User Research

Simultaneous EEG-fMRI: Avoiding the ballistocardiogram artifact by pulse-triggered presentation of stimuli.

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The acquisition of electroencephalography (EEG) during Functional Magnetic Resonance Imaging (fMRI) measurement offers the chance to combine the high spatial resolution of the fMRI with the great time resolution of the EEG. It provides the possibility of enhancing the current understanding of brain (dys-) function in a non-invasive way (1). However, the quality of the EEG data acquired in a MRI scanner is limited by several artifacts which are directly or indirectly related to the magnetic field of the scanner. Some of these artifacts can easily be removed from the EEG using averaging methods. The most prominent artifact in this category is the scanner artifact which occurs during switching the gradient-coils. Because of the technical origin the scanner artifact and the high stability of its spectral content over time, it can be removed from the EEG data by several well performing algorithms, especially if hardware synchronization is used during data acquisition. In general, these algorithms create a template of the scanner artifact by various averaging strategies and subtract this template from the data.

The other prominent artifact occurring in simultaneous acquired EEG/fMRI data, the ballistocardiogram artifact (BCG) is even more difficult to remove from EEG signals. During the last decade various strategies for BCG artifact removal have been developed and discussed. One of the first methods used for BCG artifact correction was a channel-wise subtraction of an averaged artifact template. Several algorithms for generating such a template have been suggested. Nevertheless, results based on averaged artifact subtraction (AAS) methods can be diminished because of the variability of the BCG artifact.

Accordingly, the search for strategies to deal with the BCG artifact goes on. Blind source separation was suggested in this context and is still a widely used method. While there are different ways to perform a blind source separation, Independent Component Analysis (ICA) is the most common blind source separation technique in the context of BCG artifact correction. Although ICA is a powerful technique to separate independent sources which are linearly mixed in several sensors by minimizing the Gaussianity of the data, not all related problems have yet been solved. Recent studies (2) suggest that different parameters affect the quality of ICA based artifact correction. A widely discussed topic is the identification of artifact representing components. In fact, the quality of BCG artifact correction based on ICA strongly depends on the removed set of components. For that reason many identification strategies were published ranging from identifying components by visual inspection, by calculating correlations with templates, by frequency analyses or by variance contributions. Another parameter affecting the artifact correction quality is the type of ICA algorithm and the calculated number of components. To perform a good BCG artifact correction by ICA, an adjustment of parameters has to be done. Thus the automating of ICA correction strategies is not easy to realize. Inexperienced users could overcorrect the EEG data by using inadequate parameters. Accordingly, today there is no standard BCG artifact correction procedure available, which is both easy to handle and effective.

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For that reason, we were interested in developing a data acquisition method which is based on the characteristic time-course of the BCG artifact in order to avoid BCG-contamination of EEG data during EEG recording. Although the BCG artifact can be varying across individuals, channels and MR-scanners, it has a characteristic time-course. The BCG artifact (for example at Cz) can be described as a signal with two prominent polarity reversals with maximum amplitudes at about 200ms and 450ms after the r-peak in the electrocardiogram (ECG). During a standard EEG-fMRI experiment, the BCG artifact gets mixed up with the EEG / ERP signal in a random way. In the worst case, the ERP signal, e.g. an auditory evoked N100 potential, is superimposed by the peak of the first polarity reversal of the BCG artifact (with amplitudes that can be substantially higher than the ERP amplitudes). At best, the evoked potential occurs after the dying out of the second polarity reversal of the BCG artifact. While this optimal timing usually occurs only by chance, the main idea of the present approach (3) is to get such an optimal timing for a whole data set. In order to reach the optimal timing for each single event in a systematic way, stimuli have to be presented in a fixed relationship to the r-peak of the ECG.

To be able to present stimuli in a fixed relationship to the r-peak several problems have to be solved. Firstly, an online scanner artifact correction is needed in order to be able to detect the QRS-complex continuously, even if the coils are switched. Additionally, a fast real time r-peak detection is needed to be able to calculate a possible time window for the stimulus presentation. In our set-up, we used both the online gradient correction and the online pulse detection implemented in the BrainVision RecView software. The relevant information was directly transferred to the presentation software. With this setup, we were able to present stimuli relative to the r-wave of the BCG in order to generate ERPs in periods less affected by BCG and Scanner artifacts in real-life test situations.

In order to quantify the benefit of a pulse triggered stimulus presentation a simulated dataset was used. We generated a model of an auditory evoked N100 potential using averaged EEG data from a single subject recorded simultaneously with fMRI in a former study. This N100 potential was superimposed by several segments of BCG-artifacts which were retrieved from subjects of the same experiment. The N100 potential was added to the BCG artifact during different defined time periods. Initially we simulated a typical experimental setup with the ERP being randomly superimposed by the artifact. In addition, we inserted the N100 potential time locked to the r-peak during three periods simulating the pulse triggered presentation of stimuli. It was shown that pulse triggered data acquisition was able to reduce the mean failure significantly. Moreover, we were able to demonstrate that the ERP quality could be reduced by choosing inappropriate time windows for the stimulus presentation. A combination of pulse triggered stimulus presentation and an offline AAS based BCG artifact correction was able to reduce the mean failure by about 40%.

While no all-purpose and easy to use BCG artifact correction method is available today, pulse triggered stimuli presentation is able to offer improved ERP signal quality in comparison to a conventional data acquisition procedure. Furthermore, the possibility to combine pulse triggered measuring with every offline correction strategy makes this approach an interesting and powerful option for acquisition of ERPs in the MRI scanner environment. ●

References

1) *Christoph Mulert & Louis Lemieux (2010) EEG-fMRI: Physiological Basis, Technique, and Applications. Springer, Heidelberg, Dordrecht, London, New York.*

2) *Katrien Vanderperrena, Maarten De Vos, Jennifer R. Ramautar, Nikolay Novitskiy, Maarten Mennes, Sara Assecondi, Bart Vanrumste, Peter Stiers, Bea R.H. Van den Bergh, Johan Wagemans, Lieven Lagae, Stefan Sunaert, Sabine Van Huffel (2010). Removal of BCG artifacts from EEG recordings inside the MR scanner: A comparison of methodological and validation-related aspects. Neuroimage. 2010 Apr 15;50(3):920-934.*

3) *Matthias Ertl, Valerie Kirsch, Gregor Leicht, Susanne Karch, Sebastian Olbrich, Maximilian Reiser, Ulrich Hegerl, Oliver Pogarell, Christoph Mulert (2010). Avoiding the ballistocaridogram (BCG) artifact of EEG data acquired simultaneously with fMRI by pulse-triggered presentation of stimuli. J Neurosci Methods. 2010 Feb 15;186(2):231-41.*