Detection versus physiological noise suppression in Event-Related fMRI: Optimisation of an adaptive Cardio-Respiratory Filter

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Introduction:

Blood flow pulsations related to the cardiac cycle (CC), and variations of the local magnetic field and bulk tissue motion caused by the respiratory cycle (RC) are potential artifact sources in MRI. Recent approaches to attenuate this noise can be coarsely classified into spectral-domain filtering methods and time-domain filtering methods [1,2]. Spectral-domain filtering methods are limited in their value for bandwidth-demanding paradigms used in event-related fMRI experiments with non-constant inter-stimulus intervals (ISI). On the other hand, a recently proposed adaptive filtering approach, applied in the time-domain [3], shows great potential for such paradigms. However, the analysis by Deckers et al. focused mainly on the level of noise suppression, without taking into account the impact on sensitivity for functionally-related signal changes in fMRI experiments.

Here, the filter performance as a function of the "bin-size" is compared to the trade-off in sensitivity for a typical event-related fMRI scenario. This is achieved by simulating an event-related fMRI experiment with a fixed paradigm for varying repetition times and "bin-sizes".The results of the simulations were verified experimentally for a limited subset of the selected parameters.

Methods:

Simulations: In order to evaluate the effect of the "bin-size" on a "typical" event-related fMRI experiment, we evaluated the detectability of an fMRI paradigm with jittered inter-stimulus interval (ISI) as suggested by Friston et al. [4] and implemented according to Birn et al. [5] for three repetition times (0.5, 1.5, and 3.0s) for a fixed number of 340 dynamic scans. The "bin-size" of the filter [3] was varied within the range of 2-60 and for each "bin-size" 1000 artificial fMRI time-course were simulated. The adaptive RC- and CC-noise suppression filters were either applied as a separate step, as suggested by Deckers et al., or implemented as a regressor in the fMRI model. The t-score of the fMRI regressor was used to evaluate performance.

The pixel time course was assumed to be the superposition of the fMRI-signal, scanner noise, physiological noise, composed of a RC- and CC-component, and a base-line drift. The fMRI signal was modeled by convolving the haemodynamic-response-function as suggested by Cohen et al. [6] with the generated event-related paradigm (2s stimulation with a random inter-stimulus interval of $0<ISI<4s$). The TR dependent scanner-noise was implemented according to the method suggested by Purdon et al. [7]. RC-artifact was assumed to follow a harmonic oscillation between 0.28 and 0.4Hz, randomly chosen for each run, with an additional frequency-jitter of ±10% and an amplitude-jitter of ±5% per cycle in order to account for irregular breathing. The CC-artifact was modeled by firstly deriving an average blood impulse response function from the data acquired with a PPU on the right ear of a volunteer and subsequently convolving this impulse response with the peak systole of a simulated VCG data-set. The cardiac frequency was randomly chosen for each run between 0.77 and 1.4Hz. The relative amplitudes of all contributing components were adjusted based on the experimental results presented by Barret et al [8].

FMRI-experiments: All fMRI experiments were performed on a Philips Intera 1.5T with the following EPI sequence: FOV=256x256x20mm3, matrix=128x128x5, TR=505ms, TE=44ms, 340dynamics. The cardiac and respiratory cycles were measured with a VCG and a pneumatic captor. The paradigm consisted of a flickering checker-board (8Hz) of 2s duration with a random ISI of $0<ISI<4s$. The experimental data was analyzed using SPM-2002.

Results/Discussion:

Fig. 1: The t-score ratio for RC- and CC-noise affected pixels shows a maximum for the fMRI detectability between 10 bins (for long TRs of 3s) and 20 bins (for small TRs of 0.5s). The occurence of the maximum can be explained by two opposed trends:

On one hand, a higher number of bins leads to a better physiological noise suppression and thus to a decreasing residual variance. This effect would increase the fMRI detectability with an increasing bin number. On the other hand, an increasing number of bins also affects the fMRI signal: Firstly, it decreases the number of degrees of freedom that remains for fitting the fMRI-model. Secondly, the filtering method implemented as a separate step preceding fMRI analysis diminishes the fMRI signal, an effect which increases with the number of bins since this causes an increase in the amount of correlation between the filter function and the fMRI signal. The latter effects would lead to a reduction in fMRI detectability which increases with an increasing number of bins. This also explains the loss of fMRI detectability in regions which are not affected by physiological noise. Even if the optimal filter is applied, these regions suffer for the presented experiment a loss of detectability of 2.5% compared to an unfiltered analysis. Although the filter is able to remove the temporally under-sampled noise at a TR of 3s, its filtering performance improves greatly for shorter TRs as reported by Deckers et al.[3]. Fig. 2 shows an activation image for the event-related fMRI experiment of one volunteer before and after both optimized RC and CC filtering were applied. It can be seen that the activation region size has increased in the vicinity of the superior sagittal sinus while the overall activation remains unaffected.

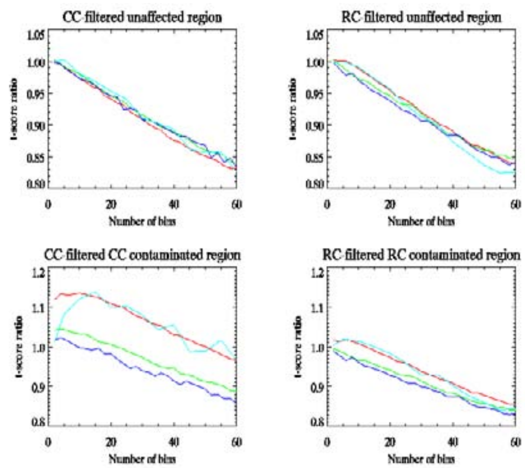

Figure 1: T-score ratio of the filtered and unfiltered experiment dependence on the bin-size for the simulated data (TR=0.5s red, 1.5s green, 3s blue) and the averaged experimental data obtained with a TR of 0.5s (light blue).

Conclusion:

We found in this study that the adaptive filter suggested by Deckers et al. can be optimized by adapting the bin-number to selectively suppress physiological noise in affected areas and thus increase fMRI detectability of up to 13% for CC noise and 3% for RC-noise. Since *any* additional filtering step before fMRI analysis will cause an fMRI-signal attenuation besides noise removal,a 2.5% loss of detectability in unaffected areas has to be accepted as a trade-off for the evaluated filtering method. Although this loss limits the use of this type of filtering for generic fMRI experiments, it makes this filter an interesting alternative for fMRI-experiments which rely on a good suppression of physiological noise such as model-free functional connectivity experiments.

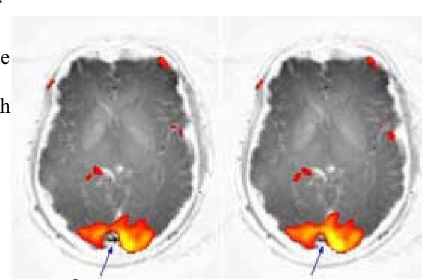

Figure 2: T_2^*-weighted image of a healthy volunteer with superimposed activated area ($p<0.001$) before filtering (left) and after both RC and CC filtering (right).

References:

[1] Glover et al. Magn Reson Med 44:162-167 (2000)
[2] Chuang et al., Magn Reson Med 46:344-353 (2001)
[3] Deckers, R. et al. Proc Intl Soc Magn Reson Med 13:2294 (2005)
[4] Friston, K. J. et al. Neuroimage 10(5) 607-619(1999)
[5] Birn R. M. et al. Neuroimage 15, 252-264 (2002)
[6] Cohen, M. S. Neuroimage 6(2):93-103 (1997).
[7] Purdon, L.P. et al. Human Brain mapping 6:239-249 (1998)
[8] Barret et al, poster 335, Proceedings of the 22nd Annual Scientific Meeting of the ESMRMB September 2005, Basel