Fundamental Research 5 (2025) 1–2

Contents lists available at ScienceDirect

Fundamental Research

journal homepage: http://www.keaipublishing.com/en/journals/fundamental-research/

Editorial

Multimodal technologies for neural modulation and sensing

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The pursuit of understanding the brain is often considered as the last frontier in biological science. The ability to selectively and precisely modulate and detect neural activities with high spatiotemporal resolution represents a powerful tool for neuroscience research and clinical therapeutics. The advancement of materials, devices, algorithms, and systems, as well as the use of electrical, optical, thermal, magnetic, acoustic, and chemical signals, is progressing rapidly to achieve advanced brain-machine interfaces. These techniques have found widespread applications in fundamental neuroscience research as well as in clinical neuroengineering practices.

In the field of multimodal neural modulation and sensing technologies, numerous domestic and international research teams have recently achieved a series of outstanding research outcomes based on their diverse disciplinary backgrounds, including materials science, chemistry, electronics, mechanics, and biomedical engineering. To achieve further breakthroughs in basic scientific research and promote the transition and application of these technologies, there is an urgent need for more interdisciplinary collaboration and international cooperation. Against this background, the IDG/McGovern Institute for Brain Research at Tsinghua University hosted the Workshop on Multimodal Neural Modulation and Sensing Technologies on August 17-18, 2023 in Beijing. This symposium, sponsored by the Department of Interdisciplinary Sciences in the National Natural Science Foundation of China, attracted more than 20 speakers from universities and research institutes worldwide, along with over 300 researchers and students. Attendees engaged in lively discussions on topics such as the interaction and related mechanisms between physical/chemical signals and biological signals, interface issues between biomaterials and neural cells/tissue, materials, devices, and systems of novel neural interfaces, as well as new directions for clinical medical applications.

This special issue extends the discussions from the aforementioned workshop. We present 11 papers showcasing the latest advancements in technologies for exploring and detecting neural activities. These papers cover a range of topics, including electrical, optical, and chemical approaches for recording and stimulating neural activities, as well as their clinical applications in treating neurological diseases.

Developing neural sensing technologies to record electrical, optical, and chemical signals in the nervous system is critical for unraveling complex neural activities and understanding brain function. A review paper discussed the current research status, development directions, potential innovations, and applications of high-density, high-throughput microscale electrocorticography (μECoG) materials and devices [1]. A research paper by R. Hu et al. introduced four-shank 32-channel implantable microelectrode arrays (MEAs) for real-time recording of single-cell neural information in the rat hippocampal CA1 [2]. Another review paper provided an overview of recent progress in bio-integrated electrochemical sensors, highlighting their relevance to neuroengineering and neuromodulation [3]. Finally, combined microelectrode arrays with extended-field-of-view microscopy simultaneously record claustrum (CLA) electrophysiology and wide-field cortical calcium imaging at single-cell resolution, investigating the synchronous changes of these electrophysiological and optical signals under anesthesia [4].

Neural modulation methods, which influence brain activity and function through electrical, optical, chemical, magnetic, and acoustic cues, are valuable in both research and clinical applications. They are widely used for treating neurological disorders, promoting neuroplasticity, pain relief, and more. A research article developed computational methods and identified key biomarkers for responsive brain stimulation in epilepsy [5]. Moreover, modulation of beta oscillations in the basal ganglia was simulated using dual-target optogenetic stimulation [6]. In a review article, Y. Pan et al. examined the opportunities and challenges of chemical modulation techniques, including microinjection, electrode/nanoparticle-based delivery methods, in situ electrochemical synthesis, and chemogenetics, along with their potential applications in neurophysiology and neuropathology [7].

Overall, neural sensing and modulation techniques are pivotal in clinical applications for diagnosing, monitoring, treating, and understanding various neurological and psychiatric conditions. Their integration into clinical practice not only improves patient care but also advances our knowledge of brain function and disease mechanisms, paving the way for innovative therapeutic strategies. A review by H. Ruan et al. explored studies describing the effects of deep brain stimulation (DBS) on the nucleus accumbens (NAc) in humans and animals, discussing mechanisms that may underlie its clinical efficacy [8]. X. Lu et al. reported recent advances in synaptic positron emission tomography (PET) imaging and the potential of synapse-targeted small-molecule

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https://doi.org/10.1016/j.fmre.2024.11.011

drugs for diagnosing and treating dementia [9]. A study investigated the use of cognitive reappraisal to modulate emotion regulation in suicide attempters, exploring the physiological mechanisms underlying this process [10]. Lastly, a comprehensive overview of signal acquisition technologies was provided in brain-computer interface research [11].

In summary, this special issue offers a platform for discussing advanced materials, devices, algorithms, and systems for neural modulation and sensing. These innovative concepts and strategies not only deepen our understanding of neuroscience but also offer promising directions for clinical diagnostics and treatments. Although this issue offers only a snapshot of the expansive field of neural modulation and sensing, we hope it will spark interest and inspire new ideas among researchers in this emerging area.

Declaration of competing interest

The authors declare that they have no conflicts of interest in this work.

Acknowledgments

The guest editor team acknowledges the support of all the authors, reviewers and staff members of *Fundamental Research* for their contributions and efforts to the feature issue.

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