RF PULSE COMPARISON FOR THE HYBRID GRADIENT AND SPIN ECHO EPI PULSE SEQUENCE FOR FMRI

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Introduction: The interest for hybrid or simultaneous gradient and spin-echo echo planar imaging (EPI) sequence (here called hybrid EPI) has recently grown for different applications [1-3] like vessel size imaging [1], perfusion weighted imaging [2] and functional MRI (fMRI) [3]. This pulse sequence is composed of a classical gradient-echo (GRE) EPI followed by a refocusing pulse and a second EPI read-out to sample the spin-echo (SE). Hence, both the GRE and the SE are sampled in a single excitation. A difficulty associated with this pulse sequence is to maintain the same slice profile for both GRE and SE, as the SE profile is determined by the multiplication of the GRE profile and the refocusing pulse profile. This slice profile mismatch problem has been shown to be problematic for quantitative imaging (R2/R2*) [4], but is also expected to confound the other techniques mentioned above. Unfortunately, the impact of this problem has not been widely investigated. Here we present preliminary work to reduce the difference between the GRE and the SE profiles. A new pair of RF pulses was developed using the Shinnar-Le-Roux (SLR) algorithm [5] (like in [6]) and compared to the original pulse pair (described below) using simulations. Both pairs of pulses were then implemented in a hybrid EPI pulse sequence and used in an fMRI experiment to determine (i) if slice profile mismatch is problematic for fMRI and (ii) which pulses perform better in the context of fMRI.

Methods: To maintain the minimum achievable TE, the duration of all RF pulses was kept constant and equal to the original SE-EPI RF pulses (referred as original pulses). The main RF pulse design parameters are given in table 1. The newly developed adapted pulses were designed with SLR and a minimum phase constraint to enable a more selective refocusing profile compared to

	Pulse	Phase	Flip (°)	PW (ms)	BW (Hz)	in-band ripple (%)	out-band ripple (%)
Original	Excitation	Minimum	90	5	712	0.1	0.3
	Refocusing	Linear	180	3.2	908	2	0.1
Adapted	Excitation	Minimum	90	5	614	0.1	1
	Refocusing	Minimum	170	3.2	897	0.1	1

Table 1: SLR RF pulses design parameters (PW=pulse width, BW=Bandwidth).

its linear phase counterpart [5]. On the other hand, it introduces additional dephasing. To compare the simulated profiles, the slice profiles of the two pairs of RF pulses were simulated assuming 3mm slice thickness and equivalent slice selective gradients for the excitation and the refocusing pulses.
FMRI data were then collected on two healthy volunteers with a 3.0T scanner (MR750, GEHC, Waukesha, WI) and an 8-channel head coil. Data was acquired in axial orientation with the hybrid EPI with both pairs of RF pulses in a random order. A flashing checkerboard paradigm was used consisting of a 30s block of a flashing checkerboard (2Hz) following a 30s of a fixation cross, repeated 5 times and preceded by 15s of dummy acquisition. Common acquisition parameters were (TE GRE=30ms, TE SE=80ms, TR=3s, FOV=22cm, thickness=3.0mm, 29 slices, gap=0.4mm, matrix=64x64, acceleration factor=2, fat saturation). In all cases, the same slice selection gradient was used for the excitation and refocusing pulse.
The fMRI data were analyzed using SPM8 [7]. Head motion parameters and global signal fluctuations (within white matter and cerebrospinal fluid) were included as nuisance regressors in the general linear model (GLM) in addition to the stimulation regressor of interest. The GLM was performed separately on the GRE and the SE data using a fixed effect analysis. Two analyses were performed: the first to detect the visual cortex activation due to the fMRI paradigm; the second to compare the GRE and SE data acquired with each pair of pulses separately (i.e. GRE adapted versus GRE original, SE adapted versus SE original).

Results: Comparison of simulated slice profiles of the two pulse pairs is given in terms of Full Width at Half Maximum, at 30% and at 70% of the Maximum (FWHM, FW30 and FW70, respectively) in table 2. Results in table 2 show that the adapted pulses reduce the difference between the GRE and the SE profile compared to the original pulses. The profile mismatch difference at FWHM relative to the GRE FWHM is 6.0% for the original pulses and 1.5% for the adapted pulses. In table 2, θmax is the maximum in-plane dephasing introduced by the RF pulses themselves. It shows that, as expected, the minimum phase refocusing pulse introduces substantial dephasing.
Each data set (both pulse pairs, GRE and SE) shows the expected result in terms of visual activations (p<0.05, whole brain family-wise error (FWE) corrected, figure 1 shows an example), with the SE exhibiting less intense signal change (table 3). However, the comparison between RF pulse pairs (adapted versus original) does not show any statistically significant differences (p>0.3, cluster-wise FWE corrected).

Discussion and Conclusion: Simulation experiments demonstrate that a ~0.2mm (6%) at FWHM slice profile difference is observed in non-optimized RF pulse pairs. SLR RF design principles have been used to minimize this difference to negligible levels (0.04mm, 1.5% at FWHM) enabling slice mismatch confounds to be minimized in hybrid EPI sequences. Limited in-vivo data did not exhibit statistically significant differences between activation maps acquired with optimized and non-optimized RF pulse pairs. Note that the two pulse pairs used in this work has limited slice profile mismatch, the maximum being 6% for the original pulses. In previous work [4], the mismatch was greater than 23% at FWHM which corresponds to a 0.7mm difference for a slice thickness of 3mm. However, when looking at individual results as assessed by maximum T-value, a larger in-plane dephasing (θmax in table 2) corresponds with smaller maximum T-value for both the GRE and SE data (table 3) and seems to play a more important role than a 6% slice mismatch. This phenomenon is not surprising due to the underlying physical mechanism used in fMRI. Overall, these preliminary results suggest (i) keeping the profile mismatch limited (6% seems currently safe), (ii) determining when the profile mismatch become problematic and (iii) investigating in detail the relation, if any, between the dephasing introduce by RF pulses and the activations results. However, additional in-vivo data is required for robust statistical inference to draw a final conclusion.

		GRE	SE	Diff
Original	FW70	2.62	2.48	0.14
	FWHM	3.00	2.82	0.18
	FW30	3.39	3.17	0.22
	θmax	0.15	0.15	x
Adapted	FW70	2.60	2.59	0.01
	FWHM	3.00	2.96	0.04
	FW30	3.41	3.33	0.08
	θmax	0.07	0.25	x

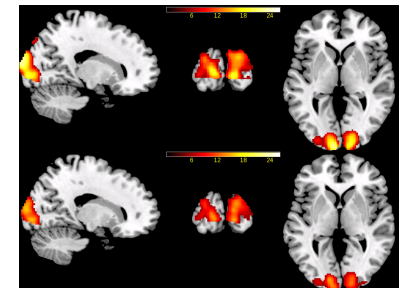**Table 2:** Comparison of the two RF pulse pairs (measurement in mm, except θmax in radians).

Figure 1: Visual cortex activations with the adapted pulses for the GRE (top) and the SE (bottom) (p_{FWE}<0.05). Displayed with the same scale.

	Original		Adapted	
Vol.	GRE	SE	GRE	SE
1	17.05	14.46	19.56	12.69
2	21.91	17.34	25.02	16.42

Table 3: Maximun T-value of the visual cortex activations for each volunteer (GRE and SE).

References: [1] Kiselev et al., MRM, 53:553-563 (2005). [2] Schmiedeskamp et al., MRM, 68:30-40 (2012). [3] Schwarzbauer et al., NeuroImage, 49:316-326 (2010). [4] Schmiedeskamp et al., MRM, 67:378-388 (2012). [5] Pauly et al., IEEE TMI, 10:53-65 (1991). [6] Fernandez et al., ESMRMB, Lisbon, Portugal, 779 (2012). [7] SPM8, Wellcome Trust center for neuroimaging, UCL, London, UK, www.fil.ion.ucl.ac.uk/spm/.