Inter-scan motion artefacts in quantitative R1 mapping require correction of coil sensitivity profiles

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TARGET AUDIENCE: Researchers and clinicians combining multi-scan data to estimate quantitative MRI parameters

PURPOSE: Methods for quantitative R1 mapping such as multi-parameter mapping (MPM[1]) or DESPOT1[2] frequently rely on multiple scans for parameter estimation. Any motion between scans is considered negligible or corrected using rigid body motion correction methods[1]. The rapidly varying local sensitivity of multi-channel coils means that rigid-body motion correction is insufficient, since the signal intensity is additionally modulated by position-specific coil sensitivity profiles. We demonstrate the impact of this effect, both in terms of increased variance and in terms of a low spatial frequency variation in an R1 map, and introduce and validate a correction method based on measuring coil sensitivity profiles.

METHODS: R1 maps were estimated from two high-resolution 3D FLASH acquisitions with different excitation flip angles (FA=21 ^{o} (T1-weighted) or 6^{o} (PD-weighted)); common parameters were: 3T MAGNETOM TRIO TIM system (Siemens AG, Healthcare Sector, Erlangen, Germany), FoV=256x240x176mm^3, TR=25ms, 8 echoes with TE/echo spacing/echoes=2.34/2.3ms, GRAPPA 2x2, elliptical scanning, 1mm isotropic resolution, RF receive 32-channel head coil. For each high-resolution acquisition a coil sensitivity map was estimated by acquiring two low-resolution scans with identical FoV (TR/TE=4.64/2ms, FA=6^{o}, 4mm isotropic resolution), one using the RF receive body coil, and one using the RF receive 32-channel head coil. The low-resolution images were co-registered to the high-resolution images and up-sampled to 1mm resolution. The low-resolution 32-channel data were voxel-wise divided by the body coil data, resulting in a coil sensitivity map that combined the effect of all the coil elements. The original high-resolution images were divided voxel-wise by the sensitivity map, removing the modulations due to the coil sensitivity profile from the images. A custom-made 3D EPI acquisition of spin and stimulated echoes was performed at the beginning of the session to correct for local RF transmit field inhomogeneities, along with B_0 field mapping used to correct for susceptibility-related distortion[3]. All data analysis was performed in MATLAB (The Mathworks, Natick, USA) using SPM12b and custom-made programs.
To assess motion artefacts in R1 maps caused by inter-scan head motion, four volunteers (age: 33-43y, 2 m, 2 f) were scanned twice with the R1 mapping protocol. The second protocol acquisition was performed at a different head position but in the same session. The motion between scans was estimated by rigid body motion correction implemented in SPM12b[4]. Motion parameters covered a wide range from 6.1mm to 31.7mm translation and 1.4^{o} to 16.1^{o} in rotation to demonstrate the robustness of the proposed method.
All possible combinations of PD-, and T1-weighted acquisitions were used to estimate a total of four R1 maps per volunteer: two with inter-scan motion, and two without. A second set of R1 maps was calculated using the proposed correction scheme to account for the position-dependent sensitivity profile modulation. The R1 maps were segmented into grey (GM) and white matter (WM) probability maps. A brain voxel mask was created using a probability threshold of 95% on GM and WM. A coefficient of variation (CoV), defined as the standard deviation divided by the mean, was calculated across all voxels within grey and white matter, respectively.

RESULTS: Table 1 shows the coefficient of variation for R1 values calculated from data with and without correction for inter-scan motion, averaged over all volunteers. In uncorrected data, inter-scan motion increases the CoV by 54.5% and 67.9% in grey and white matter respectively, while in corrected data the increase is 3.9% and 3.7% respectively. Fig. 1 shows R1 maps for the second volunteer. An anterior-posterior (A-P) intensity gradient can be observed in the uncorrected, inter-scan motion affected map, also reflected in the pairwise difference maps (Fig. 2).

Data type	Coefficient of variance in grey matter			Coefficient of variance in white matter		
	No inter-scan motion	Inter-scan motion	Difference	No inter-scan motion	Inter-scan motion	Difference
Uncorrected	0.134±0.015	0.207±0.031	54.5%	0.084±0.007	0.141±0.026	67.9%
Corrected	0.129±0.009	0.134±0.007	3.9%	0.082±0.007	0.085±0.008	3.7%

Table 1 Coefficients of variation (mean±sd) for corrected and uncorrected R1 maps by tissue class.

CONCLUSIONS: We have demonstrated the negative impact of inter-scan motion on the accuracy of quantitative R1 mapping. The proposed method effectively corrects for the position-specific coil sensitivity modulation. It can be extended to other multi-scan methods that rely on combining separate acquisitions, and are thus affected by inter-scan motion.

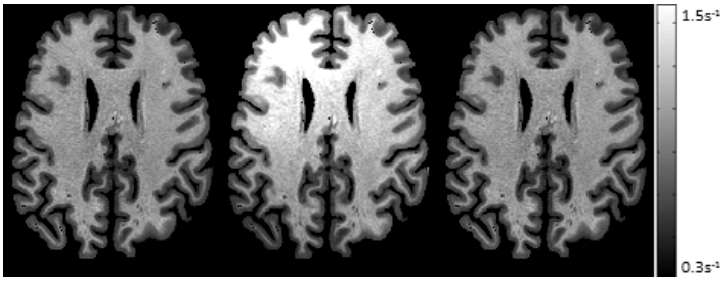

Figure 1: R1 maps without inter-scan motion (left), with inter-scan motion (middle), and with correction for inter-scan motion (right).

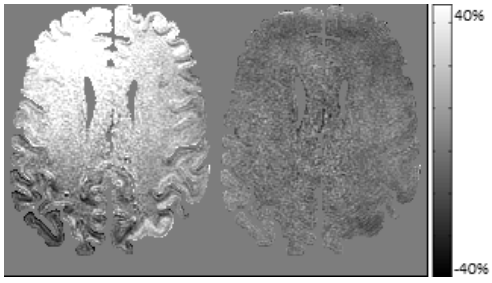

Figure 2: Difference maps between R1 estimates with and without inter-scan motion, using uncorrected data (left) and corrected data (right). A clear A-P gradient is visible in the uncorrected data, which is corrected for by our method.

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References: 1, Weiskopf, N. *et al*, Front Neurosci, 2013; 2, Deoni, SC *et al*, Magn Reson Med, 2005, 3, Lutti, A. *et al*, Magn. Reson Med, 2010; 4, Frackowiak, R.S.J. *et al*, Human Brain Function, 2004