Biomed. Eng. Lett. (2017) 7:183–184
DOI 10.1007/s13534-017-0042-3

EDITORIAL

Recent advances in biomagnetism and its applications

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Received: 1 July 2017 / Revised: 2 July 2017 / Accepted: 8 July 2017 / Published online: 12 July 2017

Biomagnetism is an interdisciplinary field of research that aims to understand, modulate, image, or repair human organs and tissues with internal or external magnetic fields. During the last few decades, biomagnetism has been growing rapidly and its applications have been extended from diagnosing neuronal or cardiac diseases to understanding the underlying mechanisms of human brain and heart. The development of new technologies in the field of biomagnetism has been led by researchers working in biomedical engineering and its associated disciplines. This special issue includes six high quality papers showing recent technological developments in the field of biomagnetism.

Magnetoencephalography (MEG), which measures magnetic fields produced by the human brain, became one of the major non-invasive imaging modalities to study human brain, especially thanks to its excellent temporal resolution. Compared with its high temporal resolution, however, its spatial resolution is often limited due to several factors such as limited numbers of sensors, external noises and artifacts, inherently low signal-to-noise ratio (SNR), and cancellation of magnetic fields produced by multiple sources. It has been widely accepted that spatial resolution of MEG can be improved by performing source localization, or solving MEG inverse problems. The article entitled "MEG and EEG Dipole Clusters from Extended Cortical Sources" shows extensive simulation results performed using realistic volume conductor models and extended cortical sources under different sensor configurations to investigate the effect of signal-to-noise ratio (SNR) on the size and distribution of dipole clusters reconstructed from interictal epileptic spikes [1]. The results showed that the size and shape of reconstructed dipole clusters were strongly dependent on the SNR of the recorded MEG or electroencephalography (EEG) data. On the other hand, establishing the significance of observed effects is of importance for the interpretation of EEG or MEG data. In the article entitled "Statistical Non-Parametric Mapping in Sensor Space" [2], the authors applied statistical non-parametric mapping (SnPN), which is a non-parametric permutation test that does not need any assumption on the distribution properties of the data, to MEG sensor data. They showed that SnPN could effectively identify sensors of significantly different activity between stimulus types. It is expected that both articles [1, 2] from the same research group would significantly contribute to improving the reliability and accuracy of MEG analyses.

In the study of cognitive neuroscience using MEG, a specially designed apparatus sometimes needs to be developed. In the article entitled "A wearable system for adaptation to left–right reversed audition tested in

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combination with magnetoencephalography” [3], a new apparatus for investigating adaptation to left–right reversed audition was proposed. The authors developed a wearable left–right revised stereophonic system and asked participants to wear it for 4 weeks, during which MEG responses were measured under selective reaction time task. The analysis of the recorded MEG signals showed that a 4-week exposure to the reversed audition led to the modulation of early auditory processing. It is expected that their wearable device might be a useful tool to study changes of the brain functions when a person is exposed to unusual environments.

Recently, various emerging applications have been developed using human bio-signals originating from hands or fingers as well as brain, heart, and eyes. In the article entitled “Non-magnetic compliant finger sensor for continuous fine motor movement detection” [4], the authors investigated the feasibility of the proposed non-magnetic sensor for detecting finger movements with the advanced MEG system. This device would attract wide interest from neuroscientists and neural engineers because it may be used to characterize brain regions associated with force and velocity relative to individual digits or movement pattern; along with the use of recently developed machine learning algorithms [5], it may be applicable for the development of exoskeleton systems and brain–computer/machine interfaces (BCI/BMI).

Development of methods for removing noises and artifacts is of great importance in the field of biomedical signal processing [6, 7]. Biomagnetic recordings including MEG and magnetocardiography (MCG) also suffer from large environmental electromagnetic noises, and thus they often require special signal processing methods such as signal space separation (SSS) [8] and independent component analysis (ICA) [9]. In the article entitled “Dimensional contraction by principal component analysis as preprocessing for independent component analysis at MCG” [10], the authors evaluated the impact of the criterion used for dimensionality contraction after principal component analysis (PCA) on the performance of the ICA-based noise reduction of MCG signals. They showed that a proposed kurtosis-based index outperformed the conventional indices such as contribution ratio, especially under low SNR conditions. It is expected that their method can be used to implement more reliable automatic noise reduction software.

It has been questioned from numerous investigators how subcortical-cortical or cortico-cortical information processing works in human brain. Thanks to in-depth studies using advanced brain imaging techniques such as MEG/EEG and fMRI, some strong commonalities in rhythmic brain network properties have been observed. However, efforts to develop a unified framework to situate such various neuroscientific observations are rare. In the article entitled “Unified principles of thalamo-cortical processing: The neural switch” [11], the authors tried to find a unified framework to explain how coordinated cross-frequency and interregional oscillatory cortical dynamics underlie typical and atypical brain activations. With a comprehensive review into the animal and human literatures, they found that local regional activation by an external stimulus via a sensory pathway entails attenuated alpha and increased theta & gamma oscillatory activities, and increased interactions among theta and gamma rhythms. Finally, they proposed an alpha–theta–gamma (ATG) switch as a possible unified framework.

In closing this editorial, we would like to express our deepest gratitude to the authors who contributed in this special issue as well as many reviewers whose professional comments guaranteed the high quality of the selected papers. We hope you will find this special issue helpful for your future study.

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