Dipole Sources Localization of MRPs using ICA and Cortical Dipole Layer Imaging

Junichi Hori and Naotoshi Aoki

Department of Biocybernetics, Niigata University, Niigata 950-2181, Japan
hori@eng.niigata-u.ac.jp

Abstract

We have developed new estimation method for equivalent dipole sources inside of the brain. An inverse problem that estimated an equivalent dipole-layer distribution from the scalp EEG was solved by a parametric inverse filter. In the present study, the dipole layer distributions overlapped with several sources were separated into each component using independent component analysis. The position and moment of equivalent dipole sources were estimated from multilayered dipole source distributions. The present simulation results indicated that the equivalent dipole sources was accurately estimated by our methods. We also applied the proposed method to human experimental data of movement-related potentials.

1. Introduction

Brain electrical activities have been represented by either few dipole sources or dipole source distribution. Dipole sources have been estimated directly from the scalp electroencephalogram (EEG) [1]-[4]. However, the number of dipole sources should be exactly determined in advance. Furthermore, the dipole fitting took a lot of times to trace the dipole sources in three dimensions because the position and moment of dipoles have to be estimated from blurred scalp potential (SP).

On the other hand, equivalent dipole imaging was proposed to estimate cortical dipole layer (DL) distribution accounted for SP [5]-[7]. We have developed an inverse procedure for cortical dipole DL imaging, using the parametric projection filter (PPF), which allows estimation of inverse solutions in the presence of noise information [6],[7]. The information on noise distribution, as defined by the covariance matrix, was assumed to be known. The DL imaging has an advantage that the high resolution brain electrical activity can be estimated without ad hoc assumption on the number of source dipoles. However, when sources adjoin each other, the distributions made from each source overlap complexly. Moreover, it is difficult to estimate the depth of dipole sources.

Thus, in the present study, we considered to estimate the location and moment of the equivalent dipole sources from high spatial resolution DL imaging. Since each DL with different depth has information on the dipole sources, we used multilayer dipole distributions for source estimation. The overlapped distributions caused by multiple sources were separated by independent component analysis (ICA). We confirmed our estimation techniques by computer simulation and experimental studies of movement-related potential (MRP).

2. Method

2.1. Estimation Procedure

The procedure of dipole source estimation is as follows: first, the cortical DL distributions overlapped by multiple dipole sources were estimated from EEG by means of spatiotemporal inverse filter; second, the DL distributions were separated into each DL distribution caused by one dipole source using ICA; third, separated EEG data were obtained by multiplying a transfer matrix from the DL distribution to the SP; finally, each equivalent dipole source were estimated from separated EEG data by way of multilayered dipole distributions.

2.2. Cortical dipole layer imaging

Let the head be simulated by an inhomogeneous three-concentric-sphere model. An equivalent DL which assumed within the brain simulates the brain electrical activity. The transfer matrix from the DL to the SP was obtained by considering the geometry of the head model. The DL distribution was reconstructed from the recorded SP by solving an inverse problem of the transfer matrix. To solve the inverse problem, we adopted the parametric projection filter (PPF) that considering the statistical information of noise distribution [6],[7].

2.3. Independent component analysis

When multiple dipole sources are intricately distributed in brain, it is difficult to estimate each dipole source from overlapped SP. In that case, each DL distribution were separated by ICA that extracts independent sources from the observed signal based on statistical independence of the original signal. Suppose that the observed signals are described by mixing the independent sources. The number of sources was decided by principal component analysis. Independent signals were estimated by the appropriate restoring matrix. Finally, the original signal was estimated from principal components.

2.4. Dipole source estimation

Each dipole source was estimated by means of DL imaging. Peak points that exceed a certain threshold were extracted from estimated DL distributions with various radii. These peak points were approximated by lines. We supposed that dipole source existed on this line. Various SP were calculated by changing the depth and moment of candidate dipole sources. The optimum dipole source was decided by minimizing a relative error between the observed and estimated SP.

3. Results

In our simulations, two radial dipole sources were supposed to exist in the head model. Even if there was a big difference in strength between first and second dipole sources, DL distributions were accurately separated by ICA. Our simulation also demonstrated that the position and moment of estimated dipole sources were in good agreement with that of actual dipole sources.

In our MRP experiments, the subject performed fast repetitive finger movements which were cued by visual stimuli. Cortical dipole imaging analysis of the MRPs was conducted during the period of the MF, which was determined to be around 50 ms after the peak of EMG. As a result, the localized areas for MF in both hands were located in the premotor cortex, which is consistent with the hand motor representation (Fig. 1).

4. Conclusion

We developed a new localization method of equivalent dipole sources composed of dipole sources imaging, separation, and estimation. In our simulations, the dipole sources were accurately estimated by means of DL imaging and ICA. The present experimental study indicates that contralateral predominant activity of MF would occur after the EMG peak for both hands, which extends previous evidence supporting a hemispheric functional asymmetry of motor control. Further investigation using more realistic head conductor model and experimental data is necessary to fully validate the performance of the proposed model in cortical dipole source localization.

References

[1] M. Scherg and D. von Cramon, "Two bilateral sources of the late AEP as identified by a spatio-temporal model," Electroenceph. Clin. Neurophysiol., vol.62, pp.32-44, 1985.

[2] J.C. Mosher, P.S. Lewis, and R.M. Leahy, "Multiple dipole modeling and localization from spatio-temporal MEG data," IEEE Trans. Biomed. Eng., vol.39, pp.541-557, 1992.

[3] B. He, T. Musha, Y. Okamoto, S Homma, Y. Nakajima, and T. Sato, "Electric dipole tracing in the brain by means of the boundary element method and its solution accuracy," IEEE. Trans. Biomed. Eng, vol.34, pp.406-414, 1987.

[4] X. Xu, B. Xu, and B. He, "An Alternative Subspace Approach to EEG Dipole Source Localization," PMB-Rev, Oct. 2003.

[5] Y. Wang and B. He, "A computer simulation study of cortical imaging from scalp potentials," IEEE Trans. Biomed. Eng., vol.45, pp.724-735, 1998.

[6] J. Hori and B. He, "Equivalent dipole source imaging of brain electric activity by means of parametric projection filter," Ann. Biomed. Eng., vol.29, pp.434-445, 2003.

[7] J. Hori and B. He, "Spatio-temporal cortical source imaging of brain electrical activity by means of time-varying parametric projection filter," IEEE Trans. Biomed. Eng., vol.51, pp.768-777, May 2004.
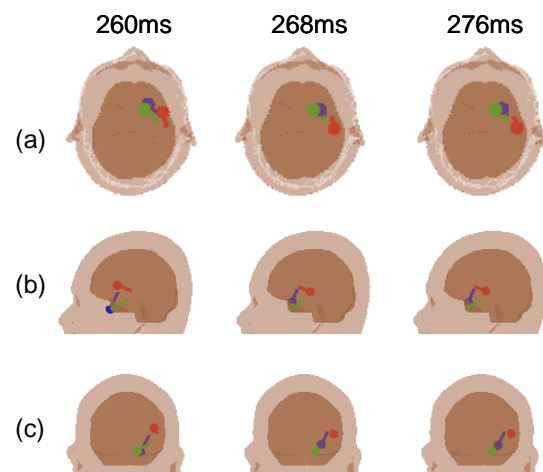
Fig. 1. Estimated dipole sources of MRPs for left-hand movement projected over (a) horizontal, (b) sagittal, and (c) coronal planes.