

Accelerating Real-time MRI of speech using spiral through-time GRAPPA

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PURPOSE: Real-time MRI (RT-MRI) is a powerful tool to safely assess and quantify the vocal tract dynamics during speech production. Applications are numerous including addressing open questions in speech science, and informing treatment plans in clinical applications (e.g., oropharyngeal cancer). RT-MRI is intrinsically challenged by trade-offs amongst the spatio-temporal resolution, slice coverage, and signal to noise. Several rapid MRI methods have been previously applied to improve the above trade-offs including non-Cartesian imaging [1], parallel imaging [2], and joint non-Cartesian-parallel imaging with constrained reconstruction [3-5]. In this work, we evaluate the potential of a fast linear reconstruction method through-time GRAPPA (TT-GRAPPA) [6-7] to efficiently exploit the acceleration capabilities offered by a custom 8-channel upper-airway coil and spiral trajectories. We report feasibilities of 3 to 4 fold acceleration, and demonstrate the utility of TT-GRAPPA in improving the temporal resolution and slice-coverage in dynamic speech imaging.

METHODS: Experiments were run on GE Signa Excite 1.5 T scanner with a custom 8-channel upper-airway coil; the coil was designed to provide high sensitivity over all upper-airway articulators (lips, tongue, glottis, velum). Gradient echo based multi-shot short interleaved spiral sequences ($T_{read}=2.4$ ms, $TR=6.004$ ms; Flip angle= 15°) were implemented at different spatial resolutions, while making maximum use of gradients (40 mT/m amplitude and 150 mT/m/ms slew rate). TT-GRAPPA in all experiments was performed with 100 calibration frames, and block sizes of 1x1 in the read x azimuthal directions:

(a) **Retrospective down-sampling:** To determine feasible acceleration levels, we retrospective down-sampled fully-sampled spiral data acquired with linear angle increments (12 interleaves, 2.5 mm²). Two speech tasks were considered in the mid-sagittal plane (a) 10 sec of fluent speech production at normal speaking rate, which was used for TT-GRAPPA calibration; and (b) 10 sec of counting numbers at a normal speaking rate, which was used as reference fully-sampled data. Under-sampling factors, $R=2,3,4,6$ were considered, and image quality was evaluated in terms of mean square error, and visual analysis of spatio-temporal fidelity of moving articulator boundaries.

(b) **Golden angle view-order acquisition:** Golden-angle TT-GRAPPA [8] was implemented to evaluate the gains in enabling high temporal resolutions. Pseudo-golden angle time interleaved data with periodicity of 13 interleaves at 2.4 mm² spatial resolution was acquired in the mid-sagittal plane. During calibration, the golden-angle interleaves were sorted linearly and played, while fluent speech data was acquired for 10 sec. A task of counting numbers at a rapid speech rate was considered during acquisition. TT-GRAPPA reconstructions of this task were performed at different time resolutions (5 interleaves, 3 interleaves), and visually evaluated against gridding reconstruction from fully-sampled data (13 interleaves).

(c) **Self-calibrated acquisition:** Self-calibrated TT-GRAPPA [9] was implemented, where the number of fully-sampled interleaves/frame (4 interleaves/frame) equaled the desired acceleration factor (4 fold). This corresponded to a spatial resolution of 4.5 mm². A simultaneous 3-slice sequence (axial, coronal, sagittal) was realized to visualize the rapid speech task of producing the sound “*loo-lee-la-za-na-za*”. TT-GRAPPA reconstructions were performed for each slice using 1 interleave at a net time resolution of 3TR/frame.

RESULTS: Figure 1 demonstrates that acceleration rates of 3-4 fold are feasible with TT-GRAPPA ($nRMSE \leq 10\%$). The spatio-temporal dynamics of the articulator boundaries are robustly depicted at up to $R=4$. At $R \geq 6$, spatial blurring artifacts appear at moving edges, which is attributed to the large gaps in k-space coupled with the limited number of receiver coils. Figure 2 demonstrates the improved time resolution enabled by the 5TR, and 3TR TTGRAPPA reconstructions in depicting rapid articulatory movements (eg. tongue tip hitting the palate) during the task of counting numbers at a rapid speech rate. Figure 3 demonstrates extremely rapid multi-slice imaging, where the vocal tract shaping is characterized in three planes with a net time resolution of 3TR/frame. This allowed capture of tongue grooving (in the coronal plane), and pharyngeal airway shaping in two-dimensions (in the axial planes) with high temporal fidelity.

DISCUSSION: We have demonstrated improved RT-MRI of speech using acquisitions with a custom upper-airway coil, spiral trajectories, and linear TT-GRAPPA reconstruction. Acceleration factors of 3-4 fold were achieved. Up to 52 frames per second (18ms/frame) was achieved in single slice (2.4 mm²), and three-slice (4.5mm²) imaging. The performance can be further improved by adding spatio-temporal constraints (not shown). The linearity of TT-GRAPPA allows for fast reconstruction (latency <500 ms, with efficient code implementations [10]), which is important for experiment designs that require real-time feedback (e.g, on-the-fly visualization of rapid speech stimuli in different orientations to localize a desired slice, immediate visualization of events such as swallowing). Self calibration enables linear spiral interleaf order with small angle increments, and produces less acoustic noise compared to golden-angle and bit-reversed interleaf orders, making it compatible with simultaneous recording of high quality audio [11].

REFERENCES:

- [1] Narayanan, S., Nayak, K., Lee, S., Sethy, A., & Byrd, D., An approach to real-time magnetic resonance imaging for speech production. Journal of the acoustical society of America, 115(4), 1771-1776, 2004.
- [2] Scott, A. D., Wylezinska, M., Birch, M. J., & Miquel, M. E., Speech MRI: Morphology and function. Physica Medica.vol.30; pp 604-618, 2014. [3] Fu, M., Zhao, B., Carignan, C., Shosted, R. K., Perry, J. L., Kuehn, D. P., ... & Sutton, B. P. High resolution dynamic speech imaging with joint low-rank and sparsity constraints. Magnetic Resonance in Medicine, 73(5), 1820-1832, 2015.
- [4] Iltis PW, Frahm J, Voit D, Joseph AA, Schoonderwaldt E, Altenmüller E. High-speed real-time magnetic resonance imaging of fast tongue movements in elite horn players. Quantitative Imaging in Medicine and Surgery., 5(3): 374-381, June 2015.
- [5] Lingala SG, Zhu Y, Kim YC, Toutios A, Narayanan S, Nayak KS. High spatio-temporal resolution multi-slice real time MRI of speech using golden angle spiral imaging with constrained reconstruction, parallel imaging, and a novel upper airway coil. Proc. ISMRM 23rd Scientific Sessions, June 2015, p689.
- [6] Seiberlich N, Ehnes P, Duerk J, Gilkeson R, Griswold M, Improved radial GRAPPA calibration for real-time free breathing cardiac imaging, Magn. Res. Medicine, 65(2):492-595, Feb 2011.
- [7] Seiberlich N, Lee G, Ehnes P, Duerk J, Gilkeson R, Griswold M, Improved temporal resolution in cardiac imaging using through-time spiral GRAPPA, Magn. Res. Medicine, 66 (6):1682-8, Dec 2011.

[8] Han et al. Golden Angle Through-Time Radial GRAPPA for Real-Time Cardiac MRI. Proc. of ISMRM 2013, #3834.
 [9] Hamilton et al. Self-Calibrating Interleaved Reconstruction for Through-Time Non-Cartesian GRAPPA. Proc. of ISMRM 2013, #3836.
 [10] J. M. Santos, G. A. Wright, J. M. Pauly, Flexible real-time magnetic resonance imaging framework, *Proc. 26th Ann. Int'l Conf. IEEE EMBS*, p. 1048-1051, 2004.
 [11] E Bresch, JF Nielsen, KS Nayak, S Narayanan. Synchronized and noise-robust audio recordings during real-time magnetic resonance imaging scans. *Journal of the Acoustical Society of America*. 120(4):1791-1794. October 2006.

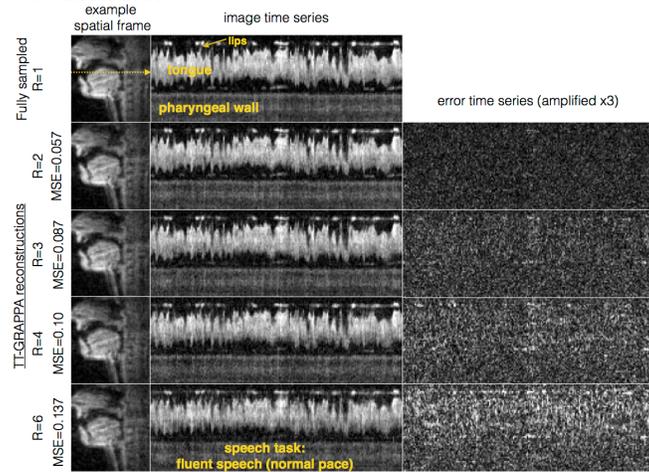


Figure 1: TT-GRAPPA reconstructions from retrospective downsampled data of fully-sampled spiral data (12 interleaves/frame, 2.5mm²). Graceful degradation of the reconstructions are observed with increasing R. Spatio-temporal fidelity is maintained up to R=4. At R>=6, spatial blurring of the high frequency edges is visually evident.

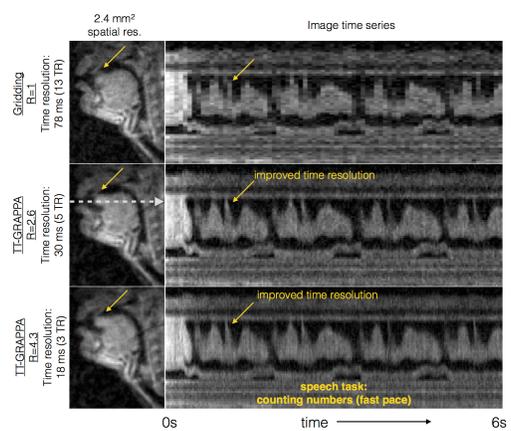


Figure 2: TT-GRAPPA enables reconstruction at 5TR, 3TR time resolutions, and provides improved depiction of rapidly moving articulators (as noted by the crisp image time profiles). The first column depicts improved fidelity in visualizing the tongue-tip hitting the palate by TT-GRAPPA.

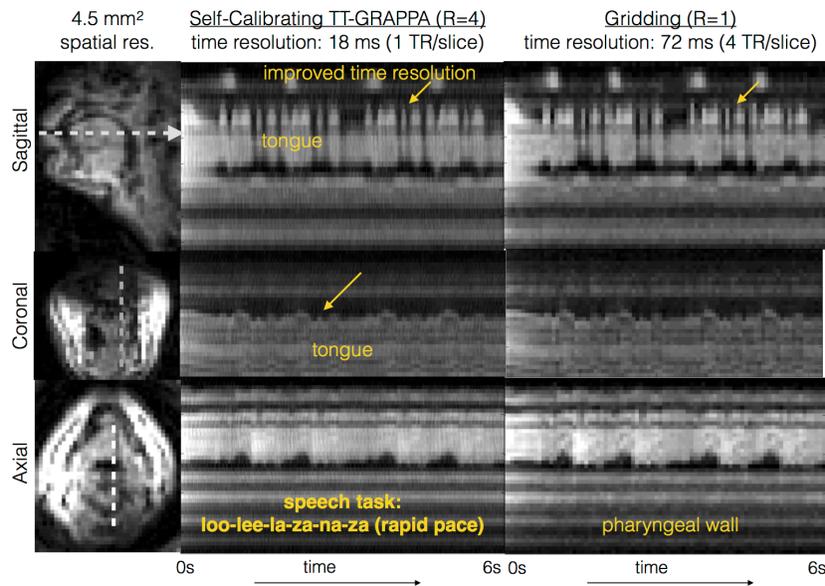


Figure 3: Rapid multi-slice imaging at 18 ms/frame (R=4, self-calibrated TT-GRAPPA) as compared to 72 ms/frame (R=1, gridding). Note the superior temporal fidelity of TT-GRAPPA in depicting rapidly changing articulatory dynamics in different planes.