3D single-shot VASO fMRI using a Maxwell-gradient compensated GRASE sequence

B. A. Poser[1,2], and D. G. Norris[1,2]

[1]Erwin L. Hahn Institute for Magnetic Resonance Imaging, University Duisburg-Essen, Essen, Germany, [2]Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Nijmegen, Netherlands

Introduction and Theory

The vascular space occupancy (VASO) method [1] was recently proposed as the first fMRI method capable of detecting activation related CBV changes, without the need for a blood-pool contrast agent. We here present a new whole-brain VASO technique based on a parallel-accelerated single-shot 3D GRASE sequence. Furthermore, we propose a flow-compensated correction for concomitant Maxwell gradients, and demonstrate this is an essential feature for 3D GRASE sequences at 3T; image quality may otherwise be compromised by smearing artifacts that result from violation of the CPMG condition with off-resonance excitation. The method is applied in an fMRI study with visuo-motor stimulation, and a cognitive Stroop task paradigm.

GE-EPI is the most widely used readout for VASO; however this method is prone to BOLD signal contamination and limited to single slice acquisition. The former can be reduced by the use of SE methods [2,3]. The latter is addressed in the MAGIC method [4]. MAGIC uses multiple inversion pulses applied in rapid succession, in between which a few slices (around three) are separately excited and acquired near, but not at, the zero crossing of the blood magnetization. The consequence is hence a slice-dependent signal intensity and CBV weighting [4,5]. Both shortcomings can be removed by use of a single-shot 3D readout following a single inversion. Here, short-TE single-shot 3D GRASE offers itself, and simultaneously features the advantages of SE-EPI. The benefits of 3D GRASE have previously been demonstrated for ASL [6]. One requirement for 3D GRASE is the application Maxwell correction gradients to ensure compliance with the CPMG condition for off-resonance slice positioning [7]. Without compensating gradients before the first refocusing pulse, the strong switching of the readout gradient G_x causes a concomitant field $\Delta B_z \approx z^2G^2/(2B_0)$ at position z, and the phase accrual over a time t_G is $\theta(z) \approx \gamma \Delta B_z t_G$.

Methods

Fig. 1 shows the Maxwell-compensated 3D-GRASE sequence for whole brain coverage, implemented on a 3 T Siemens Magnetom Trio system (Siemens, Germany) equipped with 12- and 32-channel head coils. Volume-selective inversion is achieved by an adiabatic 180º pulse; at time TI slab-selective excitation is performed using a 90º *sinc* pulse with a high BW-time product (20.8) to yield a good slab profile. The 90-180 interval is used to acquire three navigator echoes for phase correction, and to apply intrinsically flow-compensated (tri-polar) correction gradients (dashed lines) that balance the readout gradient switching and associated Maxwell integrals between the 90-180 interval, and 180 pulse and echo formation. An entire k_x-k_y plane of *k*-space is acquired per RF interval. A centre-out scheme is used for the *z* (PE_2) phase encoding and parallel acceleration can be applied along PE_1 and PE_2. Three sets of experiments were performed in accordance with local ethics requirements:

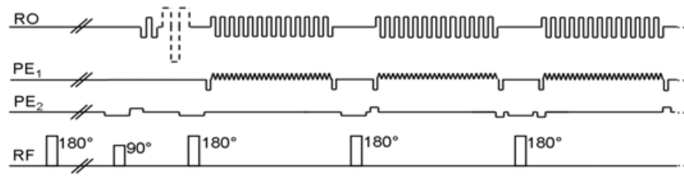

Fig 1: *VASO GRASE sequence with Maxwell compensation (dashed)*

1) To demonstrate the need for Maxwell compensation, a ball phantom was imaged at *z*=0 and *z*=5cm off-centre, with and without correction gradients (12-ch coil, FoV=100x100x50mm³, matrix 64x64x10, 5mm slices, BW=1860Hz/px).

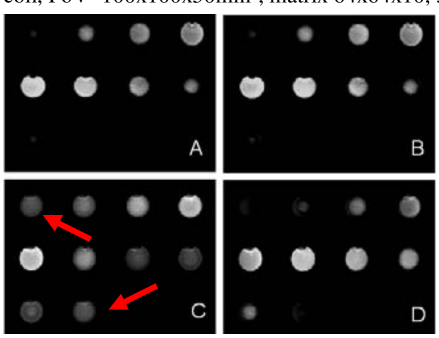

Fig 2: *Effects of Maxwell compensation. Top: z=0 without (A) and with (B) gradients active. Bottom: z=5cm without (C) and with (D).*

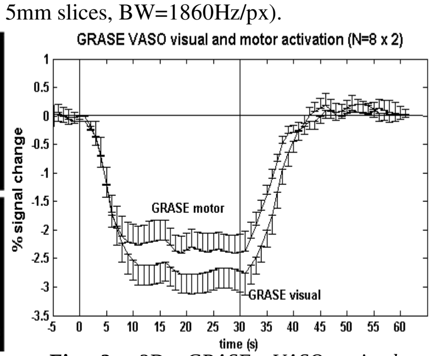

Fig 3: *3D GRASE VASO stimulus response on visual and motor areas (left/right M1, preSMA)*

2) Visual stimulation and simultaneous bilateral finger tapping on 8 subjects with 2 measurements each, using six repeats of 30/30s on/off paradigm (12ch coil, FoV= 224x224x80mm³, matrix 64x64x16+2, 5mm slices, TE= 15ms, BW=1700Hz/px, GRAPPA factor 4x1, TR=2.5s, TI=746ms). Single-slice GE-EPI VASO measurements with corresponding parameters were made for reference.

3) To investigate the applicability to ‘real’ cognitive CBV weighted fMRI studies, a Stroop task paradigm [8] was used (32-ch coil, FoV= 224x224x100mm³, matrix 64x64x20+4, 5mm slices, TE= 14ms, BW=2170Hz/px, GRAPPA factor 4x2=8, TR=2.5s, TI=746ms, T_{acq}=12min). GE-EPI BOLD measurements (TE=35ms) with corresponding geometric parameters were made as a reference. All fMRI data were preprocessed with motion correction and linear drift removal, and activation was detected by t-tests.

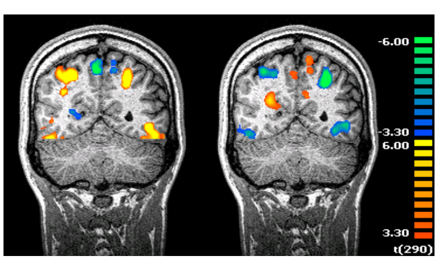

Fig 4: *Whole-brain BOLD (left) and VASO (right) activation maps for the cognitive Stroop task paradigm. Positive signal changes in BOLD are matched by a negative VASO response.*

Results and Discussion

1) The effect of Maxwell compensation is shown in Fig 2. No artifacts are present at the iso-centre irrespective of compensation (A, B). Off-resonance (*z*=5cm, $\Theta_z \approx 98º$) a strong smearing occurred along the *z*-direction (C), but was removed entirely by the compensation (D). **2)** Average CBV response in visual and motor areas is shown in Fig 3 (N=8, 2 runs each, t-test at p<0.01). Activation was detected robustly in visual (-3.11±1.02%, t=-8.42±1.56) and motor areas (-2.75 ±0.91%, t=-6.70±1.65); all but one subject showed activation in preSMA. The visual activation compares extremely well with that of conventional VASO (-3.39±1.22% and t=-6.93±1.40). The obvious advantage is much increased volume coverage for the same TR. **3)** Stroop task experiments with the 32-channel coil and 8-fold acceleration indicate that GRASE VASO is well suited for real CBV-weighted whole-brain fMRI studies. Fig 4 shows the corresponding BOLD and VASO activation maps of one subject.

In conclusion: The new 3D GRASE VASO technique allows robust detection of activation induced CBV changes even outside the primary cortices, with full brain coverage and acceptable scan durations. Unlike in other multi-slice VASO methods, slice dependent signal intensity and CBV changes are not an issue.

[1] Lu H, et al. Magn Reson Med 2003;50(2):263-274; [2] Donahue MJ, et al. Magn Reson Med 2006;56(6):1261-1273; [3] Poser BA, Norris DG. Magn Reson Mater Phy 2007; [4] Lu H, et al. Magn Reson Med 2004;51(1):9-15; [5] Scouten A, Constable RT. Magn Reson Med 2007;58(2):306-315. [6] Gunther M, et al. Magn Reson Med 2005;54(2):491-498; [7] Norris DG, Hutchison JM. Magn Reson Imaging 1990;8(1):33-37. [8] Zysset S, et al. Neuroimage 2001;13(1):29-36