Ballistocardiogram artefact correction taking into account background physiological signal preservation in simultaneous EEG-fMRI

Rodolfo Abreu[1], Marco Leite[1,2], Alberto Leal[3], and Patrícia Figueiredo[1]

[1]Institute for Systems and Robotics and Department of Bioengineering, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal, [2]Department of Clinical and Experimental Epilepsy and The Wellcome Trust Centre for Neuroimaging, University College London Institute of Neurology, Queen Square, London WC1N 3BG, United Kingdom, [3]Centro de Investigação e Intervenção Social and Department of Neurophysiology, Centro Hospitalar Psiquiátrico de Lisboa, Lisbon, Portugal

Target audience: Neuroscientists, engineers and clinicians interested in simultaneous EEG-fMRI and EEG data quality assessment.

Purpose: Simultaneous EEG-fMRI acquisitions induce severe artefacts on EEG data, the most challenging currently being the ballistocardiogram (BCG), mainly due to its non-stationary nature and high variability in both time and frequency domains. Many studies continue to be dedicated to the development of more efficient methods for BCG artefact correction, but the associated removal of background physiological signal has not been systematically assessed. Here, we propose a novel ICA-based approach (PROJIC) for BCG artefact correction as well as a novel evaluation pipeline that assesses both artefact and background signal removal, and use this to compare the novel approach with previous approaches, on data collected from a group of epilepsy patients.

Methods: 13 epilepsy patients were studied on a 3T MRI system (Siemens) using a MR-compatible 32-channel EEG system including one ECG channel (Brain Products), yielding a total of 26 intra-MR EEG datasets. Resting-state fMRI data were obtained using GE-EPI (TR/TE=2500/50ms). All EEG datasets were first gradient-artefact corrected and band-pass filtered (0.5–45Hz).
Artefact correction: Detection of QRS complexes on ECG data was performed using a modified version of the Pan-Tompkins algorithm[1] and QRS-triggered event-related potentials (ERPs) were computed and averaged across events. Pre-processed EEG was subjected to ICA decomposition (EEGLAB) and BCG-related EEG independent components (ICs) were then selected as follows: 1) The average QRS-ERPs were projected onto the IC space of the respective EEG dataset; 2) The average power of the ICs were split into *N* clusters (ranging from 2 to 10) by *k*-means clustering; 3) The ICs within the *N*–1 clusters yielding the projections with the greatest average power were selected as BCG-related. Back-projecting all ICs except those selected yielded a purely ICA-corrected EEG (PROJIC). Additionally, the state-of-the-art OBS algorithm[2] was applied to the BCG-related ICs, ranging the number of principal components (PCs) from 3 to 7, before back-projecting all the ICs onto the EEG space (PROJIC+OBS).
Correction evaluation: The ratios $R_{art} = (S_{art}^{unc} - S_{art}^{cor})/S_{art}^{unc}$ and $R_{bkg} = (S_{bkg}^{unc} - S_{bkg}^{cor})/S_{bkg}^{unc}$ were defined, where $S_{art}^{unc}/S_{art}^{cor}$ and $S_{bkg}^{unc}/S_{bkg}^{cor}$ denote the average spectral signal before/after BCG artefact correction within a 0.13Hz window centered in the fundamental frequency and the first four harmonics of the ECG signal for the BCG artefact (*art*) quantification and within a 0.39Hz window centered in a frequency of 0.52Hz apart from each BCG artefact window for the EEG background (*bkg*) quantification. While R_{art} should be maximized (~1), R_{bkg} should be minimized (~0). A combined ratio $C = w_{bkg}R_{bkg} + (1 - w_{bkg})(1 - R_{art})$ was defined, where w_{bkg} is the background weight reflecting the importance given to the preservation of the EEG signal background in relation to the removal of the BCG artefact. An exhaustive search optimization algorithm was employed to find the set of parameters (number of clusters and principal components for OBS) that minimize *C*. Both approaches were compared with previously proposed ICA-based methods[3] as well as standard OBS[2].

Results: Significant differences (repeated measures ANOVA, $p<0.001$) were found when comparing ICA-based methods, with the proposed PROJIC method outperforming all the others, except when considering $w_{bkg} = 0.9$ (Fig. 1). Significant differences ($p<0.001$) were also found when comparing both proposed methods with OBS. The PROJIC method performed better for the three lowest background weights, being outperformed, however, by the PROJIC+OBS method when considering higher values of w_{bkg} (Fig. 2).

Conclusion: The proposed evaluation pipeline for BCG artefact correction of simultaneous EEG-fMRI resting-state data allowed different weightings of the importance of removing the artefact against preserving the signal background, showing that different methods may be preferred in different situations. Nevertheless, the proposed ICA-based approaches outperformed both previous ICA-based methods as well as the OBS approach, in all conditions.

Acknowledgements: FCT through grants PTDC/SAUENB/112294/2009, PTDC/EEI-ELC/3246/2012 and Pest-OE/EEI/LA0009/2013.

References: 1. Pan J. and Tompkins W. *IEEE* Trans. Eng. Biomed. Eng. 1985; 32(3): 230-236. **2.** Niazy R.K., et al. NeuroImage 2005; 28: 720-737. **3**. Vanderperren K, et al. NeuroImage 2010; 50: 920-934

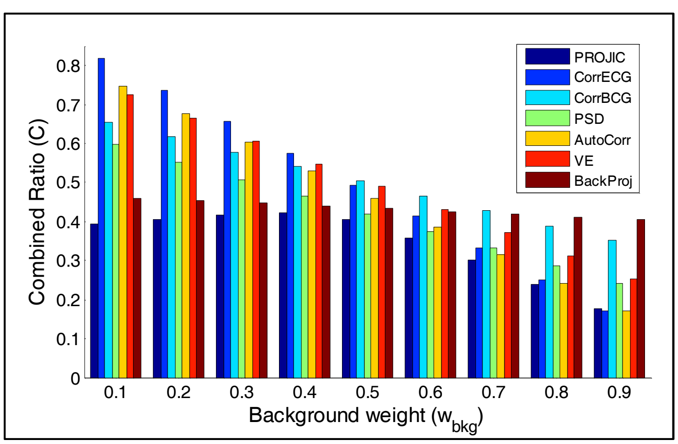

Fig. 1: Comparison between the purely ICA-based methods. The first proposed method (PROJIC, darker blue) outperformed all the other approaches, yielding the lowest values of *C*, except when considering $w_{bkg} = 0.9$.

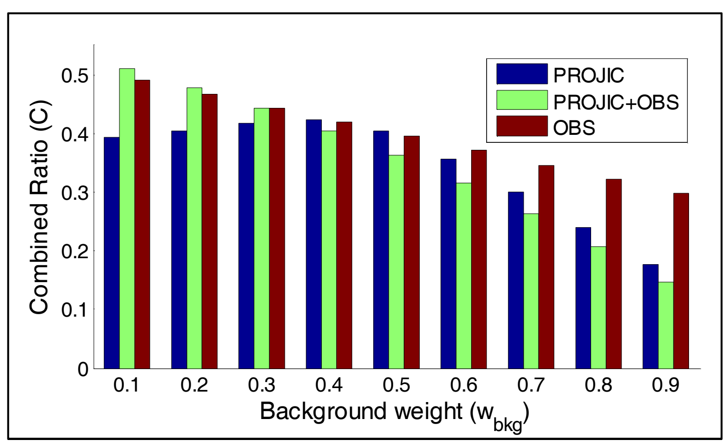

Fig. 2: Comparison between the proposed ICA-based methods and the OBS. The first proposed approach (ICA, blue) performed better when the removal of BCG artefact was of most interest. For $w_{bkg} > 0.3$, the second approach (PROJIC+OBS, green) outperformed both PROJIC and OBS approaches, yielding minimal values of *C*.