Flexible retrospective selection of temporal resolution in real-time speech MRI using a golden-ratio spiral view order

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Introduction In speech research using real-time MRI, the analysis of vocal tract dynamics is performed retrospectively after acquiring data in real time [1-4]. A flexible selection of temporal resolution is desirable because of natural variations in speaking rate and variations in the speed of different articulators (e.g. tongue, velum, lips). Golden-ratio view order, when applied to radial or spiral MRI, supports the retrospective selection of temporal resolution at any time point. The effectiveness of the golden-ratio view order was recently demonstrated in real-time cardiac MRI with radial trajectories [5]. In this work, we apply a golden-ratio view order to real-time spiral speech MRI.

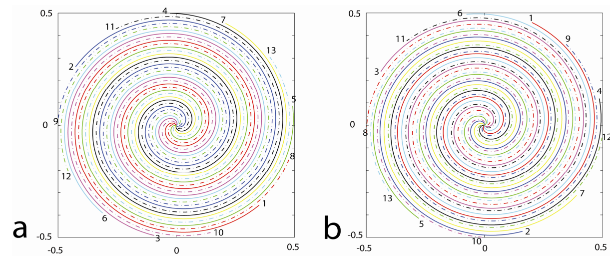

Figure 1. *k-space trajectories for (a) bit-reversed 13-interleaf UDS and (b) golden-ratio spiral view order when the samples from 13 consecutive TRs are combined. Temporal view orders are marked with the numbers on each end of the spiral interleaves.*

Methods and Results ***(Simulation)*** A simulation study was performed to illustrate either a penalty or benefit of spiral golden-ratio view order. This was based on the imaging protocol routinely used in real-time MRI speech research conducted by Speech Production and Articulation kNowledge (SPAN) group at the University of Southern California. The imaging protocol was: 13-interleaf uniform density spiral (UDS), 20×20 cm^2 FOV, TR = 6.356 ms, temporal resolution = 83 ms, bit-reversed temporal view order (Fig.1a). Golden-ratio spiral view order (Fig.1b) was performed by sequentially incrementing the interleaf angle by the golden-ratio angle 360°/1.618 = 222.4969° at every TR. Because golden-ratio sampling results in non-uniform angle spacing of spiral interleaves in k-space, unaliased FOV (Fig.2) was defined to be the reciprocal of the maximum sample spacing in k-space.

Figure 2 contains a plot of unaliased FOV as a function of temporal resolution (i.e. the number of TRs (#TRs)). For #TRs = 13, the 13-intl UDS supports a larger unaliased FOV than the golden-ratio. When #TRs becomes a Fibonacci number (e.g. 2,3,5,8,13,21), there is a change in unaliased FOV for the golden-ratio (see the increase from 17.1 cm to 27.6 cm when #TRs changes from 20 to 21). For #TRs = 8, the 13-intl UDS provides inconsistent FOVs (6.7 cm and 10 cm unaliased FOVs). The FOVs for the 13-intl UDS are smaller that those for the golden-ratio when #TRs is from 8 to 12. Golden-ratio view order provides single unaliased FOV at any time point for any temporal resolution.

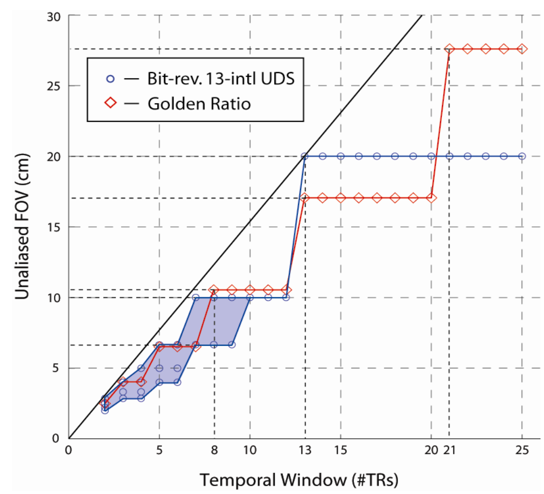

Figure 2. *Retrospective selection of temporal resolution: Comparison of the golden-ratio view order with the bit-reversed 13-intl UDS. The shaded region indicates that unaliased FOV varies in the bit-reversed 13-intl UDS case when #TRs <10. The black solid line illustrates a linear relationship between unaliased FOV and temporal resolution when designing UDS trajectories under the same spatial resolution and readout duration constraints.*

(In-Vivo) Scan was performed on a GE Signa Excite 1.5 T scanner with a 4-channel upper airway receive coil (two coils in the anterior and two coils in the posterior) using custom real-time imaging software [6]. The golden-ratio method was compared with the bit-reversed 13-intl UDS method on the same mid-sagittal scan plane of the upper airway. A female volunteer was instructed to speak "go pee shop okay" and "bow know" for both the 13-intl UDS and golden-ratio acquisitions in the real-time MRI scan. Prior to the scan the volunteer was trained to hear the 160 bpm metronome sound and keep the same speech pace. Gridding reconstruction was used in the reconstruction of real-time spiral data.

Figure 3 compares the 13-intl UDS and golden-ratio images reconstructed from the data acquired when the subject paused. Because of little or no motion, a longer temporal window was applied in the golden-ratio data. Aliasing artifacts are removed (see the arrows in (b)) due to a larger FOV available from the golden-ratio. Figure 4 contains dynamic frames. Less temporal blurring is seen in tongue tip (see the solid arrows in (b)). Velum opening is better visualized in long temporal window (see the hollow arrow in (d)).

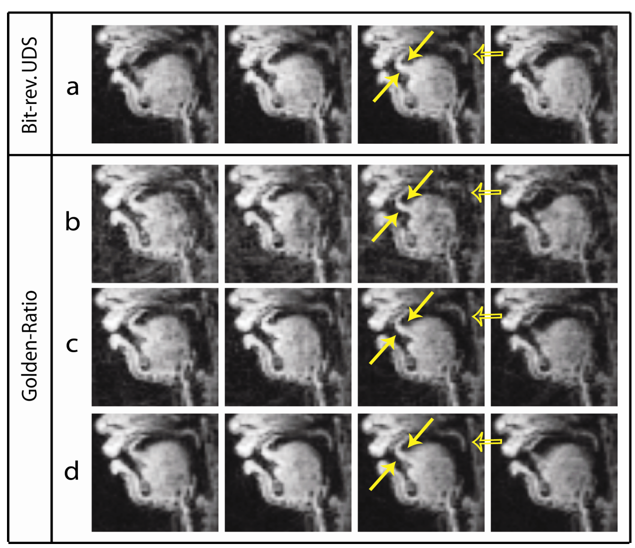

Figure 4. *Vocal tract dynamics when producing /n/ in the articulation of /bono/. The frame update rate was 51 ms. (a) Bit-reversed 13-intl UDS with 83 ms (=13TRs) temporal resolution. Golden-ratio view order with (b) 51 ms (=8TRs), (c) 83 ms (=13TRs), and (d) 133 ms (=21TRs) temporal resolution. (b-d) results were obtained after retrospective selection of temporal resolution from the same real-time data.*

Discussion The dynamic speech imaging results (Fig. 4) suggest that the analysis of the timing of velum and tongue tip coordination may be improved by using golden-ratio view order. Parallel imaging reduction factor can also be flexibly chosen and applied to dynamic golden-ratio data to remove aliasing in the images from undersampled data and potentially further improve temporal resolution.

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References [1] Narayanan *et al.*, J. Acoust. Soc. Am. 1771-1776 (2004); [2] Byrd *et al.*, J. Phonetics 37:97-110 (2009); [3] Bresch and Narayanan, IEEE TMI 28:323-338 (2009); [4] Conway *et al.*, ISMRM p2005 (2008); [5] Winkelmann *et al.*, IEEE TMI 26:68-76(2007); [6] Santos *et al.*, IEEE EMBS (2004).

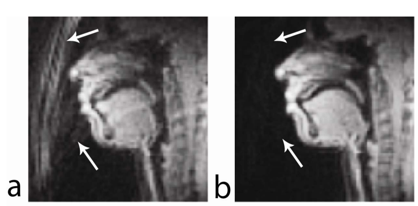

Figure 3. *Static-posture images reconstructed using (a) 13-intl UDS and (b) golden-ratio view order with a 133 ms (=21 TRs) temporal window.*