Using ECG-derived respiration for explaining BOLD fMRI fluctuations during rest and respiratory modulations

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Abstract

INTRODUCTION: Physiological signal acquisition during fMRI may be used for multiple purposes, though it usually requires additional setup which may increase complexity and cause subject discomfort. Since ECG is modulated by respiration, an ECG-derived respiration (EDR) may be obtained without needing extra equipment for EEG-fMRI studies, which inherently use the ECG[1,2]. In this work, EDR signals were computed for resting-state and two respiratory challenges modulating respiration patterns, to validate their use in the MR environment.
METHODS: EEG-fMRI, ECG and respiration (Resp) data were acquired from healthy subjects during: resting state (RS) (N = 10), a slow paced breathing (SPB) task with a 2-min 0.1Hz respiration preceded and followed by 1-min free breathing periods (N = 9) and a breath-hold (BH) task, comprising 4 cycles of post-exhalation breath-hold (N=12). Following ECG preprocessing, EDRs were extracted with 7 method categories: ECG envelope (ENV), heart-rate variability (HRV), amplitude modulation (AM), QRS-area modulation (QRS-AM), principal component analysis (PCA), kernel PCA (kPCA), and empirical mode decomposition (EMD). To investigate the contribution of respiratory fluctuations measured by EDR to the BOLD-fMRI data, cardiac and respiratory regressors were obtained from Resp and EDR[3,4,5,6]. The BOLD data was preprocessed (corrected for distortion and motion, and high-pass filtered) and three general linear models were fitted to the average BOLD signal in gray matter (GM): Basic (6 motion parameters and motion outliers), Physio-rRetr (Basic + Cardiac rate; RETROICOR cardiac/respiratory terms); and Physio-RVT (Basic + Cardiac rate; RETROICOR cardiac terms; respiratory volume per time, RVT). The variance explained (VE) was computed from the adjusted R^2 (R^2_{adj}).
RESULTS & DISCUSSION: Regarding physiological regression of the BOLD signal, both Physio models (using Resp and EDRs) fitted the data well, following it more closely in the case of respiratory tasks. The performance of EDRs when estimating VE differs for rRetr and RVT, and is dependent on the task. Nevertheless, results suggest that HRV is the most consistent method. In general, though smaller, the VE obtained from the EDRs was not significantly different from the one obtained with Resp, indicating the feasibility of using EDRs as a physiological regressor in resting-state EEG-fMRI as well as tasks with substantial respiratory modulations.

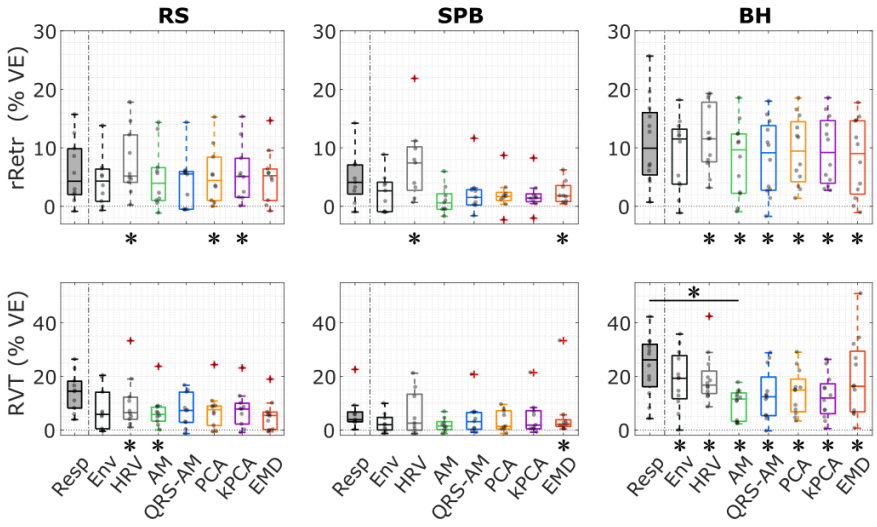

Figure 1: Distributions across subjects of the GM Variance Explained (%VE) by respiratory terms (VE_{Physio}-VE_{basic}), with Physio including the RETROICOR respiratory terms (Top) or RVT (Bottom) for Resp and each EDR method. Stars (*) for boxplot pairs denote significant differences (Kruskal-Wallis test, Bonferroni corrected p-values); * under each plot denote values significantly larger than zero for the EDR methods (Wilcoxon signed-rank test, Bonferroni corrected p-values).

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