A time efficient high resolution multi-echo FLASH sequence

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Introduction:

EPI is the commonly used technique for measuring the BOLD contrast in fMRI experiments, but for high resolution fMRI the SNR of EPI and the measurement time is limited. Thus, a suitable sequence should be faster than a FLASH sequence and at the same time yield more SNR than an EPI sequence. Voit and Frahm [1] proposed echo train shifted multi echo FLASH for high resolution fMRI. This method can be used to reduce ringing and ghosting artefacts but not SNR efficient. Here we present a modified, more SNR efficient acquisition scheme.

Methods:

A multi-echo FLASH sequence divides the k-space in *n* segments where *n* is the number of echoes per excitation (fig. 1a). The gradient echo time of each segment in k-space is different because a line in segment *i* is acquired with the i^{th} ADC after each excitation. Thus, the signal amplitude is weighted with a step function in phase encoding direction. To avoid ringing artefacts caused by these inhomogeneities in k-space echo train shifting [2] was implemented (fig. 2). Fig. 1b shows the effect of echo train shifting on the weighting of k.space. Unidirectional readout is used to reduce phase errors known in EPI . The time required for the readout gradient rewinder is not used for data acquisition. Therefore a second contrast is acquired in this period (marked green in fig. 2).The echo times of the two contrasts differ by the duration of one readout gradient. The two contrasts finally are averaged to enhance SNR. Fig. 3 shows the sequence scheme. All measurements were performed on a 1.5 T whole-body scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) with a 12 channel head coil. The measurements presented here are performed with 9 echoes per acquisition and the following sequence parameters: TE_1=69,2ms, TE_2= 76,3ms, TR=152ms, Bandwidth=150Hz/pixel;

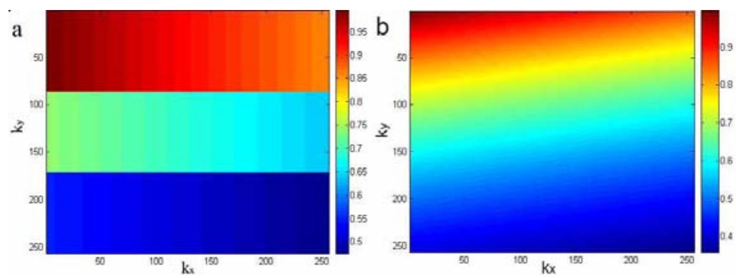

*Figure 1. Colour coded relative weighting of the k-space for a multi-echo sequence with three echoes. **a.** The different echo times of each part divide the k-space in three parts. **b.** Weighting of k-space for a multi-echo FLASH sequence using echo train shifting.*

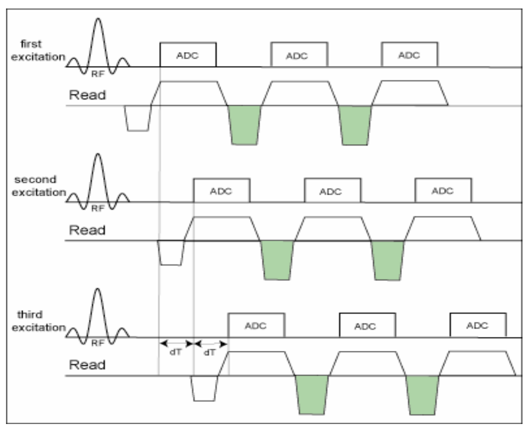

Figure 2. Multi-echo readout using echo train shifting as an example shown with three echoes. The start time of the readout train is shifted linear with the excitation number by a delay of dt to avoid inhomogeneities in phase encoding direction of k-space.

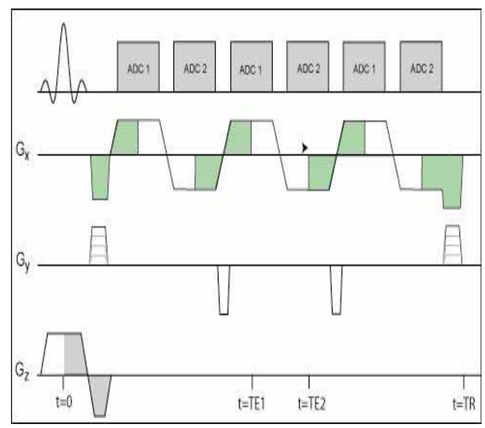

Figure 3. Timing scheme of a multi-echo FLASH with two contrasts. The green and white areas in the readout scheme show the gradient echoes at the boundaries between the areas.

Results:

Fig. 4a shows the image after averaging over the two different contrasts. There are no noticeable artefacts. In comparison fig. 4b shows a single contrast image. The SNR of the image in fig. 4a is about 1.4 times higher than in the image presented in fig. 4b.The measurement time is increased by a factor of 1.5, due to longer readout rewinding gradients which are required to acquire the second contrast.

Discussion:

We have presented a SNR efficient sequence suitable for high resolution fMRI experiments.

The improvement of SNR and the influence of the sequence parameters on the BOLD contrast currently are investigated in fMRI experiments on a 3T system. Initial fMRI experiments have been performed and show that the technique is sensitive to BOLD contrast.

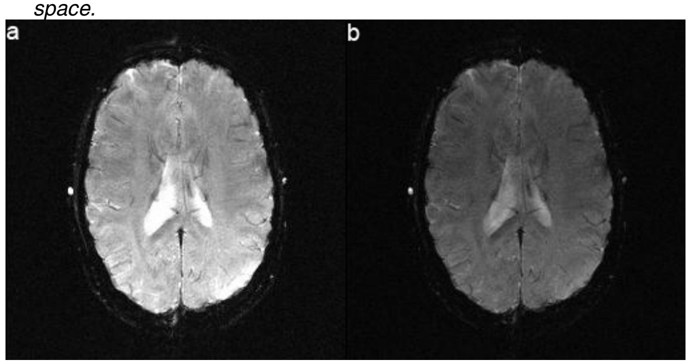

Figure 4. Echo train shifted multi-echo FLASH images with 9 echoes per acquisition at 0.7 x 0.7mm in-plane resolution and 3 mm slice thickness. TE_1 is 69,2ms and TE_2 76,3 ms at a TR of 152 ms and a bandwidth of 150 Hz/pixel. The SNR of the image acquired by averaging over the two contrasts (a) is improved by a factor1.4 ± 0,3 compared to the single contrast image (b).

References:

[1] Voit D, Frahm J. Echo train shifted multi-echo FLASH for functional MRI of the human brain at ultra high spatial resolution. NMR Biomed . 2005; **18:** 481-488.

[2] Feinberg DA, Oshio K. Gradient-echo shifting in fast MRI techniques (GRASE imaging) for correction of field inhomogenity errors and chemical shift . *J. Magn. Reson. 1992;* ***97:***177-183.