Abstract No : 3541

3D Real-Time MRI of Vocal Tract Shaping

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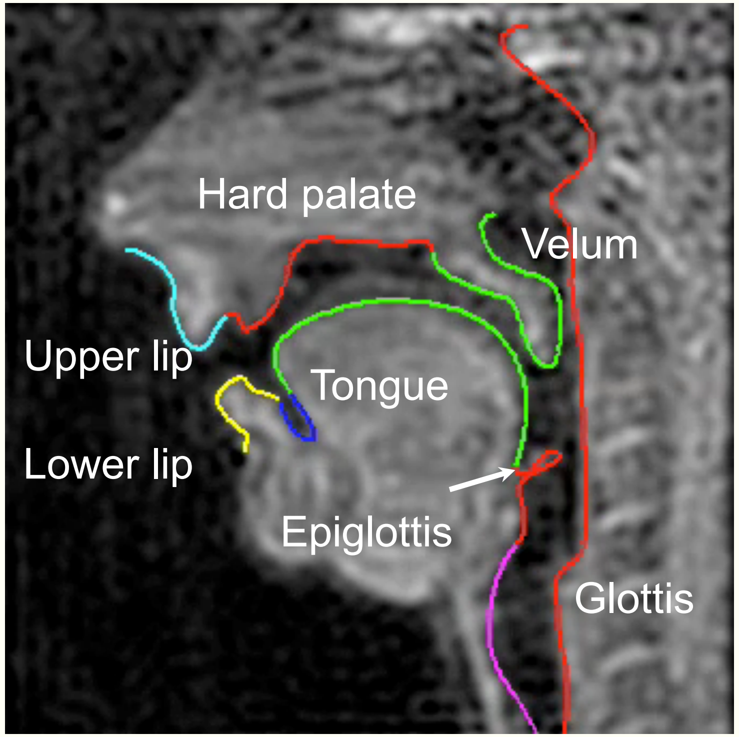
Introduction – RT-MRI of Speech

Spiral 2D RT-MRI of speech

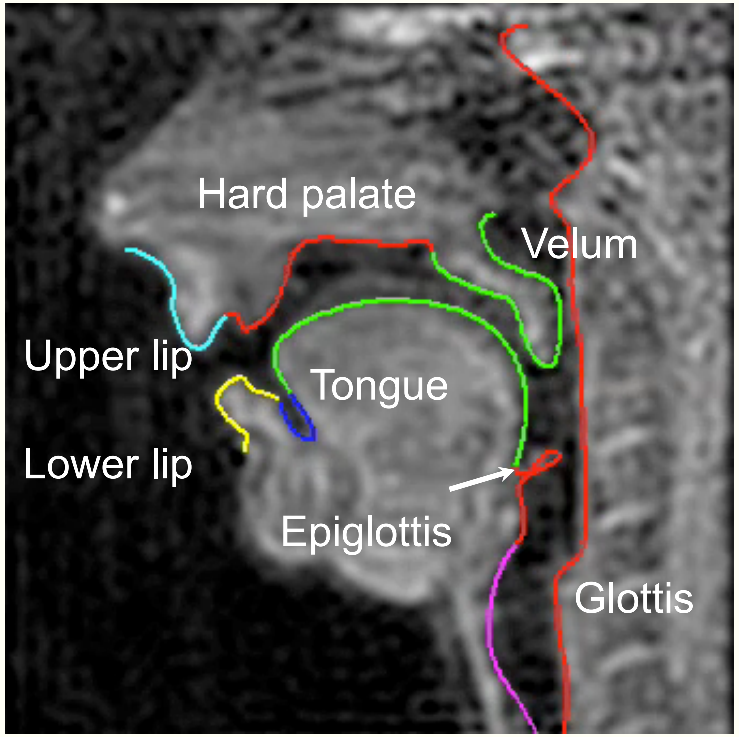


1. Lingala SG et al., JMRI. 2016;43:28–44
2. Scott AD, et al., *Med Phys.* 2014;30:604–618.

Introduction – RT-MRI of Speech

- Speech scientists seek a comprehensive understanding of human vocal tract shaping and its dynamics.
- RT-MRI techniques are being used to study dynamic function of articulators non-invasively[1,2].
- However, most of RT-MRI techniques have been limited to one mid-sagittal or a few 2D imaging planes[1].

Spiral 2D RT-MRI of speech



1. Lingala SG et al., JMRI. 2016;43:28–44
2. Scott AD, et al., *Med Phys.* 2014;30:604–618.

Introduction – Vocal Tract Shaping During Speech

- Enormously complex in **geometry** and **temporal structuring**

- Cannot be fully understood from mid-sagittal constriction posture along the vocal tract.[3,4]
  - E.g., grooving/doming/lateral shaping of tongue, asymmetries in tongue shape, resonate cavity volume

- **3D vocal tract shaping and its dynamics is essential.**

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3. Narayanan SS et al, *JASA*. 1999;106:1993–2007.
4. Kim YC et al, *JMRI*. 2012;35:943–948.

Goal of This Work

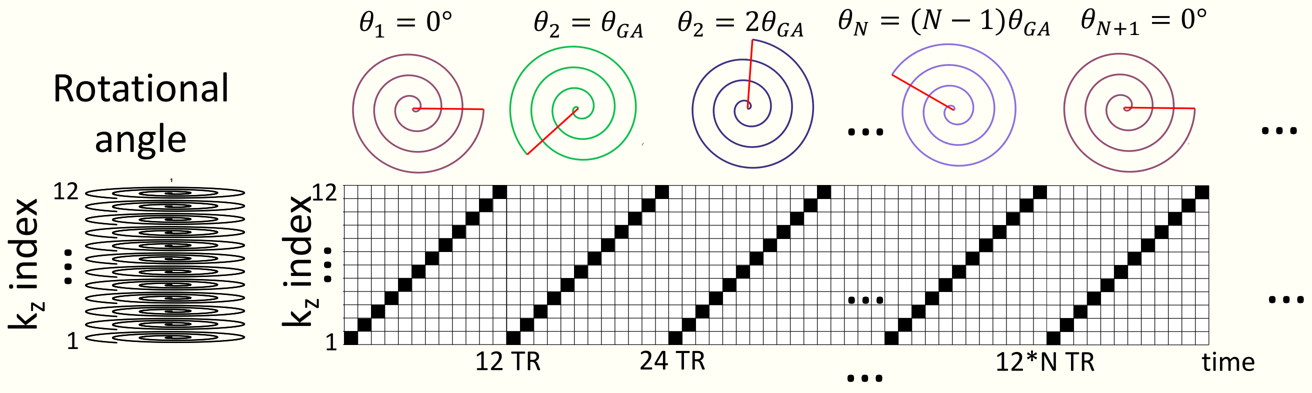
- To develop 3D RT-MRI technique of the full vocal tract at high temporal resolution during natural speech.

- To evaluate this technique using in-vivo vocal tract airway data and via comparison with interleaved multislice 2D RT-MRI.

Methods – Overview of 3D RT-MRI

Pseudo Golden Angle

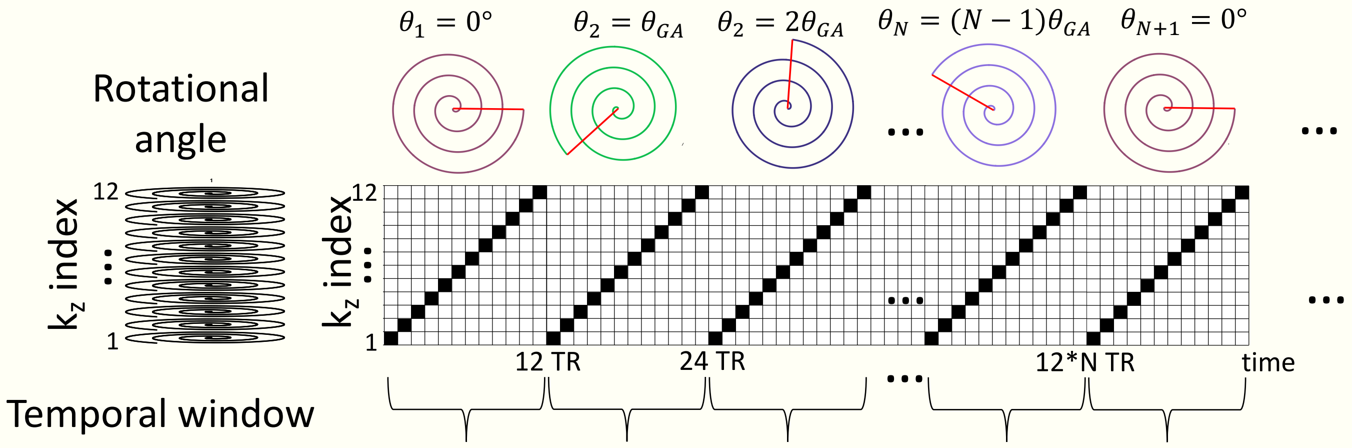
Stack-of-spirals



Methods – Overview of 3D RT-MRI

Pseudo Golden Angle

Stack-of-spirals



Methods – Overview of 3D RT-MRI

Pseudo Golden Angle

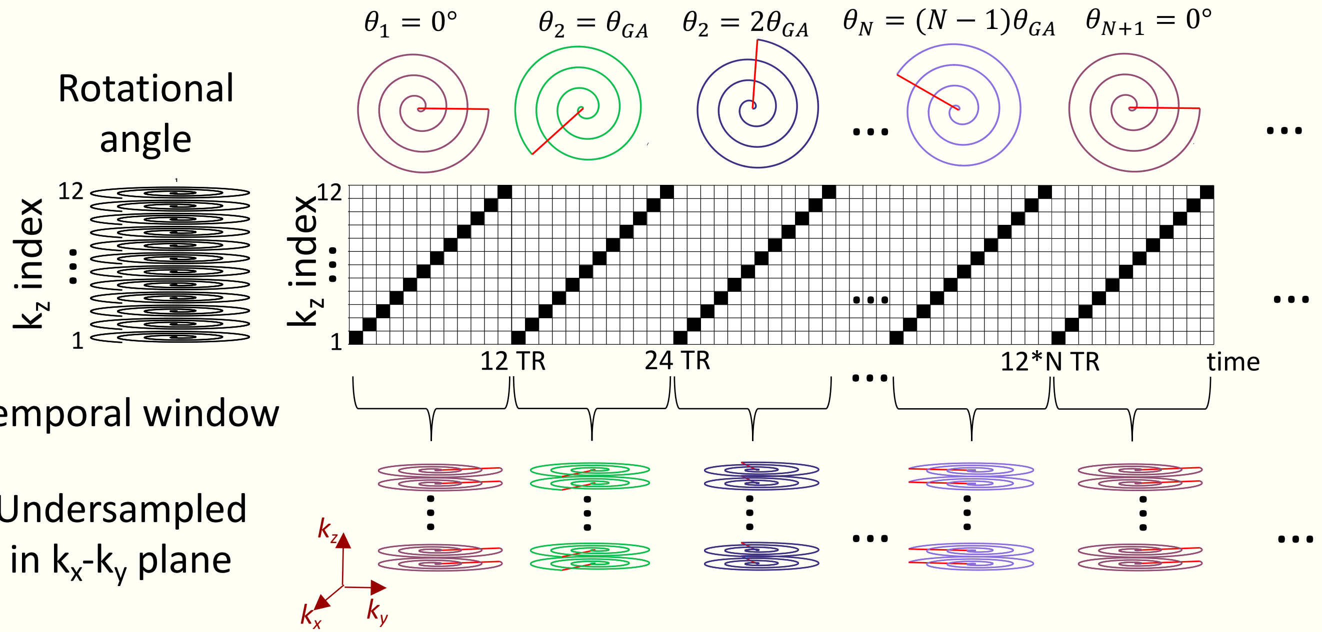
Rotational angle

Stack-of-spirals

Temporal window

Undersampled by 13

Undersampled in k_x-k_y plane



Methods – Overview of 3D RT-MRI

Pseudo Golden Angle

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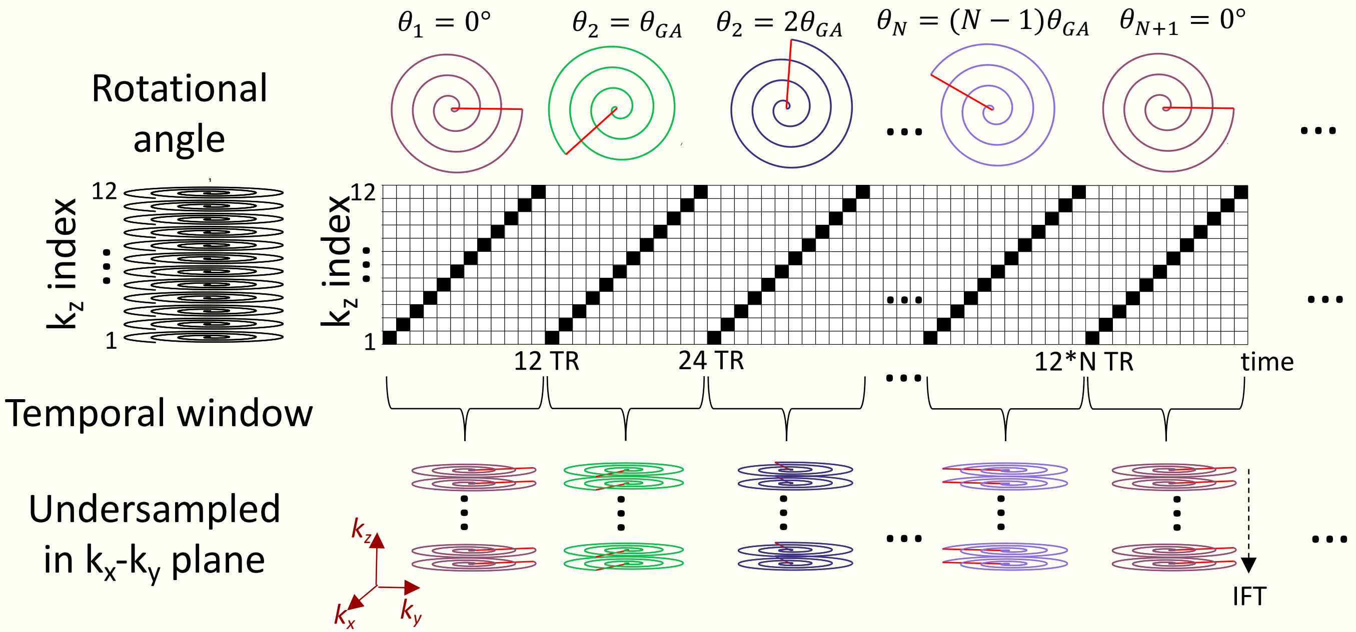
Undersampled by 13

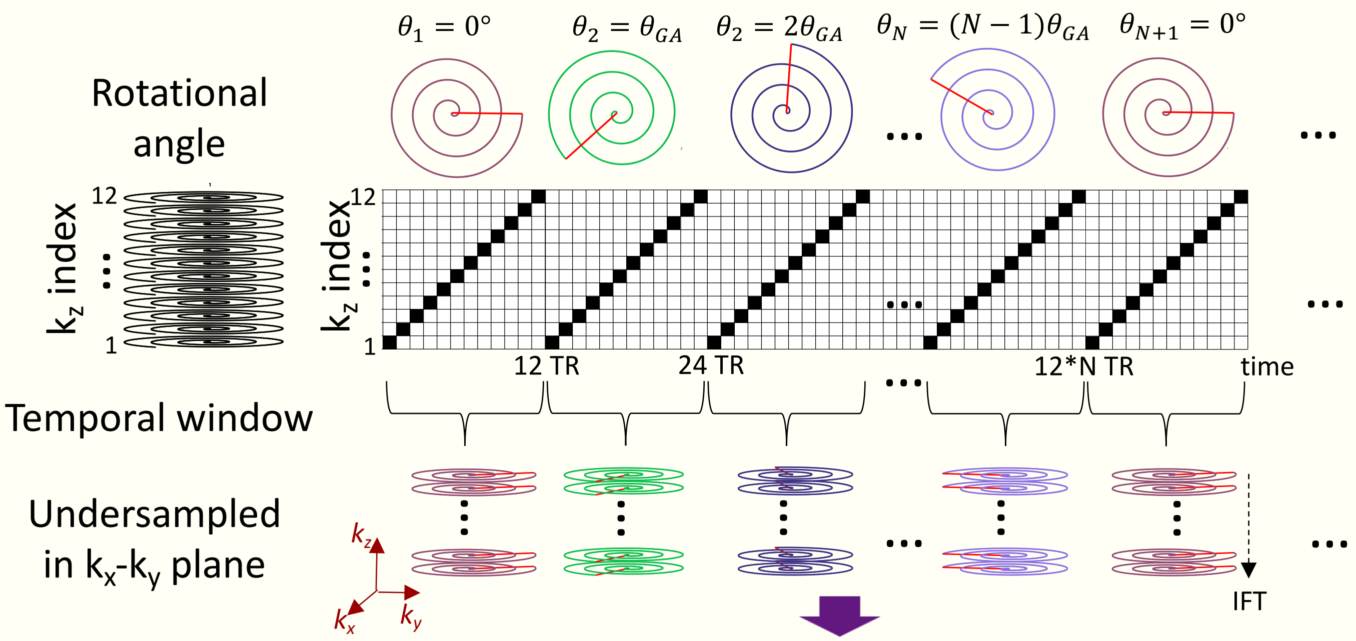


Methods – Overview of 3D RT-MRI

Pseudo Golden Angle

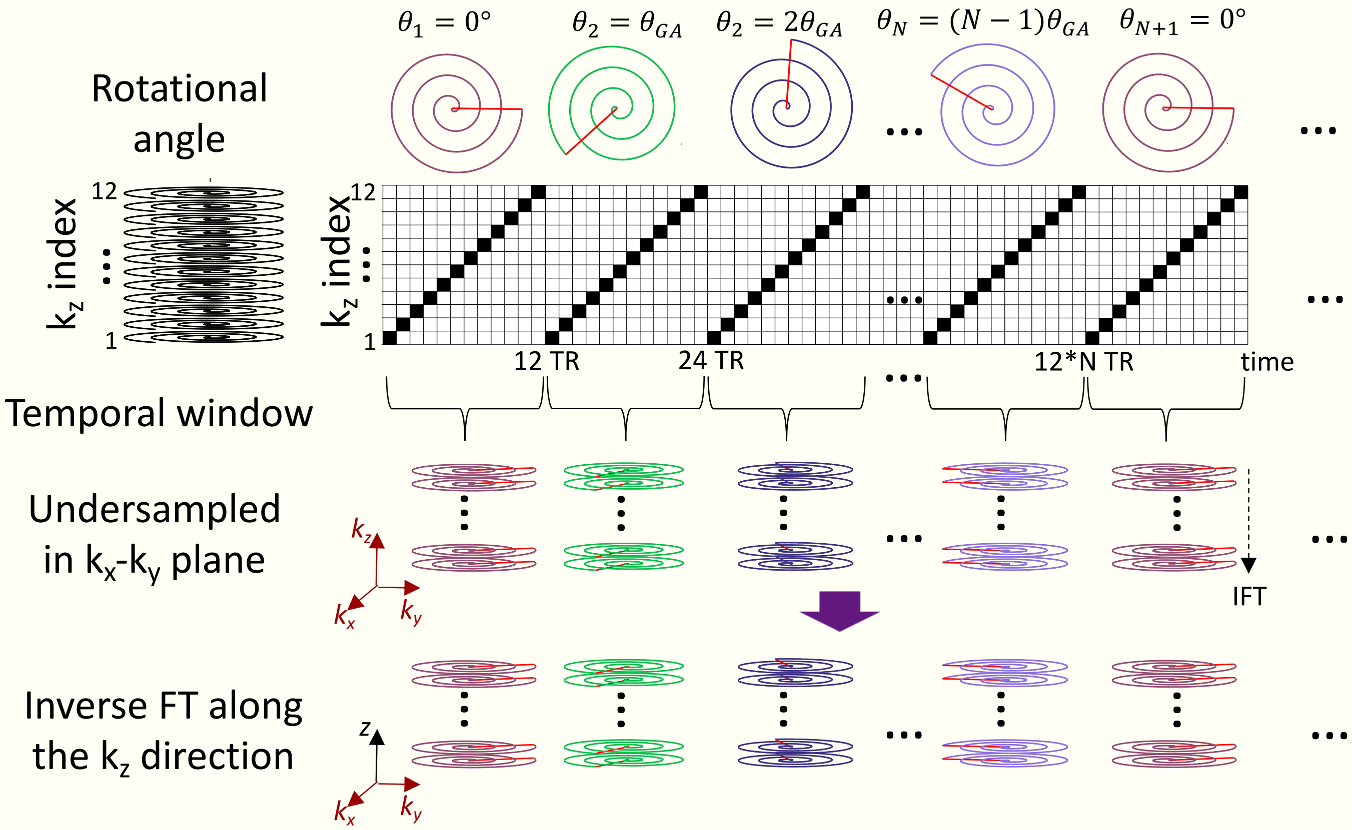
Stack-of-spirals

Undersampled by 13



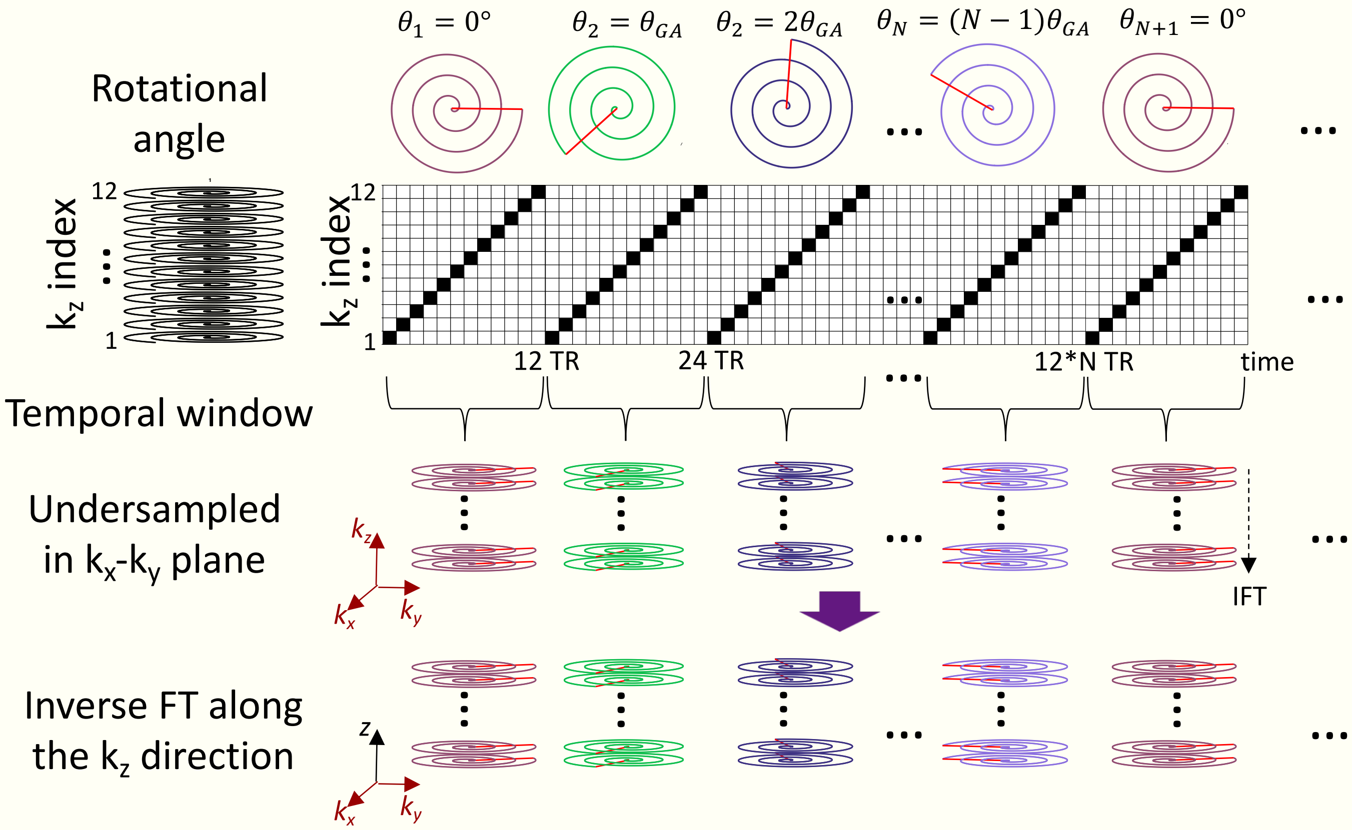
Methods – Overview of 3D RT-MRI

- Pseudo Golden Angle
- Stack-of-spirals
- Undersampled by 13



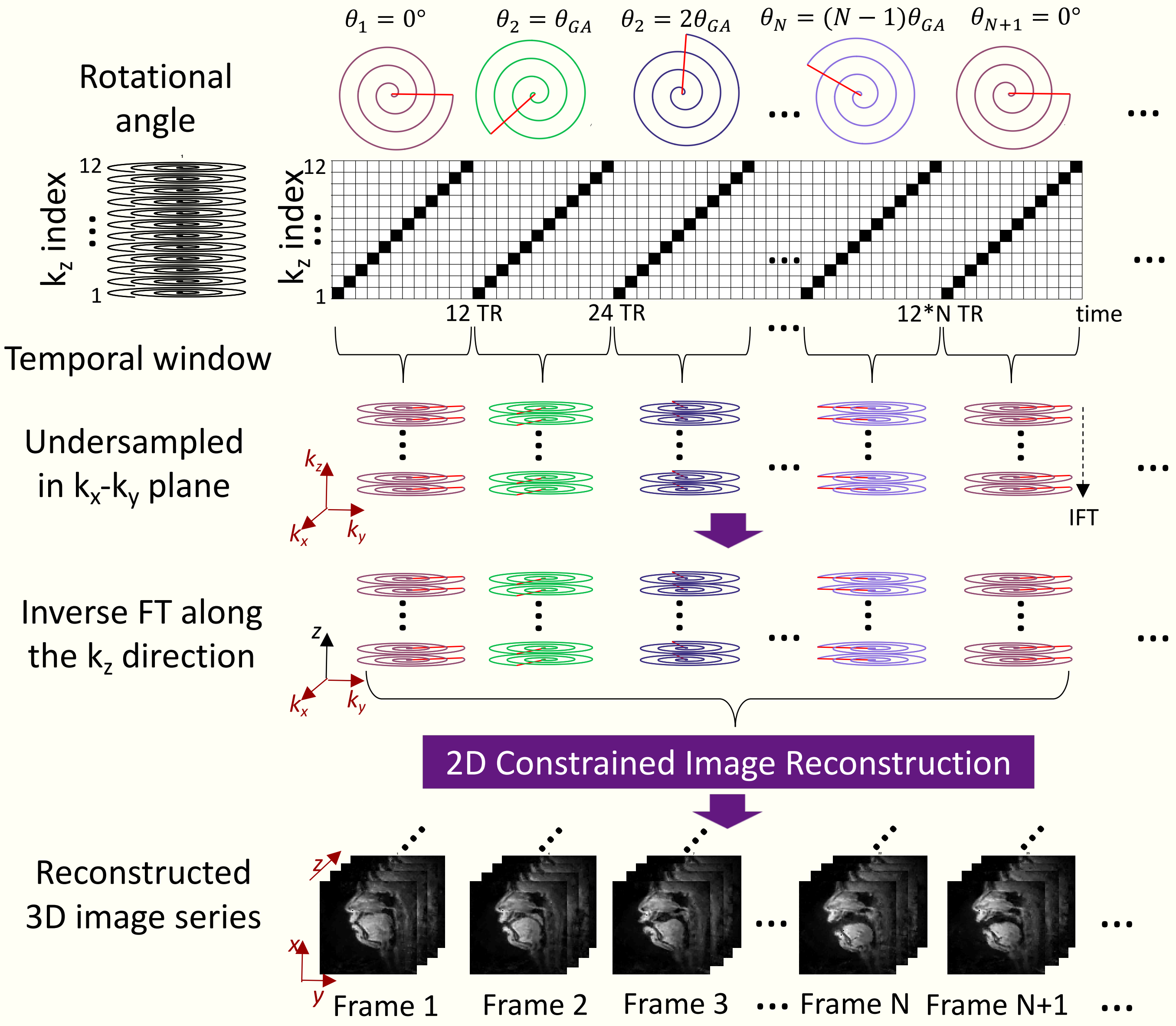
Methods – Overview of 3D RT-MRI

- Pseudo Golden Angle
- Stack-of-spirals
- Undersampled by 13
- Decompose 3D data into 2D slice data



Methods – Overview of 3D RT-MRI

- Pseudo Golden Angle
- Stack-of-spirals
- Undersampled by 13
- Decompose 3D data into 2D slice data
- Slice-by-slice 2D Constrained Reconstruction



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Methods – Some Details

- A minimum-phase slab excitation pulse[5]
  - Slab thickness = 50 mm, FA = 5 degree, TBW = 16

- Reconstruction
  - Sparse-SENSE with spatiotemporal TV constraints[6,7]

$$argmin\ \frac{1}{2}\|FSm - y\|_2^2 + \lambda_s \left\| \sqrt{|\mathrm{D}_x m|^2 + |\mathrm{D}_y m|^2} \right\|_1 + \lambda_t \|\mathrm{D}_t m\|_1$$

  - Coil maps : ESPIRiT[8] using time-averaged 3D data

5. Pauly J et al., IEEE TMI. 1991;10:53–65.
6. Lingala SG et al, *MRM.* 2017;77:112-125.
7. Chen J et al, ISMRM, 2017.
8. Uecker M et al, *MRM,* 2014;71:990–1001.

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Methods – Imaging Parameters

- MRI Protocols
  - GE Signa 1.5T scanner

	2D RT-MRI[9]	3D RT-MRI
# of slices	3 orthogonal (interleaved)	12 (# of kz encode)
TR (ms)	6	5.05
TE (ms)	0.8	0.68
FA (degree)	15°	5°
FOV (mm^3)	200 x 200 x 6	200 x 200 x 70 mm^3
Spatial resolution (mm^3)	2.4 x 2.4 x 6 mm^3	2.4 x 2.4 x 5.8 mm^3
Temporal resolution (ms / frame)	18 ms (1 spirals / frame)	61 ms (1 spirals in k_x-k_y + 12 k_z / frame)
Acceleration	**13x**	

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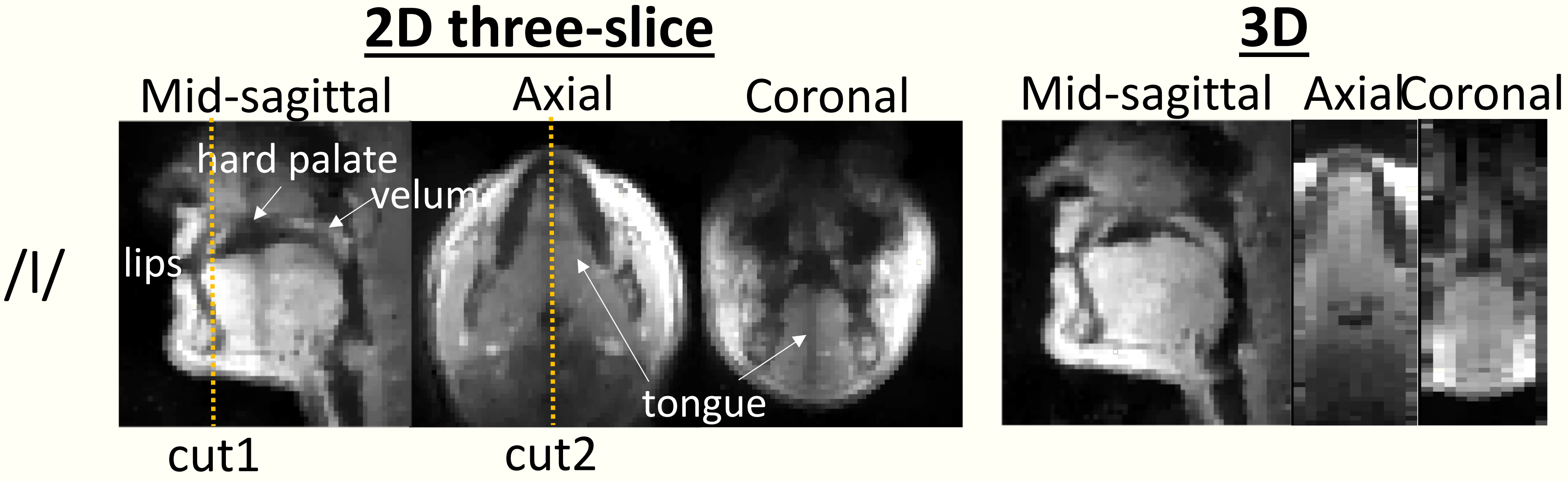
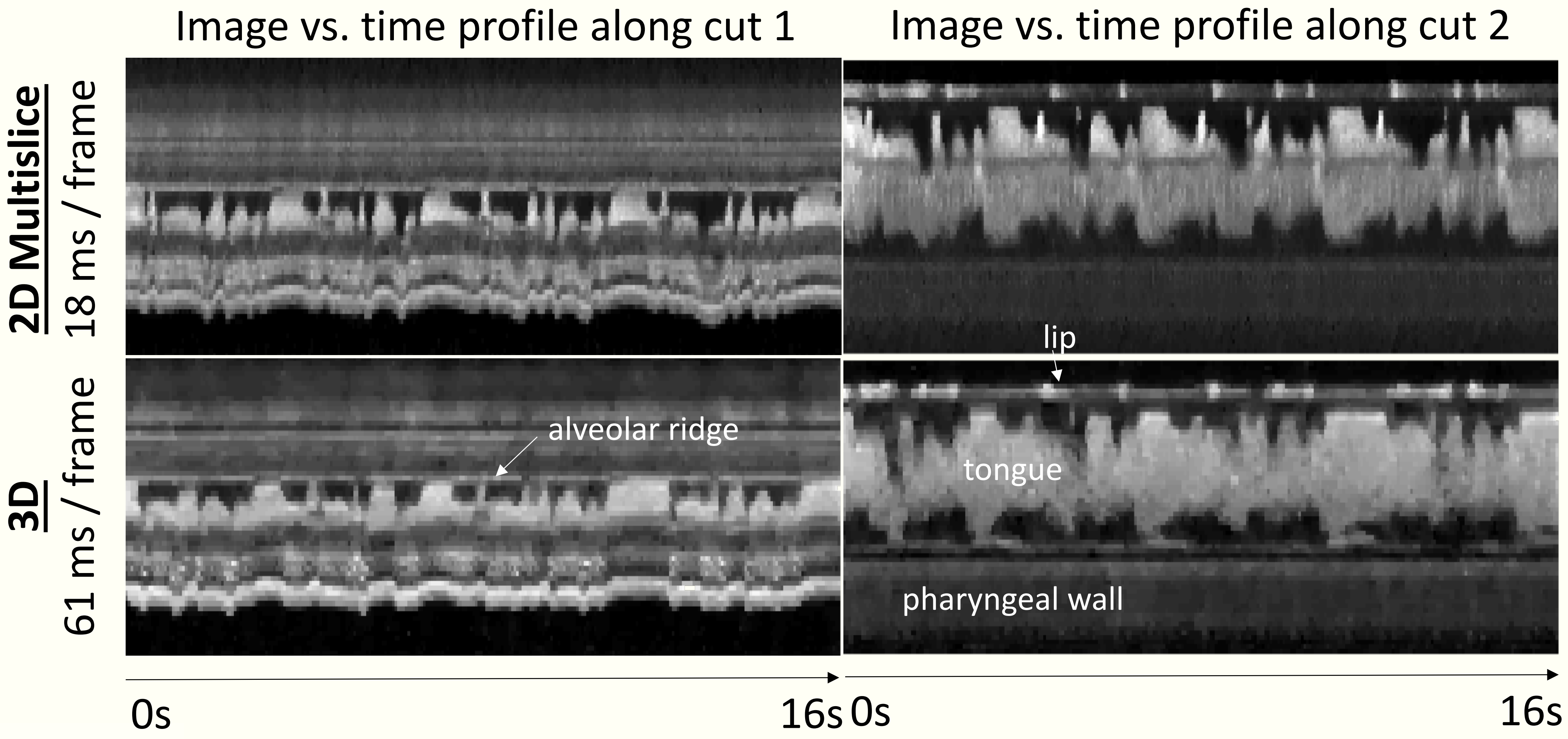
9. Kim YC et al, JRMI. 2012;35:943–948.

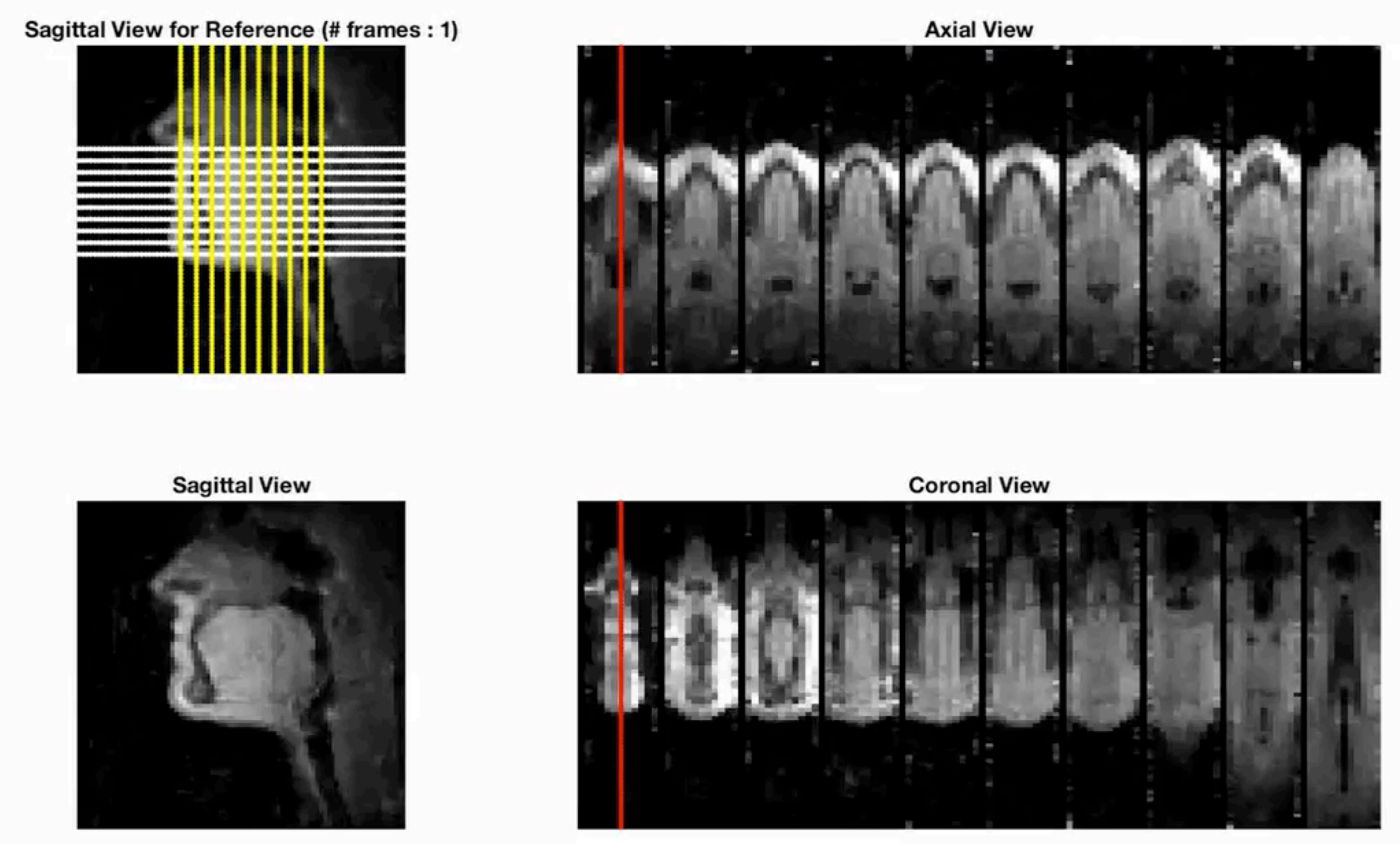
Results – 2D Multislice vs 3D RT-MRI



Results – 2D Multislice vs 3D RT-MRI



Results – 3D RT-MRI with Sync. Audio



Stimuli

Type ‘a slab,’ Abigail.
Type ‘pass lab,’ Abigail
Type ‘a Sal,’ Abigail
Type ‘a say lab,’ Abigail
Type ‘a sap lab,’ Abigail

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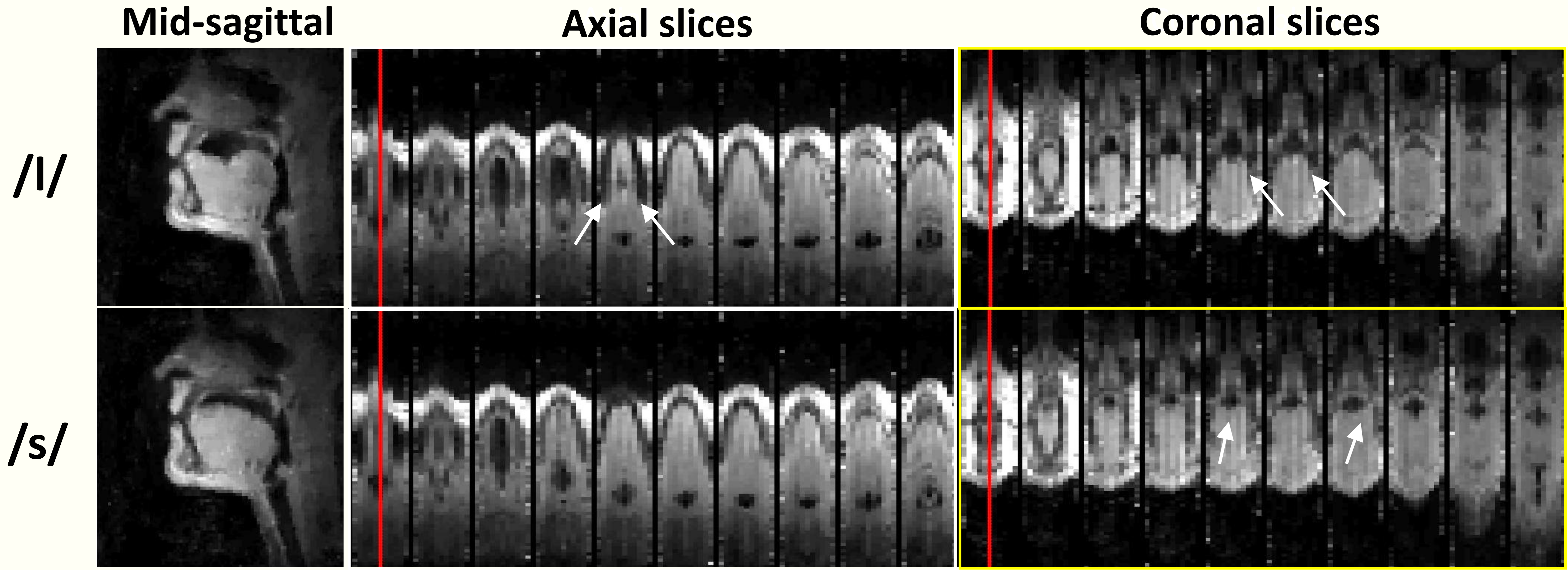
Reformatted image planes

Results – Consonants /s/ and /l/



[l]: tongue sides low, allowing lateral airflow

[s]: tongue sides up and braced and the tongue surface grooved for central airflow

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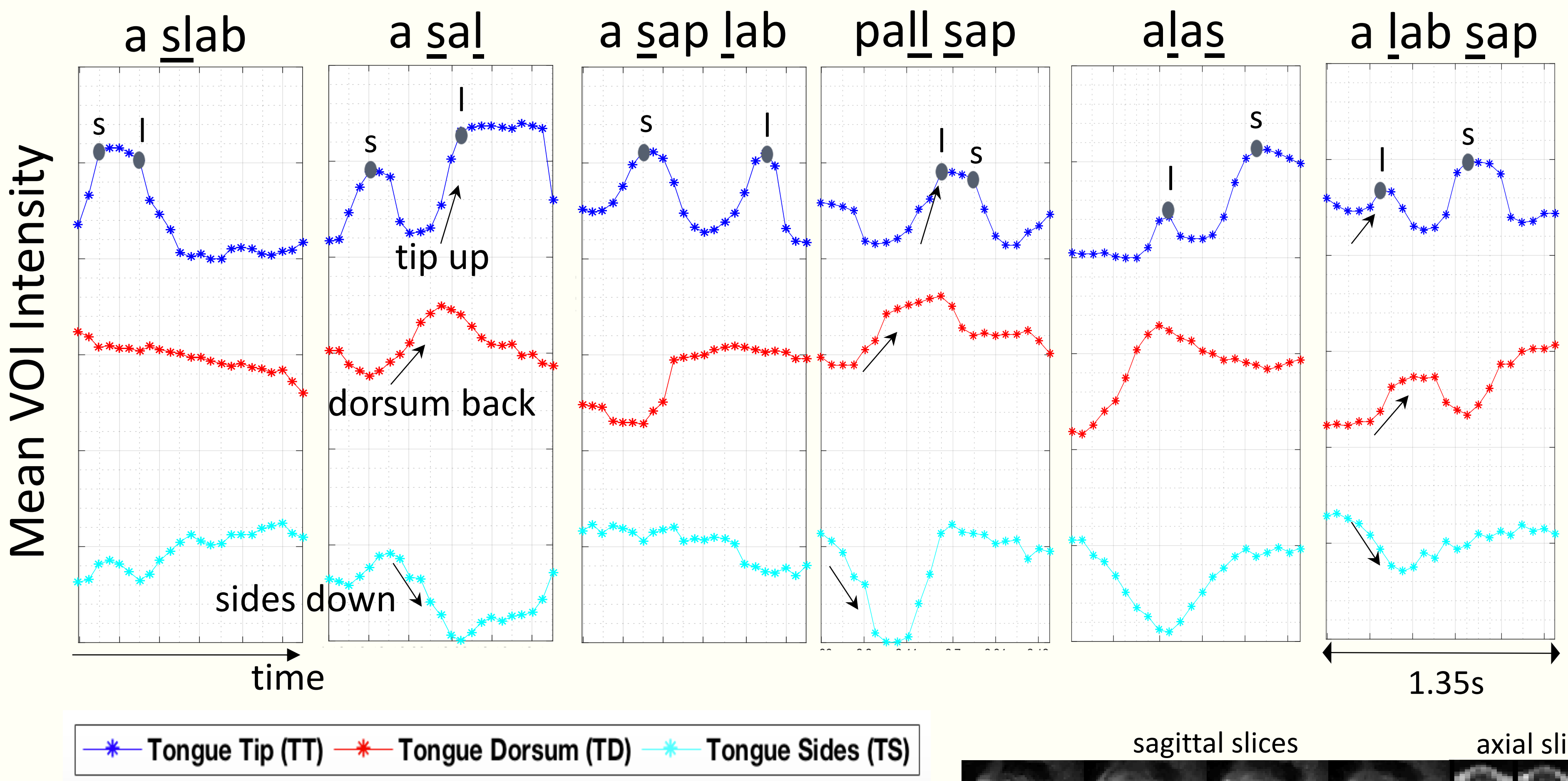
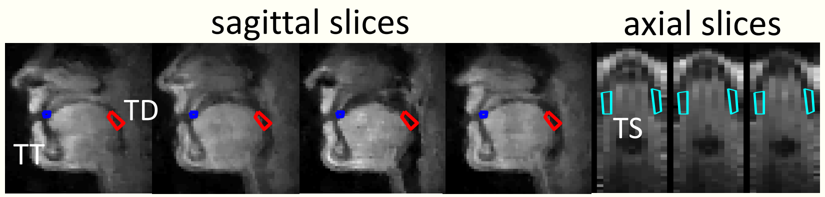
Linguistic Study – Contrasting /s/ and /l/





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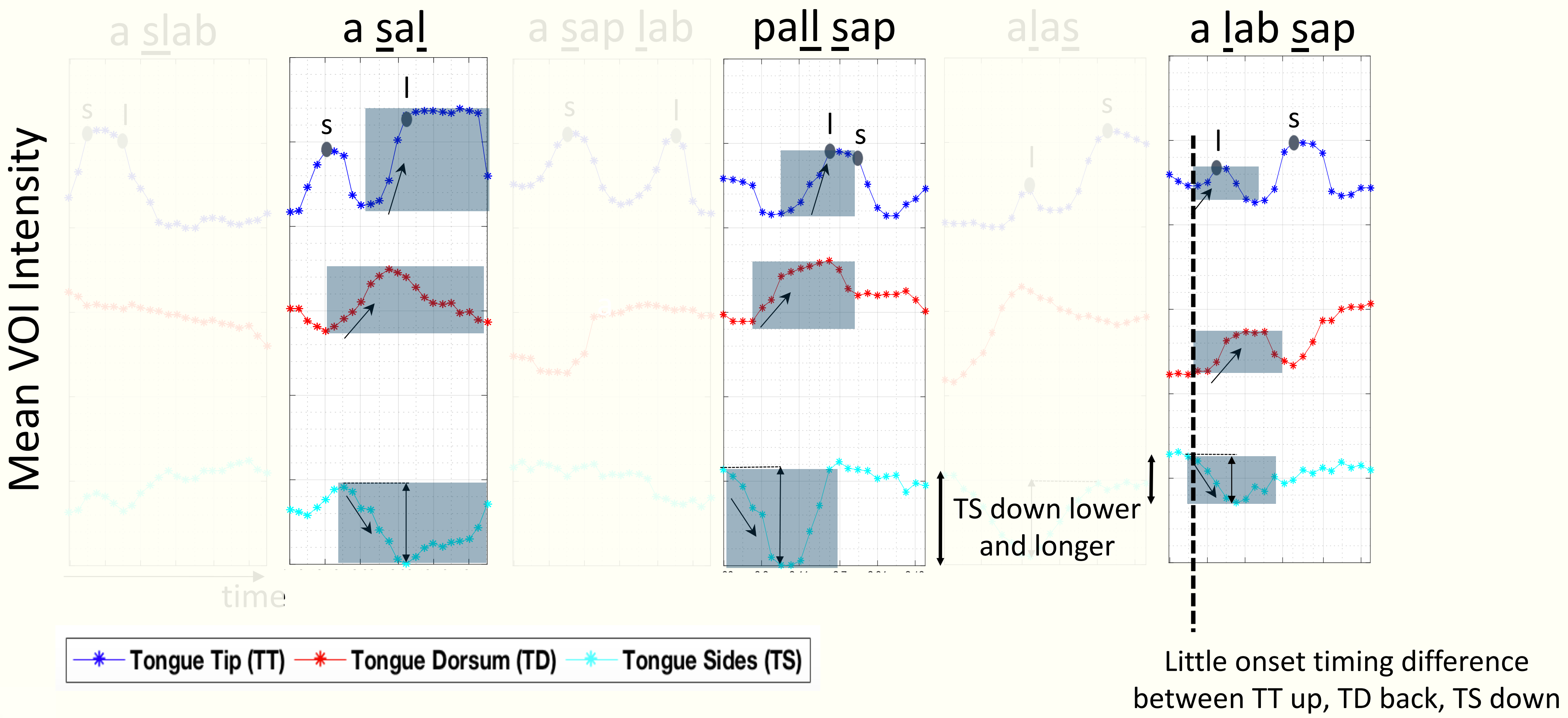
Linguistic Study – Syllable-Final and Initial /l/



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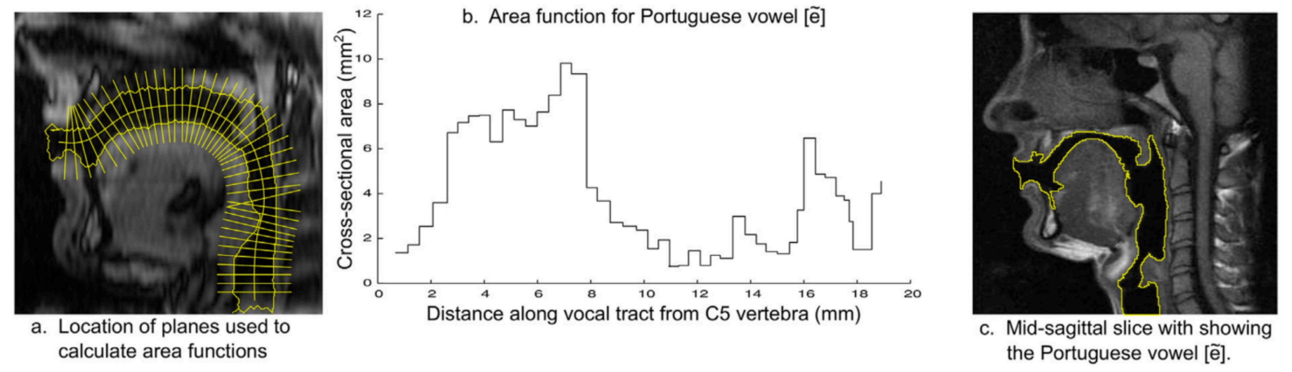
Results – Vocal Tract Area Function

2D static MRI (multi-slice)

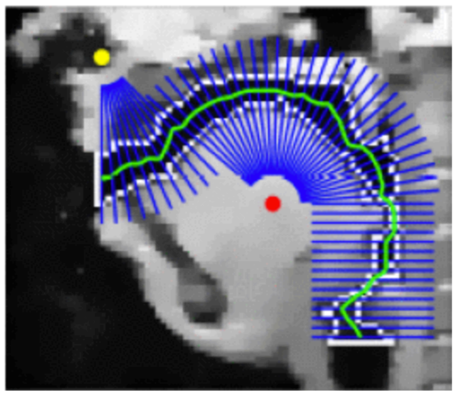


a. Location of planes used to calculate area functions

c. Mid-sagittal slice with showing the Portuguese vowel [ẽ].

Martins, P et al, Speech Commun, 2008

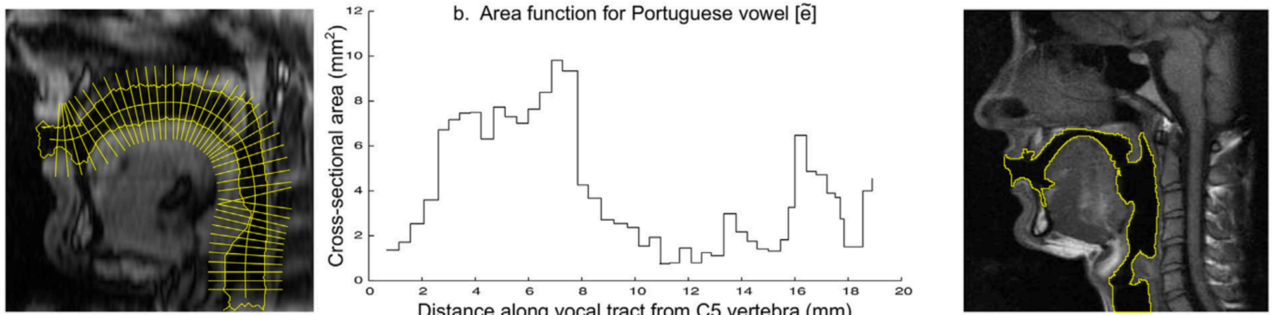
3D static MRI



Skordilis Z et al, ICASSP, 2017

Results – Vocal Tract Area Function

2D static MRI (multi-slice)



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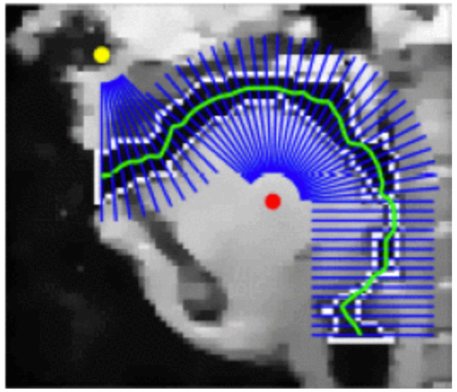

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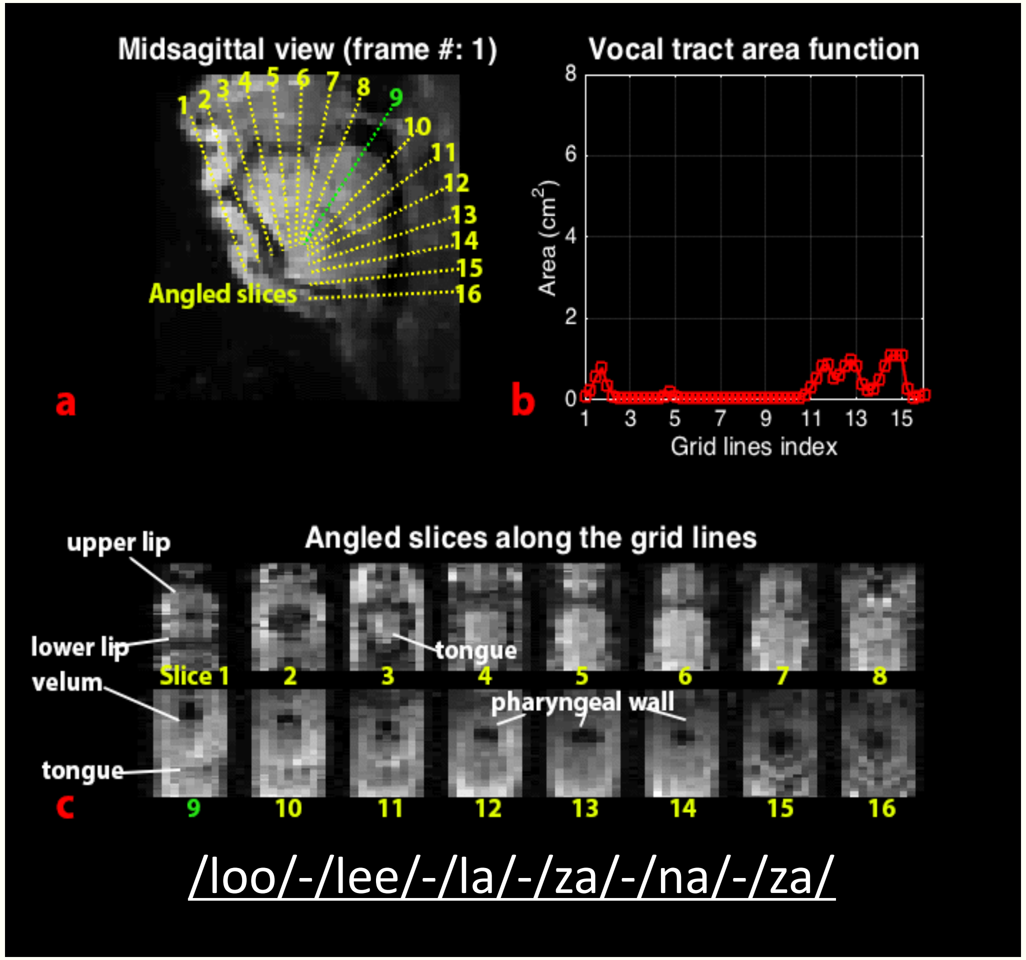
3D RT-MRI



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Conclusion

- Demonstrate feasibility of 3D RT MRI of the full vocal tract, with spatiotemporal resolution adequate to visualize lingual movements and vocal tact shaping occurring during natural speech.
- Use a minimum-phase slab excitation, pseudo GA stack-of-spirals gradient echo, and spatio-temporal finite difference constrained reconstruction.
- Achieve 2.4 x 2.4 x 5.8 mm^3 spatial resolution, 61 ms temporal resolution, and a 200 x 200 x 70 mm^3 FOV, with 13-fold acceleration.

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