Sensitivity of quantitative RT-MRI metrics of vocal tract dynamics to image reconstruction parameters

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Background

- The vocal tract is a complex soft-tissue organ
- Information about dynamic function can be used to…
  - Understand language[1]
  - Improve speech synthesis[2] and recognition[3]
  - Clinical applications such as swallowing,[4] glossectomy,[5] velopharyngeal insufficiency,[6] …

1: Ramanarayanan et al. PLoS One 9, e104168 (2014)
2: Birkholz et al. PLoS One 6, e60603 (2013)
3: Reynolds et al. Digit. Sign. Proc. 10, 19-41 (2000)
4: Zu et al. JAMA Otolaryng. Neck Surg. 139, 1312-1319 (2013)
5: Stone et al. JSLHR 57, 707-717 (2014)
6: Beer et al. J Magn Reson Imag 20, 791-797 (2004)

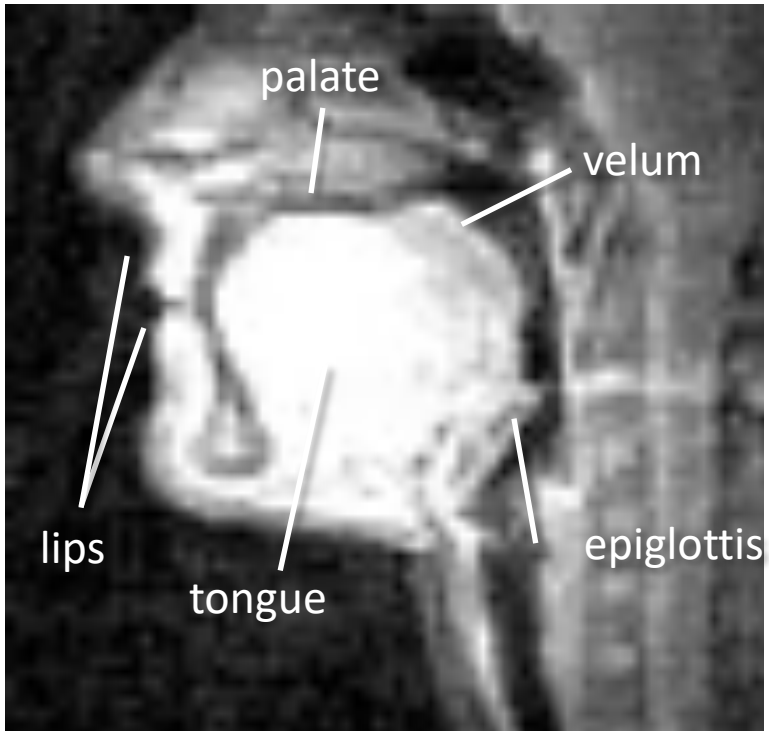
Background

- Using 2D real-time MRI (RT-MRI), dynamic function of the vocal tract can be studied non-invasively[1,2]
- State-of-the-art methods use constrained reconstruction to improve temporal resolution and image quality[3,4]

1: Lingala et al. J Magn Reson Imag 43, 28-44 (2016)
2: Scott et al. Phys Med 30, 604-618 (2014)
3: Lingala et al. Magn Reson Med. (2016)
4: Fu et al. Magn Reson Med 73(5):1820 (2015)

Background

- Our lab: spiral sequence and custom upper airway coil[1]
- Reconstruction based on temporal finite differences
- Spatial resolution 2.4 x 2.4 mm^2
- Temporal resolution up to 83.3 frame per second (fps)



1: Lingala et al. Magn Reson Med. (2016)

Background

- Constrained reconstruction – solve for image f:

$$\min_f \|A(f) - b\|_2^2 + \lambda \|D_t(f)\|_1$$

Imaging forward model

Reconstructed image

Measured MRI data

Regularization parameter

Temporal finite difference operator

Reconstructed image

- Regularization parameter λ is chosen heuristically[1], without quantitative guidance

1: Lingala et al. Magn Reson Med. (2016)

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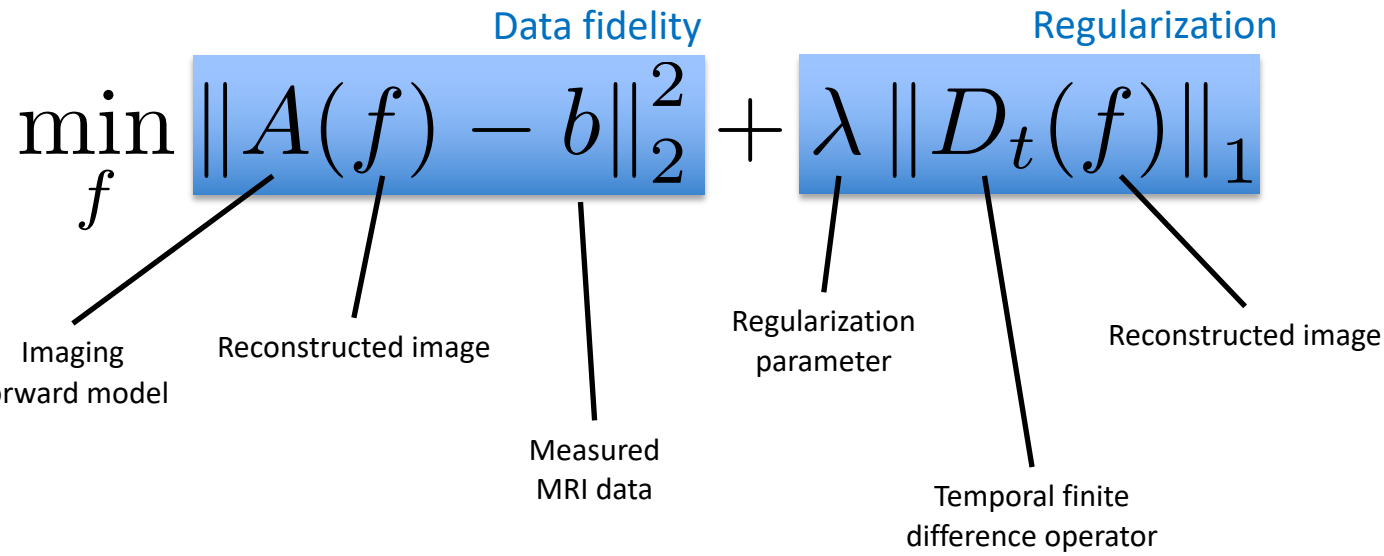

- Regularization parameter λ is chosen heuristically[1], without quantitative guidance

1: Lingala et al. Magn Reson Med. (2016)

Background

- Regularization parameter λ, tradeoff:
  - Higher λ
    → less noise/aliasing
    → more smoothing
  - Lower λ
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$\lambda = 0.04$

$\lambda = 0.0025$

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- Variable number of spirals per frame, tradeoff:
  - More spirals
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    → but lower fps
  - Fewer spirals
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8 spirals (21fps)

2 spirals (83fps)

*13 spirals for full (Nyquist) sampling → a native temp. resl. of 12.8 fps

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Background

- What is the optimal value of λ?
- What is the optimal number of spirals per frame?
- How to quantify 'optimal'?

- In this work: Optimize for *repeatability* of quantitative measures of dynamic speech function

Aim

- Explore the influence of temporal resolution and the reconstruction parameter λ on the repeatability of quantitative measures of speech derived from 2D RT-MRI scans of the human vocal tract

Methods

Magnetic resonance imaging

- GE Signa 1.5T MRI scanner
- Custom upper airway coil
- Bit-reversed spiral sequence[1]
- Spatial resolution : 2.4 x 2.4 mm^2
  slice thickness : 6 mm
  TE/TR/FA: 0.8 ms / 6 ms / 15°

1: Lingala et al. Magn Reson Med. (2016)

Methods

Image reconstruction

- Constrained reconstruction based on temporal finite differences[1]

Variable number of spirals per frame		Regularization parameter λ
2 (83 fps) 3 (56 fps) 4 (42 fps) 8 (21 fps)	X	0.00025, 0.0005, 0.001, 0.0015, 0.002, 0.004, 0.006, 0.008, 0.012

*13 spirals for full (Nyquist) sampling ➔ a native temp. resl. of 12.8 fps

- Reconstruction performed for all 36 combinations

1: Lingala et al. Magn Reson Med. (2016)

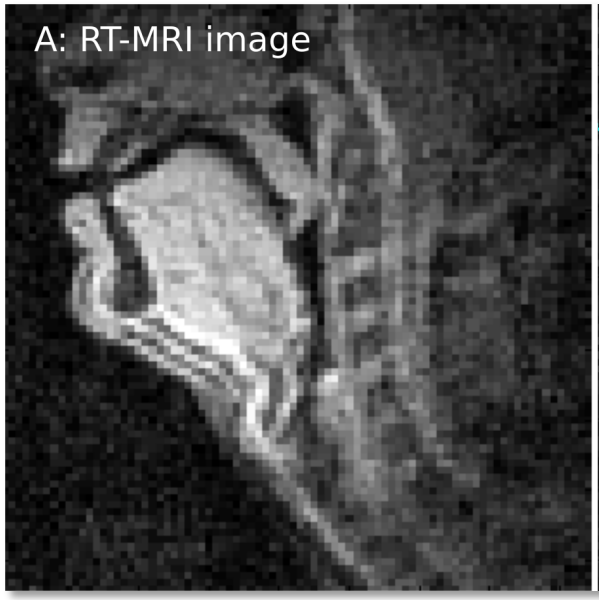
Methods

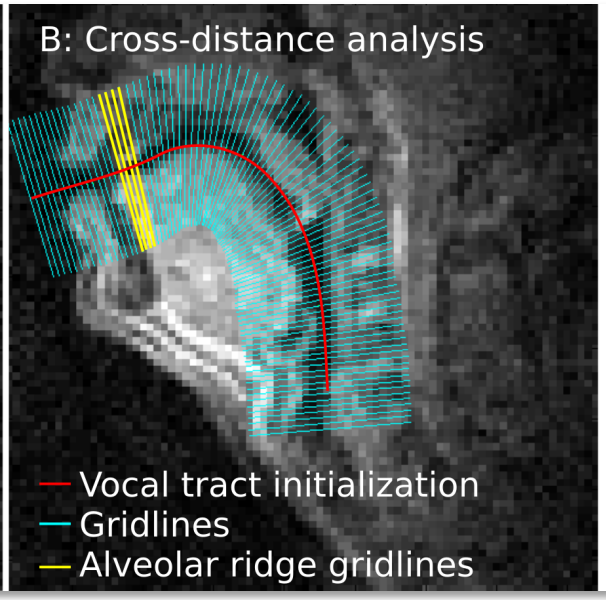
Subject and speech task

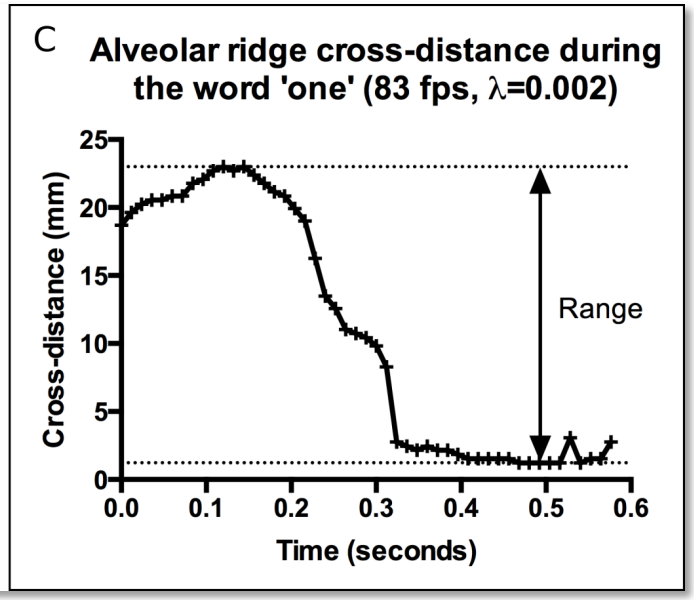
- One healthy volunteer recruited
- Speech task: ‘one-two-three-four-five’ at a normal pace
- 8 repetitions

Methods

Data analysis



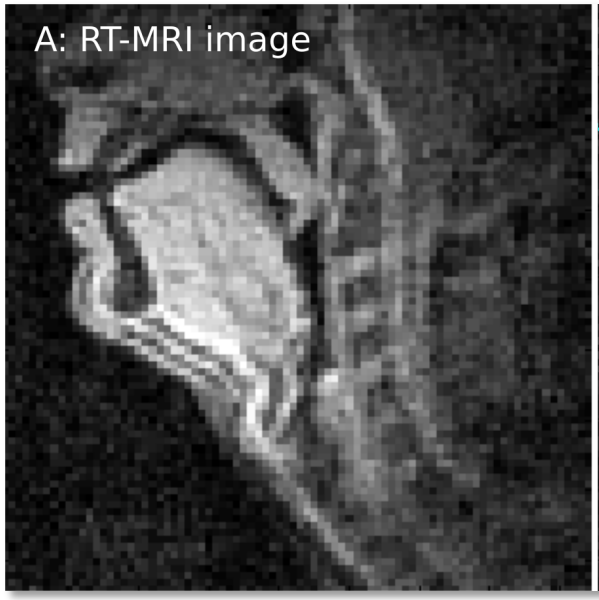


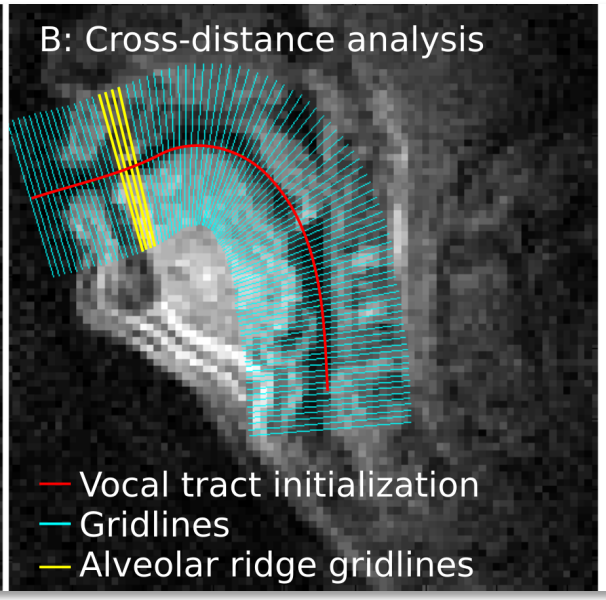


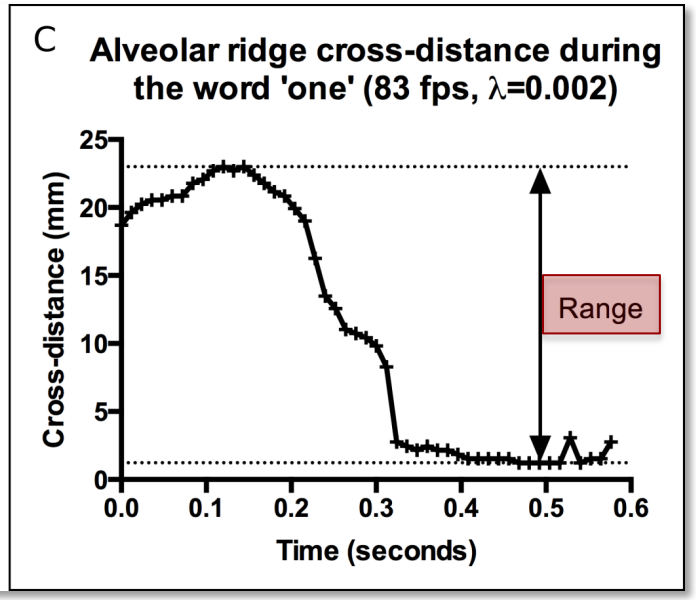
Kim et al. *Proc. 10th Int. Semin. Speech Prod.*, pp. 222–225, 2014.

Methods

Data analysis







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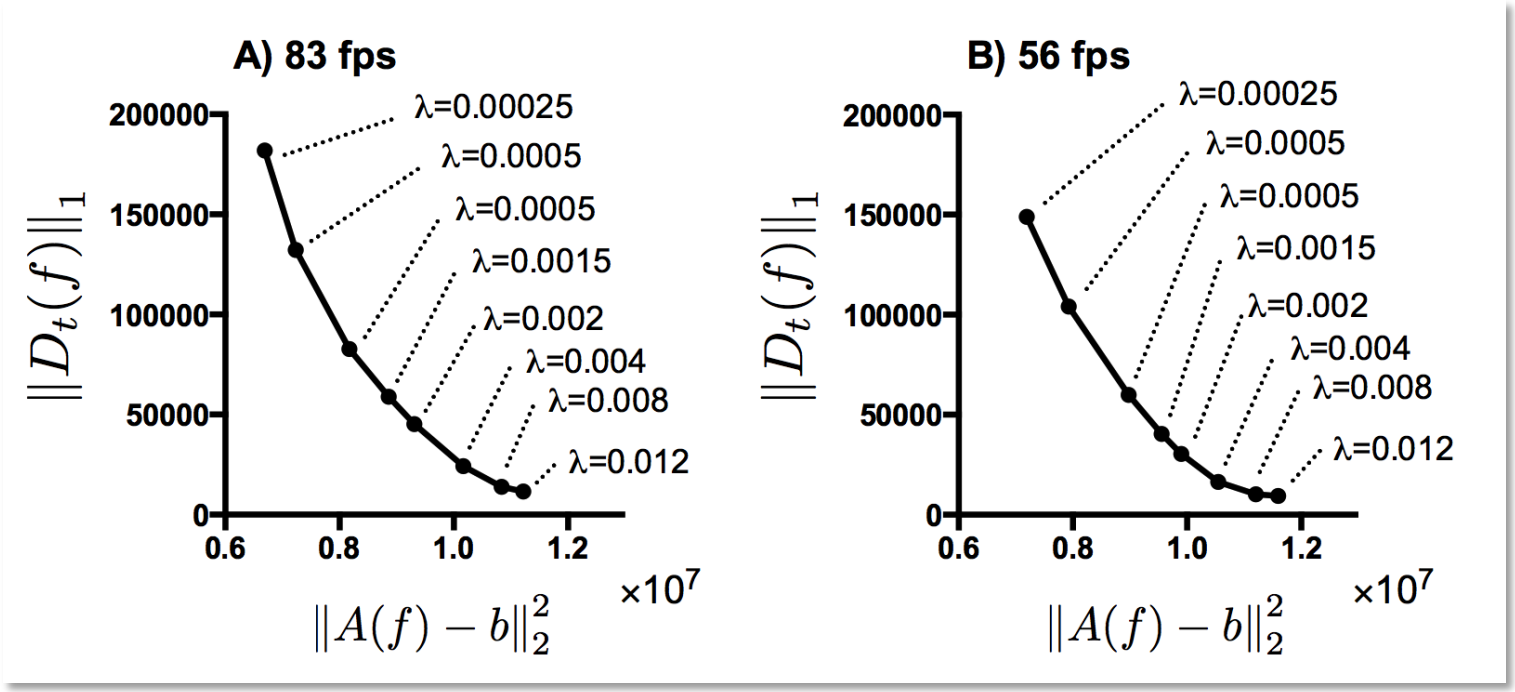
Methods

Data analysis

- Mean of motion range over 8 repetitions
- Standard deviation (SD)
  - Low SD indicates strong repeatability

Results

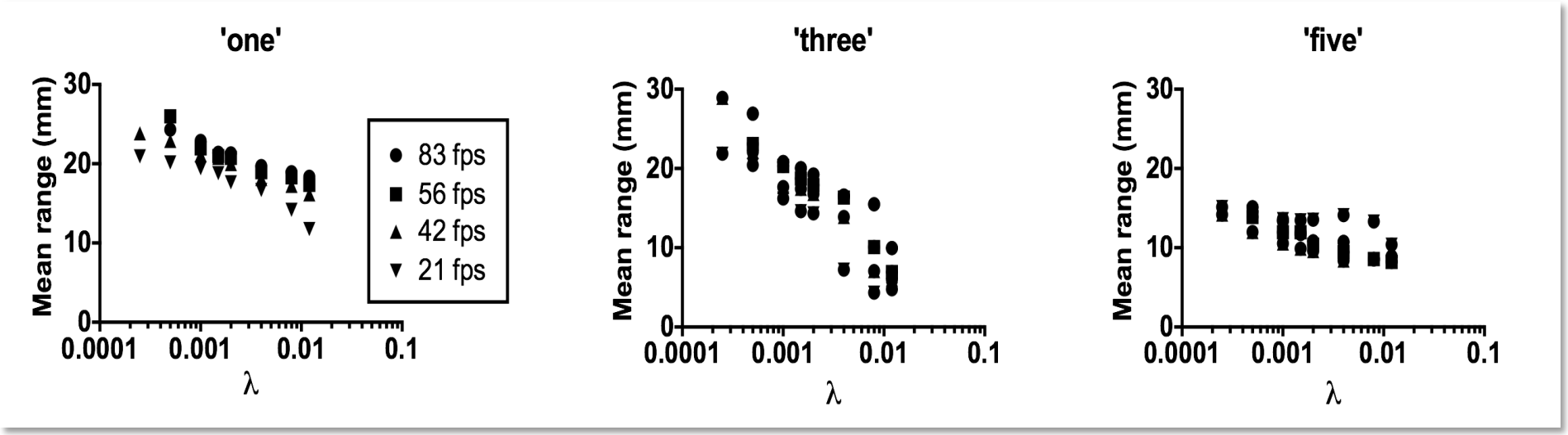
L-curves



Hansen, SIAM review 34(4):561-580, 1992

Results

Mean range values



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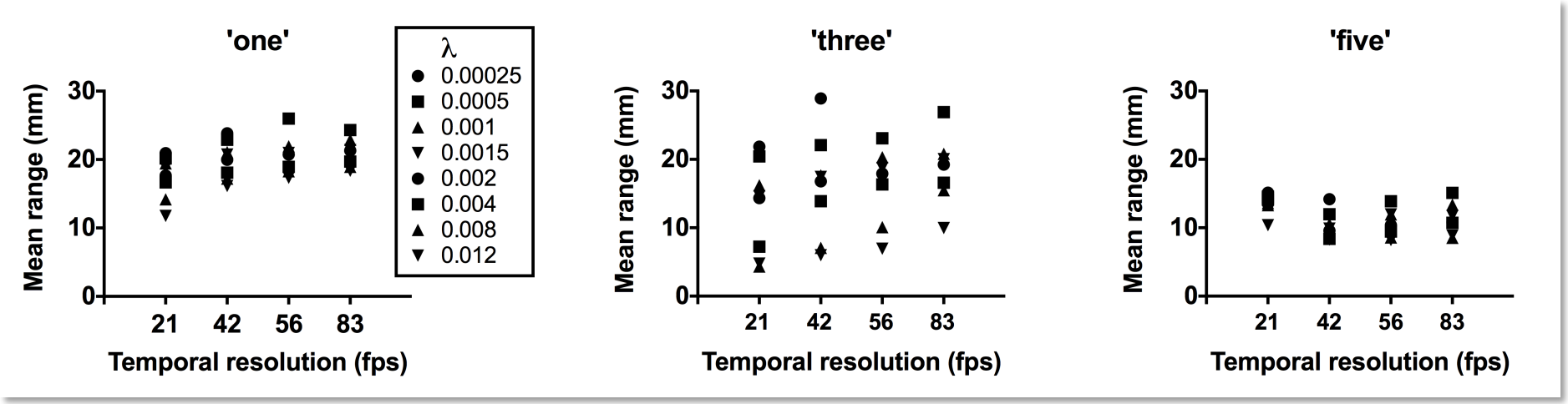
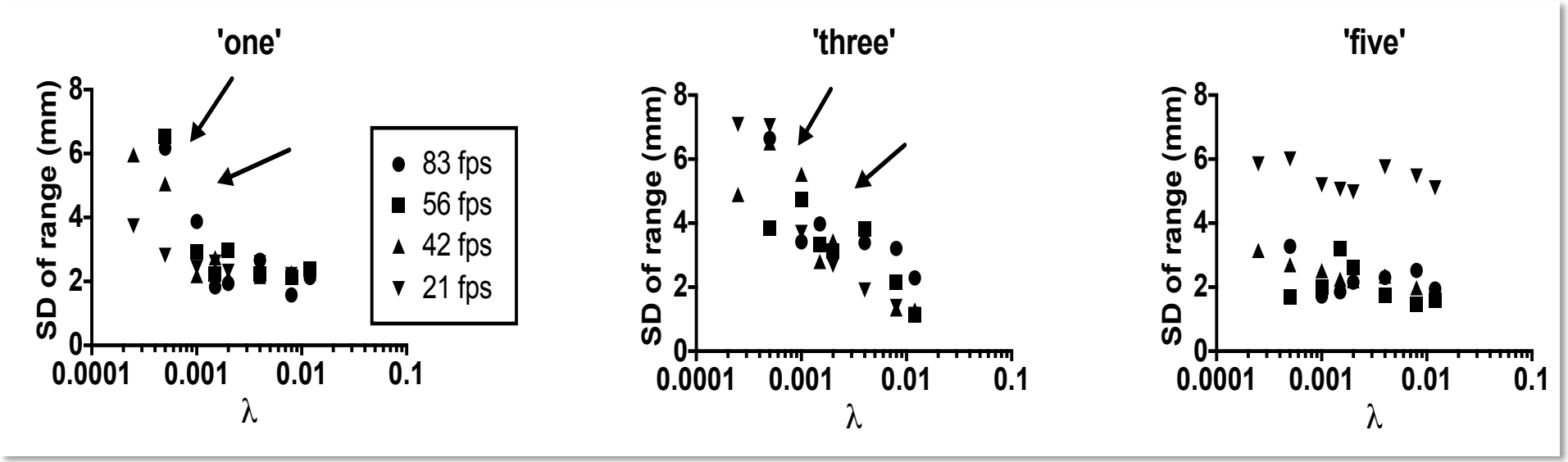


Results

Repeatability: standard deviation



Results

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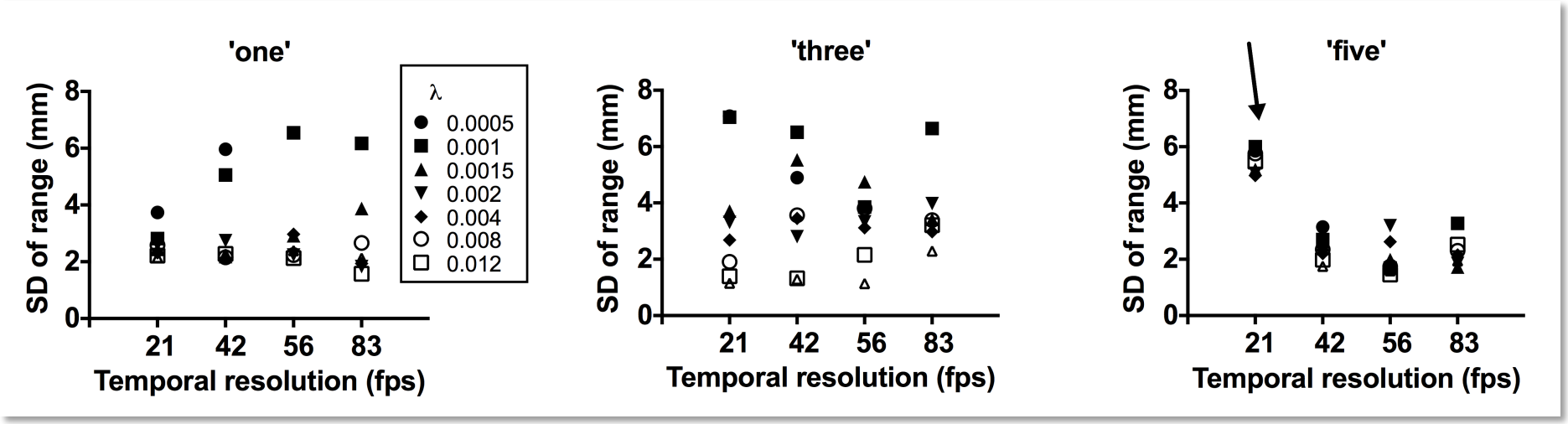

Conclusions

1. We investigate the sensitivity of quantitative metrics of dynamic vocal tract function to choice of reconstruction parameters for real-time vocal tract MRI using constrained reconstruction

Conclusions

2. The regularization parameter λ can influence quantitative metric of speech
   - Choosing a too small λ (<< 0.002) gives poor reproducibility
3. A temporal resolution of at least 42 fps is needed to achieve good repeatability for normal-paced speech in this study
   - Higher or lower depending on speech task

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