Removal of ballistocardiographic artifacts from EEG recorded inside the MR scanner using an optical motion-tracking system

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Introduction

Simultaneous electroencephalography and functional MRI (EEG-fMRI) are commonly used to investigate neuronal and hemodynamic signatures of brain function. However, the EEG is very sensitive to even slight movements of the subject in the strong magnetic field of the scanner. In particular, a well-known source of EEG artifacts is ballistocardiographic (BCG) motion, which can be partially corrected for, but still prevents an EEG quality comparable to that recorded outside the scanner environment [1]. The current study investigates an MR-compatible motion-tracking system, which allows the accurate measurement of subject motion and could thus provide a better correction of BCG artifacts.

Methods

Four resting-state fMRI datasets (5 minutes eyes open and 5 minutes eyes closed, each from 2 healthy subjects) were acquired on a 3T Trio Tim scanner (Siemens Healthcare, Germany). During the scans, an in-bore camera was used to track the motion of a marker placed at the base of each subject's forehead (fig. 1). The marker consists of layers of gratings generating moiré patterns sensitive to position and orientation, yielding 6-degree-of-freedom motion information sampled at 80 Hz [2]. Subjects were instructed to relax and to avoid frowning or performing other similar motion. EEG and EKG sampled at 5 kHz were also acquired using an MR-compatible 64-channel EEG cap and amplifier (Brain Products, Germany). After gradient artifact correction, three methods were compared for removal of BCG artifacts: standard averaged artifact subtraction (AAS) [3], regressing out the measured motion parameters, and a sequential application of both methods. The quality of the resulting corrected EEGs was then compared with reference EEGs recorded outside the MR scanner using the same resting-state paradigm.

Fig. 1. Moiré marker location

Results

Average motion across cardiac cycles was dominated by longitudinal translation of average amplitude of 150 ± 61 µm and accounting for 31.7% of raw EEG signal variance, or 12.8% of residual EEG variance after AAS. Among the rotational components, the largest deviation was seen about the left-right axis, corresponding to a nodding motion of the head of 0.06 ± 0.02 degrees, and accounting for 6.1% of raw EEG variance, or 2.7% of residual EEG variance after AAS. Simply regressing out the motion parameters did not reduce the average residual artifact to zero, unlike the AAS and combined methods (fig. 2A). However, the average root-mean-square (RMS) residuals after AAS show artifacts across cardiac cycles, which disappear in the combined approach (fig. 2B). In 2 of 4 datasets, the average RMS residual energy across cardiac cycles was significantly reduced after application of the combined method compared to AAS, and was not significantly different than that of EEG recorded outside the scanner (Friedman test and post-hoc Tukey test, $p < 0.05$). In all 4 datasets, RMS variance across time within each cardiac cycle was also significantly reduced in the combined method compared to AAS ($p < 0.05$).

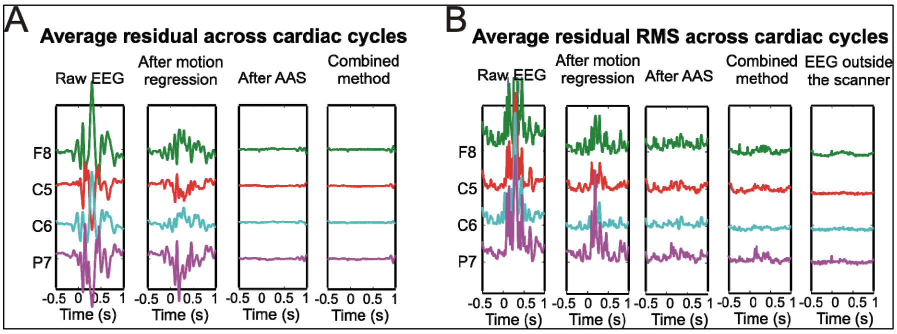

Fig. 2. Average residual (A) and residual RMS (B) across cardiac cycles for the various BCG correction methods.

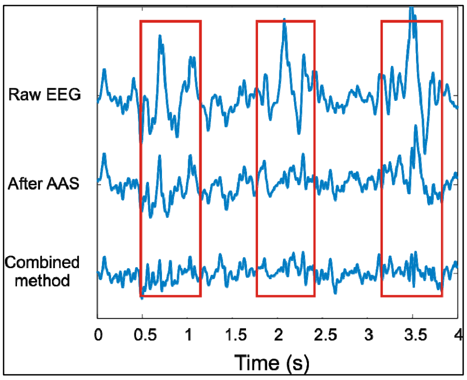

Fig. 3. Example of residual BCG artifacts after AAS that are removed by the combined method.

Discussion

BCG artifacts show slight variations across cardiac cycles, preventing their complete removal by AAS. This study shows that an accurate measurement of BCG motion could be used to model and subtract much of the residual variance across cardiac cycles in EEG signals measured inside the MR scanner (fig. 3). Longitudinal translation accounted for most of this variance, indicating that rigid-body head motion induces non-rigid effects in the EEG wires (such as bending), since pure rigid translations would not induce any current in the EEG wires. The resulting BCG artifacts can nevertheless be well modeled by a linear combination of the measured motion parameters.

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