Ballistocardiac artifact removal from the EEG recorded in fMRI and its application to the epileptic interictal spikes

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Introduction

Ballistocardiac artifact appears in all EEG channels, which is one of the difficult problems in measuring and interpreting electroencephalogram (EEG) signals. Removal of the artifact is quite essential in carrying out researches of the epileptic interictal spike with simultaneously measured EEG and fMRI. To remove ballistocardiac artifact (BA), we propose a new approach using the information obtained indices that are peak positions of QRS complex in EKG channels and BA in EEG channel. We applied the developed technique to the analysis of the epileptic interictal spike, which is one of challenging problems.

Methods

As a pre-processing, Delta (1~4Hz), Theta (4~8Hz), Alpha (8~13Hz), and Beta (13~35Hz) signals are obtained from EEG and EKG channels. Using K-teager energy operator (TEO) as defined in equation (1), the indices of EKG signal are detected.

$$\psi_k\{x(n)\} = x^2(n) - x(n-k)x(n+k), \text{ where x(n); signal from one channel} \quad (1)$$

Using K-TEO with empirically determined k (k=40), peak positions of the signal in EKG channel are detected. The detected peak position means R-peak in QRS complex and is called positive indices. To decide the adaptive window size which means a temporal width for obtaining an averaged BA, the negative index in EKG signal is additionally detected using the same process. In this case, the EKG signal is inversed in polarity and flipped horizontally before applying the TEO. The result from this process is a strong peak between R-peak and T-wave in P_QRS_T timing. From the information of two sorts of indices, we could define the window size, which is three times the distance between the positive index and the negative index. In order to calculate each delay between EEG and EKG signals, positive indices of BAs in EEG channel are measured in the same way as the EKG channel. The individual delay is obtained as a time interval from positive indices in EKG and EEG channel. According to the interval between adjacent indices, the indices of EEG signal can be classified into regular indices and irregular indices (unexpected cases). Finally, an averaged BA [1] utilizing previously acquired adaptive window sizes and individual delays is obtained from the regular indices. In the case of regular indices, the averaged BA is subtracted from the EEG signal using adaptive window size and individual delay. Whereas in the case of irregular indices, the average window size and the average delay from the regular indices are used instead of the individual adaptive parameters.

Results

The proposed algorithm is applied to an EEG data including epileptic interictal spikes. The 18 channels were measured, such as Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Cz, and Pz. BAs appear in almost all channels. The shape of all BAs is considerably various and timing of artifacts is slightly varying. After filtering BAs, it seems that BAs are almost removed and the original EEG data is remained. Before applying the proposed algorithm, the epileptic interictal spikes were invisible due to the ballistocardiac artifacts. The epileptic interictal spikes are shown clearly (P3, P4, O1, O2, F7, F8, T7, T8, P7, P8) after applying the algorithm.

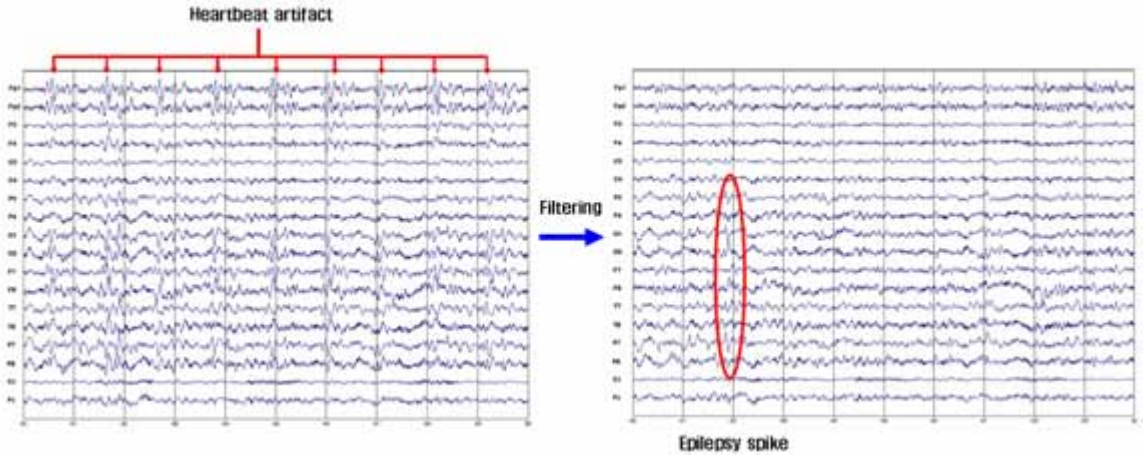

Fig.1. EEG data including the epileptic interictal spike after filtering

Discussions

The applied heartbeat detector shows high-performance and has fast processing time based on a slight modification of the TEO, which has been proved to be useful for detection of for the pulsatile wave form. The ballistocardiac artifacts are successfully removed by adopting the adaptive window size and individual delay. As shown in Fig.1, when the proposed algorithm is applied to the EEG data with epileptic interictal spikes, BAs are removed clearly preserving epileptic interictal spikes. The experimental results demonstrate the improvement of the EEG signal recorded in MR-scanner by removing BCG artifact. In addition, the proposed algorithm could be used for the clinical research.

Reference

[1] P.J. Allen et al., NeuroImage **8**, 229-239, 1998.