INTRODUCTION: The novel method PRESTO-CAN [4], [5] for 3D-plus-time resolved MRI includes a radial-Cartesian hybrid sampling, see Fig. 1, right. Golden ratio angular sampling [2] and hourglass filtering provides high temporal resolutions, see Fig. 2. When the method is used for fMRI-imaging, the echo times are used, TE=37.40 ms, and this result in both field inhomogeneities and phase variations in the reconstructed images. Therefore, PRESTO-CAN also includes an internal calibration and correction procedure. Reconstruction is performed using gridding [1]. Without hourglass filtering, the image quality is almost identical to what can be obtained with conventional Cartesian sampling. With hourglass filtering, data points are first removed and then rectified by angular interpolation. This procedure affects the image quality to some extent, we present here a method for circumventing this.

MATERIALS AND METHODS:

K-space sampling: 3D sampling of k-space is normally performed using Cartesian sampling as in Fig. 1, left. PRESTO-CAN, on the other hand, uses a hybrid radial Cartesian sampling as in Fig. 1 right, i.e. radial sampling in the (k0,k1)-plane and Cartesian sampling in the y-direction. In Fig. 1, each profile in k-space is sampled using one excitation only, i.e. single-shot. In actual experiments, we used lower EPI factors. The focus of the following discussion is on the radial data, which is in 2D-space.

Time order sampling: K-space was sampled using N radial profiles at fixed angle positions. Let the profile numbers be n=0, 1, 2, …, N-1 with the corresponding angles in $360\degree/N$. The smallest angular difference between profiles will then be $\Delta \varphi=360\degree/(2N)$. Among all possible angles, the one with profile number n=N and closest to 180° divided by the golden ratio was chosen. Consequently, the angular increment was chosen to be $\Delta \varphi=360\degree/150\times2/(\phi+1)\times111^\circ$. This is different from [2], where the angular increment was exact $180\degree-2\times(\phi+1)$. To guarantee that all profiles were visited before repeating the first profile, N was chosen to be a prime number. The sampling pattern for N=7 profiles is illustrated in the left in Fig. 2 and to the right the profiles were plotted with respect to time. The profile numbers n= 0, 1, 2, 3, 4, 5, 6, 0, 1, 2, 3, 4, 5, 6, 0, 1, 2...

Hourglass filtering: The center of k-space is thus over-sampled and to increase time resolution, 'too old' and 'too new' data may be removed using a non-causal filter. In Fig. 2, the time point of interest was chosen to be profile 3. Then, as much data as possible were removed from the outer profiles (0 and 6) and then data from profile 1 and 5 and finally 2 and 4 were removed. This procedure resulted in the hourglass shaped filter in Fig. 2. The hourglass filter will move forward in time as indicated by the arrow. For each time position a new volume will be reconstructed.

Reconstruction: The gridding method [1] was used for image reconstruction. The algorithm consists of the following steps: 1) pre-compensation with the local sampling density, 2) resampling with forward mapping using the Kaiser-Bessel interpolation function $C(k_x,k_y)=C(x,y), 3)$ inverse Fourier transform, 4) division with the inverse Fourier transforms of $C(x,y)$.

In pre-compensation, without hourglass filter, the pre-compensation was trivial and proportional to the radius (except for the samples at the origin). When the hourglass was applied, it was much more elaborate to determine the pre-compensation. In [5], this was solved by restoring the removed data points by using angular interpolation prior to pre-compensation. However, linear interpolation in k-space introduces small errors. An alternative is to use the method proposed in [3] where the pre-compensation is then exactly calculated to be used for the pre-compensation. The idea is that sampling of k-space with profile numbers weighted with the obtained weight function will give no aliasing in the image domain. In [3], a truncated jinc function $J_{\text{trunc}}(r)$ was utilized in the iterative process. The jinc-function is similar to the sinc-function and $J_{\text{trunc}}(r)=J(r)/r$ where J is a Bessel-function. The important quality of $J_{\text{trunc}}(r)$ is that its inverse Fourier transform $J_{\text{trunc}}(r)$ has the properties $\langle 0|\varphi=0\rangle$ and $\langle \alpha|\varphi=0 \rangle$ for $\langle \alpha\rangle=P$, where P is the field of view.

RESULTS: Here we show comparisons of the image quality of the human brain for conventional Cartesian-sampling and PRESTO-CAN in Fig. 1. As the data acquisition aimed for fMRI-imaging, the echo times were long, TE=37.40 ms, which resulted in field inhomogeneities and phase variations in the reconstructed images, see the phase image in Fig. 3. A novel calibration and correction procedure therefore had to be developed for PRESTO-CAN. [5] It utilizes an initial reference scan and contains 1) conventional forward-and-back correction for EPI, 2) rotation angle position determination, and correction and 3) determination of phase drift in the original k-space. The experiments were performed on a Philips 1.5T Achieva scanner. A modified PRESTO pulse sequence was utilized. The repetition time (TR) and echo time (TE) was TR/TE=34/40 and the EPI factor was 15. The reconstructed volumes were (80x80x41), but in the final step, they were zero-padded once in the Fourier domain. The four experimental types of data can be described as follows: 1) the result from PRESTO-CAN without hourglass filtering (shown in Fig. 3). 2) The result from conventional Cartesian sampling was almost identical to Fig. 3. 3) The result from PRESTO-CAN with hourglass filtering and angular interpolation was somewhat degraded compared to Fig. 3. 4) The result from PRESTO-CAN with hourglass filtering and pre-compensation with the weight function suggested in [3] almost identical to Fig. 3.

CONCLUSION: We aim to use the novel 3D method PRESTO-CAN for fMRI. It has shown to provide excellent temporal resolution and also satisfactory image quality. Hourglass filtration followed by angular interpolation improves the temporal resolution, but affects the image quality slightly. Replacing the angular interpolation with the weight function suggested in [3] was proposed to solve this problem.


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