# A simulation on motion artifacts in segmented spiral event-related fMRI

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**Synopsis**

Segmented spiral MRI offers both high resolution and high signal-to-noise ratio and seems therefore to be suitable for event-related fMRI. The major drawback is that motion results in inconsistent k-space data. To investigate the artifact dependency on the temporal order of spiral interleaves and on the timing of the motion, a simulation was conducted with a "head" phantom with two "activated" areas. Two order of interleaves were evaluated for different types and timing of motion. It was demonstrated that pattern and severity of motion artifacts is sensitive on both interleaf order and motion timing.

**Introduction**

The main intention of event-related functional MRI (er-fMRI) is to map the temporal characteristics of the hemodynamic response in activated brain areas [1]. A promising tool for er-fMRI is interleaved spiral MRI which offers a high temporal resolution and a higher signal-to-noise ratio compared to single shot techniques [2]. In this k-space segmented technique, a single spiral interleaf per image is acquired after the application of each stimulus (Fig.1). The major drawback of this method is the fact that motion results in inconsistencies of the k-space data and not in spatial offset between consecutive images [3]. In this work, we investigated the dependency of motion artifacts on the temporal order of the spiral interleaves and on the timing of the motion.

**Methods**

All simulations were conducted with a numerical "head" phantom; an ellipse of 150 mm width and 200 mm length. The phantom was sampled onto a 128x128 matrix with a spatial resolution of 2x2 $mm^2$. Two "activated" areas (4x6 $mm^2$, 14x4 $mm^2$) had twice the intensity of the "background tissue". The k-space data of the original object was scanned on twelve spiral interleaves with 900 data points each. With the chosen spatial resolution, the readout time for one interleaf was 9 ms [4], so T2* signal decay was neglected. The reference image (Fig. 2) was then reconstructed from the resulting raw data set as proposed in [5]. Two different interleaf orders were evaluated: linear order (collecting interleaf 1,2...,12) and alternating order (first the odd interleaves, then the even). The effects of three different motions were simulated separately for each order: a displacement of 2 mm in x direction, the same in y direction and a clockwise rotation of 2°, which are typical values in an fMRI experiment. The motion occurred after the $6^{th}$ interleaf (50% of k-space), after the $9^{th}$ interleaf (75%) or after the $11^{th}$ interleave (92%). The resulting k-space data was used to reconstruct the according images, which were then subtracted from the reference image.

**Results**

As an example, the results for displacement in x are presented for alternate order (Fig. 3) and for linear order (Fig. 4). In the upper row of each figure, the resulting images are shown with the motion occurring after 50% of k-space (a), 75% (b) and 92% (c). The respective difference images can be seen in the lower row. The scaling of the difference images is sixteen times magnified to display subtle artifact pattern. As expected, the results for motion between the $11^{th}$ and $12^{th}$ interleaf (case c) are the same for alternate and linear order (the respective images are omitted in Fig. 4). The integrated intensity loss in the "active" areas was up to 15%, the maximal difference between the disturbed images and the reference image was 54% for the linear order and 59% for the alternate order (yellow arrows). The artifact pattern differs significantly between the interleaf orders, but converge for motion late in the data acquisition. For both orders, the severity of the artifacts is maximal for motion occurring between the $6^{th}$ and $7^{th}$ interleaf.

**Discussion**

The different amplitude and pattern of the artifacts can be explained from a k-space perspective. Motion during data acquisition causes two holograms (that of the original object and that of the displaced one) to be added in complex k-space. Motion after half of the interleaves means that both holograms have the same power, hence phase interferences are maximal in that case. The different artifact pattern can be explained by the different k-space periodicity for the two interleaf orders [3].

For the application in er-fMRI it is important to take into account that not only the intensity of motion artifacts can change in segmented spiral MRI, but also the pattern depends on the timing of the motion. Also, there is a strong dependency between interleaf order and artifact pattern. Frequently, different randomized event classes are presented in er-fMRI to avoid habituation [6]. In such (pseudo-)randomized designs one has to ensure that the interleaf order is kept constant for all event classes.

**References**

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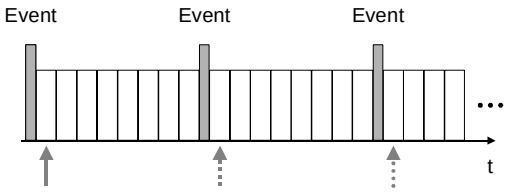


**Figure 1:** Segmented spiral event-related fMRI. After each event one segment of k-space (spiral interleaf) is acquired to attain high temporal resolution. The arrows denote the acquisition of the first (solid), the second (dashed) and the third (dotted) k-space interleaf of the first image of the time series.

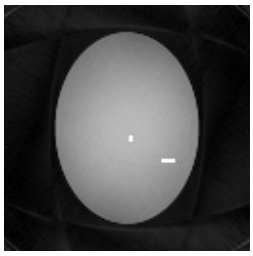

**Figure 2:** Head model for numerical simulations. An ellipse of 150x200$mm^2$ with two "active" areas (4x6$mm^2$, 14x4$mm^2$).

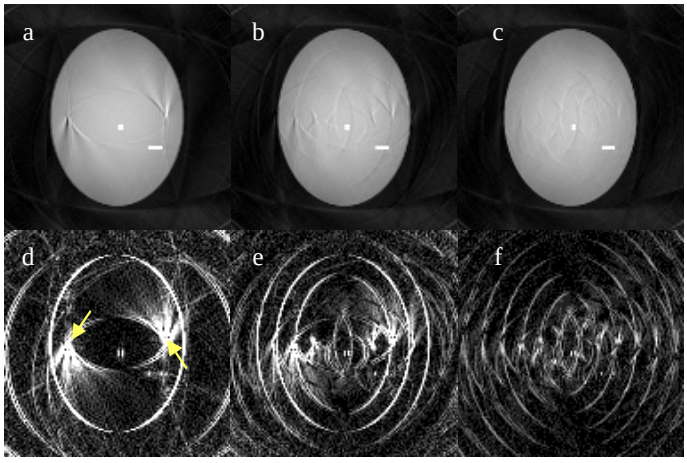


**Figure 3**: Motion artifacts for the **alternating** interleaf order. A displacement of 2 mm in x occurred after acquisition of 50% of k-space (a), 75% (b) or 92% (c). (d-f) show the respective differences to the reference image (Fig.2). Scaling is 16 times magnified compared to (a-c). Yellow arrows are pointing to the maximum of difference.

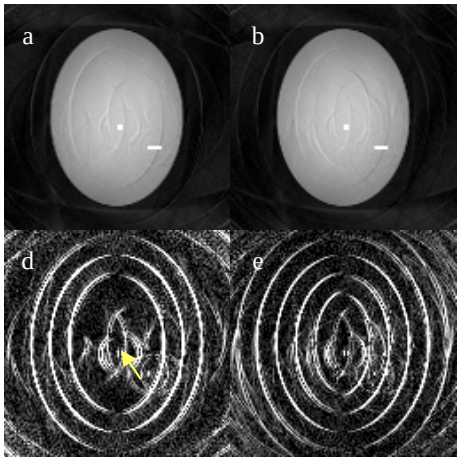


**Figure 4**: Motion artifacts for the **linear** interleaf order. The image description is the same as in Fig. 3. As the artifact pattern for motion occurring after eleven of twelve interleaves is identical for both interleaf orders, the respective images are omitted.

It is shown that artifacts increase with TR for 2DFT methods, and that projection reconstruction (PR) and spiral methods have significantly reduced artifact intensities, because these trajectories collect low spatial frequencies with every view. The spiral technique is found to be superior in terms of efficiency and motion insensitivity. Authors. G H Glover, A T Lee. Department of Diagnostic Radiology, Stanford University School of Medicine, CA 94305-5488, USA. Journal Magnetic Resonance in Medicine : Official Journal of the Society of Magnetic Resonance in Medicine / Society of Magnetic Reson...