# Comparison of Ballistocardiac Artifact Removal Algorithms for Detection of IED

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## Introduction

A simultaneous recording of electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI) is an effective method for epilepsy diagnosis. Using the temporal information of interictal epileptiform discharge (IED) detected in the EEG signal, the brain region related to the epilepsy can be detected with high spatial resolution in the fMRI data. To detect the IEDs more accurately, however, the measured EEG signal is analyzed after removing the ballistocardiac artifact (BA), which is induced by subject's heartbeat in a high magnetic field. In this study, three different BA removal methods, such as AAAS (advanced average artifact subtraction [1]), OBS (optimal basis set [2]), and ICA (independent component analysis [3]), were applied to the epilepsy data and their performances were evaluated in terms of preservation and restoration of the IED shapes.

## Methods

To evaluate the IED shape preservation, the IEDs located between adjacent BAs (Group I) were used. The group I IEDs are rarely affected by the BAs and the shape is well preserved in a simultaneous fMRI-EEG measurement. If they are falsely corrected, however, the shape will be deformed from the original IED shape. T he quality of the BA removal algorithms was evaluated using the similarity of IED shapes before and after correction by calculating the %MSE as follows,

$$\%MSE = 100\times\sqrt{\sum(IED_{Before} - IED_{After})^2} / \sum\left|IED_{Before}\right| \quad [\%].$$

To analyze the restoration performance, the IEDs overlapped with the BA (Group II) were used. Since group II IEDs are affected by the BA, the IED shapes are usually deformed. Thus, the BAs should be correctly removed to extract the IEDs. In case of group II IEDs, the quality of IEDs was evaluated by comparing the IEDs of group II to group I. For this, the correlation coefficients between group II IEDs and the IED template, which is obtained by averaging the group I IEDs before correction, were compared.

For this experiment, four patients (one male and three females) with intractable partial epilepsy were recruited and written informed consents were signed before experiments. In addition, a neurologist supervised the experiments for the safety of the patients. For BA removal, the ICA and OBS methods were performed using the EEGLAB v8.0.3.5b [4], where ICs related to the BA were manually selected for ICA. While the number of ICs ranged from two to five in ICA, the number of principal components in OBS was set to three as recommend in [2, 5]. After EEG signal is corrected by AAAS, ICA and OBS, the IEDs were independently identified from the corrected signal. The selected IEDs were then classified into group I and group II IEDs for the analysis in terms of preservation and restoration.

## Results

Table 1 shows the analysis results of group I and group II IEDs. When group I IEDs before and after correction were compared, AAAS produced lower %MSE than the other methods, while the ICA method produced higher %MSE than the other results. For group II IEDs, AAAS produced IEDs having higher correlation with the IED template than the other methods.

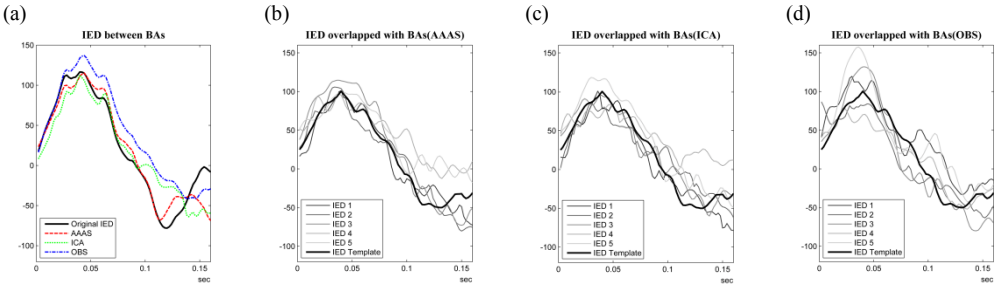


**Fig. 1.** Group I and II IEDs after correction (a) group I IEDs, (b) group II IEDs in TAS, (c) group II IEDs in ICA, (d) group II IEDs in OBS

Figure 1 shows group I and group II IEDs of a subject after BA removal. In the group I IED, the shape of the IED was mostly preserved when the EEG signal was corrected by AAAS as shown in Fig. 1(a). In Figs. 1(b), (c) and (d), group II IEDs corrected by AAAS, ICA, and OBS were respectively demonstrated. The standard deviation of correlation coefficients of OBS is higher than those of other methods, and the shapes of IEDs are more deformed. Therefore, the results show that AAAS and ICA restored better IEDs than OBS for group II IEDs.

## Conclusions

In the quantitative analysis, the performance of AAAS regarding the preservation of the IED shape was better than those of OBS and ICA, while all three methods showed similar performance in restoring the IED shape. However, considering the IED shape after the correction, the AAAS method could preserve and restore the epileptic spikes while removing BAs more accurately than the other methods.

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| Subject (Channel) | No. of group I IEDs | %MSE between group I IEDs (before and after correction) | | | No. of group II IEDs | Correlation between IED template and group II IEDs (after correction) | | |
|---|---|---|---|---|---|---|---|---|
| | | AAAS | ICA | OBS | | AAAS | ICA | OBS |
| A (T7) | 5 | 8.251 | 35.663 | 9.346 | 5 | 0.88 (0.02) | 0.871 (0.05) | 0.867 (0.046) |
| B (T8) | 6 | 2.222 | 5.695 | 4.927 | 15 | 0.968 (0.016) | 0.96 (0.031) | 0.964 (0.022) |
| C (P8) | 5 | 3.695 | 7.083 | 8.833 | 5 | 0.959 (0.014) | 0.954 (0.018) | 0.925 (0.029) |
| D (T7) | 6 | 5.572 | 6.647 | 8.441 | 10 | 0.959 (0.022) | 0.91 (0.086) | 0.939 (0.057) |

**Table 1.** Analysis of similar-shaped IEDs for group I and group II IEDs

## References

[1] Oh et al., Organization for Human Brain Mapping #497, 2010.
[2] Niazy et al., Neuroimage **28:** 720-737, 2005.
[3] Bénar et al., Clinical Neurophysiology **114**:569-580, 2003.
[4] Delorme, et al., Journal of Neuroscience method **134**:9-21, 2004.
[5] Venderperren, et al., Neuroimage **50**:920-934, 2010.