Weisskoff Stability Metrics Dependence on k-space Trajectory

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Introduction: Quality assurance (QA) of an MR scanner's signal stability is an important aspect of quality control, especially when acquiring data known to be adversely affected by system instabilities such as functional MRI. The FBIRN approach [1] for quality assurance for fMRI is well-known and has become a *de facto* standard in the field. One measurement in particular, the Weisskoff plot [2] and its associated radius of decorrelation (RDC) metric, is often used to compare systems. The RDC is known to be strongly influenced by the noise level of the data. For example, it is possible to produce an improved (larger) RDC simply by adding artificial noise to the acquired data. However, it has not been widely reported that the observed RDC is affected by the k-space trajectory type. Here we present stability measurements from a single scanner collected over the timeframe of one week using four distinct k-space acquisition trajectories: Cartesian, multivane (propeller), spiral and radial. The vane (blade) width of the multivane scans was varied to range from more cartesian-like to more radial-like.

Methods: Six complete data sets were acquired on an Achieva 3T scanner (Philips Healthcare, Best, The Netherlands) over the course of one week. Each data set included 8 stability scans each with 100 dynamics. All scans used 256 k-space data vectors to reconstruct a single image. Each dynamic scan consisted of a single 256×256 2D gradient echo slice with TR/TE/FA = 10ms/3.5ms/30° and sampling bandwidth = 200 Hz/pixel. The acquisition data window length (5 ms) was consistent across all trajectory types: Cartesian, multivane, radial and spiral. A 17cm diameter spherical FBIRN gel phantom (UCSD, CA) was imaged in a T/R bird cage head coil. Two scans used a Cartesian trajectory – one with a single acquisition per dynamic and another using the average of two acquisitions (2 NSA) per dynamic. Four scans used a multivane (propeller) trajectory with vane (blade) width set to either 64, 32, 16 or 8 lines of k-space. Scans using a spiral-out and radial trajectory were also acquired. The data sets were analyzed automatically using a prototype fMRI quality assurance tool developed in-house. The tool automatically places the largest possible rectangular region of interest within the imaged phantom and calculates summary metrics according to the FBIRN procedures described in [1]. Mean metric values and 95% confidence intervals were calculated. Finally, cross correlation coefficients across the 8 scan types were calculated between metrics using their raw and logarithmic values.

Results: Table 1 lists the mean metric values plus or minus the 95% confidence interval (CI) half-width. Signal-to-noise ratio (SNR) and signal-to-fluctuation-noise ratio (SFNR) values are grouped closely together across the 8 scan types. As expected, the two acquisition Cartesian scan has roughly sqrt(2), 1.41, higher SNR and SFNR than its single acquisition counterpart. The 95% confidence intervals for SNR and SFNR for the multivane scans all overlap. Similarly, the SNR and SFNR confidence intervals for spiral and radial overlap. RDC varies significantly across the trajectory types. For the two Cartesian scans, the RDC confidence interval overlaps despite the large difference in SNR/SFNR between the two Cartesian scan types. There is a trend towards larger RDC as the scan becomes less Cartesian-like, i.e. as multivane vane widths decrease. The spiral and radial scan types have the largest RDC values. Spectral noise peak (SNP) follows a similar, but opposite trend, as compared to RDC. The relationship between RDC and SNP is supported by the cross-correlation values presented in Table 2. Among all considered metrics, RDC correlates well (absolute value > .80) only with SNP. The best RDC correlation (-0.925) occurs between the log of RDC values with the log of SNP values.

Table 1. Stability metric values versus k-space trajectory types (mean ± 95% CI half-width)

	SNR	SFNR	RDC [pixels]	Spectral Noise Peak [%]
Cartesian (2 acquisitions)	57.68 ± 1.65	59.26 ± 1.34	11.70 ± 0.43	2.95 ±0.37
Cartesian (1 acquisition)	41.20 ± 1.00	42.02 ± 1.07	13.24 ± 1.42	3.58 ±0.73
Multivane 64×4	50.74 ± 1.00	51.96 ± 1.20	19.88 ± 2.04	1.93 ±0.35
Multivane 32×8	50.78 ± 1.20	51.94 ± 1.23	25.87 ± 2.28	1.41 ±0.19
Multivane 16×16	51.02 ± 1.01	52.18 ± 1.20	37.82 ± 6.55	1.22 ±0.28
Multivane 8×32	50.84 ± 1.19	51.88 ± 1.20	44.01 ± 4.94	0.94 ±0.28
Spiral	45.90 ± 1.40	46.88 ± 1.47	49.57 ± 6.56	1.17 ±0.35
Radial	44.36 ± 1.04	45.76 ± 1.07	61.65 ± 13.06	1.18 ±0.55

Table 2. Cross correlation values between stability metrics

	log(SNP)	log(RDC)	log(SFNR)	log(SNR)	SNP	RDC	SFNR	SNR
SNR	-0.002	-0.293	0.998	0.998	-0.068	-0.341	0.999	1.000
SFNR	0.000	-0.289	0.998	0.997	-0.067	-0.332	1.000	
RDC	-0.843	0.977	-0.296	-0.309	-0.807	1.000		
SNP	0.988	-0.898	-0.121	-0.119	1.000			
log(SNR)	-0.051	-0.252	0.999	1.000				
log(SFNR)	-0.051	-0.245	1.000					
log(RDC)	-0.925	1.000						
log(SNP)	1.000							

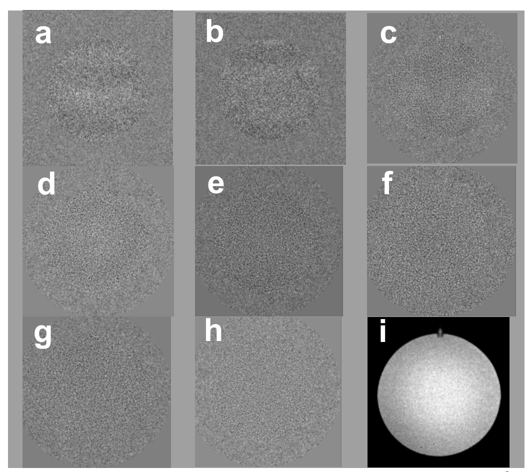

Figure 2. Example static spatial noise images (**a**-**h**) acquired using the different trajectories: one acquisition (**a**), and two acquisition (**b**) Cartesian, Multivane 64×4 (**c**), 32×8 (**d**), 16×16 (**e**), 8×32 (**f**), spiral (**g**) and radial (**h**). An example SFNR image is shown for the spiral trajectory (**i**).

Conclusions: Though increased noise can yield higher Weisskoff RDC values, SNR and SFNR differences cannot explain the observed RDC differences when using different k-space acquisition trajectories. Non-cartesian trajectories such as multivane, spiral and radial yield higher RDC values when compared to equivalent Cartesian acquisitions. The larger RDC values of the non-cartesian scans correlates with a lower spectral noise peak percentage. In fact, the trajectory types known to produce colored noise in the spatial domain (denser sampling of the center of k-space) yield a whiter (more uniform) noise spectrum in the temporal domain. Most importantly, any site seeking to use Weisskoff stability metrics to compare the performance of multiple MR scanners should take into account differences in the k-space trajectory type.

References: 1. Friedman L and Glover G. JMRI (2006) 23:827-839 2. Weisskoff RM. MRM (1996) 36:643-645