Combined correction for geometric distortion and its interaction with head movement in fMRI

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Introduction

The introduction of an object (head) in a magnetic field causes geometric distortions, the specifics of which depend on the object and its orientation. This means that the apparent shape of the brain will vary with its position in the scanner, leading to movement related variance in fMRI time-series that cannot be corrected by rigid body realignment [1]. Correcting this by acquiring a field-map at each time point would lead to increased repetition time and may, due to errors in the measured field-maps, not always decrease variance [2]. Previous work has shown that the rate of change of the field with respect to subject movement can be estimated directly from the variance of the time-series [3], alleviating the need for measuring the field at each time point. This method explicitly minimizes variance under constraints given by the physics of the imaging process. Therefore variance will always be reduced or remain unchanged. This can have particular impact on fMRI time-series with task-correlated head motion because motion artefacts can be corrected without removing true activation, which can happen when using movement parameters as regressors of no interest in the statistical model [4]. However, using the method presented in [3] means the images will be undistorted to some average distortion over the whole time-series rather than to the true anatomy. Here we present a method that combines geometric distortion correction using a single measured EPI-based field-map with the model-based approach that estimates change in field at each time point. This method yields an unwarped time-series corrected for both geometric distortions and the interaction of head movement with distortion.

Theory

We represent the field at each and every time point as a first order Taylor expansion with respect to the movement parameters. The movement parameters and the corresponding component fields of the expansion (the rate of change of the field w.r.t. head movement) are estimated from the time-series. The zeroth order term, i.e. the static field is measured at the beginning of the time-series using dual echo-time images followed by phase unwrapping [5]. The resulting field map for each time-point is then calculated by combining the measured field-map with the estimated change in field (figure 1) and used to unwarp the time-series.

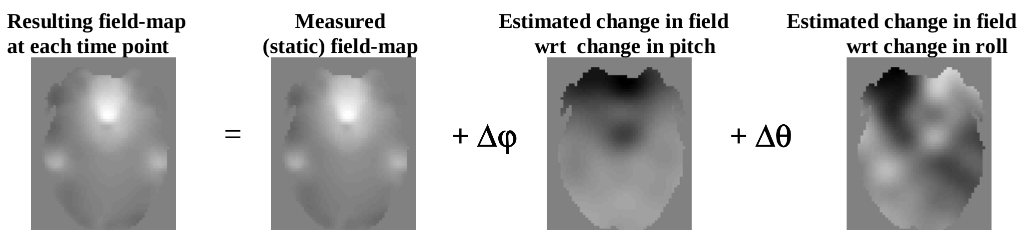

Figure 1 - Field-map at each time point calculated using measured field-map and estimated rate of change of field with respect to head motion (pitch and roll).

Methods and Materials

The method was evaluated by acquiring fMRI time-series with voluntary task-correlated head movements. EPI images were acquired on a Siemens Vision 2T scanner (matrix size=64x64, FOV=192cm, slice thickness of 1.8mm with a 1.2mm gap, 32 slices) during 3 cycles of visual stimulation using a flashing checkerboard alternating with rest. The subject voluntarily moved their head (pitch and roll) as the visual stimulus appeared or disappeared. FMRI time-series were processed in three different ways using: a) rigid body realignment, b) rigid body realignment with movement parameters included as regressors of no interest in the statistical model and c) the presented unwarping method. Motion corrected images were analysed for activation effects.

Results and Discussion

Figure 2 shows visual activation maps after analysis with the three methods described above. Figure 2a shows activation in visual cortex but also false positives particularly in regions affected by distortions (frontal and around sinuses). Figure 2b shows that including movement parameters in the statistical model lead to a complete elimination of all activations. Figure 2c shows that the presented unwarping method significantly reduced false positives while leaving activations intact. Further analysis showed that the presented method reduced residual variance by up to 50%. Also, combining a measured field-map with the estimated change in field allowed us to unwarp the images to a non-distorted space, as indicated by visual comparison to anatomical scans. This method is most effective for fMRI time-series in which the interaction between geometric distortion and head motion is a major source of variance, i.e. in data where there are appreciable distortions.

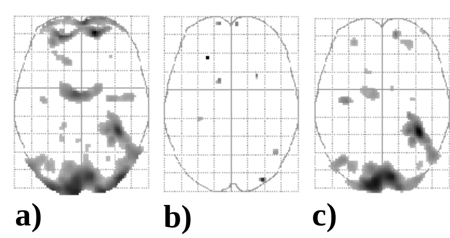

Figure 2-Visual activation maps for time series realigned using a) rigid body realignment, b) rigid body realignment with movement parameters, c) the presented unwarping method.

References

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