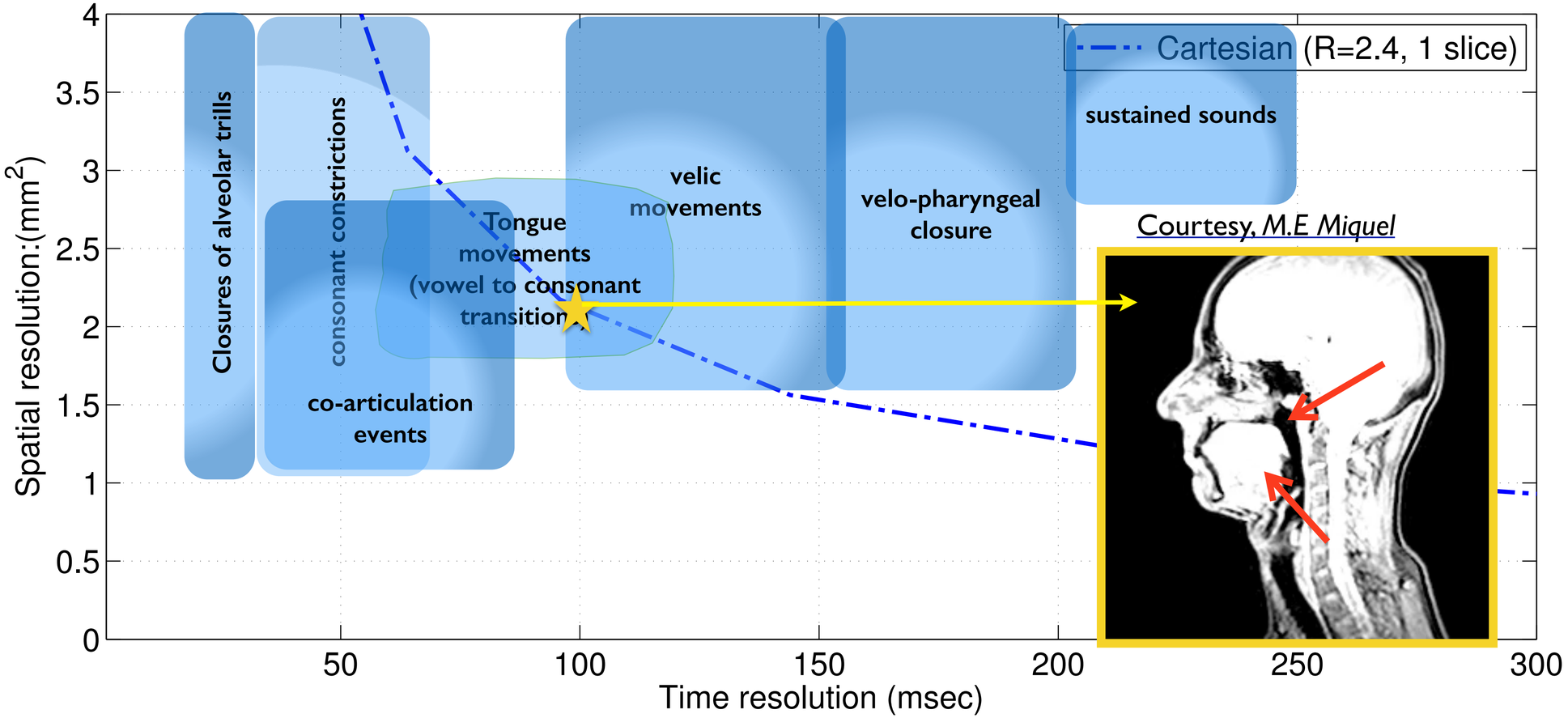
- Schematic placement of speech tasks as "***zones"***
  - Consensus amongst Speech scientists (Linguists)
    - ISMRM endorsed **Speech MRI summit** held at Univ. of Southern California, February 2014



S.G. Lingala, B.P. Sutton, M.E. Miquel, K.S. Nayak, "Recommendations for Real time Speech MRI", *JMRI, (in review)*

Spatial v/s Temporal resolution

- Cartesian imaging using parallel imaging, and Partial Fourier



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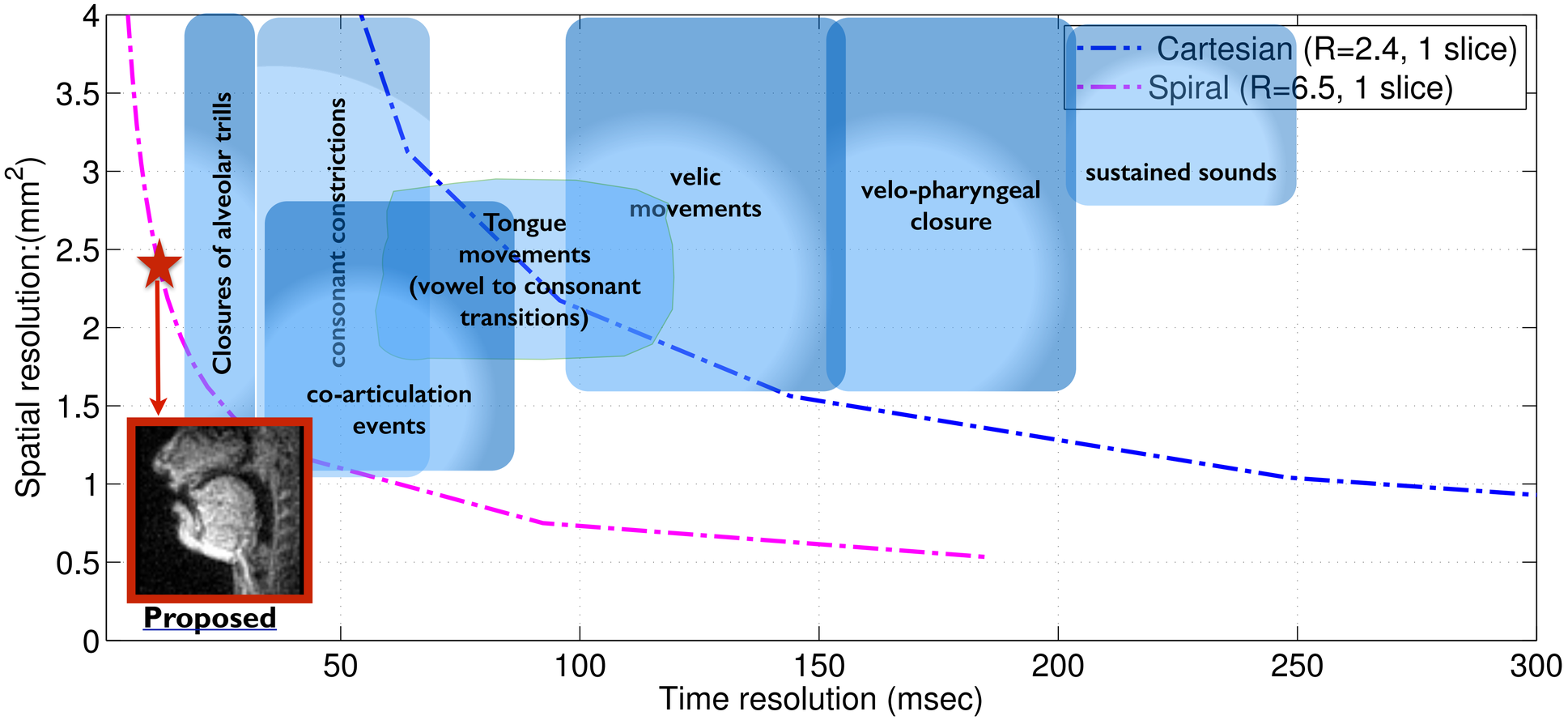
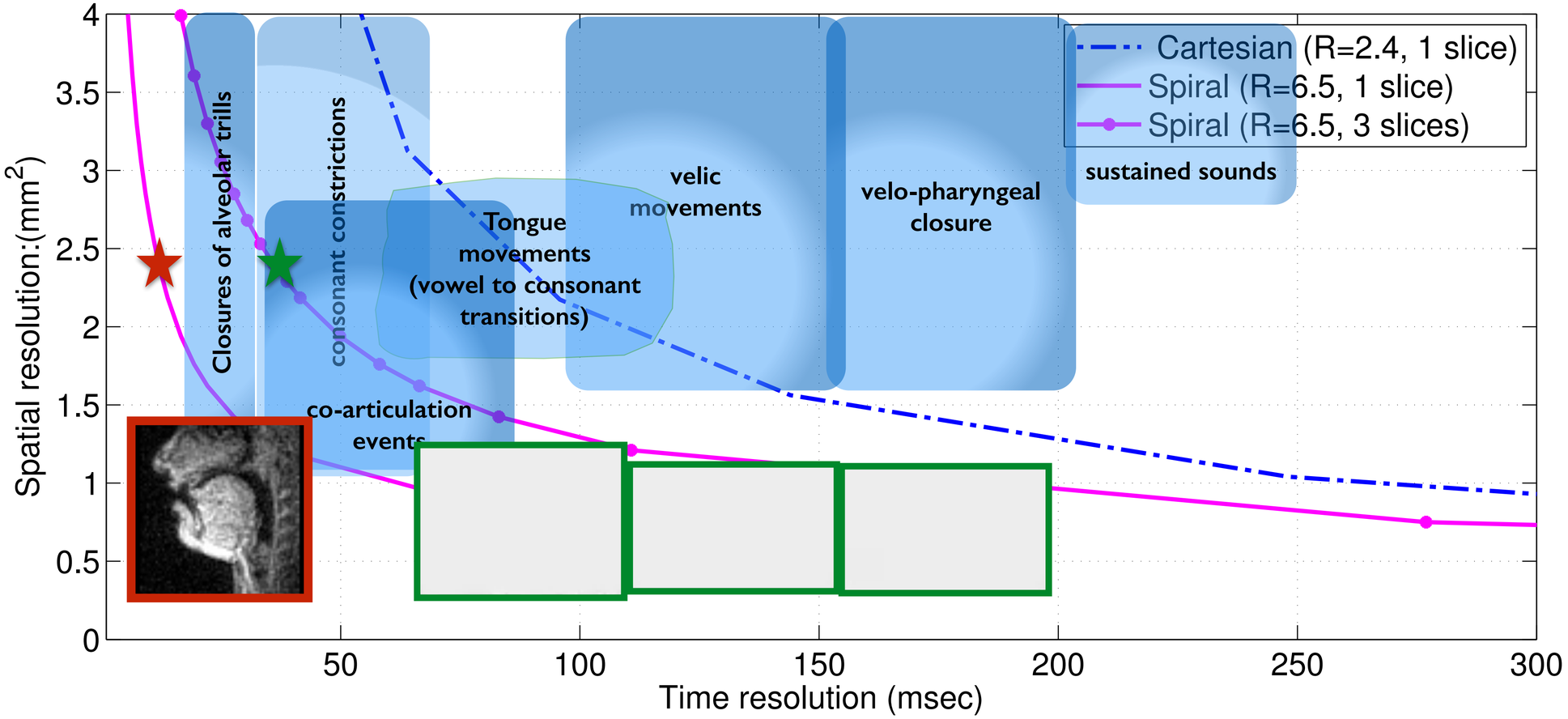
Purpose of this work

- To enable highly accelerated RT MRI of speech
  - Single slice imaging upto **12 ms/frame**



Purpose of this work

- To enable highly accelerated RT MRI of speech
  - Single slice imaging upto **12 ms/frame**
  - Three slice imaging upto **36 ms/frame**



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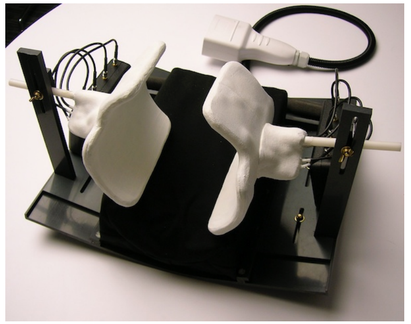
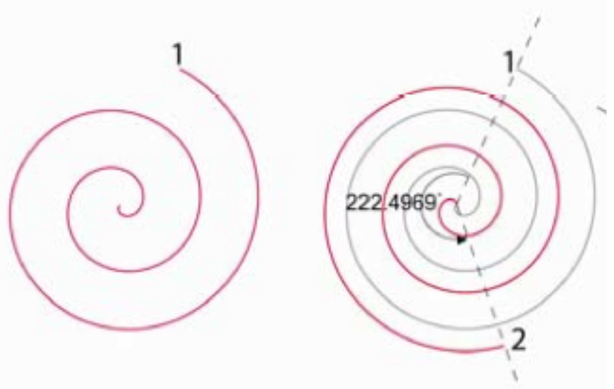
METHODS

Methods

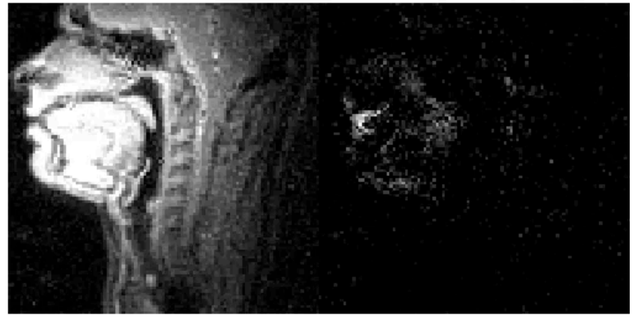
- Highly accelerated RT MRI of speech is achieved by



  - Novel custom upper airway coil



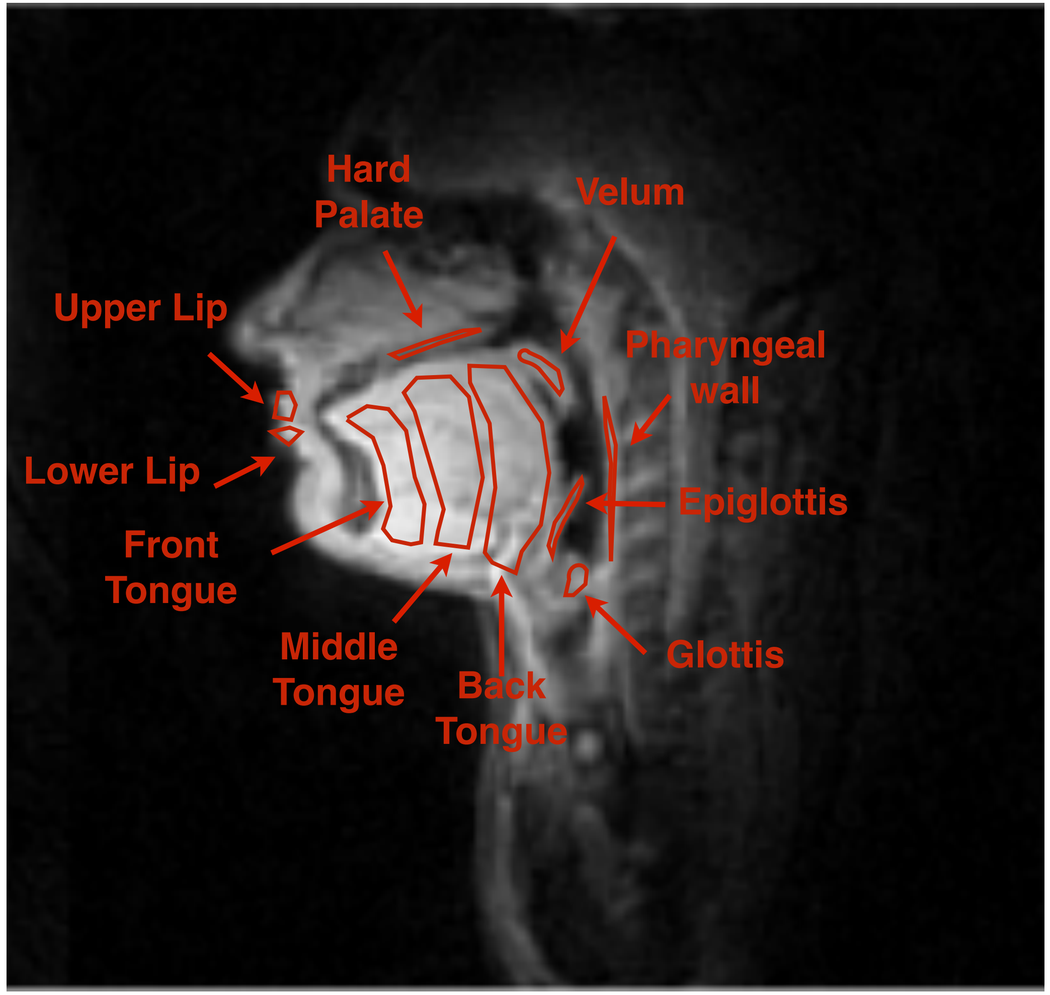
  - Fast spiral readouts with golden angle time interleaving



  - Constrained reconstruction

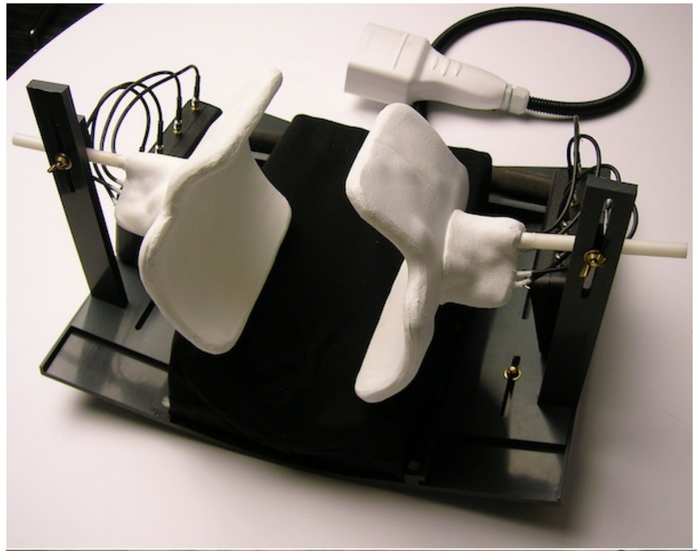
Custom upper airway coil

- We use **custom** upper-airway coils
  - Superior SNR in upper-airway regions of interest



Custom upper airway coil

(2 sizes: Adult and Kid)



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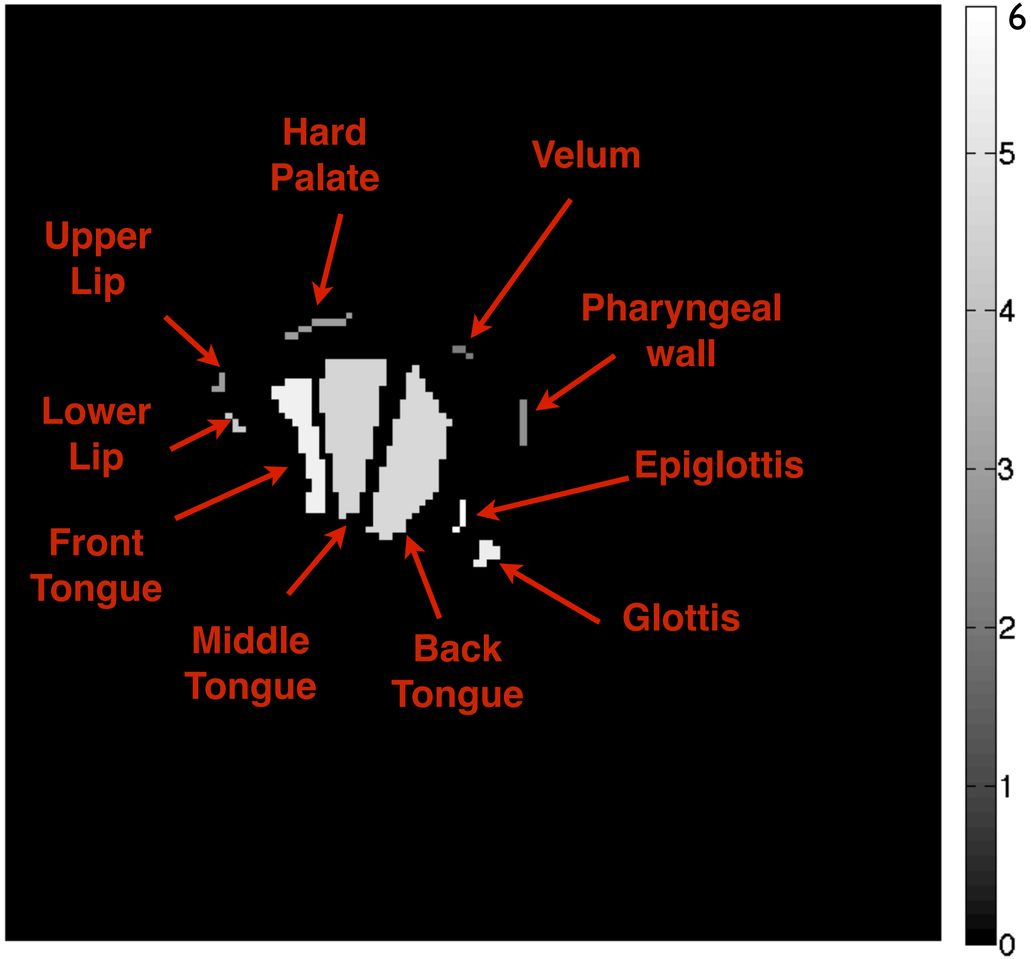
Relative SNR gain over a commercial 8-ch head coil



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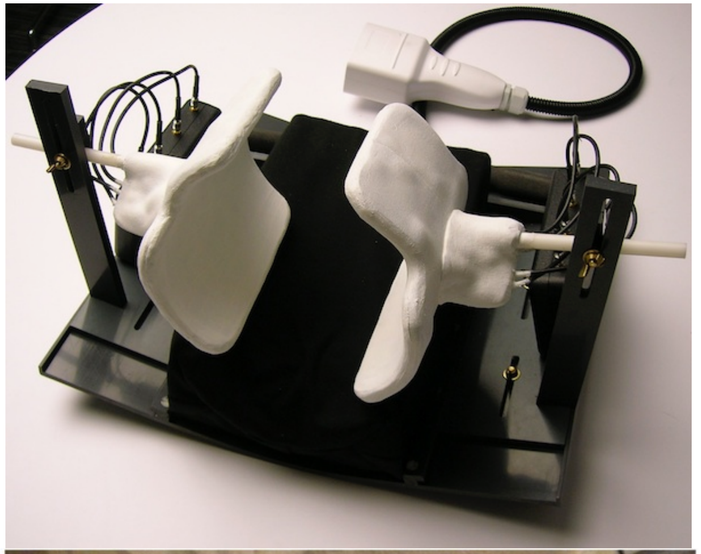
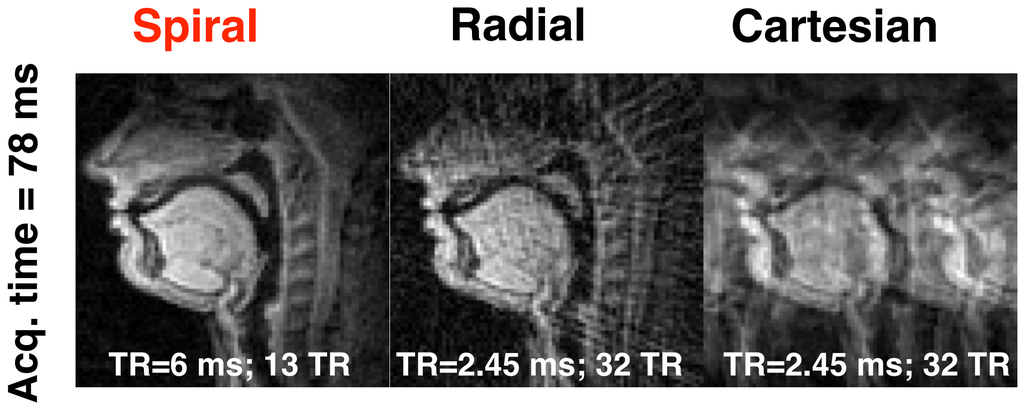


Golden angle spirals

- Spirals are naturally fast
  - Superior acquisition efficiency



Simulation
FOV: 20x20 cm^2;
spatial res: 2.4 mm^2

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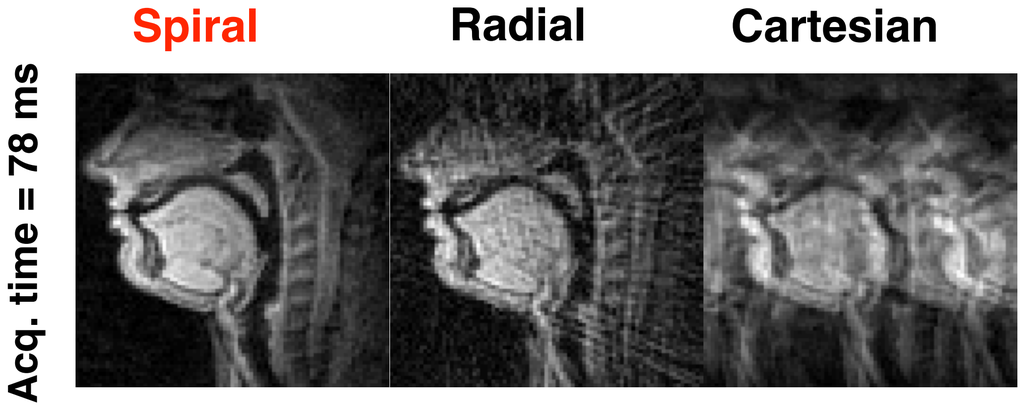

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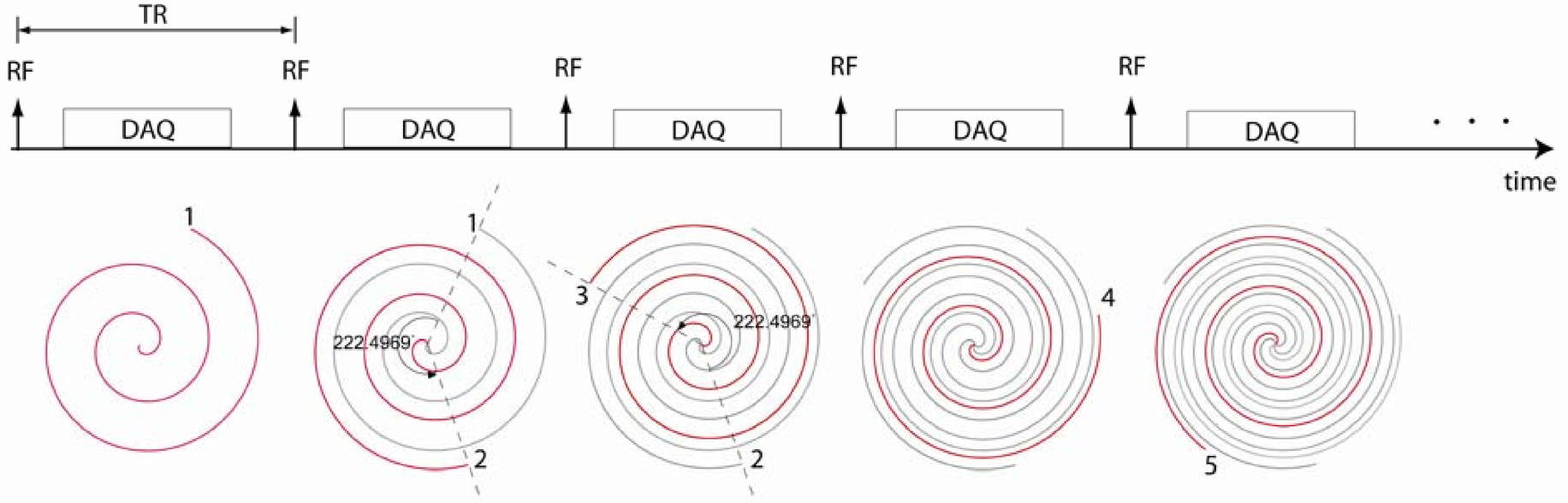
- **Golden angle sampling** offers flexibility in retrospective choice of temporal resolution
  - Guaranteed max. efficiency for Fibonacci choice of interleaves



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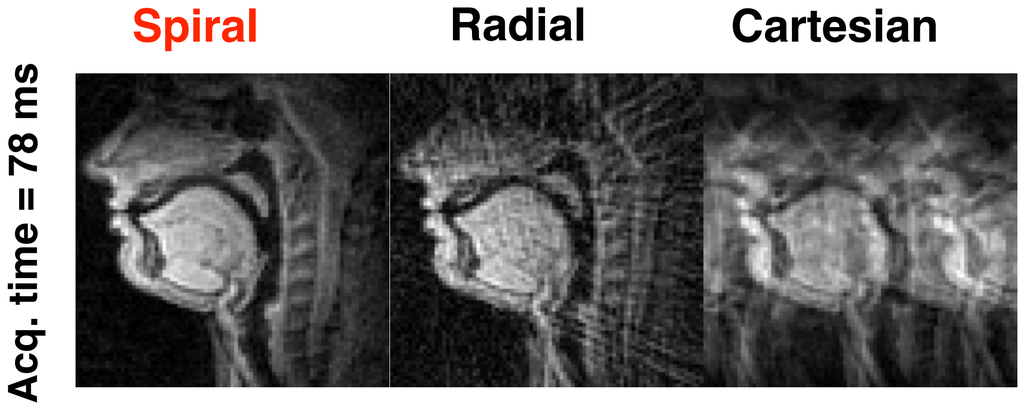

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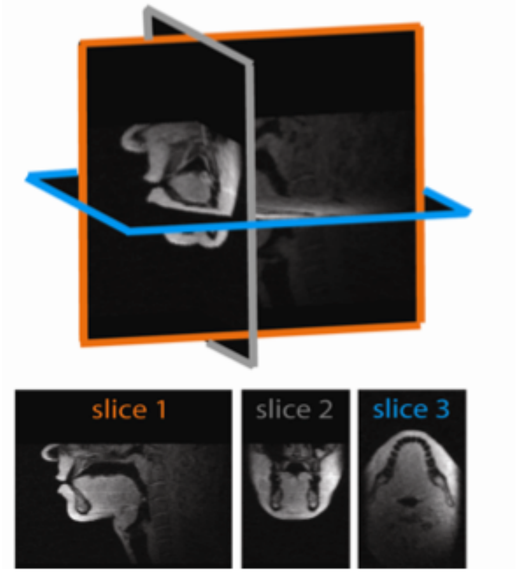
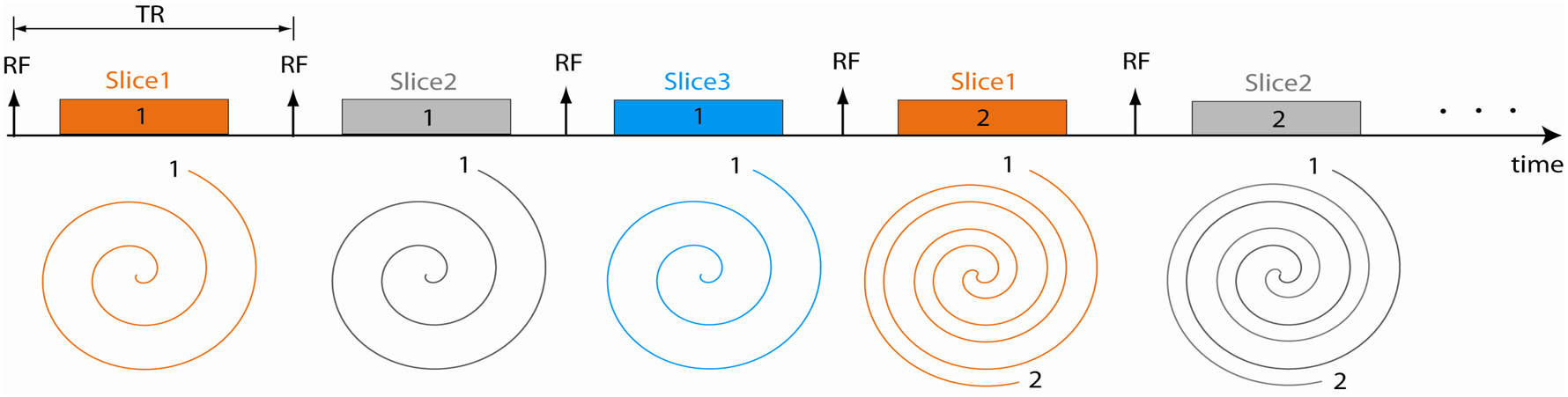
- **Multi-slice time interleaved** golden angle sampling
  - Guaranteed max. efficiency for Fibonacci choice of interleaves





Constrained reconstruction

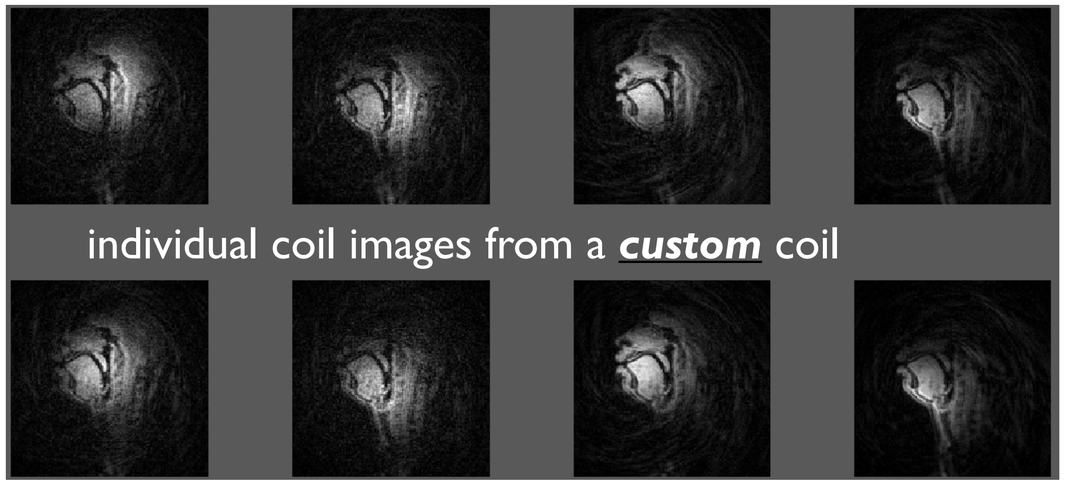
- Regularized SENSE reconstruction:

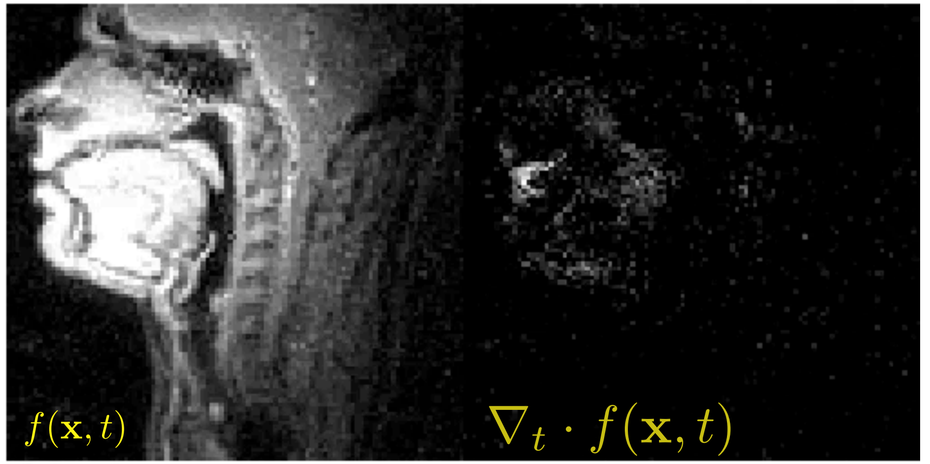
$$min_f \underbrace{\|\mathcal{A}(f) - \mathbf{b}\|_2^2}_{\textbf{data consistency}} + \underbrace{\lambda\|\nabla_t(f)\|_1}_{\textbf{temporal reg.}} ;$$

$\mathcal{A}$ - coil sensitivity encoding + NUFFT along GA spiral

∇_t - temporal finite difference

λ - regularization parameter





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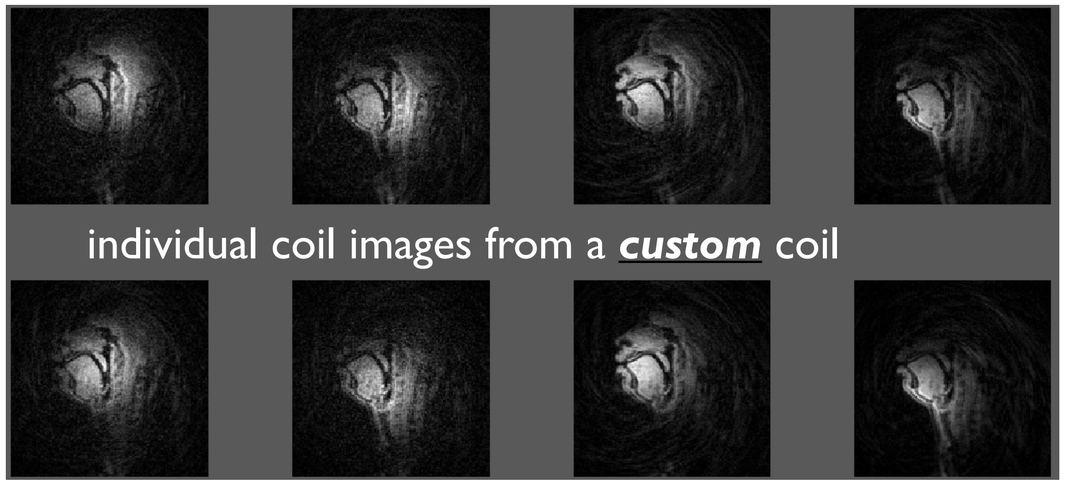
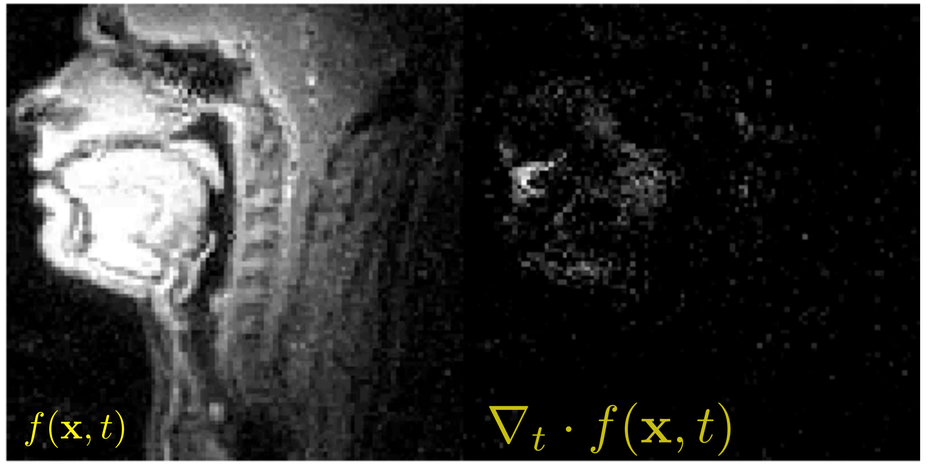
- Solved using iterative non-linear conjugate gradient algorithm
  - Recon. time **~ 60 min** for a 24 sec. speech sample with 12 ms time resolution **(N_x x Ny x Nt = 140 x 140 x 2000)**





EXPERIMENTS

Experiments

- 1.5 T GE Signa Scanner

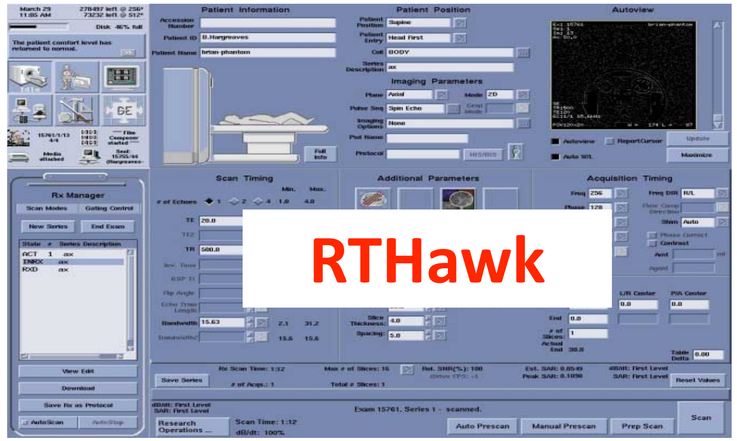
- Real time (RTHawk) interactive system
  - J. Santos, *IEEE-EMBC 2004*

- Simultaneous audio acquisition at 20 KHz, and noise cancellation
  - C.Vaz, *Interspeech 2014*

Simultaneous audio acquisition

RTHawk

Interactive control station



Scanner Hardware

Experiments

- A range of sequences implemented
  - FOV: 20cm^2; Flip angle: 15^0; slice thickness: 5 mm; TR = 6.004 ms
    - Single slice sequences
      - 2.4 mm^2; 1.76 mm^2
    - Two/three slice sequences
      - 2.4 mm^2

- Reconstruction
  - Online
    - Gridding (without and with view-sharing)
  - Offline
    - Constrained reconstruction

- 4 volunteers and 1 patient were imaged with a variety of speech stimuli
  - Counting numbers (normal and fast pace)
  - Puerto Rican Spanish stimuli
  - Sentences from the TIMIT set (standard in speech processing field)
    - S.Narayanan et al, *Journal Acoustical Society of America. 2014*

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RESULTS

Results: Volunteer

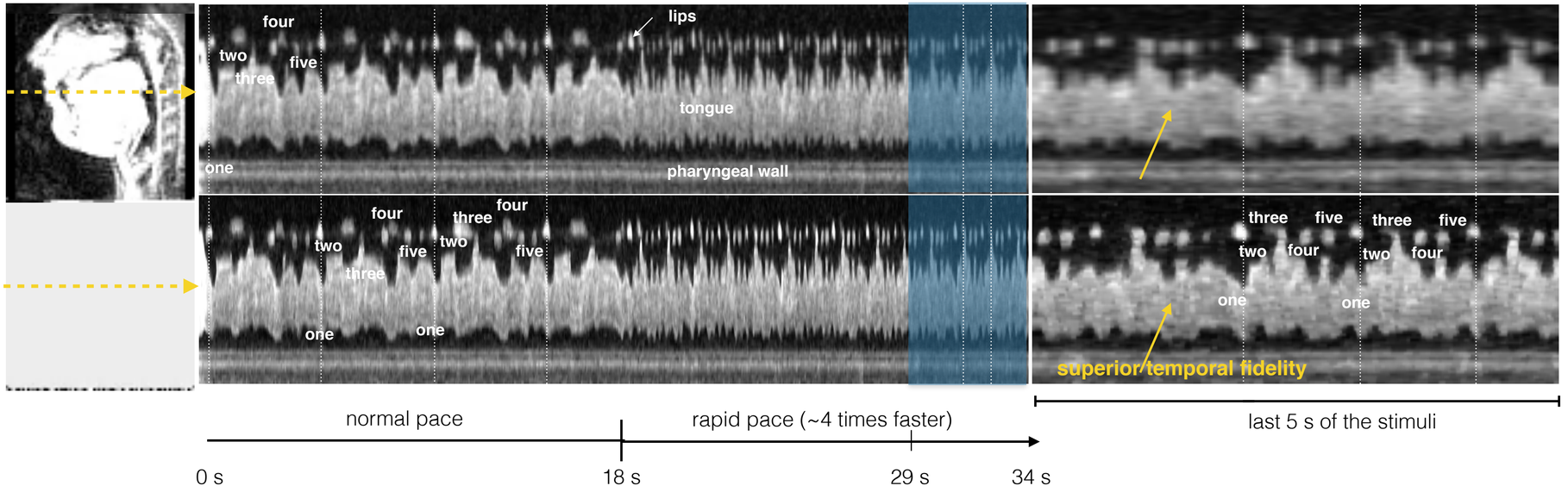
78 ms / frame
Fully sampled
Gridding

12 ms / frame
Accelerated
Const. recon

2.4 mm²

Repetitions of *"one-two-three-four-five"* at normal pace followed by rapid pace

zoomed in time profiles



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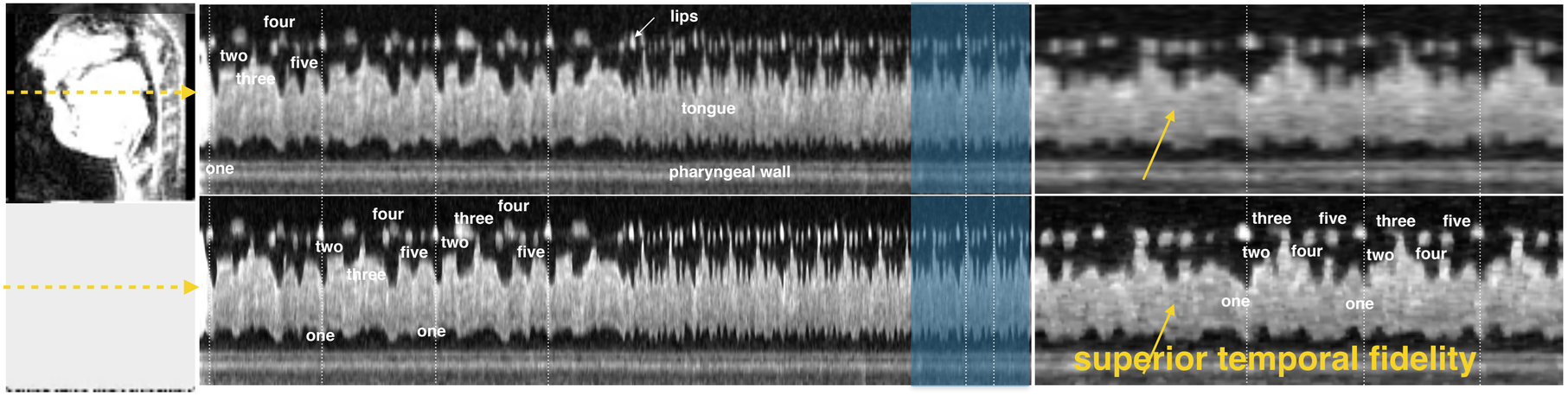
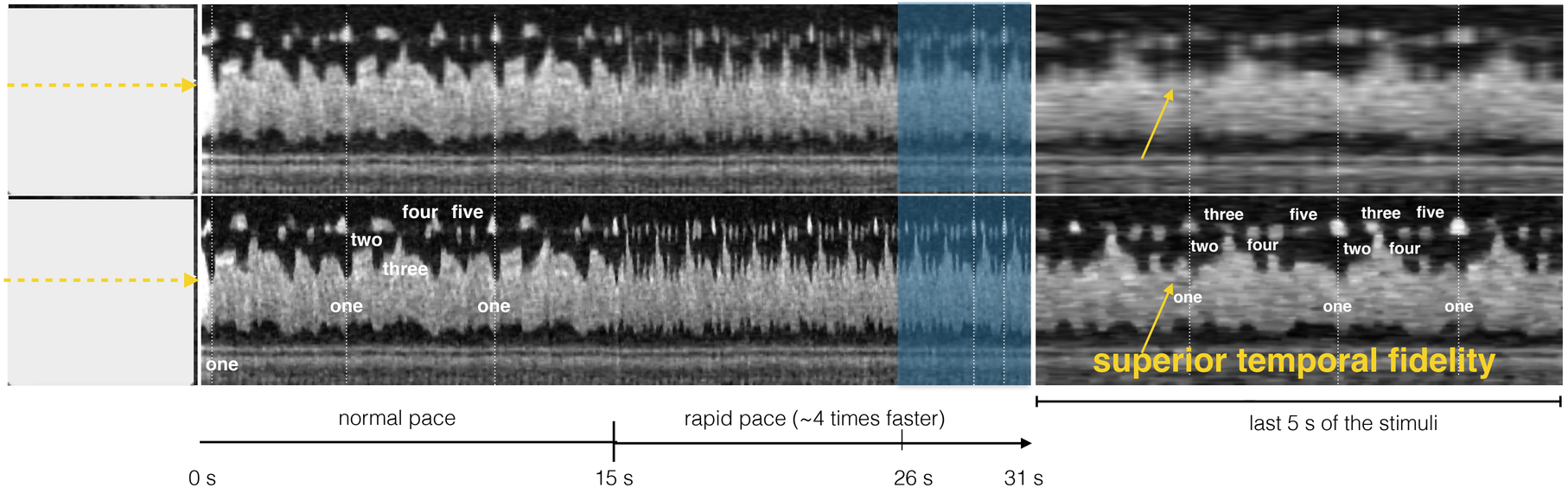


1.76 mm²

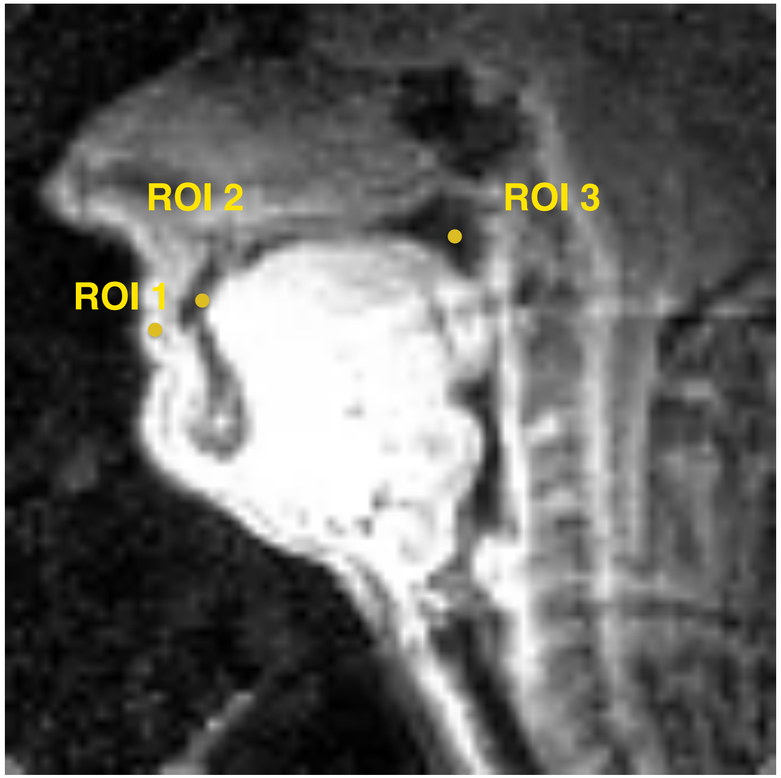
126 ms / frame
Fully sampled
Gridding

18 ms / frame
Accelerated
Const. recon



Vowel and consonant sounds @ 12 ms/frame

- Tongue cancer patient imaged prior to treatment



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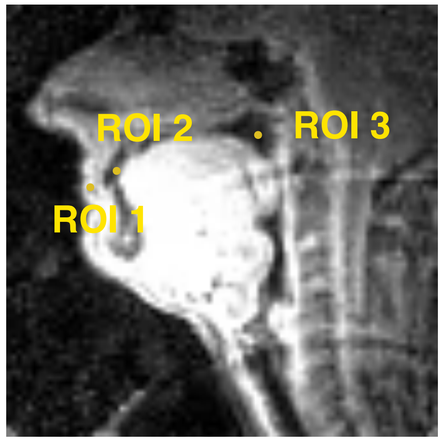
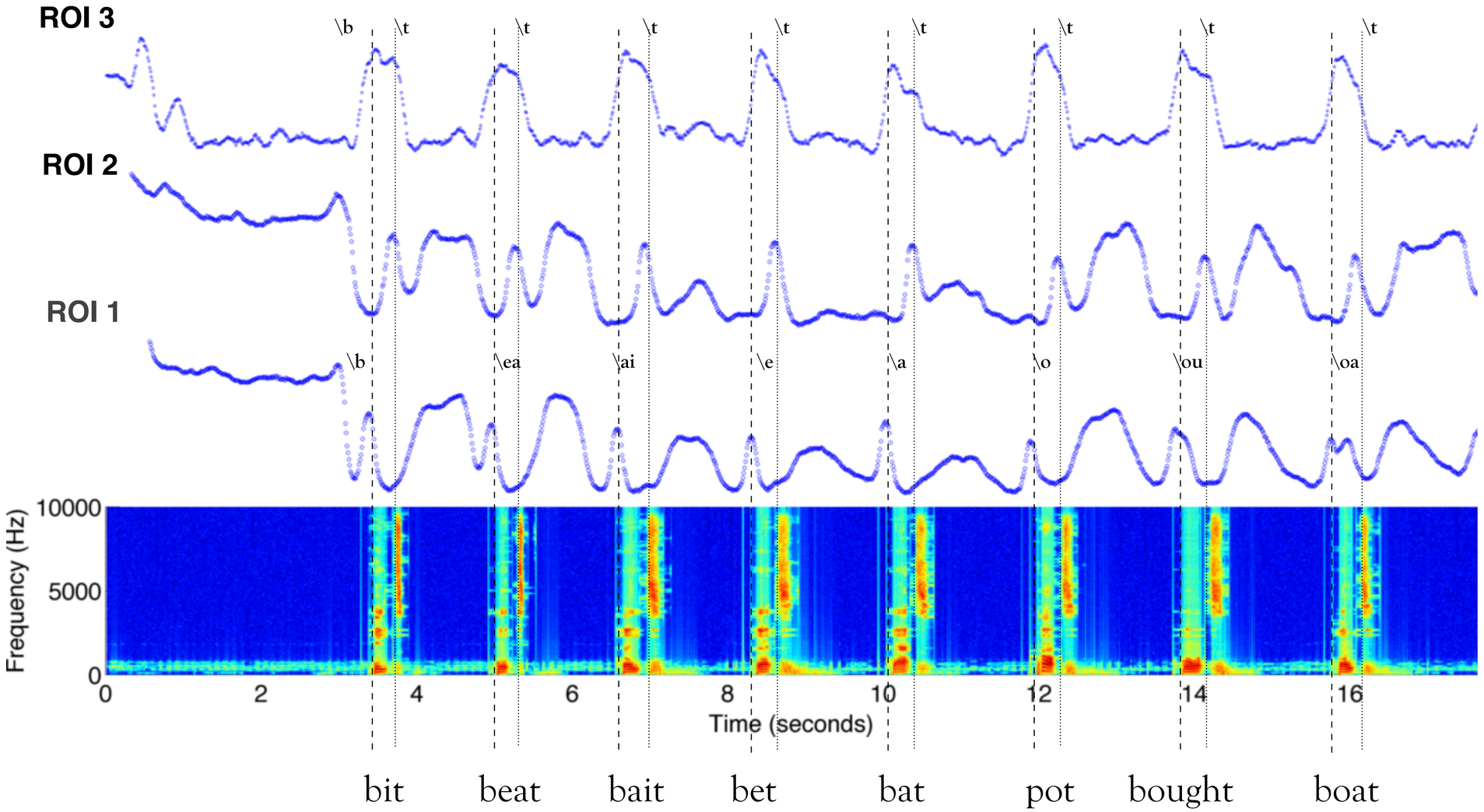
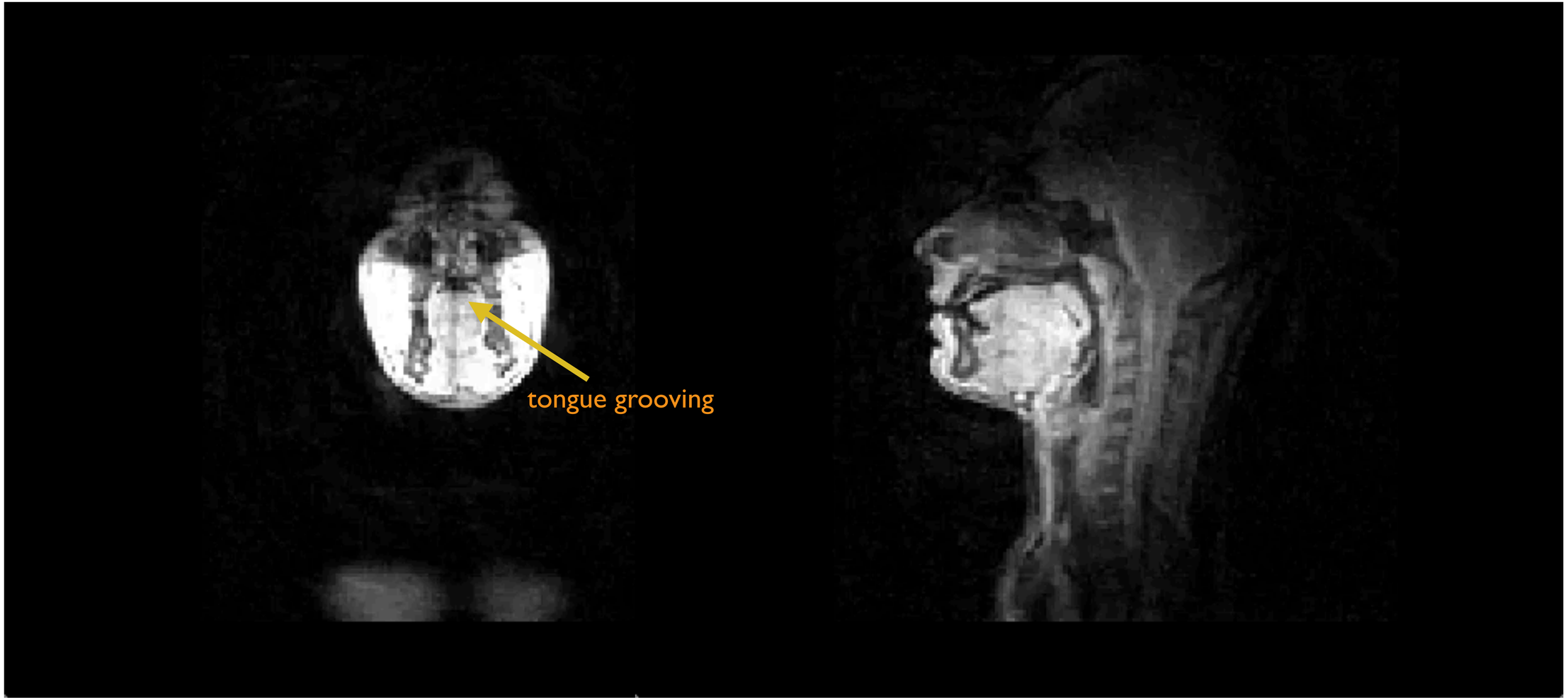


Spectrogram of the simultaneously acquired audio



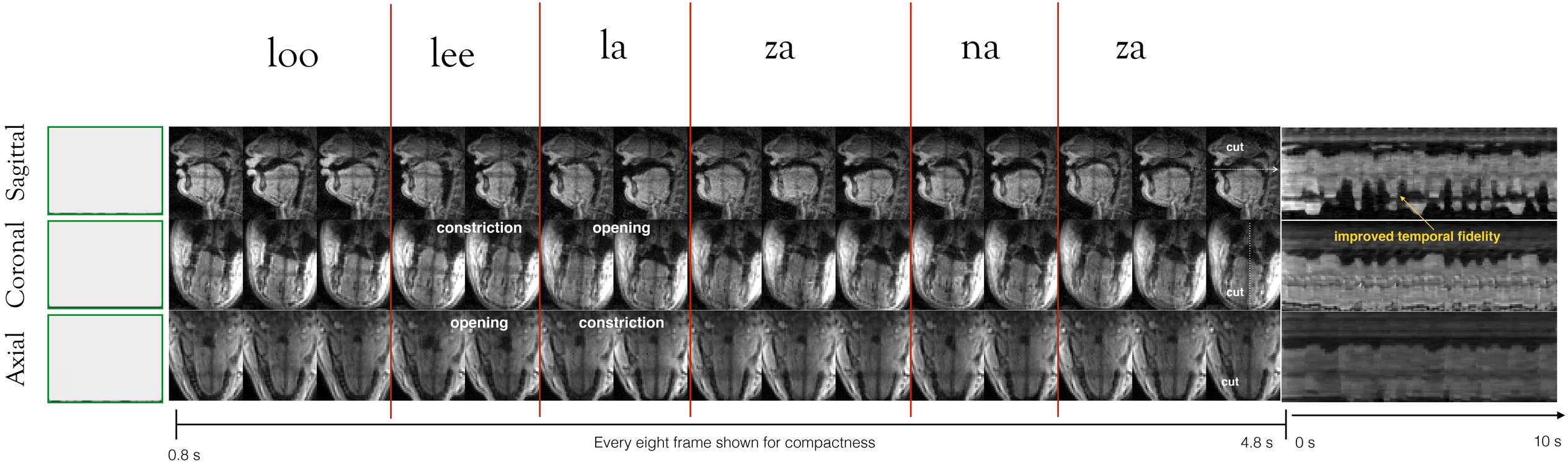
Fast multi-plane imaging: Spanish stimuli

- Puerto Rican Spanish stimuli
  - Involves rapid articulatory movements
    - Simultaneous sagittal and coronal imaging @ 24 frames/sec



Fast multi-plane imaging

- Consonants interleaved by vowels
  - /loo/-/lee/-/laa/-/za/-/na/-/za/
    - Simultaneous three slice imaging @ 36 frames/sec

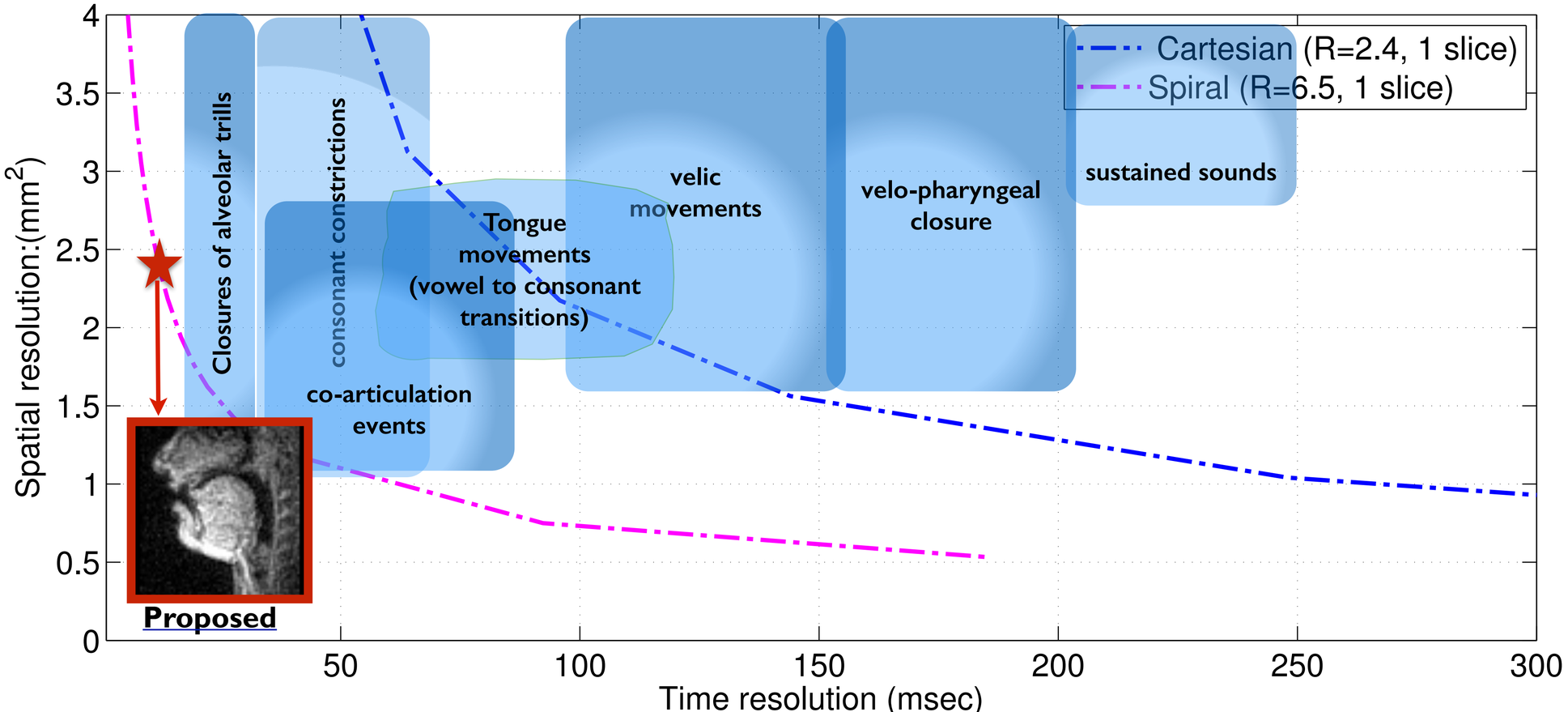


Conclusions

- Novel accelerated RT-MRI of speech framework
  - Custom upper-airway coil
  - Spiral golden angle, multi-slice acquisition
  - Constrained reconstruction

Conclusions

- Novel accelerated RT-MRI of speech framework
  - Custom upper-airway coil
  - Spiral Golden angle, multi-slice acquisition
  - Constrained reconstruction
- Potential to drive new Linguistic based hypothesis which require high time resolution



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- Funding
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- Speech Knowledge and Articulation Group (SPAN), *Univ. of S California*

span | speech production and articulation knowledge group

Louis Goldstein

- Magnetic Resonance Engineering Laboratory (MREL), *Univ. of S California*

Magnetic Resonance Engineering Laboratory

Dani Byrd

THANK YOU